

# SHORT CIRCUITS

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**VOLUME II**

CAT. BJ-8504

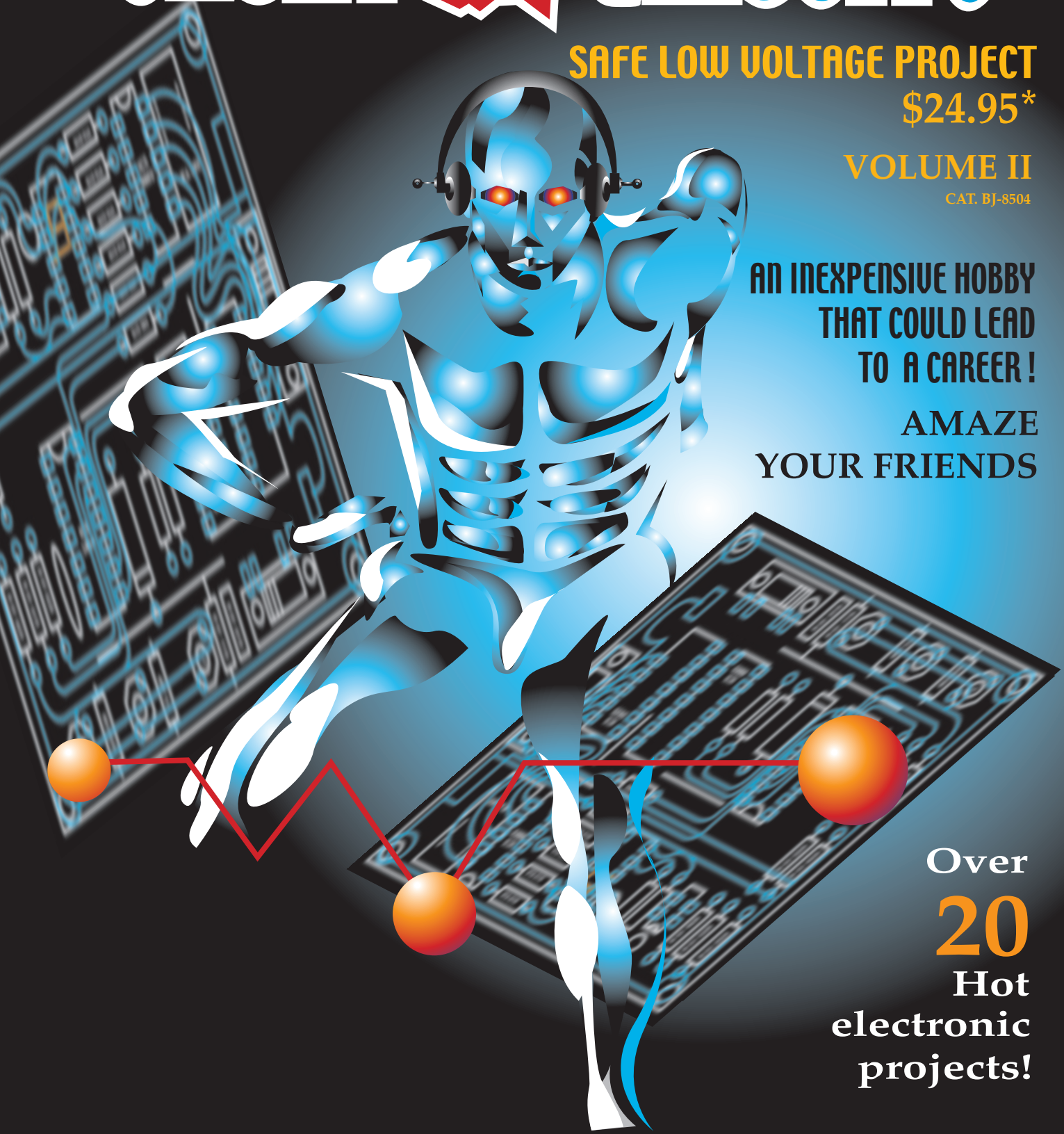
**AN INEXPENSIVE HOBBY  
THAT COULD LEAD  
TO A CAREER!**

**AMAZE  
YOUR FRIENDS**

**Over**

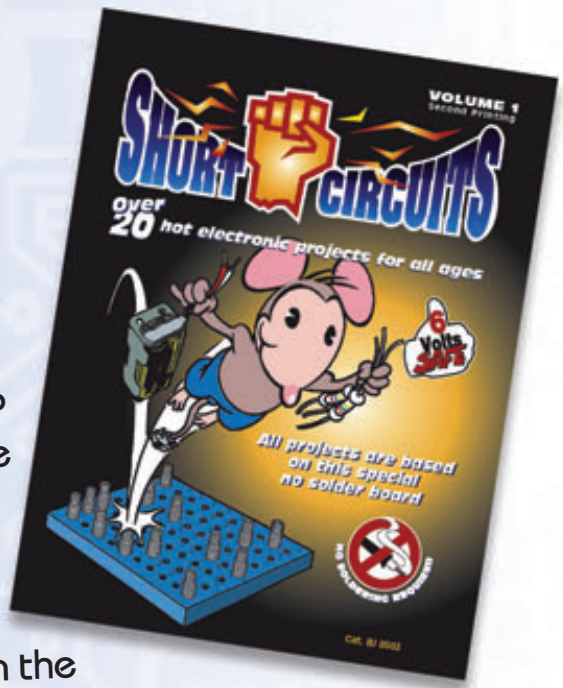
**20**

**Hot  
electronic  
projects!**



# SHORT CIRCUITS 1

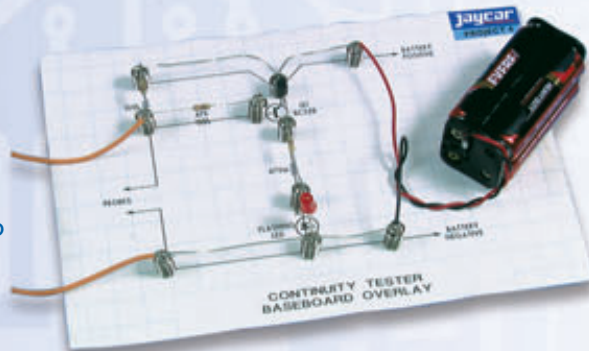
Do you know someone who is interested in electronics but doesn't know where to begin? Or maybe you need to build some confidence before attempting the projects in this book? If so, **SHORT CIRCUITS 1** is the place to start. It is the ideal introduction to electronics and is designed for the absolute beginner who has no prior knowledge, but is eager to learn the fascinating fundamentals of modern electronics.



**SHORT CIRCUITS 1** uses a brilliant yet simple system, called a baseboard, that enables anyone, but especially youngsters to build all of the projects in the book without the need for a hot soldering iron or adult supervision. Paper templates showing the circuit diagram are included and make construction an easy and straightforward process. In fact, the system is so good that projects are almost guaranteed to work - first go.



**SHORT CIRCUITS 1** projects operate from a six volt battery pack, are totally safe and come with a full technical discussion explaining how the circuit works. This helps build the readers' knowledge and confidence. As they progress through the book, readers are encouraged to experiment by changing component values and observing the results.



Whether you are 8 years old or 80, you will have fun!

## HOW DO I GET IT?

You can order the book, Cat BJ-8502 (98 pages) or the full kit of parts\* and the book Cat KJ-8502 at all Jaycar stores.

\*Less the solar cell for project #16.

**Jaycar**  
Electronics

For the location of your nearest store call:  
(Aust.) 1800 022 888 or [www.jaycar.com.au](http://www.jaycar.com.au)  
(N.Z.) 0800 452 922 or [www.jaycar.co.nz](http://www.jaycar.co.nz)

SHORT CIRCUITS 1

# Jaycar Electronics



**Editorial Director: Gary Johnston**

**VOLUME 2: FIRST EDITION**



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## **The Jaycar website — [www.jaycar.com.au](http://www.jaycar.com.au)**

There is only so much information that will fit in a book, so we have placed a lot more information on our website. If you want to know more or download a file or program, it is free to readers of this book. Just point your web browser to [www.jaycar.com.au](http://www.jaycar.com.au) and follow the prompts.

## **Where to buy the kits**

All of the parts for every project described in this book (and far more) are available from Jaycar Electronics stores and dealers all over Australia and New Zealand. There are also special deals on kits of parts for each individual project in the book, bulk rates for schools and all the tools you will need. See the inside front cover of this book for details on this.



# Welcome to Short Circuits Vol.II

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For those of you who have graduated from *Short Circuits Volume I*, welcome back! It's great to see that your thirst for knowledge is not satisfied. I hope by now you have had that great moment when something you built with your own hands started to work on its own, before your very eyes. I'm confident that you will enjoy many more of those moments with the projects in this book.

If you are **starting** at this level, welcome also! This book assumes that you have **some** electronics knowledge, but are still basically a novice. If you have no, or very little electronics knowledge, please check out *Short Circuits Volume 1* — it will definitely help you.

This book, *Short Circuits Volume II*, follows in the tradition of *Volume I* in that your learning follows a logical sequence, while being motivated by the fun you are having at the same time.

The projects in this book are more to do with the 'real world' than the projects in *Volume I*. Whilst the plastic baseboard and spring clips assembly system works well for simple projects, complexity is limited. Radio type circuits, for example, don't like the little springs — they act like antennas!

In this book you will be introduced to the printed circuit board, or 'PC board' for short. The PC board basically has the wiring printed on its underside. You simply insert the component leads through from the top side and (after making sure that the parts are in the right place and the right way around!) solder them into position.

Did I say 'solder'? Yes, you will learn how to solder from this book. Soldering is a fundamental skill you will need to master, in order to pursue electronics as a hobby or career. It is absolutely important for you to learn to do this well, as almost 90% of circuit failures at the outset are caused by poor solder joints. It's true that soldering can be dangerous if you are not careful, but it's quite safe if you take reasonable care. We do not recommend that you use a soldering iron at all if you are under 12, and then only with the supervision of a parent or a teacher until you are, say, 16 years of age.

What, then do we mean by 'real world' projects? Well, in this book you will find over 20 fantastic projects. They range from a Drought Alarm to your very own FM transmitting station!

Each project builds on the knowledge gained from those you have built earlier. The buzz that

you get from your last successful project spurs you on to build the next.

There are no dangerous voltages. Power for all of the projects is from safe low-voltage battery sources, or from a fully Electricity Authority approved AC adaptor.

As you will also see, the 'Tech Talk' is still there. It now forms the explanation of each circuit's operation. But you don't have to read it to achieve circuit success — it's just there to deepen your understanding of electronics, if you want to do this.

Of course when you have finished a project, you don't have to dismantle it as you had to do with *Volume 1* projects. As the PC board for each project is individually designed for it, you get to keep and use the project for as long as you want. The project will pay you back by giving years of service — unless..!

You may find that sometime in the future, you need a part that is sitting right there on that board. Yes, you can then remove that part from the PC board and re-use it, if you're careful. This is called (appropriately) **desoldering**. We show you how to do this as well. Taking parts off a board to use them in another project is usually called *cannibalising* the board. Once you become a regular cannibal, you are well on the way to being a hard-core electronics constructor!

Finally, we have included short biographical pieces on the Pioneers of Electronics. These people are the ones who 'worked it all out', virtually from scratch. It's important to be reminded that real people were responsible for the wonders of electronics that we routinely enjoy today. We have also added some primers on important things like the 555 timer IC, how radar and microwave ovens work, etc. So, in between soldering, put up your feet and have a good read as well!

I still love electronics construction. I routinely build projects of my own making or from local and overseas electronics magazines. Indeed, I turned an exciting and stimulating hobby into a career. Perhaps you can too!

Happy soldering.

**GARY JOHNSTON**  
Managing Director,  
Jaycar Electronics Group.

# Contents

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## Getting Started

|   |     |
|---|-----|
| Welcome to Short Circuits Volume II ..... | 5   |
| How to Recognise Components .....         | 8   |
| How to Build Kit Projects .....           | 14  |
| The Tools You're Going to Need .....      | 19  |
| Your Multimeter and How to Use It .....   | 20  |
| Soldering: How It's Done .....            | 26  |
| Desoldering Techniques .....              | 133 |

## The Projects

|                    |  |     |
|--------------------|--|-----|
| <b>Project 1:</b>  | Red/Green LED Flasher .....            | 28  |
| <b>Project 2:</b>  | A Handy Timer .....                    | 32  |
| <b>Project 3:</b>  | Hee-Haw Siren with Flashing LEDs ..... | 36  |
| <b>Project 4:</b>  | Mini Strobe Light .....                | 40  |
| <b>Project 5:</b>  | On-Off Touch Switch .....              | 44  |
| <b>Project 6:</b>  | A Wet/Dry Moisture Alarm .....         | 48  |
| <b>Project 7:</b>  | LED Audio Level Display .....          | 54  |
| <b>Project 8:</b>  | Mini Electronic Organ .....            | 58  |
| <b>Project 9:</b>  | Compact Audio Amplifier .....          | 64  |
| <b>Project 10:</b> | A Two-Station Intercom .....           | 70  |
| <b>Project 11:</b> | 'Skeet Shoot' Game .....               | 76  |
| <b>Project 12:</b> | FM Radio Microphone .....              | 82  |
| <b>Project 13:</b> | Metronome with Beat LED .....          | 86  |
| <b>Project 14:</b> | An Electronic 'Cricket' .....          | 92  |
| <b>Project 15:</b> | The 'Bionic Ear' .....                 | 96  |
| <b>Project 16:</b> | An Electronic Die .....                | 101 |
| <b>Project 17:</b> | 'Dalek' Voice Modulator .....          | 106 |
| <b>Project 18:</b> | A 'Knightrider' Scanner .....          | 111 |
| <b>Project 19:</b> | Resistance/Capacitance Bridge .....    | 116 |
| <b>Project 20:</b> | A Simple 3-Digit Counter .....         | 122 |
| <b>Project 21:</b> | A Personal FM Radio .....              | 128 |
| <b>Project 22:</b> | 3-Stage FM Transmitter .....           | 134 |

# Short Circuits Volume II

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## Useful Electronics Information

|  |     |
|--|-----|
| Resistors and their Colour Coding .....    | 25  |
| Transistors and Integrated Circuits .....  | 31  |
| Ohm's Law, and Power in a Circuit .....    | 35  |
| Capacitors and their Markings .....        | 39  |
| How Relays Work, and How to Use Them ..... | 52  |
| How a Microwave Oven Works .....           | 68  |
| The Story of Radar .....                   | 75  |
| How a 555 Timer IC Works .....             | 81  |
| Why a Fuse can be Your Best Friend .....   | 138 |
| Frequency and Wavelength .....             | 139 |
| Technical Terms Explained .....            | 140 |

## Meet the Pioneers of Electronics

|   |     |
|---|-----|
| Alessandro Volta .....                        | 63  |
| Andre-Marie Ampere .....                      | 63  |
| Michael Faraday .....                         | 85  |
| Georg Simon Ohm .....                         | 85  |
| Heinrich Hertz .....                          | 91  |
| Guglielmo Marconi .....                       | 100 |
| Thomas Alva Edison .....                      | 105 |
| Lee de Forest .....                           | 110 |
| Edwin Howard Armstrong .....                  | 115 |
| W. Shockley, J. Bardeen and W. Brattain ..... | 146 |



# How to recognise components...

## Resistors — fixed and variable

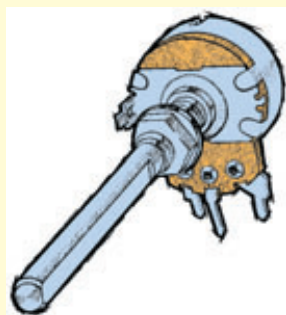
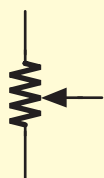
**RESISTOR**



**RESISTORS** are used to regulate the amount of current flowing in a circuit — the higher the resistor's value or resistance, the less current that flows and vice-versa. Resistor values are measured in ohms ( $\Omega$ ) and are identified by the colour bands on their bodies (see page 25). They may be connected into a circuit either way around (ie, they are not polarised).

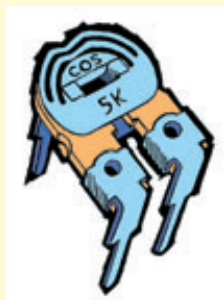
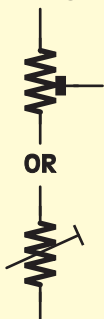
Resistors are made in different sizes, capable of dissipating or 'getting rid of' different amounts of energy (as heat). They are also made using different materials as the actual resistive element. Small low power resistors usually have an element made from either carbon or a thin film of metal. Larger resistors made to dissipate more power generally have an element wound from a wire such as *nichrome* (nickel-chromium alloy).

**POTENTIOMETER**



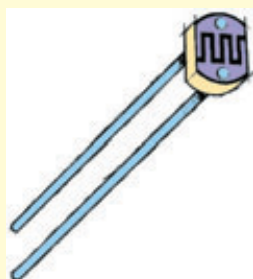
A **POTENTIOMETER** (or 'pot') is basically a variable resistor. It has three terminals and is fitted with a rotary control shaft or spindle. Rotating this shaft varies the position of a wiping metal contact on a circular carbon resistance track inside the pot body, and this in turn determines the resistance between the wiper (centre terminal) and the two outer terminals. Potentiometers are commonly used as volume controls.

**TRIMPOT**



A **TRIMPOT** is a special type of potentiometer which, while variable, is intended to be adjusted once or only occasionally. For this reason a control shaft is not included, but instead a slot or cross cutout is provided in the centre of the wiper rotor so it can be adjusted using a small screwdriver. Some trimpots are made with their total resistive element and wiper rotor exposed, while others are enclosed in a small plastic case.



**LIGHT DEPENDENT RESISTOR (LDR)**




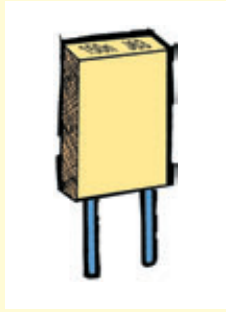
A **LIGHT DEPENDENT RESISTOR** (or LDR) is a special type of resistor that varies its resistance value according to the amount of light falling on it. When it is in the dark, an LDR will typically have a very high resistance (eg, millions of ohms), but this will fall to just a few hundred ohms when the LDR is exposed to strong light. They are not polarised.

# Capacitors – fixed and variable



**POLYESTER CAPACITOR (GREENCAP)**


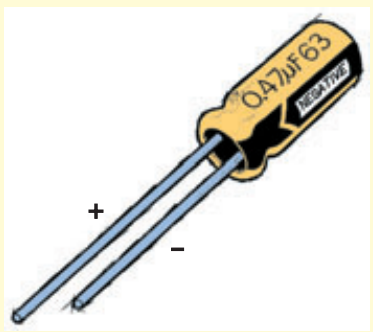
**MKT POLYESTER CAPACITOR**


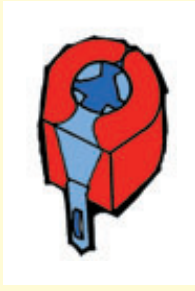
**CERAMIC CAPACITOR**

**ELECTROLYTIC CAPACITOR**

**VARIABLE AND TRIMMER CAPACITORS**

**VARIABLES**      **TRIMMER**

**CAPACITORS** block DC (direct current) while allowing varying or AC (alternating current) signals to pass. They are commonly used for coupling signals from one part of a circuit to another, and in timing circuits.

**POLYESTER** capacitors use polyester plastic film as their insulating dielectric. Some polyester capacitors are called *greencaps* since they are coated on the outside with green (or brown!) plastic to keep out dust and moisture. Their values are specified in microfarads ( $\mu\text{F}$ ), nanofarads (nF) or picofarads (pF), and range from 1nF up to about 10 $\mu\text{F}$ . (See page 39 for capacitor codes.) They are not polarised. Most of the projects in this book use greencaps for their medium value fixed capacitors.

**MKT** capacitors are another type of polyester capacitor, but they are in a rectangular 'block' shape and are usually yellow in colour. One of the major advantages of MKT capacitors is a more standardised lead spacing, making them more useful for PC boards. In most circuits, MKT capacitors can always be substituted for greencaps if you wish.

**CERAMIC** capacitors use a tiny disc of ceramic (porcelain) material for their insulating dielectric, and range in value from 1pF (picofarad) up to about 2.2 $\mu\text{F}$ . Those with values above about 1nF are often made with multiple layers of metal electrodes and dielectric, to allow the higher capacitance value to be provided in a smaller volume. These capacitors are usually called 'multilayer monolithics' to distinguish them from the lower value disc ceramics. Both types of ceramic capacitor are often used in RF (radio frequency) and filter circuits. Like greencaps and MKTs, they are not polarised.

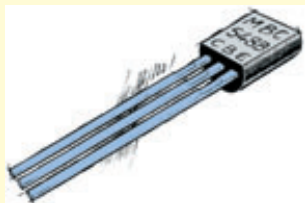
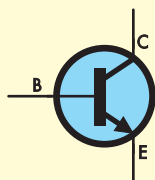
**ELECTROLYTIC** capacitors (or 'electros') use a very thin film of metal oxide as their dielectric, which allows them to provide a large amount of capacitance in a very small volume. They range in value from about 100nF up to hundreds of thousands of microfarads ( $\mu\text{F}$ ). They are commonly used to filter power supply rails, for coupling audio signals and in timing circuits. All electrolytic capacitors allow a very small DC 'leakage' current through them, but special 'low leakage' types are made so that this leakage current is much smaller than normal.

**Note that electrolytic capacitors are polarised and the positive and negative leads are clearly marked on their bodies. Be sure to connect them the right way around.**

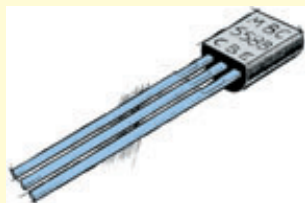
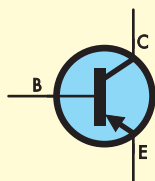
Sometimes the amount of capacitance in a circuit needs to be adjusted or 'trimmed' — setting the frequency of a tuned circuit, for example. A **VARIABLE** capacitor has one set of fixed plates, and one set which can be moved relative to them either by turning a knob (like a pot) or a screwdriver (like a trimpot). The dielectric between the two sets of plates is usually either air or a plastic film. Because of their construction, most variable capacitors have quite low maximum values — up to a few tens of picofarads (pF) for trimmer capacitors and a few hundred picofarads for larger variable capacitors used for tuning radios, etc.

# Semiconductors: Transistors and Diodes

## NPN TRANSISTOR (PN100, BC548)

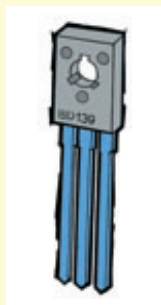


## PNP TRANSISTOR (PN200, BC558)

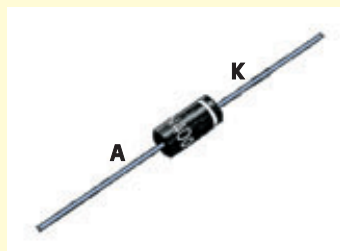


## POWER TRANSISTOR (NPN OR PNP)

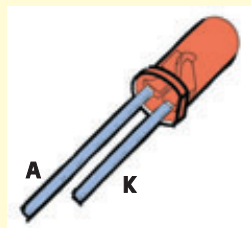
(Same symbols as above)



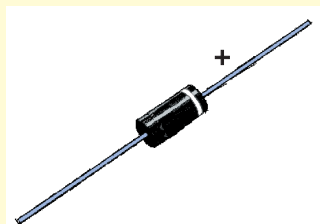
## SILICON DIODE



## LIGHT EMITTING DIODE (LED)



## ZENER DIODE



**TRANSISTORS** are semiconductor devices that can either be used as electronic switches or to amplify signals. They have three leads, called the *collector*, *base* and *emitter*. A small current flowing between base and emitter (through the base-emitter junction) causes a much larger current to flow between the emitter and collector. Two types of transistor are used in this book: **NPN** types and **PNP** types. Transistors are labelled with 'Q' numbers (Q1, Q2, etc) on the circuits, so they're not confused with transformers.

The PNP transistors used in this book mostly look identical to the NPN types specified, so be careful when selecting them. You can easily recognise a PNP transistor on a circuit, because the arrow of the emitter points towards the base 'bar', rather than away. Be sure to always use the exact type specified and always connect their leads exactly as shown in the wiring diagrams.

**POWER** transistors are (usually) larger than the 'small signal' types above and, as their name suggests, are capable of handling higher currents and voltages. Most power transistors have an exposed metal tab, or part of the case exposed, so that heat can be conducted away from the transistor's 'internals' more easily. This is done by bolting the metal tab or case to a metal radiator or heatsink, to form a close thermal bond between the two.

A **DIODE** is a semiconductor device which can pass current in one direction only. In order for current to flow, the anode (A) must be positive with respect to the cathode (K). In this condition, the diode is said to be forward biased and a voltage drop of about 0.6V appears across its A and K terminals. If the anode is less than 0.6V positive with respect to the cathode, negligible current flows and the diode effectively behaves as an open circuit.

**LIGHT-EMITTING DIODES** or 'LEDs' are special diodes which have a plastic translucent body (usually clear, red, yellow or green in colour), and a small semiconductor element which emits light when the diode passes a small current. Unlike an incandescent lamp, a LED does not need to get hot to emit light. LEDs must always be forward biased to operate. They are available in types which emit red, orange, yellow, green, blue or white light, as well as types emitting two different colours (with opposite polarity or different connections) or invisible infra-red (IR) radiation.

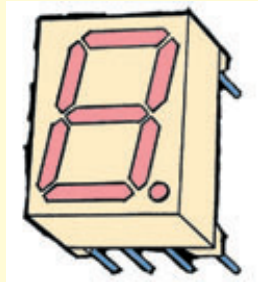
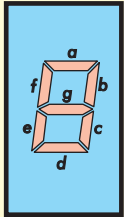
**ZENER DIODES** are another special kind of semiconductor diode which unlike other diodes, is designed to conduct current when a *reverse bias* is applied across its internal junction. Under these conditions it displays an almost constant voltage drop, for a relatively large range in reverse current levels. This voltage is often used as a reference voltage in power supply circuits. Zener diodes are made with many different reference voltages, ranging from about 3.3V up to over 75V.

**Note that the striped or 'band' end of a zener diode is its POSITIVE end — which is the opposite of normal diodes.**



# Other Semiconductor Devices

## LED DISPLAY

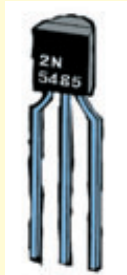


**LED DISPLAYS** consist of a number of LEDs together in a single package. The most common type has seven elongated LEDs arranged in an '8' pattern. By choosing which combinations of the LEDs are lit, any number digit from '0' through '9' can be displayed. Most of these '7-segment' LED displays also contain another small round LED which can be used to display a decimal point.

## FET — JUNCTION TYPE



N-CHANNEL

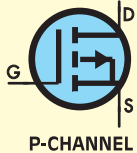


**FIELD-EFFECT TRANSISTORS** or FETs are a different type of transistor, which (usually) still has three terminals but works in a different way. Here the control element is the *gate* rather than the *base*, and it is the *gate voltage* which controls the current flowing in the 'channel' between the other two terminals — the *source* and the *drain*. Like ordinary transistors FETs can be used as either electronic switches or amplifiers. They come in both P-channel and N-channel forms (similar to PNP and NPN transistors), and are available in both small signal and power types.

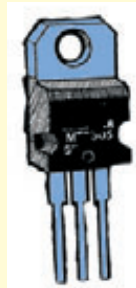
## MOSFET — POWER TYPE



N-CHANNEL

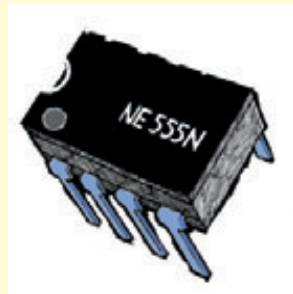


P-CHANNEL



## INTEGRATED CIRCUIT (IC)

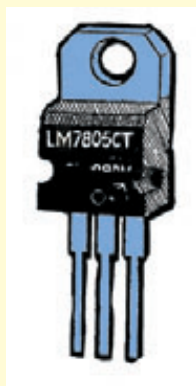
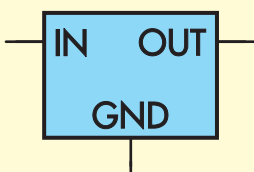
(ICs have many symbols, usually depicting their function or circuit use)



**INTEGRATED CIRCUITS** or ICs contain all, or most of the components necessary for a particular circuit function, in one package. ICs may contain as few as 10 transistors or many millions of transistors, plus many resistors, diodes and other components. There are many shapes, styles and sizes, but most of the ICs used in this book are in a DIL or 'dual-in-line' package, which is a flat rectangular block with a row of pins down each side. Some devices have two rows of 4 pins (ie, 8 pins in all), while others have two rows of 7, 8 or even 9 pins.

Pin 1 of the IC is usually indicated by a small 'dimple' or depression on the top of the package. There may also be a small semicircular notch moulded into that end of the package. Looking down on the IC, the pins are always numbered anticlockwise from pin 1.

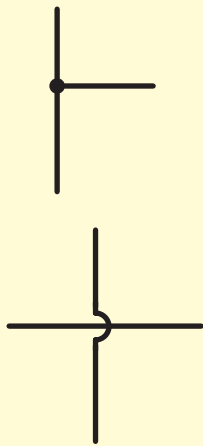
## 3-TERMINAL REGULATOR



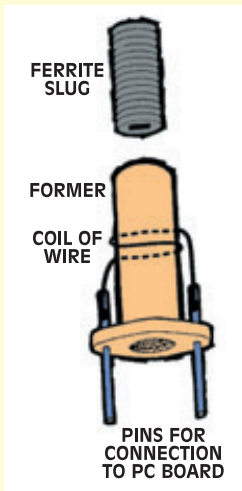
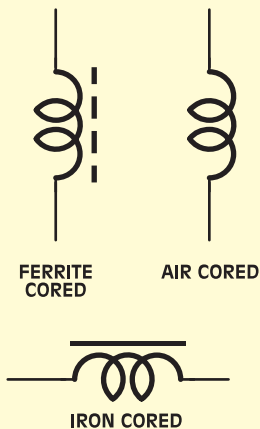
**THREE-TERMINAL REGULATORS** are a special type of integrated circuit which supplies a regulated, or constant and accurate, voltage from its output regardless (within limits) of the voltage applied to its input. They are most often used in power supplies. Most regulators are designed to give a specific output voltage (eg, a '7805' regulator gives 5V), but some are adjustable via an external potentiometer or a pair of resistors.

# Wire, cable, Inductors and Transformers

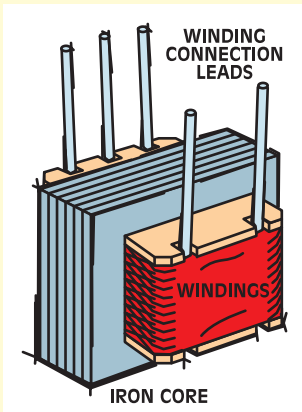
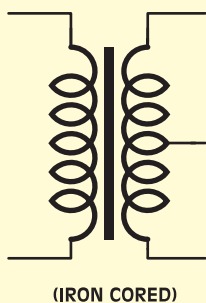
## WIRE & CABLE



## INDUCTORS (COILS)



## TRANSFORMER



A **WIRE** is simply a length of metal conductor, usually (but not always) made from copper. Copper is almost always used for wire because of its excellent electrical conductivity (the ability to conduct a current). When there is a risk of a wire touching another wire and causing a short circuit (such as in an inductor or coil), the copper is coated or covered in an insulating material. A very thin coating of enamel (like a varnish or paint) may be used for this insulation, or else it is enclosed in a sleeve of coloured PVC (polyvinyl chloride) plastic. Unless the wire gets very hot or the design voltage is exceeded, this sleeve will continue to insulate the wire.

Plain copper wire is not generally used because it will oxidise or tarnish in the presence of air. A thin metal alloy coating is therefore applied to the copper, usually an alloy of tin and lead which makes it easy to solder but doesn't oxidise as easily as copper itself. This produces *tinned copper wire*.

Single or multi-strand wire which is covered in coloured PVC plastic insulation is used quite a lot in electronics, to connect or 'hook up' PC boards and other components. As a result it is generally called *hookup wire*.

On a circuit diagram, a solid dot indicates that the wires or PC board tracks are connected or joined, while a 'loop-over' indicates that they are not joined and must be insulated from each other.

A number of insulated wires enclosed in an outer sleeve of insulating material are called a **CABLE**. Some cables may have three multi-strand wires, with insulation capable of withstanding over 240V AC — like the power cable used on most domestic electrical appliances. Other cables may have a single wire running down the centre of a cylinder of insulation, with a second conductor made of many woven strands of fine wire around it, and then a further insulating sleeve on the outside. This is generally called *screened* or *coaxial cable*.

**INDUCTORS** or 'coils' are basically a length of wire (either tinned copper or enamel-coated wire), wound into a cylindrical spiral (or layers of such spirals) in order to increase their inductance (the ability to store energy in a magnetic field). Many coils are wound on a *former* of insulating material, which may also have connection pins to act as the coil's terminals. The former may also be internally threaded to accept a small core or 'slug' of ferrite material, which can be adjusted in position relative to the coil itself to vary the inductance.

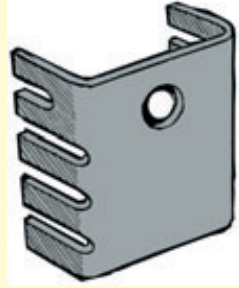
A **TRANSFORMER** consists of a number of coils or *windings* of wire wound on a common former, which is also inside a core of iron alloy, ferrite or other magnetic material. When an alternating current is passed through one of the windings (the *primary*), it produces an alternating magnetic field in the core and this in turn induces AC voltages in the other (*secondary*) windings. The voltages produced in the other windings depend on the number of turns in those windings, compared with the turns in the primary winding. If a secondary winding has fewer turns than the primary, it will produce a lower voltage; if it has more turns, it will produce a higher voltage. In other words, the voltage ratio is directly proportional to the turns ratio. Transformers can therefore be used to change the voltage level of AC power — either for stepping the voltage up or down.

Transformers are made in many sizes, and with many different combinations of windings. They are frequently used in power supplies. The larger the transformer, the more AC power it can handle.

# Microphones, Speakers and Hardware

## HEATSINK

(No circuit symbol)



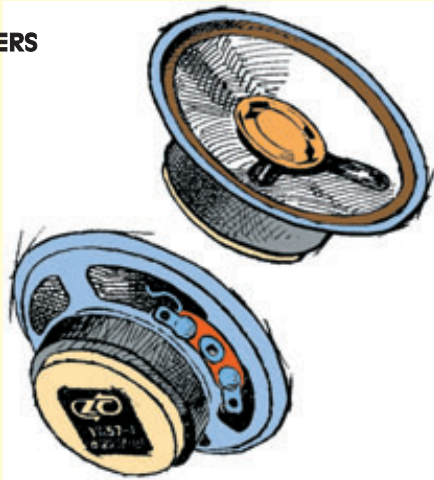
Many electronic components generate a certain amount of heat when they are operating. While most can cope with this heat, some are not capable of removing all the heat they generate and may eventually be damaged or destroyed if they aren't helped to remove it. A **HEATSINK** is a device which makes intimate thermal contact with the device (most likely a transistor or other semiconductor) and draws the heat from it, keeping it cooler and radiating the heat to the surrounding air.

## ELECTRET MICROPHONE



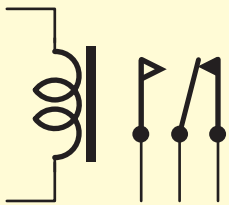
A **MICROPHONE** converts audible sound waves into electrical signals which can then be amplified (eg, in a public address system), fed to a radio transmitter or processed in some other way. In an **ELECTRET** microphone the sound waves vibrate a circular *diaphragm* made from very thin plastic material which has a permanent electric charge in it. Metal films coated on each side form a capacitor, which produces a very small AC voltage when the diaphragm vibrates. All electret microphones also contain a FET (field effect transistor), which amplifies the very small AC signals. To power the FET amplifier the microphone must be supplied with a small DC voltage. All electret microphones are therefore polarised.

## LOUDSPEAKERS



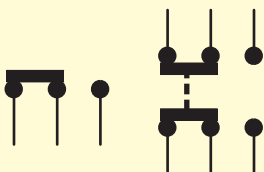
A **LOUDSPEAKER** (or 'speaker') converts electrical signals into sound waves that we can hear. It has two terminals which go to a 'voice coil' (essentially a coil of wire) attached to a circular cone made of either cardboard or thin plastic. When electrical signals are applied to the voice coil, it creates a varying magnetic field which interacts with the adjacent magnetic field from a permanent magnet at the back of the speaker. As a result the cone vibrates in sympathy with the applied signal to produce sound waves. Although the speaker terminals may be marked with '+' and '-' signs, a speaker may be regarded as a non-polarised device when used in the projects described in this book.

## RELAY



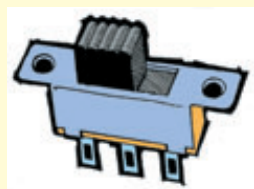
Many electronic components are not capable of switching higher voltages or currents, so a **RELAY** is used. This has a coil which forms an electromagnet, attracting a steel 'armature' which itself pushes on one or more sets of switching contacts. When a current is passed through the coil to energise it, the moving contact(s) disconnect from one fixed contact and connect to another. Then when the coil is de-energised, the moving contact(s) return to their original position(s). In most cases the relay coil needs a diode across it to prevent damage to sensitive semiconductor devices controlling the coil current.

## SWITCH - SLIDER



SPDT

DPDT



A **SWITCH** is a device with one or more sets of switching contacts, which are used to control the flow of current in a circuit. The switch allows the contacts to be controlled by a physical actuator of some kind — such as a press-button, toggle lever, rotary spindle and knob, or a slider bar. As the name suggests, this last type of switch has an actuator bar which slides back and forth between the various contact positions. In a single-pole, double throw or 'SPDT' slider switch, a moving contact links the centre contact to either of the two end contacts. In contrast a double-pole double throw or DPDT slider switch has two of these sets of contacts, with their moving contacts operating in tandem when the slider is actuated. ★



# How to Build Kit Projects

Building electronic projects isn't hard, especially when you assemble them from a kit like those we make available for the projects described in this book. But you'll be able to build them a lot more confidently and successfully once you take advantage of the practical techniques we explain here...

**IN THE VAST** majority of modern electronic projects, most if not all of the small parts or 'components' are mounted on a printed circuit or PC board which has etched copper tracks on at least one surface, to provide most of the actual wiring. This makes construction a lot easier than in the old days of electronics. All of the projects described in this book are built on a PC board, for this reason.

Although today's components are also a lot smaller than in the old days, they're usually fairly rugged and easy to work with. However at the same time it is still possible to damage them if you don't handle them the right way. And of course a damaged component can easily result in a project that doesn't work as it should. So knowing the right practical techniques and using them is generally the best way to ensure that your projects will work properly as soon as you've finished building them.

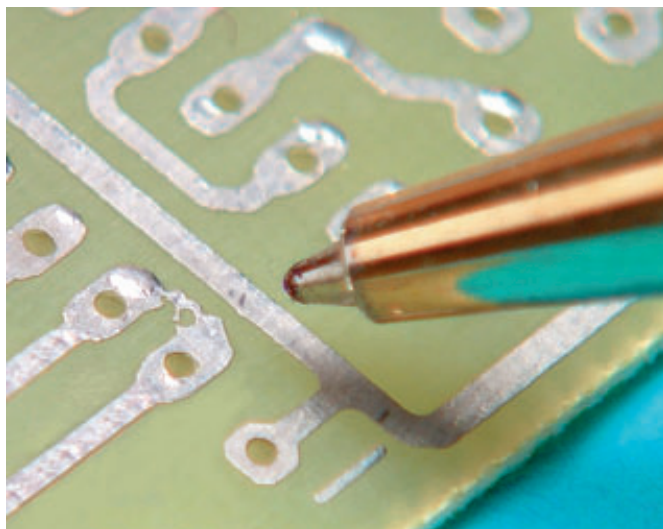
In this chapter we're going to run through most of the practical steps that you'll need to know about, in roughly the order they occur when you're building any electronic project. The only technique we won't discuss is soldering, which is covered in its own chapter.

## 1. Got everything?

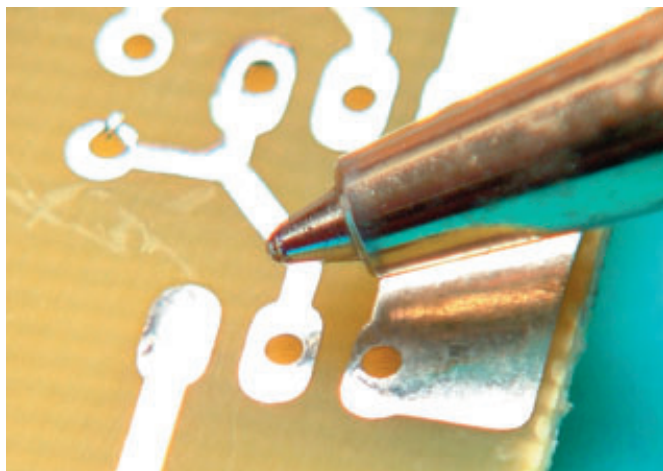
Before you start to build anything it's a very good idea to make sure you have all the parts. This is still necessary when you're building an electronics project from a kit — because mistakes can happen, and sometimes parts can be omitted from a single kit or even a batch of kits.

So clear your bench or worktable, open up the kit and lay out all the parts so you can check them off against the project's parts list. Now's the time to find out if you're missing anything, so you can get it from your supplier.

If everything is present and correct, put them all in a plastic dish or tray so none of them rolls off the bench and gets damaged or lost.



*One kind of manufacturing fault which can occur when a PC board is being made is a copper 'bridge' which provides a short circuit between IC pads. If you find one, like the example shown here, cut it away using a hobby knife...*



*Here's another kind of fault you may find in a PC board: a hole which has either not been drilled, or was drilled but then covered in solder. If you find one of these, drill it out with a 0.8mm drill before you begin assembling the board.*

## 2. Checking the PC board

Now take the PC board itself, and inspect the copper side carefully for manufacturing defects — using a magnifying glass if necessary. What you're mainly looking for is things like fine 'hairline' cracks in any of the etched tracks, or tiny slivers of solder that may have been left from the solder plating of the tracks, bridging a gap between pads or tracks and therefore forming an unwanted short circuit.

If you do find any hairline cracks, you need to re-join the tracks by either soldering a short length of tinned copper wire over the crack, or in some cases just running a small amount of solder over the crack with your soldering iron.

Similarly if you find any solder bridges between pads or tracks, remove these by using your soldering iron and some desoldering braid (Jaycar stores stock this as Cat. No. NS-3020).

If you discover that any of the component lead holes are filled with solder (this can sometimes happen when the board is solder plated), it should be sucked out using the soldering iron and braid. Otherwise you'll have trouble fitting the component leads later.

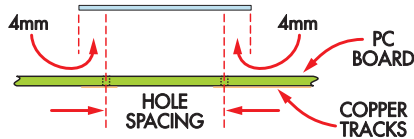
## 3. Fit any terminal pins

Many projects and kits use small terminal pins on the PC board at the points where 'off board' connections are made: in other words, connections to anything that isn't mounted on the board itself, like a battery or headphones. Fitting these terminal pins to the board makes it easier to solder connecting wires to the board, especially from above and when the board may have been mounted in a box.

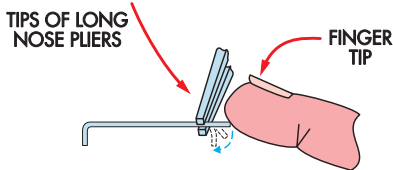
PC terminal pins are usually a piece of 1mm diameter copper or brass wire about 10-12mm long, with a small flange formed about 5mm from one end. They're often either gold or silver plated, to make them easier to solder.

The pins are fitted by pushing their 'short' ends through the 1mm holes provided in the PC board, from the top and

## MAKING AND FITTING WIRE LINKS



**A** CUT WIRE TO LENGTH, ABOUT 8mm LONGER THAN BOARD HOLE SPACING



**B** ENDS BENT DOWN BY 90° AND PARALLEL, SPACED TO MATCH BOARD HOLES



**C** ENDS PASSED THROUGH PC BOARD HOLES AND SOLDERED TO PADS

*Some PC boards use wire links to make connections that need to cross over. Here's how the links are made and fitted.*



**D** EXCESS WIRE TRIMMED OFF WITH SIDECUTTERS

## 5. Preparing & fitting resistors

Most of the resistors fitted to project PC boards are mounted 'horizontally' — that is, with their body lying down against the top of the board. The resistor's axial leads (ie., emerging from each end, on the axis) are bent down so that they pass through the holes provided on the board, usually at a spacing of either 12.5mm (0.5") or 10mm (0.4").

To mount the usual 0.25W or 0.5W carbon or metal film resistors in this way, take each one in turn and carefully bend each of its leads down through 90°, at a point about 3mm away from the resistor body. Do this by gripping the lead with the tips of the long nose pliers just inside the 3mm point, and then bending the free end with your finger down against the side of the pliers. Both resistor leads are bent in the same direction of course, because the bent portions will be passed through the holes in the PC board when the resistor is fitted to it.

Once the leads of all resistors have been bent in this way, check each one's colour code to make sure of its value and therefore where it should go on the board.

Resistors are not polarised components of course, so in most cases they can be fitted into the board either way around without making any difference electrically. However if you want your project to look professional, the idea is to fit all of the resistors so their colour coding bands can be read in the same direction. This makes it a lot easier for anyone (including you) trying to troubleshoot in your project if this ever becomes necessary later.

Fit each resistor by pushing the bent ends through the correct board holes as far as they'll go, so that the body of the resistor is now lying down against the top of the board. Now turn the board over, and while you hold the resistor's body against the board with one hand, gently push over the two protruding leads by about 45° to hold the resistor in

until the flange is resting against the top of the board. Then the board is turned copper side up, and each pin soldered to the pad around its hole. The short stub of each pin left protruding from the solder joint is then clipped off using your sidecutters.

So if the project you're building uses any terminal pins, it's a good idea to fit them at an early stage.

### 4. Any wire links to fit?

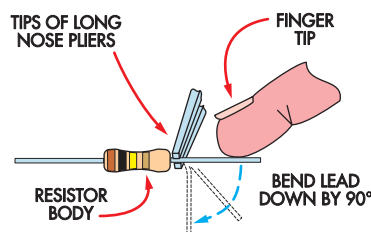
Often the designer of a low-cost single layer PC board has to make use of a wire link or two on the board, to complete connections which really need to 'cross over' other connection tracks. If the project/kit you're building uses these links (and this applies to some of the projects in this book), they too are best fitted before you fit any of the electronic parts.

When they're short, the links can often be made from 'offcuts' from resistor or capacitor leads. Otherwise you can make them from 0.5mm tinned copper wire (preferably stretched slightly, so it's straight and stiffer). On the other hand if the links are quite long and/or there are a few of them running closely next to one another, it's a good idea to make them from short lengths of insulated single-core hookup wire.

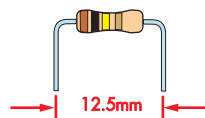
To make the links, measure the distance between the two holes provided on the board for the link ends and then add about 8mm to find the total length you need. Cut off this length of wire, and if you're using insulated wire strip off about 4mm of insulation at each end. Then using your long nose pliers, carefully bend down each end 4mm in, at 90° and with both ends bent in the same direction.

The link can then be fitted to the board by passing these two short 'legs' through the board holes. Then they're bent over at about 45° to hold the link in place while you solder them to the pads around each hole. Any surplus wire protruding from the solder joint can then be clipped off with the sidecutters.

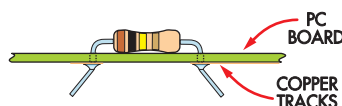
## PREPARING RESISTOR LEADS FOR HORIZONTAL MOUNTING



**A** GRIP LEADS WITH PLIERS NEAR BODY AND BEND DOWN FREE ENDS



**B** LEADS BENT DOWN AND PARALLEL, SPACED TO MATCH BOARD HOLES



**C** LEADS PASSED THROUGH PC BOARD HOLES, BENT & SOLDERED TO PADS



**D** EXCESS LEADS TRIMMED OFF WITH SIDECUTTERS

*Most resistors have axial leads as shown here, but are mounted on a PC board horizontally. Here's how a resistor is prepared and mounted on the board this way...*

place. Then you can solder the leads to the copper pads, and finally trim off the surplus lead wire with your sidecutters.

Some projects assembled on a very compact PC board have some or all of the resistors mounted vertically on end, to save space. To mount resistors this way, you have to bend one of each resistor's leads carefully around with long nose pliers, so that its end becomes parallel with the unbent lead and only about 2.5mm away from it (see diagram at right). Make sure you don't strain the resistor itself when you're bending the lead.

With the lead bent around in this way, both leads can be pushed through the holes in the board and soldered — with the resistor body vertical and one end down against the board. Make sure that you mount each resistor value in its correct position. With some projects it's also important to orientate some resistors carefully so that their longer 'bent down' lead is connected to the earthy side of the circuit. This is usually shown in the wiring diagram for the project.

By the way, what we just called the 'earthy side' of the circuit is usually the side of the circuit which is connected to the *negative* supply line — i.e., the negative terminal of the battery or other power supply. It may not actually be connected directly to earth or ground, but it's the side of the circuit which is assumed to be 'cold', or at the lowest potential with respect to earth.

## 6. Non-polarised capacitors

Most smaller value capacitors are of the disc ceramic, multilayer monolithic ceramic or metallised polyester (greencap, MKT) film type, and are not polarised. So like a resistor, they can be fitted to the PC board either way around.

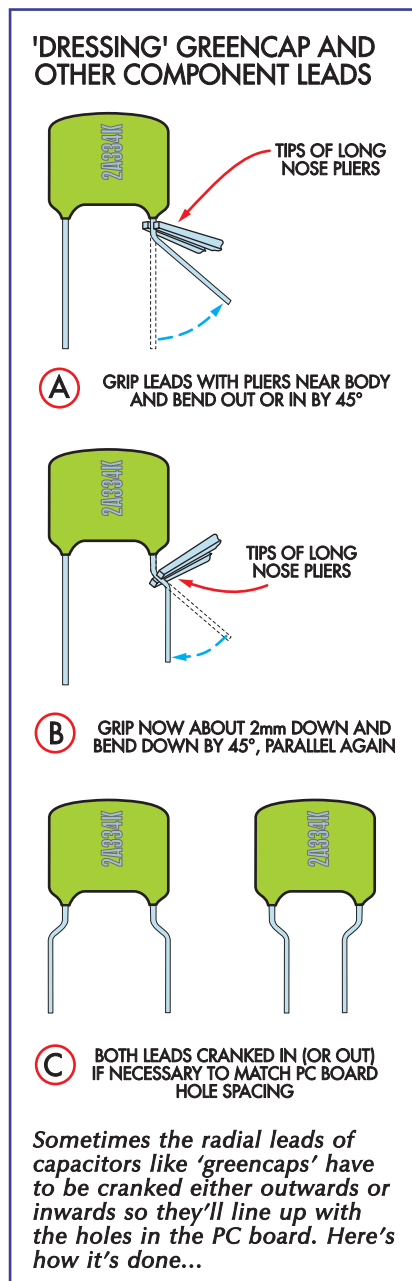
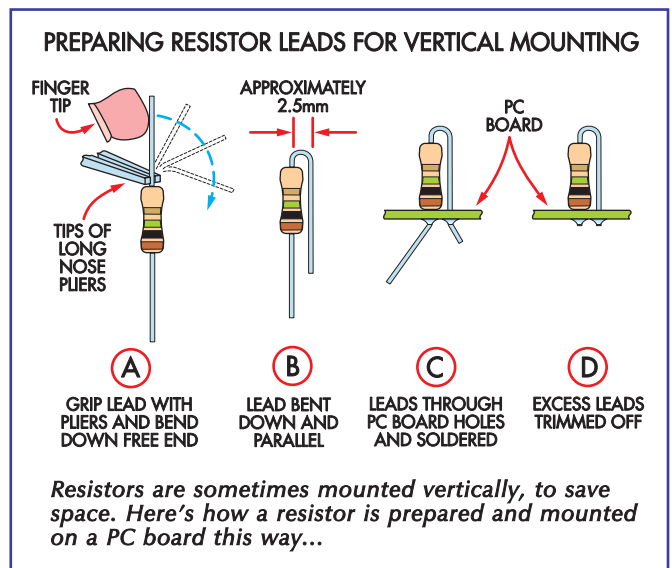
Nowadays almost all of these capacitors have **radial** leads — leads which emerge from the capacitor on the same side of its body, and roughly parallel with each other. So in many cases the capacitor is mounted on the PC board simply by passing the leads through the matching holes in the board, bending them over at about 45°, and then soldering and trimming off the excess.

It's not always quite this easy, though, because the lead spacing can vary a bit even between capacitors of the same type and with the same value. So sometimes it's necessary to 'dress' the leads, cranking one or both of them either inwards or outwards so their spacing matches the board's hole spacing. (See diagram at right)

Do this very carefully with your long nose pliers, so you don't stress the component itself or loosen the attachment of the leads inside it.

In some kit projects (including many of those in this book) you'll find that the designer has provided extra 'alternative' holes in the board to make it easier to fit capacitors with widely differing lead spacing. This often means that you won't have to dress the leads at all, or very little — simply choose the combination of holes with the nearest spacing to that capacitor's lead spacing.

Mind you, when these extra holes have been provided, you often need to be very careful not to fit the capacitor between two hole pads that are meant to be alternatives for the same 'side' of the capacitor, and therefore connected



together underneath by a copper track. If you fit the capacitor this way, it won't really be connected into the circuit. So make sure you use one hole and pad from those provided for each side of the capacitor.

## 7. Polarised capacitors

Larger value capacitors are usually of the aluminium electrolytic or solid tantalum type, of course. This means that they're **polarised**, and can only be fitted to the board one way around. This is called their **orientation**.

To help you in fitting them correctly, these capacitors always have at least one positive (+) or negative (-) marking on their body. Many electrolytics (or 'electros') have a 'stripe' of - signs along one side of the body, to make things even clearer. You'll also find that the wiring diagram for each project using polarised capacitors always shows at least a + sign near one mounting hole for each polarised capacitor, so you can be sure of its correct orientation.

Nowadays most polarised capacitors have radial leads, like their non-polarised cousins. So they're mounted in much the same way. They too can vary quite a bit in terms of lead spacing, so in some cases you may need to dress their leads inwards or outwards slightly to allow them to pass through the board holes easily. As before you need to do this very carefully with your long nose pliers, to avoid damaging the capacitor.

In the kit projects described in this book, you'll again find we've provided extra holes for some of the polarised capacitors, so you shouldn't need to dress their leads very often.

## 8. Fitting diodes

Most diodes are in an axial-lead package which is very similar in size and shape to a resistor. This means they're mounted in much the same way, by bending their leads down carefully at 90° so they will pass through the holes provided in the board — usually spaced either 12.5mm



(0.5") or 10mm (0.4") apart.

There's one big difference between a diode and a resistor, though: diodes are polarised, and must be orientated correctly if they're to work properly. Almost all diodes have a band of paint or ink around one end to indicate their cathode (K) end.

In the wiring diagrams for all of the projects in this book we've not only shown the diodes with their cathode bands clearly visible, but also provided 'A' and 'K' markings. So if you follow the wiring diagram carefully you shouldn't fit any of the diodes the wrong way around.

## 9. Fitting LEDs (light-emitting diodes)

The vast majority of LEDs are in packages with radial leads, with a standardised spacing of 2.5mm (0.1"). This means that they're usually very easy to fit to a PC board: you simply pass the two leads down through the holes in the board by the suggested distance, bend them over at 45° or so and then solder and trim.

In some cases both leads might have to be bent at 90° nearer the LED's body, if the LED is to project its light output in a horizontal direction rather than upwards. In these cases you'll probably find it easier to make this bend before you fit them to the board.

Don't forget that like ordinary diodes, LEDs are polarised and must be fitted to the board with the correct orientation. There are two ways to tell the orientation of most LEDs: If you check each one carefully you'll see that there's a 'flat' on one side of the plastic body. This indicates the cathode (K) lead. The two leads are also of unequal length, with the anode (A) lead about 2mm longer than the cathode lead.

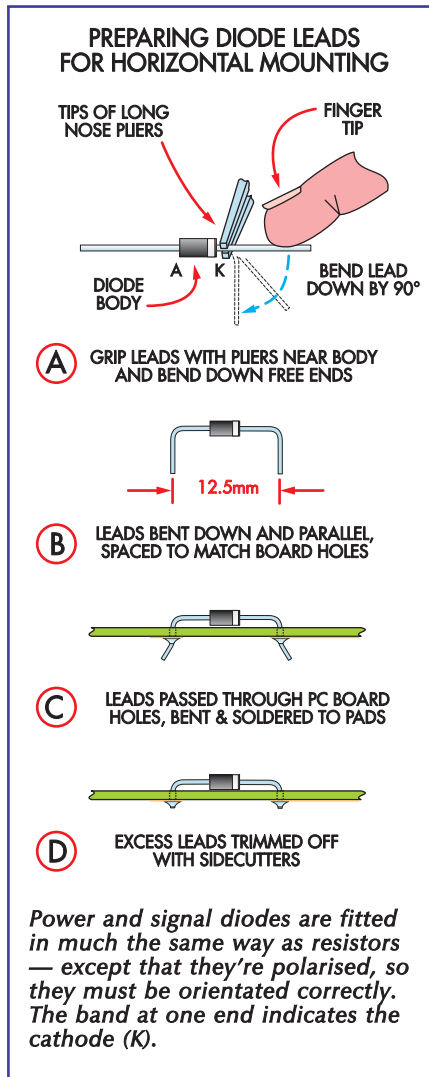
In the wiring diagrams for most projects (including those for all the projects in this book) you'll find that the orientation of all LEDs is indicated with not only an 'A' and a 'K' but also a circular symbol with the flat clearly visible. So if you follow the diagram carefully, you shouldn't make any mistakes.

## 10. Fitting transistors

Most of the transistors used in project kits nowadays come in a small moulded 'TO-92' plastic package with the three leads emerging radially from the bottom, either close together in line or in a triangle formation. Often you'll find that they emerge from the package in line, but the centre lead has been 'cranked' to space it away from the other two and so form a triangular arrangement. (See diagram at right)

In the projects described in this book, most of the transistors we've used come with their leads inline, but spaced only about 1.25mm (0.05") apart. These could obviously have been fitted to the PC boards simply by passing the leads down through the board holes, if we had spaced the holes by the same small distance. However we haven't done this, because it would have meant that the copper pads around the holes would have to be both very small and with very tiny spaces between them — both of which would have made soldering much trickier, especially for newcomers. So we've spaced the board holes 2.5mm (0.1") apart, to make soldering easier.

As a result, though, you'll need to dress the outer leads of



each transistor carefully outwards and away from the centre lead, so they become parallel again and spaced 2.5mm apart. Then the transistors can be mounted in each board position without any problems. This should be fairly clear from the diagram overleaf.

Of course transistors are again polarised, so they too have to be orientated correctly. In this case the transistor package shows the polarity quite clearly, because it has a 'D' cross-section with one side quite flat. In all of the wiring diagrams we show this flat side clearly to guide you in orientating each transistor correctly. So again, follow the wiring diagram closely and you shouldn't go wrong.

How far do you push the transistor's leads through the board holes, before you splay them and solder? Usually, as far as you can without straining the leads — which usually means up to the point where the outer leads are cranked.

## 11. Fitting ICs

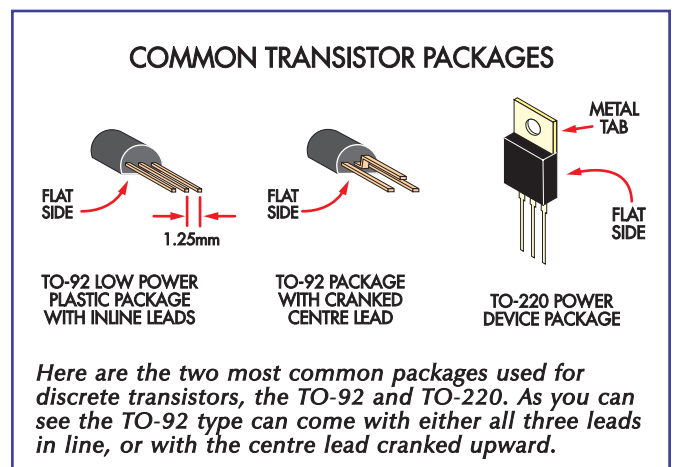
All of the ICs (integrated circuits) used in the projects in this book are in standard 'DIL' (dual-inline) packages. These are rectangular in shape, with rows of connection pins emerging along opposite longer sides. Many ICs are in an 8-pin DIL package, with two rows of four pins, while others are in 14-pin DIL (2 x 7 pins), 16-pin DIL (2 x 8 pins) or 18-pin DIL (2 x 9 pins) packages. The pins in each row are spaced 2.5mm (0.1") apart.

All of these devices have the pins already bent downwards with the two rows about 7.6mm (0.3") apart. This is the standard spacing for DIL packages, and the holes and pads on all PC boards designed to take them have the same spacing. So the idea is that the ICs are

mounted by passing all of the pins through the board holes, and then soldering them underneath.

The only complication is that in many cases the IC pins are not bent down by 90°, but a bit less — so the two rows are spaced a bit wider than 7.6mm apart, and won't easily pass down through the board holes. They have to be bent inwards until their spacing is reduced to 7.6mm.

There are special 'IC insertion' tools available to do this, but these are a bit expensive. The alternative is to gently and carefully bend the two rows of pins inwards by hand,



holding the body of the IC at the ends and rolling it with each row of pins against the benchtop (or another flat surface) so they're pushed evenly inwards a small amount. This is shown in the diagram below. Once you get the hang of this it isn't hard to do — just hold the IC carefully to avoid dropping it.

The only other thing to watch is that before you do this pin bending with CMOS devices like the 4093, 4017, 4024, 4066, 4511 or 4553, it's a good idea to discharge any static electric charge on yourself by touching some earthed metalwork (like a cold-water tap). Otherwise you might damage the IC.

Of course ICs are again polarised components, and must therefore be orientated the correct way around in order to work. The polarity of all ICs in DIL packages is indicated by a small semicircular notch at the centre of one end of the body, and often by a small 'dimple' depression on the top very close to the IC's pin 1. The wiring diagram for all of the projects in this book shows both the notch and dimple for each IC on the board, to guide you in fitting it correctly. So again, follow the wiring diagram.

## 12. Power transistors & regulators

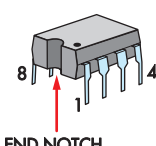
Many power transistors and three-terminal regulators are in a rectangular package with a small metal 'heatsink' tab on one flat surface ('the back') and emerging at one end, and the three connection pins emerging inline at the other end, spaced 2.5mm (0.1") apart. This is known as the 'TO-220' package.

These devices are only used in one or two projects in this book, and where they are used they're fitted quite simply by passing the three pins down through the PC board holes and soldered. Like other transistors and ICs these devices are polarised though, and have to be orientated correctly. The wiring diagram always shows how to orientate them, with the metal heatsink tab on the correct side. So as before if you follow the wiring diagram carefully you shouldn't have any problems.

## 13. Any coils to wind?

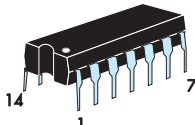
There's only one project in this book that uses small air-wound coils (project 22), and we hope to be able to supply

### DIL IC PACKAGES & PREPARING THEM FOR INSERTION



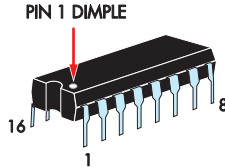
8  
1  
4

END NOTCH

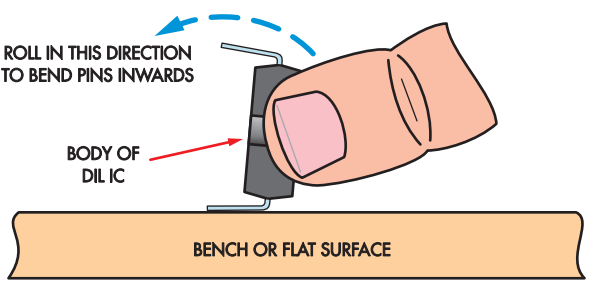


14  
1  
7

PIN 1 DIMPLE



16  
1  
8



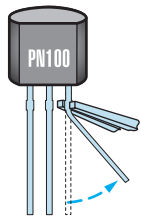
ROLL IN THIS DIRECTION TO BEND PINS INWARDS

BODY OF DIL IC

BENCH OR FLAT SURFACE

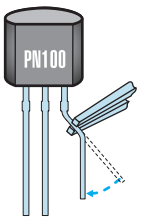
*All of the ICs used in the projects we describe in this book come in DIL packages like those illustrated at the top here, with either 8, 14, 16 or 18 pins. The rows of pins of many DIL devices are often splayed out so they're slightly wider than the correct spacing of 7.6mm, and need to be bent inwards slightly before they'll fit into the board holes. An easy way of doing this is shown here.*

### 'DRESSING' TO-92 TRANSISTOR LEADS



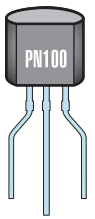
**A**

GRIP OUTER LEAD NEAR BODY AND BEND OUT BY 45°



**B**

GRIP ABOUT 2mm DOWN AND BEND DOWN BY 45°, PARALLEL AGAIN



**C**

BOTH LEADS CRANKED TO MATCH 2.5mm PC BOARD HOLE SPACING

*With transistors in the TO-92 package, you often need to crank their two outer leads to increase their spacing to match that of the holes in the PC board...*

these coils pre-wound in all of the kits for this project. However just in case this isn't possible in the occasional batch, we tell you how to wind these coils yourself in that chapter. It's really quite easy, as you'll see.

## 14. Checking before powering up

The last step of all, before you connect the battery to any project you've built, is to check everything very carefully all over again just in case you've made a wiring mistake. It's better to find and fix any mistakes now, because they might easily result in a component being damaged when the battery is connected.

Check that you've placed all resistors and capacitors in their correct position on the board, and that all of the polarised parts (electrolytic capacitors, diodes, LEDs, transistors and ICs) are orientated correctly as shown on the wiring diagram. Also examine all of your solder joints under the board, to make sure there aren't any dry joints or otherwise faulty connections — including slivers of solder forming short circuits between pads. In our experience, poor soldering accounts for over 70% of problems in electronics kit construction. Don't say you weren't told!

Everything look OK? Good, because this means that as soon as you hook the project up to a battery it should spring to life and do exactly what it's supposed to do. ★

### It just won't go? Some handy advice

What happens if your project doesn't work, even after you have 'tried everything'?

It is not at all unusual to find that your circuit will not 'go' at first. You proceed through your troubleshooting (checking solder joints, component orientation, the right resistors in the right place, flat battery etc.) and STILL it doesn't work! It may give you little comfort, but this is pretty common. Before you decide that the 'circuit god' is picking on you, though, consider this:

**If all the parts are functional, they are all in the right location and orientated correctly, and reliable power is available, THE LAWS OF PHYSICS DEMAND that the circuit will work. There is no alternative!**

Don't forget that thought. Cling to it. No one is picking on you, so go back to the beginning. Assume nothing, and methodically check through everything again. You WILL find the fault, if you try hard enough.

One of the greatest lessons you will learn from electronics construction is the discipline of logical, rational thought and analysis. It will pay you back in everything you do for the rest of your life.

# The Tools You're Going To Need

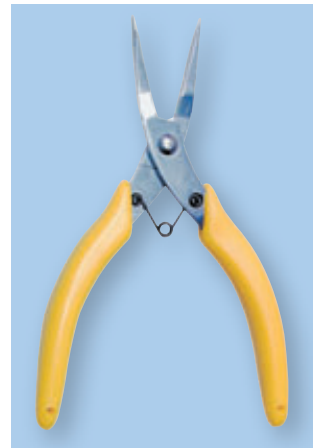
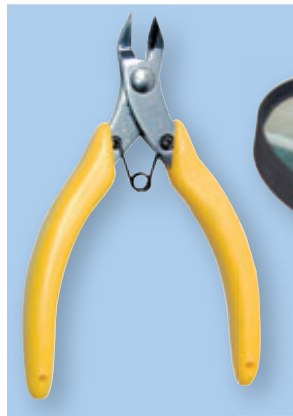
If the projects in this book are your first experience with “hands on” electronics experimenting and construction, here's a quick guide to the basic hand tools you'll need for this kind of work. There are quite a few other tools which will make things even easier (including a multimeter, which is discussed separately) but these are the ones you'll use the most often.



A set of small screwdrivers is essential for all kinds of jobs: loosening and tightening terminal blocks, opening and reassembling instrument boxes, fitting printed circuit boards and other parts inside boxes, fitting cables with plugs and sockets and so on. The Jaycar TD-2017 Precision Screwdriver Set gives you four flat-

bladed drivers plus two cross-bladed drivers for Phillips-head screws, all mounted in a handy wall holder.

Small side cutters or “nippers” are almost essential. You use them to trim off the excess component leads, cut wire links to length, remove outer insulation from cables and so on. These are the Jaycar TH-1890 cutters, which are 115mm long.



Small long-nose pliers are also very useful for jobs like bending component leads correctly, forming wire links and also holding small items like nuts in confined spaces. The Jaycar TH-1893 pliers shown here are spring-loaded and just the shot for most electronics work.

A properly designed wire stripper makes removing insulation from wires much easier, faster and safer. The Jaycar TH-1824 stripper shown here automatically adjusts to the insulation diameter and is well worth adding to your toolbox.



A low-power, electronics type soldering iron is a must. In the Jaycar TS-1651 Soldering Kit shown here, you get the soldering iron, a stand (to hold it when it's hot), some resin-cored solder wire and even a solder sucker to suck up solder if you make a mistake and need to unsolder a component.



A PC board holder can make things much easier when you're soldering components to a printed circuit board, holding it in place while leaving both of your hands free to hold the solder and the hot iron: an artificial 'third hand'! This is the Jaycar TH-1983, which is easily adjustable, has a magnifying glass and features a solid cast-iron base for stability.

A clip-on heatsink is handy when you're soldering small components, especially semiconductors. It prevents overheating by drawing the heat away from the body – and frees up your hands as well! This Jaycar TD-2122 is low in cost but all you need.



Pointed-end tweezers can help hold wires and component leads while you're soldering them, or small nuts while you're trying to fit them to screws. The low-cost Jaycar TH-1754 tweezers shown here are a good choice. ★



# Your Multimeter...

Multimeters make great tools for checking how well a circuit is operating— or for tracking down the cause of the problem, if it *isn't* working. But there are some basic DOs and DON'Ts to bear in mind, to make sure you take accurate measurements and don't risk damaging either your meter or the circuit you're testing. Follow this easy pictorial guide and you shouldn't strike any problems.

The main thing to remember when you're using a multimeter is that before you connect its probes to the circuit or component to be tested, make sure you have:

- Set it for the correct KIND of measurement — in the main, VOLTS DC if you're measuring DC voltages; VOLTS AC if you're measuring AC voltages or you are not sure whether the voltage is AC or DC; AMPS (or more likely, MILLIAMPS) if you're measuring current; or OHMS if you're measuring resistance.
- Set the right range — that is, a range higher than the highest voltage, current or resistance you expect to be measuring. If you don't know, select the highest range available.
- Plugged the probe leads into the correct sockets on the meter itself, for that kind of measurement and range.



For checking any of the circuits and components in this book (and in fact for most electronics work), a digital multimeter (DMM) or an analog type (as shown above right) are equally suitable. A wide range of digital multimeters is available from Jaycar Electronics stores, along with the QM-1020 analog multimeter shown above.

If you don't check these points, there could be an expensive BANG when the probes touch that circuit or component!



For most measurements, the black probe lead's plug goes into the multimeter's COM (common) socket, and the red lead's plug goes into the V-Ω-mA socket. Push them into the sockets as far as they'll go, to make sure there's a good connection and no exposed metal (which could allow accidental shocks if you're measuring high voltage).



Before measuring a DC voltage, set the meter to its highest DC voltage range (here 600V). That way, there shouldn't be any damage done if the voltage is higher than you expect. You can always click down a range or two to take the measurement more accurately, if you need to.



The same applies when you're about to measure an AC voltage — set the meter to its highest AC voltage range first, to avoid mishaps. Here the switch is set to 600V again, but this time on the AC voltage ranges (the V with a ~, a small sinewave 'wiggle', indicates AC voltage).



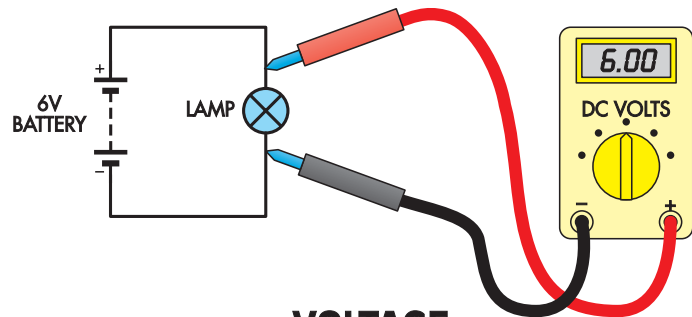
# and how to use it

## Measuring VOLTAGE — volts (V) and sometimes millivolts (mV)

Voltage is measured by connecting the meter across the component or circuit under test while power is connected. In other words, the meter is in PARALLEL with the circuit or part of the circuit under test.



When you're measuring voltage (also known as potential difference), the two meter probes are simply connected between the two points concerned — such as the terminals of a battery or the terminals of a lamp.



### VOLTAGE

METER IN PARALLEL WITH COMPONENT UNDER TEST



Let's start by measuring the terminal voltage of a battery. Turning the knob from 'OFF' to any other position (in this case the 200V DC range) also turns the digital multimeter on. Connect the red (positive) meter probe to the positive battery terminal and the black (negative) meter probe to the negative battery terminal. Here a fresh lantern battery reads just over 6V.

Since we now know the reading is below the maximum limit of the next range down (ie, 6V is less than 20V), we can click the knob to that range and the reading will be one digit more accurate. Note that it now says 6.21V, instead of 6.2V. Sometimes that extra accuracy is very important.

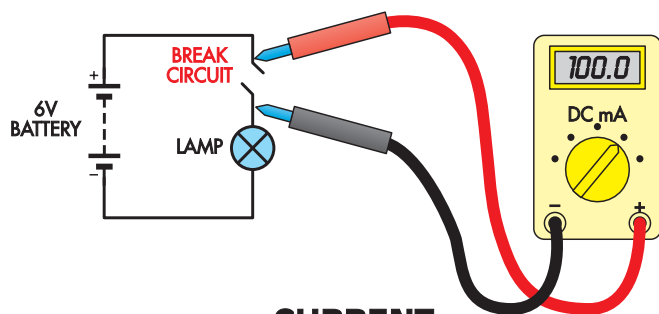


If you accidentally connect a digital multimeter's test probes to the battery terminals the wrong way around (ie, red to negative, black to positive), it will still read the correct voltage — but with a minus sign to show the reversed polarity. No harm done — but it's important to know what that minus sign means. With an analog meter you should never connect the probes back to front, because it may be damaged.

## Measuring CURRENT — amps (A), milliamps (mA) or microamps ( $\mu\text{A}$ )

Current is measured by making the current flow out of the circuit, through the meter and then back into the circuit again. In other words, the meter is connected in **SERIES** with the circuit or part of the circuit under test.

*When you want to measure the current in a circuit, you need to break the circuit at that point and connect the probes so that the current to be measured flows **THROUGH** the meter — which must be switched to the correct current range, of course. Here the small lamp is seen to be drawing close to 100mA.*

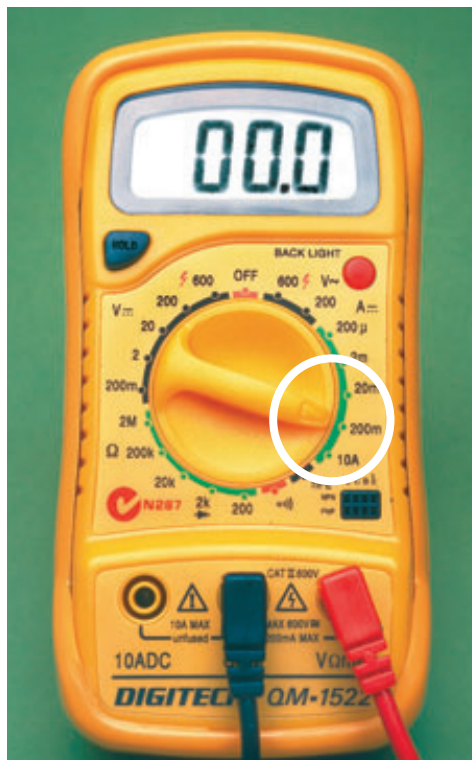


### CURRENT

METER IN SERIES WITH COMPONENT UNDER TEST



*When you are going to measure a current, it's again important to switch to a higher range than you expect before connecting the meter into circuit, to prevent accidental overloads. Here (below) the meter has been switched to the 200mA range, before making the measurement of lamp current — because, according to the manufacturer's data, the lamp should draw about 100mA from a 6V supply.*



*With many multimeters, the red (positive) probe lead needs to be changed over to a special 'high current' socket before you can measure currents of more than a few hundred milliamps — as well as switching to the appropriate higher current range. Here (above) the red lead has been plugged into the meter's '10A DC' socket on the left hand side, to measure currents up to 10A. Just remember to change the red lead back to the 'V- $\Omega$ -mA' socket before you try to make any other kinds of measurement, or there could be an expensive BANG!*

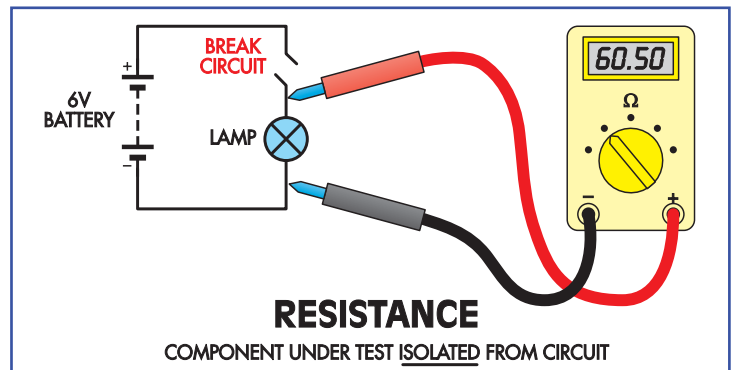


## Measuring RESISTANCE — ohms ( $\Omega$ ), kilohms ( $k\Omega$ ) and megohms ( $M\Omega$ )

Resistance is measured by passing a tiny current (provided by a battery inside the meter) through the component under test. The component must be isolated from other components and any other source of current, as this would upset the measurement — and could even damage the meter.

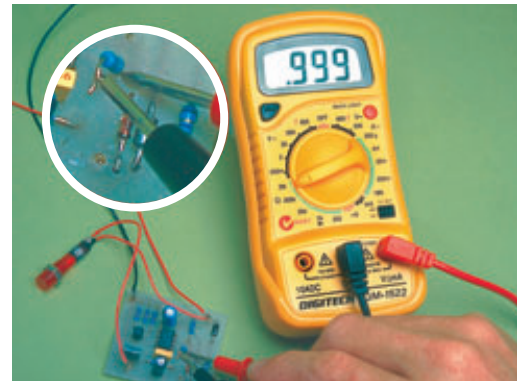


When you switch to any of the resistance ranges on a DMM and before you make a measurement, it generally gives the kind of 'over range' indication shown at left when there's no connection between the probes. If it doesn't, the battery inside the meter may need replacing.



Although you can measure the value of resistors that are soldered into a PC board by simply connecting the meter probes across them, this can give a false and lower reading because the board's tracks may be connecting other components in parallel with them. Here (left) a  $1M\Omega$  resistor is reading only  $665k\Omega$ , because of this problem.

To make an accurate measurement of a resistor on a PC board, one end should be carefully unsoldered from under the board and lifted so the meter can measure just the resistor by itself. As you can see on the right, the  $1M\Omega$  resistor is now measuring  $999k\Omega$  — which is well within its tolerance.



When you're trying to measure fairly high resistances, make sure you don't cause errors by connecting yourself in parallel with the probes. As you can see on the left, the human body is not a good insulator; here the resistance between the user's hands reads only  $1.51M\Omega$ .

With the user's hands well back from the probe tips and behind the guard rings on the plastic sleeves (which is the correct position for safety, in all measurements), the meter now reads 'over range' — as it should, with an open circuit between the probes.

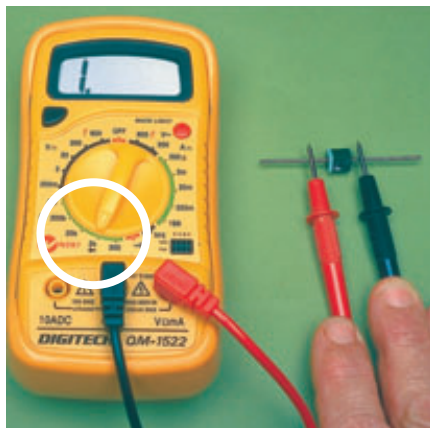


## Other ranges: diode/transistor checking, continuity, etc

Many modern meters, even low cost models, have a handy selection of other ranges which are used to check other components — semiconductors, especially. Some also have inbuilt buzzers to help check continuity. Here's how to make these measurements.



Many meters have a 'continuity' range, a low resistance setting which is used to check for breaks in cables and PC board tracks. When the two probes are touched together (or connected via a low-resistance circuit such as a cable conductor), the meter reads the approximate resistance between them. A buzzer or beeper may also sound, so you don't have to look at the meter to know that the circuit is OK.



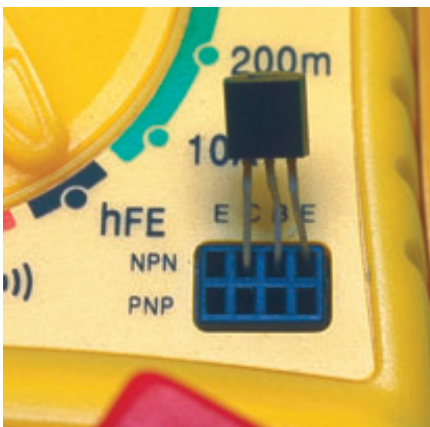
Checking the forward conduction of a silicon diode is very easy using the 'diode check' function. With the switch in the diode position, you simply connect the test probes across the diode one way and then the other. Here the positive (red) probe is on the cathode (striped) end, which reverse biases the diode. The meter reads '1' or over-range, just as a reverse-biased diode should read.



Reversing the probes (or the diode itself as shown here) forward biases the diode, with the meter now reading its voltage drop for a specified small forward current. Here the silicon power diode has a drop of 0.741V, showing that it's fine. Silicon diodes can be expected to show a forward voltage drop of between about 0.5V and 0.8V in this test, depending on their type. Higher voltages may indicate a fault.



Many multimeters can also be used to measure the current gain (also called the  $h_{FE}$  or 'beta') of bipolar transistors. In most cases, it's just a matter of switching the meter to the  $h_{FE}$  range and plugging the transistor into a multi-way transistor socket on the meter's front panel.



Just how the transistor is plugged into the meter to measure  $h_{FE}$  depends on whether it's an NPN or PNP type, and on the way its 'works' are connected to the three leads. As you can see both rows of holes have an emitter (E) socket at both ends, to allow for almost any possible combination of lead connections.



With the transistor plugged in correctly, the meter reads its  $h_{FE}$  current gain directly (in this case 461). If you get a very low reading, the transistor may be a dud, or you might have accidentally swapped the collector and emitter connections. If changing these connections over gives a much higher reading, that was the problem and your transistor is OK.

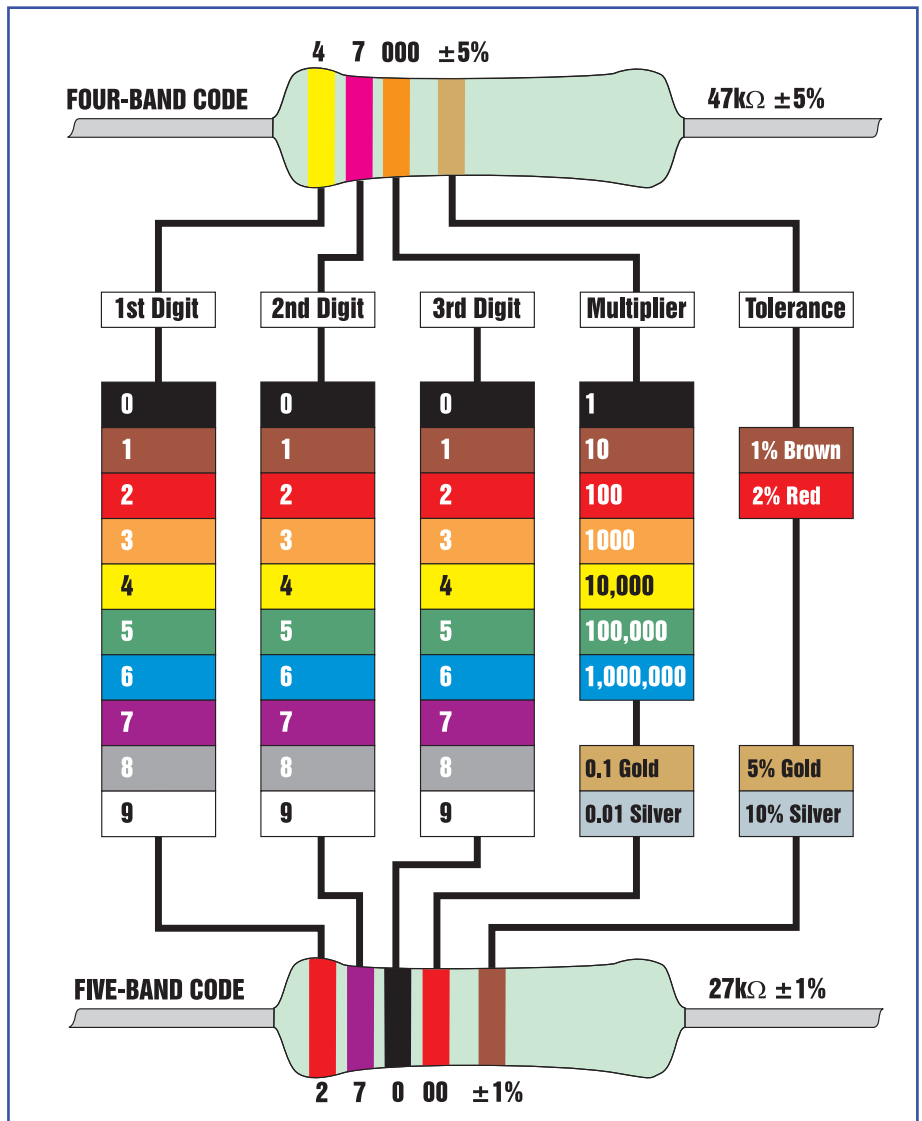


# Resistors & their Colour Coding

Resistors are one of the most common components in electronic circuits, but many of their bodies are too small to carry their **nominal value** and **tolerance** (or margin of error) printed in numerals. To get around this problem, a system of using tiny bands of coloured paint has been used for many years. Each colour band is used to represent either a numeral, or a particular decimal multiplier, so it's generally not too hard to work out the value of a resistor by checking its 'colour code' (see drawing at right).

The bands are normally nearer one end of the resistor than the other, and they're read from that end. What can make things a little confusing is that most modern resistors can have either four or five bands in all. With a four-band type, the first two bands show the basic value (there are only 12 possibilities for this type, in each 1:10

| Preferred Resistor Values<br>(in each decade or 1:10 range) |                               |                              |
|---|-------------------------------|------------------------------|
| E6 Series<br>(20% Tolerance)                                | E12 Series<br>(10% Tolerance) | E24 Series<br>(5% Tolerance) |
| 10  | 10                            | 10                           |
|   |                               | 11                           |
|   | 12                            | 12                           |
|   |                               | 13                           |
| 15  | 15                            | 15                           |
|   |                               | 16                           |
|   | 18                            | 18                           |
|   |                               | 20                           |
| 22  | 22                            | 22                           |
|   |                               | 24                           |
|   | 27                            | 27                           |
|   |                               | 30                           |
| 33  | 33                            | 33                           |
|   |                               | 36                           |
|   | 39                            | 39                           |
|   |                               | 43                           |
| 47  | 47                            | 47                           |
|   |                               | 51                           |
|   | 56                            | 56                           |
|   |                               | 62                           |
| 68  | 68                            | 68                           |
|   |                               | 75                           |
|   | 82                            | 82                           |
|   |                               | 91                           |



Use the diagram above to work out the value of any resistors you find in a project kit. The examples show resistors with 4-band (top) and 5-band codes (above).

range or **decade** — see table), while the third band shows the 'number of noughts' (i.e., the decade it's in) and the fourth band (often spaced slightly further away) shows the **tolerance** — how close to the specified 'nominal value' the actual value is likely to be.

With five-band resistors, which can have 24 possible values in each decade (they're generally of closer tolerance), the first three bands can be used to show the basic value — even though in most cases only the first two are really needed, and the third band is set to black (meaning '0'). In this case the fourth band signifies 'the rest of the noughts', to indicate the decade, and the fifth band gives the tolerance.

Note that the '0' represented by a black third band on a five-band resistor doesn't mean it can be ignored. That nought is still counted, so that a black third band followed by a red fourth band means there are THREE noughts — the equivalent of an orange third band on a four-band resistor (see lower example).

Sometimes the body of the resistor can have a colour which makes it hard to decide the exact colour of some bands by eye. The best plan here is to check the resistor value with a multimeter, before wiring it into your circuit. The same applies if the bands seem to be equally spaced from both ends, so you don't know which end to start from. Where there's a gold or silver band, though, this will often help you work that one out — because these bands always go at the end of the code. ★

# Soldering: How it's done

**ALL OF THE PROJECTS** in this book are built on printed circuit (PC) boards. These are thin sheets of epoxy fibreglass (or resin bonded paper — SRBP) which have etched copper tracks on one side to form the 'wiring'. The components which make up the circuit are on the other side, with their leads passing through holes drilled in the board.

It's easy to understand why they're called *printed circuit boards*, because the copper tracks and pads look as if they've been 'printed' onto the board.

To make the projects work, you have to make good metal-to-metal connections between the component leads and the copper tracks and pads on the PC board, so that electrical currents can flow easily between them. The way this is done is by making the joins using **solder** — an alloy of two metals (lead and tin) which is easily melted at a relatively low temperature.

You'll need to be able to solder properly to build these projects. Which means that they're not just good fun, but a great way to learn about soldering as well as about electronics. Don't worry, though; soldering is easy once you get the hang of it.

The basic idea is that the two metal surfaces to be joined (say the lead or 'pigtail' of a resistor, and a copper 'pad' on the PC board) are brought together and both heated up quickly using the tip of an electric soldering iron. They're heated to above 183°C, which is the melting temperature of the '60/40' solder alloy (60% tin, 40% lead) used in most electronic work.

Then the solder (usually in the form of fairly fine wire with a resin core) is touched on both surfaces. The solder melts and the resin acts as a 'flux' which dissolves any oxide on the metal surfaces so that the molten solder can 'wet' them and form a good permanent bond. Finally the soldering iron tip is removed carefully, allowing the solder to solidify again as a smooth and relatively strong metal 'joint'.

Sound easy? It really isn't hard, although it is a bit like riding a bike: you generally have to practice a while

before you can make good solder joints without even thinking about it.

Here are some practical tips, to get you off to a good start with your soldering:

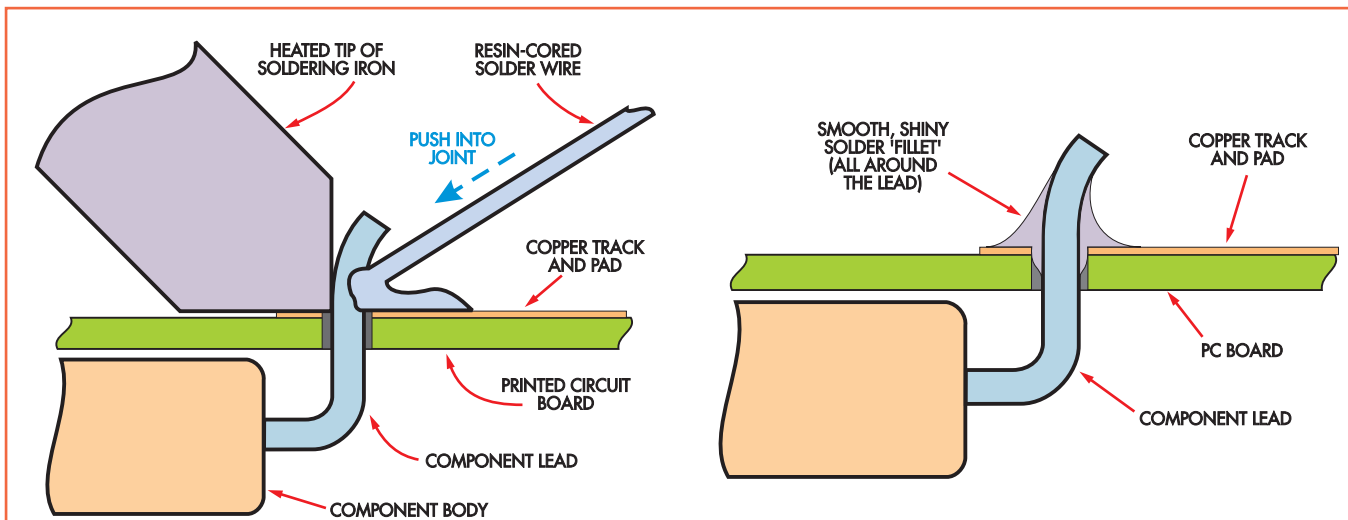
① Get yourself a good lightweight 'electronics' type soldering iron, with a small tip and not too much heating power. An iron rated at 25 watts is more than enough for building any of the projects in this book, and most general electronics work. A good example is the Jaycar Cat No. TS-1465. This is also available as part of the Jaycar Soldering Kit TS-1650, which comes complete with a nifty bench stand/holster, a tip cleaning sponge, some resin-cored solder and even some 'solder wick' braid to help remove solder when you need to.

Even better, if your budget will stretch that far, is a temperature controlled soldering station like the Duratech (Jaycar Cat No. TS-1380). This has a professional-type low voltage soldering iron with an adjustable thermostat to control tip temperature, plus a really solid bench stand and cleaning sponge, etc.

Don't try to use a heavyweight plumber's soldering iron — it'll not only make your arm and hand tired, but also risk overheating your delicate electronic parts and PC board. The same applies to gas-fired soldering torches and irons — although when you get skilled, one of the very small gas-fired soldering pencils is OK.

② Any two metal surfaces to be soldered need to be clean and preferably already 'tinned' — either plated with pure tin, like the leads of many modern components or cleaned and given a thin coating of solder using a soldering iron and solder.

③ The tip of your soldering iron also needs to be clean, and it should have a coating of tin or solder. Most modern iron tips are tin plated, but before making each joint it's a good idea to clean off any oxide, burnt flux etc by wiping it over a small piece of sponge which is moistened with water. The hot tip turns some of the water to steam, which in turn 'steam cleans' the iron tip.



1: How to solder a component lead to its PC board pad. The tip of the iron heats both the lead and the copper pad, so the end of the solder wire melts when it's pushed into contact with them.

2: A good solder joint. Notice that it has a smooth and shiny 'fillet' of solder metal, bonding all around to both the component lead and the copper pad of the PC board. This joint provides a reliable electrical connection.

## About Lead-free Soldering

Because the lead in traditional tin-lead solder is considered by some to be quite toxic, the world's electronics industries are in the process of changing over to **lead-free solder** in an effort to increase safety and reduce environmental pollution.

If you decide to use lead-free solder when you are building electronics projects, be aware that because this solder has a higher melting point (240°C) than traditional tin-lead solder, you'll need to set your soldering iron for this higher operating temperature.

Just be careful not to overheat the components when you're soldering their leads at this higher temperature. 'Speed with care' is still the motto.

- ④ Make sure the soldering iron tip has reached the correct temperature. If it isn't hot enough, you won't be able to make a good joint. If you're using a soldering station or iron with a thermostat, this usually begins making a ticking sound when the correct temperature is reached. Otherwise, try touching the end of the solder wire against the (cleaned) tip — it should melt and flow easily.
- ⑤ Try to touch the iron tip to both metal surfaces together, so they both heat up to soldering temperature in the shortest time. Otherwise one might get too hot before the other gets hot enough. This can cause damage to delicate components like ICs, and it may also overheat the PC board copper pad so that it lifts away from the board.
- ⑥ Almost immediately after applying the iron tip, touch the end of the solder wire to both metal surfaces. That way, the solder itself will melt and run into the joint the instant the right temperature has been reached. Push just enough solder into the joint to flow a nice 'fillet' of molten solder around the two surfaces, then remove the solder. Finally move the iron away too, taking care not to bump the joint before the solder solidifies again.  
Mind you, you'll solder each joint much quicker than the time it took to read the above lines of text. The

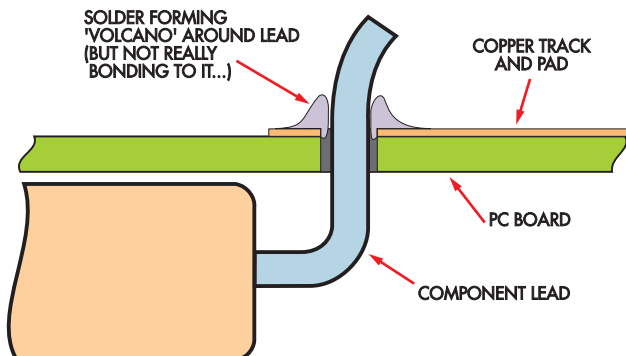
secret of good soldering is to do it quickly — heat up the joint, touch the solder to it so that it wets both metal surfaces and flows nicely, then pull the solder and the iron away without bumping the joint as it solidifies. It takes just a second or two to make each connection.

If the solder doesn't seem to want to melt against one of the metal surfaces, a good trick is to brush the end of the solder wire against the tip of the iron — so it starts to melt and flow between the surfaces. The molten solder itself will help bring the two metal surfaces up to temperature and 'start the ball rolling'.

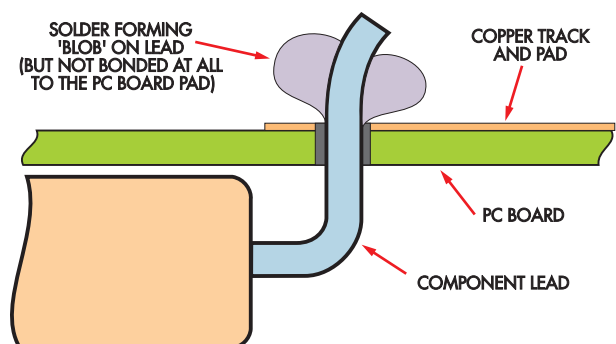
- ⑦ As we've already said, try to make the joint as quickly as possible because the longer you take, the higher the risk that the component itself and the PCB pad and track will overheat and be damaged. But don't work so quickly that you can't make a good joint — having to do it over again will also increase the risk of damage. So 'speed with care' is the motto.
- ⑧ As the solder solidifies, take a careful look at the joint you've made, to make sure there's a smooth and fairly shiny metal 'fillet' around it. This should be broadly concave in shape, showing that the solder has formed a good bond to both metal surfaces. If it has a rough and dull surface or just forms a 'ball' on the component lead, or a 'volcano' on the PCB pad with the lead emerging from the 'crater', you have a 'dry joint'. This will have to be done again — perhaps after cleaning one of the metal surfaces again. See the drawings for what you need to look for.
- ⑨ For projects that use one or more ICs, with their closely-spaced pins, you may find it easier to use fairly fine gauge solder (less than 1mm diameter). This reduces the risk of applying too much solder to each joint, and accidentally forming 'bridges' between pads or tracks.

Well, that's the basics of soldering. But if you're new to soldering, why not get in a bit of practice before you start work on your first real project? Find yourself a piece of old PC board and a few surplus resistors or bits of hookup wire, and try making a few solder joints. You'll soon get the hang of it.

By the way when you get a little further into electronics, you'll also need to know how to **desolder**. You'll find more about this on page 133. ★



3: One kind of 'dry' joint. As you can see, the solder has bonded to the PC board pad, but isn't bonded at all to the component lead. It'll cause trouble if it isn't re-soldered properly, so that it looks like drawing 2.



4: Another kind of dry joint. Here the solder has bonded to the component lead, but not to the PC board pad. Again it needs to be re-done to look like drawing 2, because there's no reliable electrical contact.

## Project 1:

# Red/Green LED Flasher

Here's a really simple and easy to build project to get you going. It flashes two LEDs (light emitting diodes) — one red and the other green — alternately, a bit like the lights on a police car. They're quite eye-catching, so you could use the flasher as a 'look at me' badge for parties, or as a warning light outside a darkroom...

### Putting it together

There are only a handful of parts used in this project: just three resistors, one capacitor, two LEDs, a diode and an IC (integrated circuit). They all fit on a printed circuit (PC) board measuring only 43 x 30mm, and coded SHRTC201. As with all of the other projects in this book the board connects to a standard 9V alkaline battery for its power.

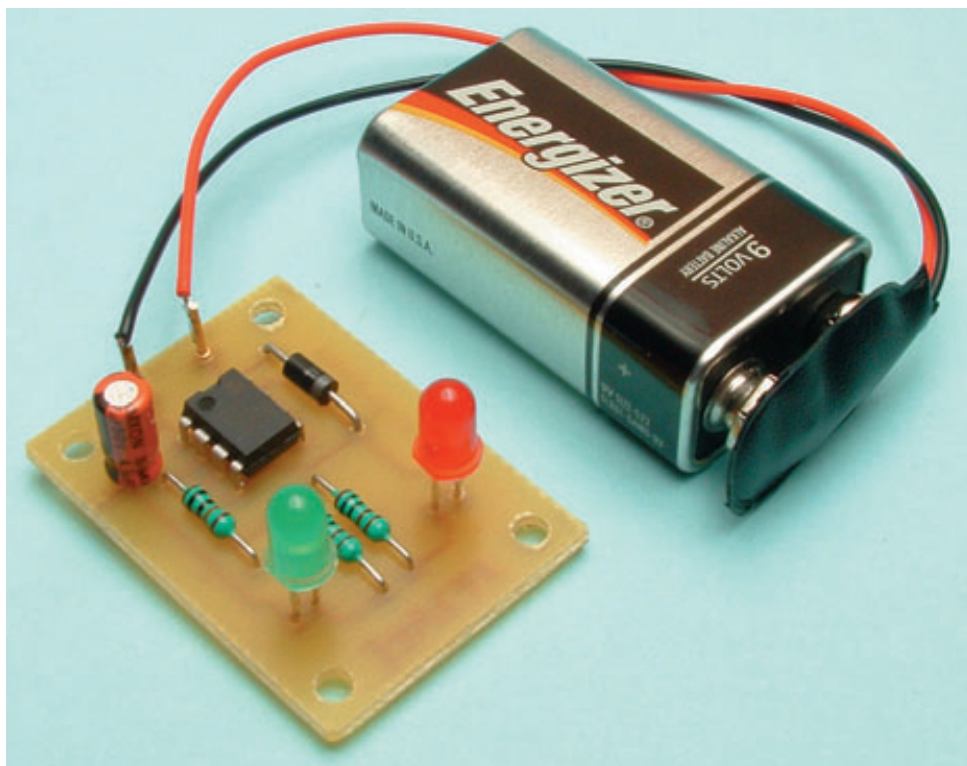
Before you begin construction, open up the kit and check that it includes everything. While you're doing this you can also make sure you can identify them all, work out the polarity of parts like the electrolytic capacitor and the diode, and 'read' the resistor colour code bands to get their values. If you're in doubt about any of these things you may need to refer back to an earlier chapter.

It's also a good idea to check the underside of the PC board for manufacturing defects, and fix them if you find any.

Start the actual construction by fitting the two PC board terminal pins. Then fit the three resistors, making sure that you fit each one in the correct position according to its value and as shown in the wiring diagram.

With the resistors fitted and their leads soldered, you can fit diode D1. This mounts in very much the same way as the resistors, except of course that it's polarised — so that it must be fitted the correct way around. As you can see from the wiring diagram this is with the cathode band towards the centre of the board and away from the terminal pins.

Next you can fit the 4.7 $\mu$ F capacitor, which is a single-ended 'RB' electrolytic component with both lead wires emerging from one end. These are parallel to each other, and should be ready to pass through the holes in the board. The main thing to make sure of is that you fit the capacitor



the correct way around, because it's again polarised. In this case the negative lead (shown by the black stripe on the side of the body) is towards the outside of the board, and the positive lead towards the centre.

You'll find that the board actually provides three holes for this capacitor, because they can come with the leads spaced either 2.5mm or 5mm apart. So if your capacitor has the leads spaced 5mm apart they can use the two outer holes, while if the leads are only 2.5mm apart you can make use of the 'extra' centre hole. Just be careful that you use the correct outer hole, because the pad under the hole nearest the board edge is already connected to the pad under the centre hole. So in this case use the third hole nearest the centre of the board for the capacitor's positive lead, and the centre hole of the three for the negative lead.

### The parts you'll need for this project:

- 1 PC board, code SHRTC201, 30 x 43mm
- 2 PCB terminal pins, 1mm dia.
- 1 9V battery, 216 type
- 1 Battery clip lead to suit

- 1 Small pack of resin-cored solder

#### Semiconductors

- 1 555 timer (IC1)
- 1 5mm red LED (LED1)

- 1 5mm green LED (LED2)
- 1 1N4004 silicon diode (D1)

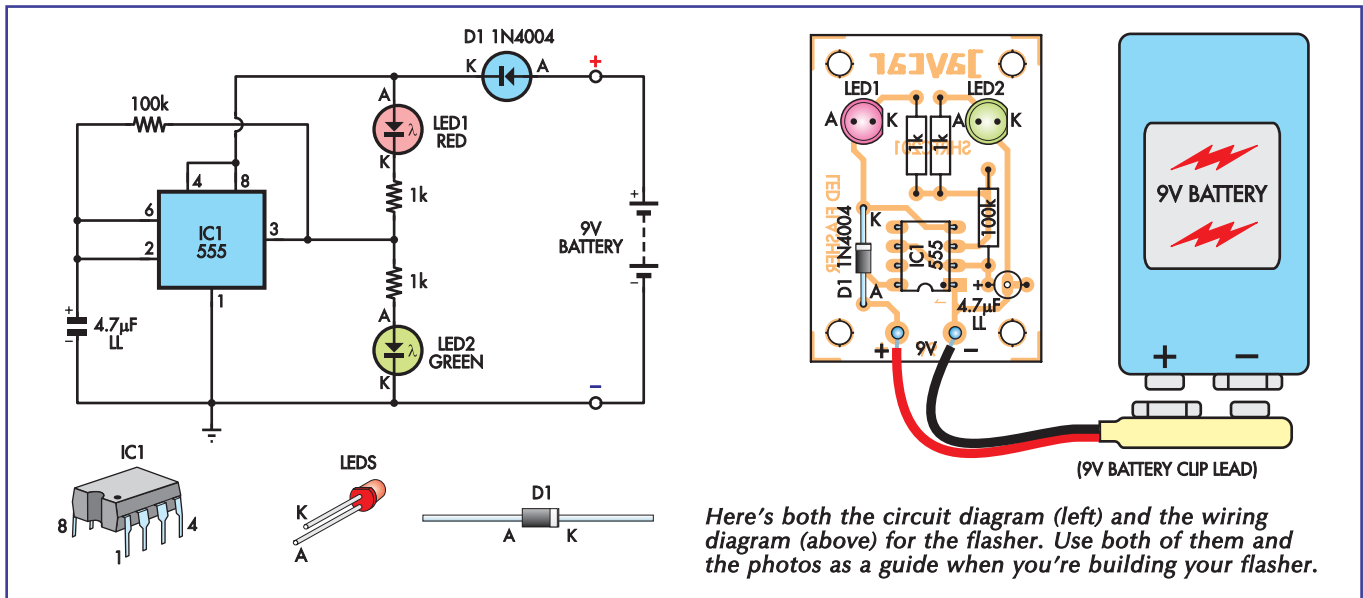
#### Capacitors

- 1 4.7 $\mu$ F RBLL electrolytic

#### Resistors (0.25W 1%)

- 1 100k                    2 1k





With the capacitor fitted and its leads soldered, we suggest that you fit the IC next. As you can see from the wiring diagram and photos this mounts with its notch or dimple end down towards the terminal pin end of the board. You may need to bend in the pins on each side of the device carefully, before they'll all pass through the holes in the board easily and without stressing them. Press the body of the IC down gently until the narrow part of each pin is passing through its hole, and then solder them all carefully to the pads underneath.

The final parts to fit are the two LEDs. The red LED is used in the LED1 position and the green one in the LED2 position, but be careful to fit each of them the correct way around. In this case both LEDs are fitted so that their flat side is towards the right, with the board held as shown in the wiring diagram.

You can fit both LEDs with their bodies down against the top of the board if you wish, although we suggest that you fit them about 8mm above the board as shown in the photos. This ensures that the LED leads can be soldered to the board pads with less risk of damaging the LED due to overheating. (It's also necessary to mount the LEDs this distance from the board if you're going to build the flasher into a UB5 box — see the What To Do Next section later.)

It's fairly easy to fit the LEDs standing away from the board in this way, if you cut a small strip of cardboard about 8mm wide and slide this between the LED pins on the top of the board, before you solder them underneath. Then remove the cardboard strip after the solder has cooled, and re-use it for the second LED. The final step of all is to solder the ends of the battery clip lead to the terminal pins on the board. As you can see from the wiring diagram, the red wire connects to the '+' pin and the black wire to the '-' pin. Once this is done, your two-LED flasher should be complete and ready to be tested.

### Trying it out

All you have to do to try out the flasher is connect up the cliplead to a 9V battery. The LEDs should immediately begin flashing

alternately: green-red-green-red-green and so on, with each LED flashing about once a second.

But what if your flasher *doesn't*, and just sits there with no sign of 'life' from either LED? Ah — this will be an opportunity to try out your troubleshooting skills, because a 'dead' flasher means you've made a mistake in wiring it up. So it's a matter of checking everything in a methodical manner, until you track down the error and fix it.

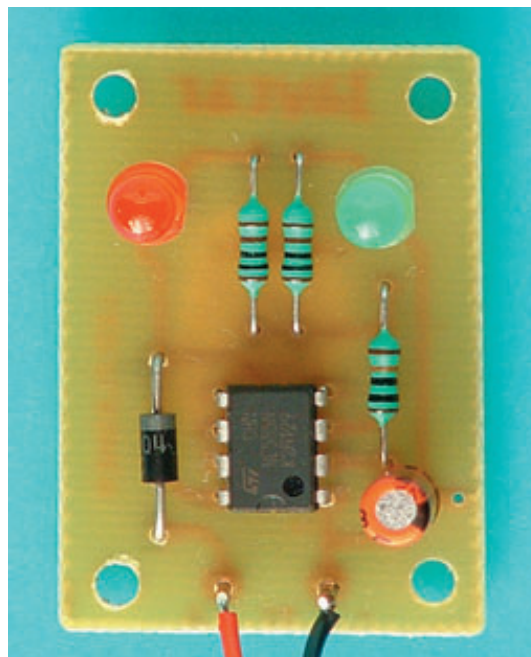
One mistake that can prevent the circuit from working is if you've connected the battery snap lead wires to the board terminal pins the wrong way around (i.e., with the red wire to the '-' pin and the black wire to the '+' pin). So first of all check that you haven't made this mistake — and if you have, heat up the soldering iron and swap them back to the correct connections.

Even if you wired up the snap lead wires correctly, you might have fitted diode D1 to the board the wrong way around. This will also prevent the circuit from operating, so check this next. If the diode is reversed, you'll have to carefully unsolder its leads (using de-soldering braid), remove the diode and then re-fit it the correct way around.

Yet another possibility is that you may have fitted the two LEDs the wrong way around, because this too will stop them flashing. So if you haven't found the cause of the problem yet, check the LEDs carefully and if they are reversed, desolder their leads and then refit them the correct way around.

Still haven't found the wiring mistake? Oh dear — there are probably only two further causes of a fully 'dead' flasher. One is that your battery might be as flat as a tack, so there's no energy to run the flasher. To check this, try another battery.

If this doesn't fix things, the only other possibility is that you've fitted IC1 the wrong way around. Let's hope that you haven't done this though, because you might have damaged the 555 device and it might have to be replaced. In any case it will be quite a job to desolder all of its pins and remove it from the board, before you can either refit it (or a new one) the correct way around.



## Tech Talk: How does it work?

The heart of the flasher is IC1, which is a low cost 555 timer circuit. These are very flexible devices, and you'll find them used in many electronic projects.

The 555 is fairly complex inside, with about 28 transistors and 12 resistors. But you don't need to know all about its innards to understand how it works here. All you need to know is that it has two input pins (pin 6 and pin 2) and an output pin (pin 3), and that it switches the output voltage at pin 3 between either the positive supply rail (here +9V, at pin 8) or the negative supply rail (-9V, at pin 1) — depending on the voltage we apply to its input pins.

Now let's see how we use it to flash the LEDs, which as you can see are connected between pin 3 and either supply rail. The red LED is connected from pin 3 to the +9V rail via a series 1k resistor to limit the current it can draw, while the green LED is connected from pin 3 to the -9V rail via a similar 1k resistor. When we first connect the battery, the 4.7 $\mu$ F capacitor connected from pins 2 and 6 to the negative rail will not have any charge, so there will be no voltage across it and pins 2 and 6 will be 'pulled low'. As a result the IC will switch its output pin 3 'high' (i.e., to +9V), and as a result LED2 and its series resistor will have very close to 9V connected across them. So LED2 can draw current, and will glow. On the other hand there will be almost no voltage across LED1 and its resistor, so LED1 will remain dark.

At the same time, the 4.7 $\mu$ F capacitor can draw current from pin 3 of the IC via the 100k resistor — so it begins to charge up. And as it charges, the voltage across it gradually rises. Since pins 2 and 6 of the IC are

connected to the top of the capacitor, the IC can of course 'monitor' this rising voltage.

When the capacitor voltage rises to about 6V (2/3 of 9V), the IC suddenly switches its output voltage down to the negative rail. As a result the voltage across LED2 and its series resistor disappears, while LED1 and its resistor now have 9V across them. So LED2 stops glowing, and LED1 glows instead.

When pin 3 switches low, the 4.7 $\mu$ F capacitor also stops charging. Instead it begins to *discharge*, because the 100k resistor now connects its positive plate to the negative rail. So the voltage across the capacitor (and as sensed by pins 2 and 6) begins to fall.

When the capacitor voltage drops down to about 3V (1/3 of 9V), the IC again switches the voltage at its output pin 3. This time it switches up to +9V again, so LED1 goes dark and LED2 begins glowing again. And so the switching cycle continues, as long as the battery is connected. LED2 is on when the 4.7 $\mu$ F capacitor is charging and its voltage rises from 3V to 6V, while LED1 is on when the capacitor is discharging and its voltage is falling from 6V to 3V. *Voila!*

What controls the flash timing? That's easy — each LED stays on for the time it takes for the 4.7 $\mu$ F capacitor to charge or discharge by three volts, via the 100k resistor. So the time for each half of the flash cycle is set by the RC 'time constant', found by multiplying the R and C values together. This gives very close to half a second in this case (100k x 4.7 $\mu$ F), so the time for a full flash cycle is about one second.

Replacing the capacitor with one of a lower value (say 2.2 $\mu$ F) will make the flasher go faster, while replacing it with one of larger value (say 10 $\mu$ F) will make it flash more slowly. Get the idea?

But what if your flasher 'kind of works', with say the green LED glowing all the time and the red LED never glowing at all — or vice-versa? The likely cause of this problem is wiring the 4.7 $\mu$ F capacitor in the wrong way around, or between the two 'outer' holes in that position on the board (which means it isn't really connected into the circuit). So check for either of these mistakes, and if necessary fix them.

### What to do next

One use for this type of LED flasher is as an attention-getting gizmo to wear at parties, etc. You can use the flasher board 'naked' in this case, perhaps even cutting off all four corners and rounding them so that it becomes an oval or 'rounded octagon' shape. You could easily cement a small safety pin or similar to the back of the board using epoxy cement, so that the flasher can be pinned to your tee shirt or jumper. The battery snap lead can be 'extended' by soldering it to a 500mm length of twin lead, so the battery can be kept in your pocket.

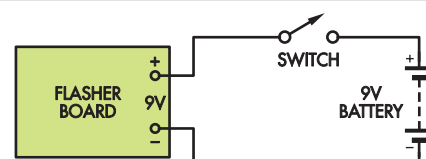
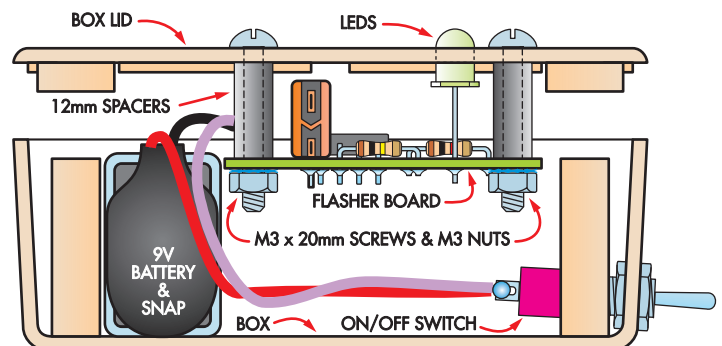
Another use for the flasher is as a warning light on the door of photo darkrooms, or other rooms where you sometimes don't want people to barge in unexpectedly. For this kind of use, you can build the flasher into a UB-5 size plastic jiffy box — the HB-6025 box stocked in Jaycar stores would be ideal. The flasher board and its 9V battery will easily fit inside this box, and there's even space to fit a miniature on/off toggle switch if you would like. The one to use would be either the Jaycar ST-0335 or the ST-0300.

The way to mount the flasher board in an HB-6025 box is shown in the diagram at right. The board itself is attached behind the lid/front panel using four 20mm long M3 machine screws, with M3 nuts and lockwashers behind the board and four 12mm long metal spacers between the lid and the board to space them by this distance. Before mounting the board a pair of 5mm diameter holes are drilled in the lid 17mm apart, so the LEDs can just protrude through when the board is mounted.

If you want to fit the on/off switch in the same box, it can be mounted in the top centre of the box near the rear (so that it clears the flasher PCB when the lid is fitted). The way to wire the switch to the battery snap lead and flasher are also shown in the diagram below.

An alternative approach would be to connect up the switch via a length of light twin-core figure-8 flex (like Jaycar WB-1702), so that you can control the flasher from a distance (inside the darkroom, for example). You'll still have to make a small hole in the box to provide an exit for the switch lead, though.

Either way, the boxed flasher can be attached to a wall or door using double-sided adhesive tape. This should hold it securely, because the complete assembly is very light — less than 100 grams, including the battery.





# Transistors & Integrated Circuits

Like virtually all electronic equipment nowadays, the projects described in this book rely for their operation on tiny amplifying and switching devices called *transistors*. Often quite a lot of transistors are combined with miniaturised resistors, diodes and other components, to form completely *integrated circuits* or 'ICs'. Transistors and ICs have taken over completely from the amplifying devices that were used for most of the first radios, amplifiers, TV sets and computers: *thermionic valves*, or 'tubes' as they were called in America.

Valves were a development from the light bulb we all know so well (more properly called an 'incandescent lamp'). Like light bulbs, valves have a glass container from which the air has been pumped out to leave a vacuum. They also have a filament (called a *cathode*) which is heated by an electrical current until it glows red hot. Electrons are 'boiled off' the cathode and head towards the other main electrode, called the *anode* or 'plate'. Other electrodes (eg, one or more *grids*) are placed in the electrons' path to control their flow.

Transistors and ICs work in a different way. In this case the electrons move around inside a solid piece of crystal.

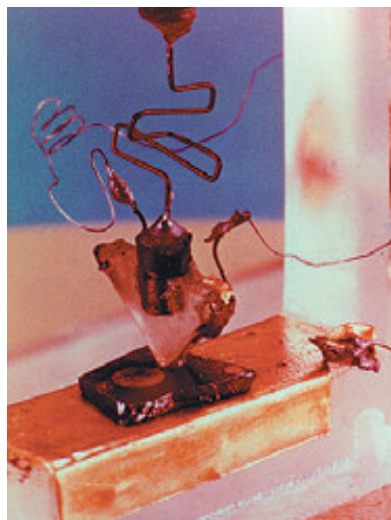
The first transistor was developed in 1947 at Bell Laboratories in the USA, by physicists John Bardeen, William Shockley and Walter Brattain. It had two tiny pointed gold electrodes touching a sliver of germanium crystal — very crude, but it had quite a useful amplification and could be made to oscillate. The era of 'solid state' electronics had begun, and in 1956 the transistor's three inventors were awarded the Nobel Prize for this important achievement.

By the way, 'solid state' is simply a reference to the way currents flow through solid material inside transistors, etc — as distinct from the way electrons flow through a vacuum inside a valve.

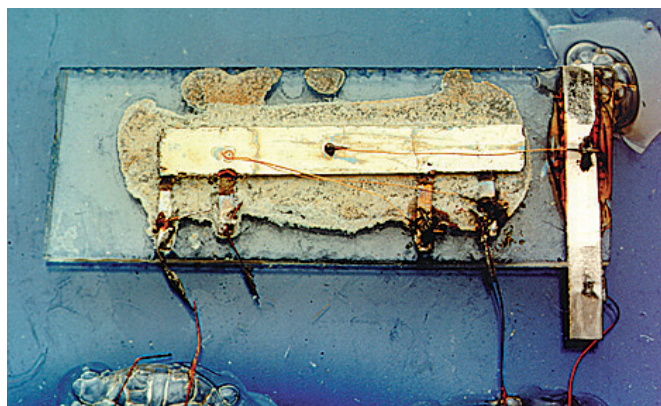
Soon it was discovered that transistors had much better performance if they were made using silicon instead of germanium, and from that point on silicon has been used for most solid-state devices. Fortunately, silicon is the most abundant mineral on Earth: every time you go to the beach, you're walking over millions of tonnes of silicon in the form of sand (silicon dioxide).

Extremely pure crystals of silicon are used to make solid-state devices, sliced into extremely thin 'wafers'. Inside the wafers different regions are 'doped' with microscopic amounts of other elements (like phosphorus or boron) to vary their electrical behaviour.

As more became known about making transistors, it was realised that they could be made very much smaller than the first models. Not only that, but engineers soon realised that other components like diodes, resistors and even capacitors could be miniaturised in the same way — suggesting that many components could be 'integrated', or built together inside a single piece of silicon. This would make complete



**The first crude transistor, developed in 1947 by Bell Lab researchers Bardeen, Shockley and Brattain.**



**Here is the first working IC, developed in 1958 by Texas Instruments engineer Jack Kilby.**

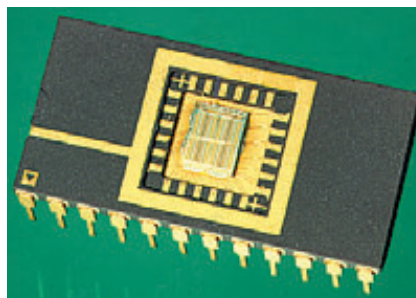
integrated circuits, much smaller than ever before.

In September 1958 in the USA, Texas Instruments engineer Jack Kilby produced the first working IC on a tiny sliver of germanium. It was a crude phase-shift audio oscillator, but it worked and showed that the idea had real potential. The following year Dr Robert Noyce of Fairchild Semiconductor worked out how to make much better ICs out of silicon, using the newly developed 'planar' technology.

The age of the integrated circuit had begun, and ICs have become more and more complex, much more powerful and yet lower in relative cost ever since. And this has been happening at a faster and faster rate, which still shows no sign of slowing down.

Nowadays the latest microprocessor, memory and signal processing ICs can contain many *millions* of transistors and other components, on a tiny 'chip' of silicon which is often less than 8 - 10mm square and only 1mm or so thick. For physical protection this chip is then usually mounted inside a larger ceramic or plastic package, with one, two or four rows of metal pins or pads to allow it to be connected to the 'outside world'.

The projects in this book generally use relatively simple and very low cost ICs containing only a few dozen transistors, like the 555 timer chip which forms the heart of projects 1, 3 and 4. This comes in a small plastic package with two parallel rows of four pins, known as the '8-pin DIP' (Dual In-line Package). Others like the 4093B logic gate used



**Today's ICs can contain millions of transistors, all in a tiny chip mounted (and usually sealed) inside a ceramic or plastic package with rows of pins or pads for the connections. This 24-pin IC has had the metal cover removed to show the tiny rectangular chip inside, with its fine connecting wires.**

in project 2 come in a larger version of the same package known as the '14-pin DIP', with two rows of seven pins.

Single individual 'discrete' transistors are still made, in a variety of different three-pin packages of their own. These usually provide the most convenient way to experiment with new circuits, and you'll find this type of transistor used in many of the projects in this book. ★

## Project 2:

# A Handy Timer

Need to control exactly how long your breakfast egg is boiled on the stove? Or how many seconds your photo enlarger's lamp stays on for making a print? Here's an easy to build electronic timer that can be used for any job like this. It can directly control things like a low-voltage lamp, keeping them on for the time you want, or if you prefer it can turn on a buzzer when the time's up.

### What does it do?

When you press the timer's Start button, it turns on a small relay and begins timing (this also happens when you first connect a battery to the timer). A red LED also begins glowing, to show that the timer is working. When the elapsed time reaches the figure you've set with the trimpot, the relay and LED are both turned off again.

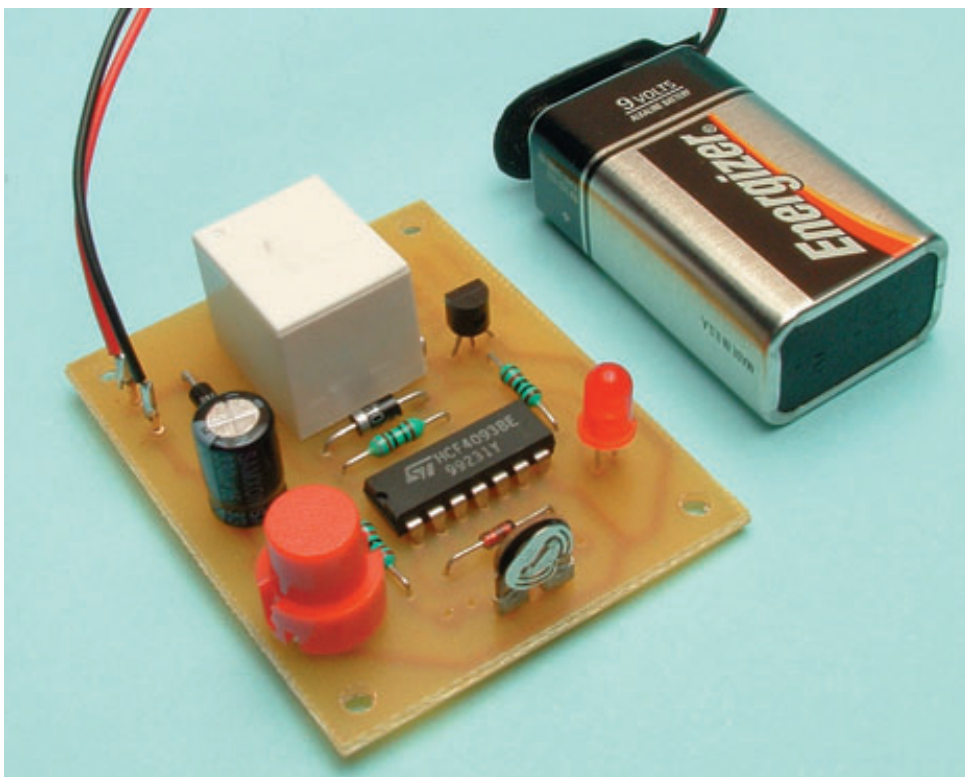
As the relay has both normally open (NO) and normally closed (NC) contacts, this allows the timer to control all kinds of things. For example using the relay's NO contacts you can have it turn on a low voltage lamp, buzzer or motor only during the timing period. Alternatively by using the NC contacts you can have it turn **off** the power to any of these kinds of loads during the timing period, and turn it on again only when the time period has ended. By using both contacts you can even have it control two different things at once — one turned on during the timing period, and the other turned off at the same time.

This makes the timer very flexible, even when you use it purely to control a buzzer to let you know when the set time has elapsed. You can have it turning on the buzzer to sound during the timing period, so the buzzer stops to signal when time's up, or alternatively have it turning the buzzer off during the timing period and on again at the end. It's your choice!

The timing period can be set between about 10 seconds and 4.5 minutes, using the small **trimpot** supplied in the kit. This range should be fine for applications like timing how

long your breakfast egg is boiled, or controlling how long a darkroom enlarger lamp is kept on to print from a negative.

If you need to be able to adjust the timing period conveniently with a knob, it's quite easy to replace the trimpot with a standard control potentiometer or 'pot'. Also if you need to be able to adjust the time period more easily over a smaller range — like just between 10 and 60 seconds, for example — this is easy to achieve as well just by changing the pot value. We tell you how to customise the timer like this later, in the 'What to do next' section.



## The parts you'll need for this project:

- 1 PC board, code SHRTC202, 61 x 47mm
- 1 6V SPDT mini relay (Relay 1)
- 1 Pushbutton switch, PC board mounting (S1)
- 5 PCB terminal pins, 1mm dia.
- 1 9V battery, 216 type
- 1 Battery clip lead to suit

- 1 1M vertical trimpot, 5mm open carbon type (VR1)
- 1 Small pack of resin-cored solder

### Semiconductors

- 1 4093B quad Schmitt NAND gate (IC1)
- 1 PN100 (Q1)
- 1 5mm red LED (LED1)

- 1 1N4148/1N914 diode (D1)
- 2 1N4004 diodes (D2,D3)

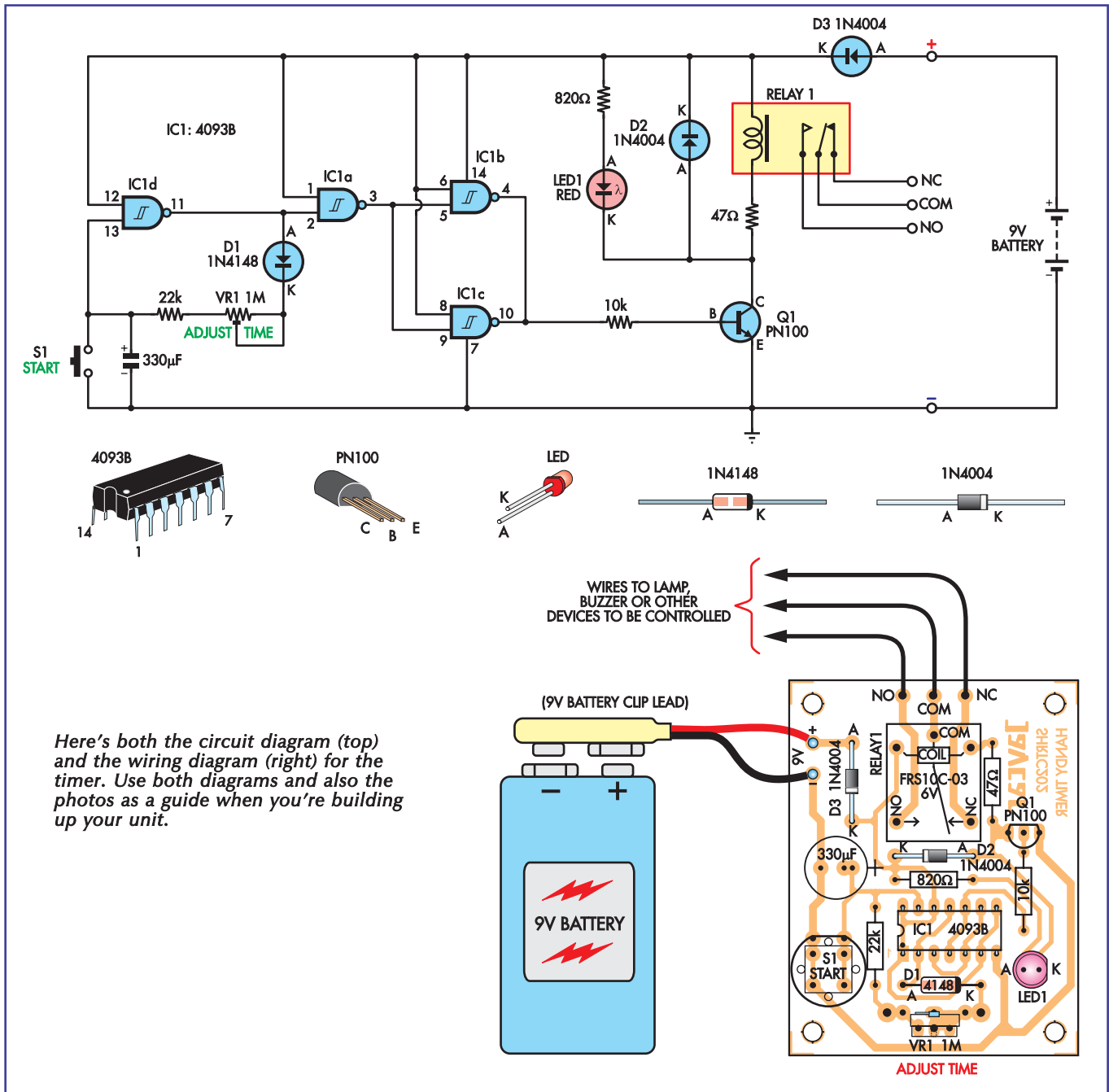
### Capacitors

- 1 330µF 16V RB electrolytic

### Resistors (0.25W 1%)

- |            |           |
|------------|-----------|
| 1 22k      | 1 10k     |
| 1 820 ohms | 1 47 ohms |





## Putting it together

The timer uses only a small number of parts, and these all mount on a PC board (SHRTC202) measuring 61 x 47mm — apart from the 9V battery used for power. This connects to the board via the usual clip lead.

Before you begin assembly, open your kit and check that it includes everything by comparing them with the parts list below. Make sure you can identify each of the resistors from their colour codes, and also that you can identify the two 1N4004 power diodes and the 1N4148 signal diode in its smaller glass package.

As usual it's also a good idea at this stage to check the underside of the PC board for manufacturing defects. If it has any, now is the time to fix them.

Start the actual construction by fitting the five terminal pins to the PC board. Then fit the four fixed resistors, making sure that you fit each one in the correct position as shown in the wiring diagram above.

Once the resistors are fitted and their leads soldered, you

can fit the three diodes. These mount in much the same way as the resistors, except of course that they're polarised so they must be fitted the correct way around. The correct orientation of each diode is shown clearly in the wiring diagram above.

Next you can fit the 330µF electrolytic capacitor, which is also polarised. We've provided two alternative holes for the capacitor's + lead, so use whichever one is closest to the lead spacing of your capacitor, in terms of its distance from the hole for the capacitor's - lead.

Now fit the pushbutton switch S1. Orientate this carefully when you fit it to the board, because although it has four pins in a square array, these are internally connected together in two pairs. So the switch is effectively polarised, and it won't work properly in this project unless it's fitted with one connected pair of pins on each side.

Check the switch carefully, and you may find that its body has a flat on one side. As you can see from the wiring diagram, it should be fitted to the board with this flat side towards the 330µF capacitor and the top of the board.

## Tech Talk: How does it work?

The basic timing circuit is built around IC1d, one section of a 4093 quad Schmitt trigger. By connecting its output (pin 11) back to one input (pin 13) via diode D1, trimpot VR1 and the fixed 22k resistor, and with the input also connected to the timer's negative rail via the 330 $\mu$ F capacitor, we turn IC1d into a simple but effective timer.

It works like this. When power is first applied from the battery, or just after pushbutton S1 has been pressed and released, the 330 $\mu$ F capacitor is completely discharged. As a result there is no voltage drop across it, and input pin 13 of IC1d is pulled down to the same low voltage level. This causes IC1d to switch its output pin 11 up to the same voltage as the positive supply rail, or nearly +9V.

The 330 $\mu$ F capacitor is now able to begin charging up, by drawing current through D1, VR1 and the 22k resistor. As you can see the setting of VR1 controls how much charging current can flow, and therefore the charging time.

When the capacitor has charged up to about 4.5V, this makes IC1d suddenly switch states and its output pin 11 suddenly switches to a very low voltage. As this makes the anode voltage on D1 more negative than its cathode voltage, the diode therefore stops conducting. This stops the 330 $\mu$ F capacitor from charging any further, and IC1d therefore stays in this state until either the battery is disconnected or pushbutton S1 is pressed to discharge

the capacitor and start the timing cycle all over again.

The rest of the circuit allows this simple timing circuit to control both the LED and relay. IC1a is used as an inverting buffer, so its output pin 3 goes low during the timing cycle and switches high only at the end. This is used in turn to drive IC1b and IC1c, which are connected in parallel as inverting buffers — so that their output pins 4 and 10 go high again during the timing cycle. All three buffers are used so we can control transistor Q1 by sensing the voltage changes at the timer's output (pin 11) without drawing any current directly from it (which would upset the timer's operation). So think of IC1a, b and c as providing **power gain** — they provide a replica of the voltage at pin 11, but with the ability to provide current to control Q1.

As you can see the outputs of IC1b and IC1c are connected to the base of Q1 via a 10k series resistor. So during the timing period, Q1 is switched on and draws current through both LED1 (via its 820 $\Omega$  series resistor) and the coil of Relay 1 (via its 47 $\Omega$  series resistor). This is how LED1 and the relay are turned on during the timing period.

Diode D2 is connected across the relay coil with its cathode to the positive supply rail to protect transistor Q1 from the **back-EMF** (see Glossary) voltage 'spike' which tends to be produced by the relay coil's inductance when Q1 switches off. Diode D3 is connected in series with the battery input to protect all of the circuit components from damage if the battery is accidentally connected with reverse polarity.

Next you can fit the trimpot VR1, which goes at the centre bottom of the board. It's a small trimpot which mounts vertically, as you can see from the wiring diagram and photos. Don't be confused by the additional holes in the board at this location; these are provided to allow you to use a larger pot instead of the trimpot. We'll tell you about this later, in the 'What to do next' section.

The next component to fit is the relay, which goes near the top of the board just below the three output terminal pins. The relay itself has five pins, three near one end and two near the other, so you can really only fit it to the board one way — the correct way. Make sure the pins are pushed through the board holes as far as they'll go, with the relay body resting flat against the board, before you solder them.

The next two components to fit are transistor Q1 and LED1. These are both polarised of course, so you'll need to follow the wiring diagram carefully to fit them with the correct orientation. Q1 fits with its flat side towards the top of the board, while LED1 fits with its flat side towards the right. You can mount the LED with its body about 8mm above the board, as shown in the photos.

The final component to fit is IC1, a 4093 integrated circuit. This mounts with its notch and dimple end towards switch S1 and the left hand side of the board. Don't forget that the 4093 is a CMOS device, so it's susceptible to electrostatic charge damage. Before you handle it, discharge your body by touching some earthed metalwork (like a cold water tap), preferably while you're also

touching the copper tracks on the board (so they're discharged too). Then there shouldn't be a problem when you handle the IC and fit it to the board.

To finish building your timer, solder the two wires of the 9V battery clip lead to the terminal pins at the top left of the board, near diode D3. The red wire goes to the upper + pin, and the black wire to the lower - pin.

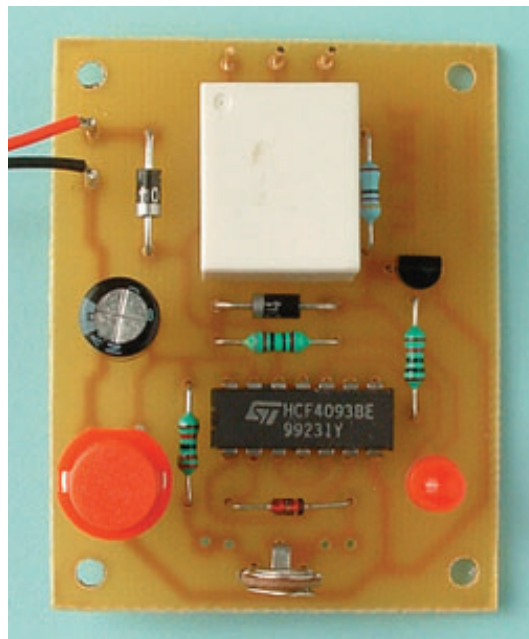
Your timer should now be complete and ready to go. But just before you try it out, check all the components carefully to make sure you haven't made any mistakes with their position or orientation. Also inspect solder joints carefully to make sure you haven't made any dry joints or solder bridges.

### Trying it out

If everything seems to be OK, connect a 9V battery to the timer's clip lead. The LED should immediately begin glowing, and you should also hear a small click from the relay as it is switched on at the same time.

How long they both remain on will depend on the setting you've given for trimpot VR1, because this sets the timer's period. So if you've set the trimpot fully anticlockwise (minimum), the LED and relay will be turned off again quite soon — after less than 10 seconds. On the other hand if you've set the trimpot fully clockwise (maximum), the LED and relay will stay on for a much longer time — about 4.5 minutes — before they are turned off again.

Setting the timing period for any time in between these two figures is simply a matter of adjusting VR1 to the right in-between



*Here's a closeup view of the timer board, to help you in wiring it up. Note that your pushbutton S1 may be slightly different and a different colour from the one shown here.*

setting. Setting it about halfway will give a timing period of about 2.3 seconds, for example.

Note that although the timer begins a timing cycle as soon as you connect the battery, further timing cycles are triggered simply by pressing the Start button S1 briefly. So there's no need to keep disconnecting and re-connecting the battery, to get new timing cycles.

### What to do next

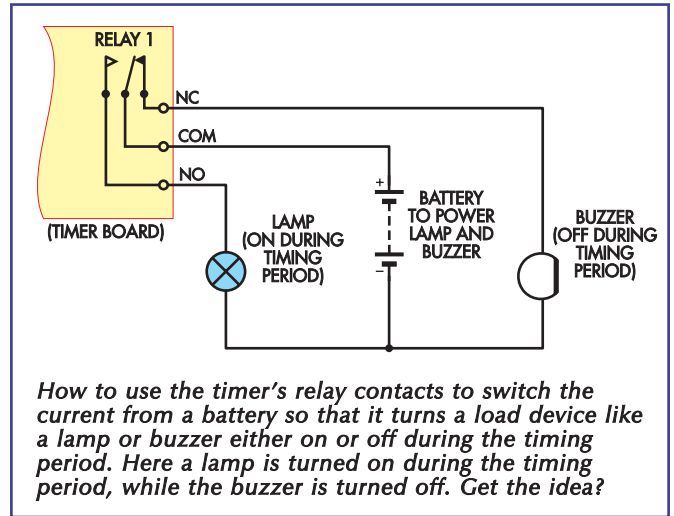
As mentioned earlier, if you want to make setting the timer's period easier than with a small screwdriver, this can be done quite easily simply by replacing trimpot VR1 with a larger 16mm or 24mm control pot. The PC board is already provided with mounting holes and pads for either of these standard pots, as you've probably noticed already. The larger pot can then be fitted with a control knob, and even a dial showing the time period for each setting if you wish.

If you still want the timer's period to be adjustable over the same 10 sec — 4.5 min range, the control pot you fit should have the same 1MΩ maximum resistance value as the trimpot. On the other hand if you want your timer to have a smaller adjustment range, you can fit a control pot with a lower resistance value. For example a 250k pot (e.g., Jaycar Cat No. RP-3520) will give a range from 10 to 70 seconds approximately.

What if you'd like the minimum timing period to be much less than 10 seconds? That's not hard either. All you have to do is replace the 330μF electrolytic capacitor with one of smaller value — like 100μF or 33μF. If you fit a 33μF capacitor, for example, the minimum timing period will drop to a little less than one second.

Ideally this capacitor should be of the low leakage (RBLL) type, because this will make the timing period more stable and reliable.

As we explained earlier, the way you get the timer to control things like a lamp or buzzer is by using the relay contacts to switch power to these 'loads'. Use the NC



contact if you want the load to be turned off during the timing period, or use the NO contact if you want the load to be turned on during the timing period. The connection from the battery you're using the power the loads goes to the COM contact.

This is all shown in the small diagram above, which also shows how you can use both the NC and NO contacts if you want to turn one load off and another load on during the same timing period. The possibilities are almost endless.

**Please note, though, that this timer and its relay are not suitable for controlling any loads or equipment that operates directly from the power mains.** Controlling mains operated equipment requires much better insulation, both to protect the equipment from damage and to protect you from potentially fatal electric shock. So don't even think about controlling mains powered things, at this stage.

## Ohm's Law – and Power in a Circuit

Way back in 1827, long before the development of radio or electronics, German physicist George Simon Ohm discovered that there was a simple relationship between the **current** that flows in an electrical circuit or component, and the **voltage** that must be applied to that circuit or component in order to make the current flow. In fact the two are directly proportional, so doubling the voltage produces double the current and so on.

The actual ratio between voltage and current differs for each circuit or component, and depends on a basic property which Ohm called its **resistance**. Ever since, in his honour, resistance and resistors have been measured in basic units called **ohms** and multiples like 'kilohms' (1000s of ohms) and 'megohms' (millions of ohms).

Also in his honour, the relationship between volts, current and ohms has long been known as **Ohm's Law**. It can be written as a formula, in three alternative ways:

$$V = I \times R \quad I = V/R \quad R = V/I$$

where V is the potential difference in volts; I is the current in amps; and R is the resistance in ohms. As you can see, when you know any two of these quantities you can easily work out the third one using one of these versions of Ohm's Law.

Not long after Ohm discovered his law, in 1845 the British physicist James Joule discovered another basic fact about electrical circuits and components: when a current

flows, the resistance of the circuit or component causes some of the electrical energy to be converted into heat energy. This heat energy then moves away from the circuit or component, so the energy is lost or **dissipated**.

The amount of heat produced each second is called the **power dissipation**, and it's proportional to both the resistance of the circuit and the **SQUARE** of the current level. This is known as **Joule's Law**, and it can again be written as a formula:

$$P = I^2R$$

where P is the power, measured in watts; I is again the current in amps; and R is the resistance in ohms as before.

By taking advantage of Ohm's Law, we can substitute for either R or I to get two further versions of this formula:

$$P = V \times I \quad P = V^2/R$$

Strictly speaking all of these formulas only apply to circuits where DC (direct current) is flowing, and containing only linear resistance. However you can generally also use them in AC (alternating current) circuits providing you work with the RMS (root-mean-square) value of the AC voltage and current. ★



## Project 3:

# A Hee-Haw Siren with Flashing LEDs

Here's a project which generates a 'hee-haw' siren sound just like an emergency vehicle. That's not all, though. As a bonus it also flashes a red LED and a green LED alternately, in time with the siren's sound. This makes it really great for grabbing anyone's attention, so you can use it for things like a simple intruder alarm for your bedroom — or dad's garden shed.

### What does it do?

At the heart of the siren is a low cost 555 timer IC, the same type we used in Project 1 to flash the LEDs. But this time we're using it as an oscillator to make the siren sound, when its output signal is fed to a small speaker.

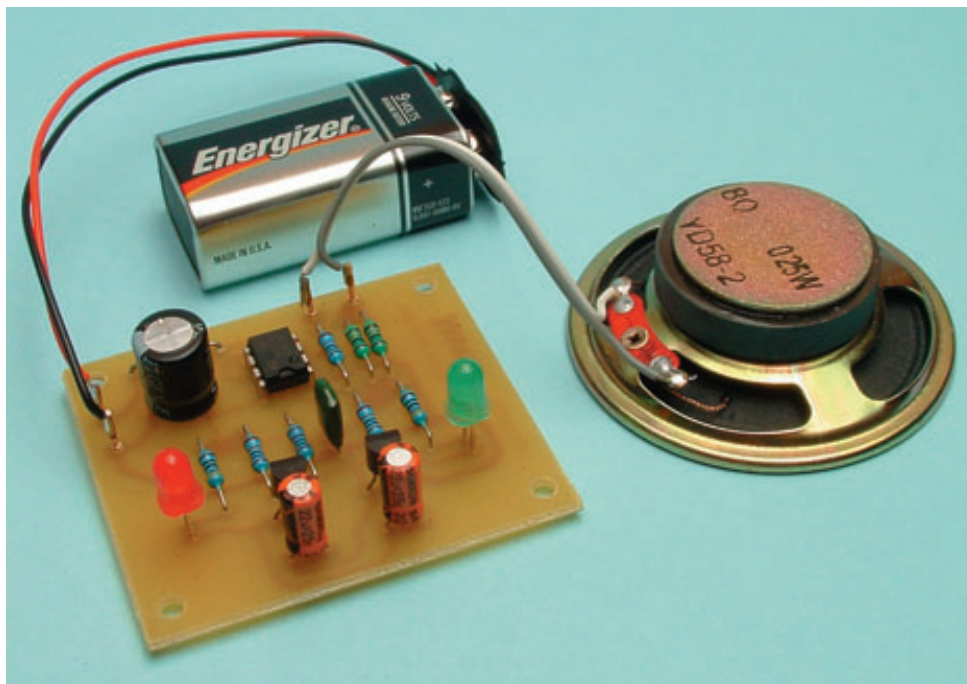
For a change, we're using a simple two-transistor 'multivibrator' oscillator to flash the LEDs. We also use the output of the multivibrator to vary the frequency of the 555 oscillator, and this is how we make it produce the up-down or 'hee-haw' sound.

Apart from the 555 timer IC the complete project uses only two very low cost PN100 transistors and a handful of small parts, plus a 57mm mini speaker to produce the sound output. As usual the project is powered from a standard 9V battery, and everything apart from the battery and speaker fits on a compact PC board (code SHRTC203) measuring only 57 x 51mm. This makes it very easy to build, so let's go!

### Putting it together

Just before you start construction, open the kit and lay the parts out so you can make sure you have everything. Then check the underside of the PC board carefully for manufacturing faults. In the unlikely event that you do find a broken track or a solder bridge between tracks, it should be easy to fix the problem quickly at this stage with your soldering iron.

The first items to fit to the board are the four terminal



pins. Two of these go where the battery clip lead wires connect, and the other two where the speaker wires connect.

There are no wire links to fit on this board, so once the pins have been fitted you can begin with the resistors. There are eight of these, but note that some of them have the same value. For example there are three with a value of 100k ohms, two with a value of 470 ohms and two with a value of 150 ohms. So it's especially important not to mix up the values when you're fitting each resistor to the board. Each resistor's value is shown clearly in the wiring diagram, so follow this closely as well as using the photos as a guide.

## The parts you'll need for this project:

- 1 PC board, code SHRTC203, 57 x 51mm
- 4 PCB terminal pins, 1mm dia.
- 1 57mm mini speaker
- 1 9V battery, 216 type
- 1 Battery clip lead to suit
- 1 Short length of speaker lead

- 1 Small pack of resin-cored solder

### Semiconductors

- 1 555 timer (IC1)
- 2 PN100 transistor (Q1,Q2)
- 1 5mm red LED (LED1)
- 1 5mm green LED (LED2)

- 1 1N4004 diode (D1)

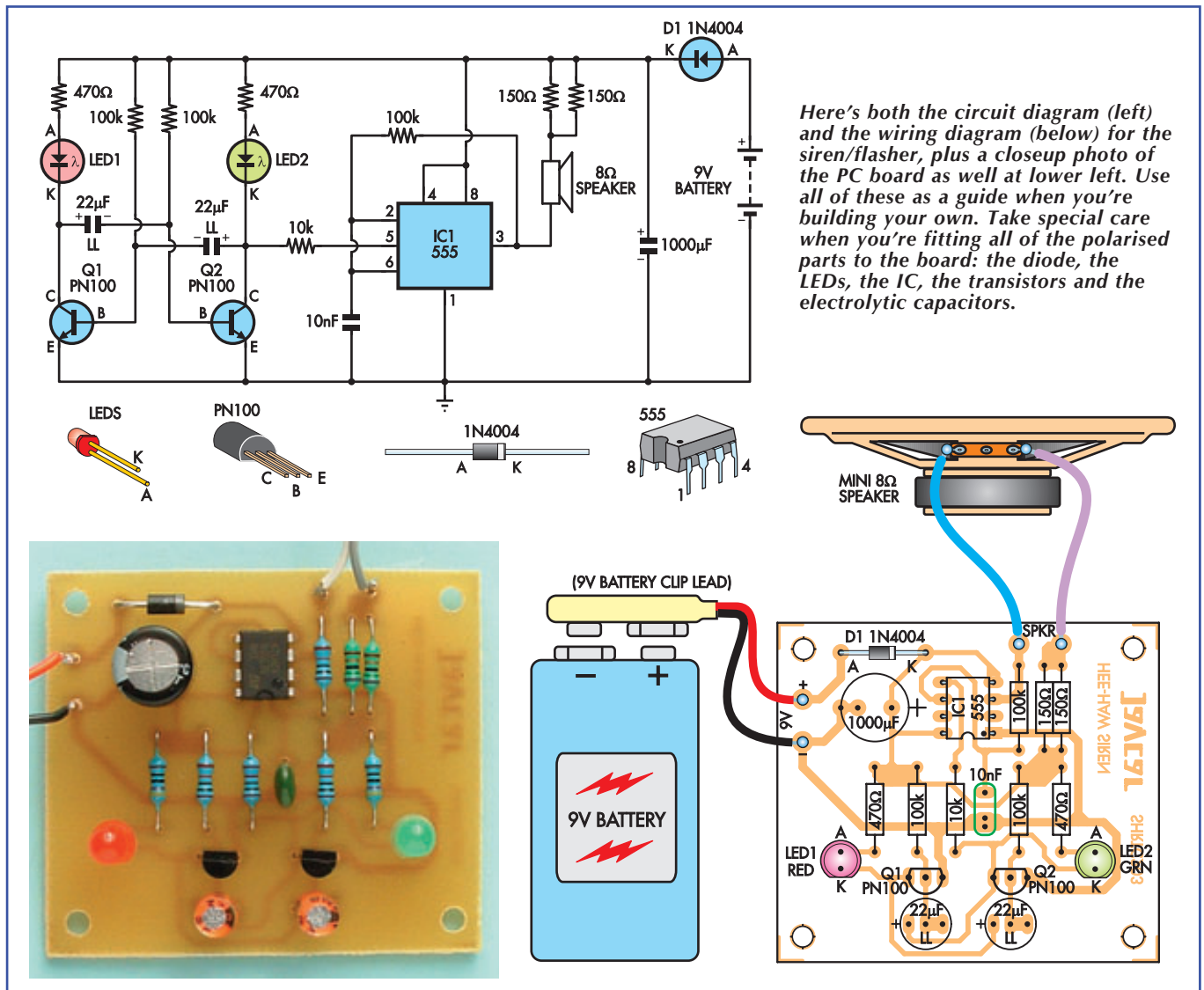
### Capacitors

- 1 1000µF 16V RB electrolytic
- 2 22µF 25V RBLL electrolytic
- 1 10nF greencap

### Resistors (0.25W 1%)

- |            |            |
|------------|------------|
| 3 100k     | 1 10k      |
| 2 470 ohms | 2 150 ohms |





As usual it's a good idea to fit the resistors so their colour codes all read the same way, even though resistors are not electrically polarised. This gives a professional look.

With the resistors fitted, you can fit the remaining non-polarised component: the 10nF greencap capacitor, which goes in almost the exact centre of the board. It too can go either way around, but notice that the board has two alternative holes for one of its lead wires. Use whichever one best suits the lead spacing of your particular capacitor.

Next to fit are the three electrolytic capacitors, the first of the polarised parts. These all fit on the board with their positive side towards the right and their negative 'striped' side towards the left, as you can see from the wiring diagram and the photos. Again the board provides a choice of holes for each one, to suit different lead spacings.

Be especially careful with the two smaller 22µF capacitors, though, because the three holes for each one are all spaced 2.5mm apart. Make sure that you fit each capacitor with its negative lead through the leftmost hole of the three.

Now you can add the semiconductor devices, starting with diode D1. Make sure this has the cathode 'band' end towards the right, as shown in the wiring diagram. Then fit the two PN100 transistors Q1 and Q2. As you can see these both fit with their 'flat' side uppermost, towards the back of the board. Their leads are all kept in line, but you'll have to crank both outer leads away from the centre lead to allow them all to pass through the board holes easily.

Next you can fit IC1, and as shown in the wiring diagram

this should be fitted with its notch/dimple end downwards towards the front of the board.

The last components to fit are the two LEDs, with the red LED on the left and the green LED on the right. (Although you can swap them if you wish.) Both mount with their 'flat' cathode side downwards, as you can see. You can fit them with their bodies about 6mm above the board, as in the photos, or with them further from the board if you prefer.

Finally, connect the wires of the battery clip lead to the terminal pins on the left-hand side of the board. Also connect up the speaker to the two pins on the back of the board, using a couple of short lengths of insulated hookup wire. Your Hee-Haw Siren with Flashing LEDs should then be complete and ready to go.

### Trying it out

There are no adjustments to make on this project, so it should start making the hee-haw siren sound and flashing the LEDs as soon as you connect the clip lead to the battery. One LED glows during the 'hee' part of the siren sound, while the other LED glows during the 'haw' part.

But what do you do if *your* siren/flasher doesn't show any sign of life when you connect the battery? Or if it starts making a continuous sound from the speaker, with no hee-haw effect? Or if the LEDs don't flash, but instead one or both of them either stays off or on? Well, any of these problems indicates that you've made a mistake in wiring up the siren/flasher. So the next step is to disconnect the battery

## Tech Talk: How does it work?

The heart of the siren section of the project is IC1, the same low cost 555 timer IC that we used in Project 1 — and used here in exactly the same type of oscillator circuit. It oscillates because of the 100k feedback resistor connected from output pin 3 back to sensing pins 2 and 6, together with the 10nF capacitor connected between pins 2 and 6 and the negative supply rail. These two components control the basic frequency at which IC1 oscillates, and when it oscillates output pin 3 switches rapidly up and down between +9V and 0V.

Because the speaker is connected between pin 3 and the +9V supply rail, via the two 150 ohm current limiting resistors, current can therefore flow through the speaker when pin 3 is at the 'low' (0V) voltage level, but not when pin 3 is at the 'high' (+9V) level. So as IC1 oscillates, a sequence of short current pulses pass through the speaker — generating the siren sound.

Although the 100k resistor and 10nF capacitor control IC1's basic frequency of oscillation, the frequency can also be varied by changing the voltage applied to pin 5 of the IC (known as its control pin). In this project we switch the voltage on pin 5 up and down, to change the oscillating frequency and produce the hee-haw effect.

As you can see from the circuit pin 5 is connected through a 10k resistor to the collector of Q2, one of the two transistors. And the two transistors are connected together to form what is known as a *multivibrator* — another simple kind of oscillator circuit.

In a multivibrator the two transistors each have their base connected to the collector of the other transistor via a capacitor. This 'cross coupled' arrangement is unstable, because when one transistor turns on and conducts, this causes the other transistor to be turned off. As a result they switch back and forth, with first one transistor on and then the other on instead. The frequency at which this switching occurs is mainly controlled by the coupling capacitor values (here 22µF) and the base bias resistors (here 100k). Larger values for these components give a lower switching frequency, while smaller values give a higher frequency. The values shown give a switching frequency of about 0.5 hertz.

Here the two transistors each have a LED connected in series with their collector resistor, so that when each transistor conducts it turns on that LED. This produces the flashing LEDs. Then by connecting the collector of Q2 to pin 5 of IC1 via the 10k resistor, we also make the frequency of IC1's oscillation vary up and down as the multivibrator switches. This is how we produce the hee-haw effect.

again, and search for the mistake.

If there's no life at all from the circuit, you may have connected diode D1 the wrong way around, or connected the battery clip lead wires to the board pins with reversed polarity. Or you may have fitted the 1000µF capacitor the wrong way around, because any of these mistakes will stop the circuit from working at all.

If there's no sound but the LEDs are flashing, you may have connected IC1 the wrong way around.

On the other hand if you're getting a continuous sound with no hee-haw effect and no flashing LEDs, the mistake is probably in the part of the circuit around Q1 and Q2. You may have fitted one or both of the 22µF capacitors either the wrong way around, or between the two board holes that are shorted together (which results in the capacitor not being connected into the circuit). Or you may have connected one or both of the transistors around the wrong way, or one or both LEDs. (This could have damaged them.)

If you check out each of these possible mistakes carefully, comparing your board with the wiring diagram, you're almost certain to find the problem in short order. Then it's simply a matter of fixing the wiring mistake and connecting up the battery to try it again. Resistors, capacitors and most diodes are pretty forgiving.

## What to do next

If you'd like to change the pitch of the siren's sound, this can be done quite easily by replacing the 10nF greencap capacitor with one of a higher or lower value. A lower value capacitor like 8.2nF or 6.8nF will give a higher pitched (more shrill) sound, while a higher value like 15nF or 22nF will give a lower pitched (deeper) sound. So feel free to experiment.

It's also quite easy to vary the hee-haw and LED flashing rate, by replacing the two 22µF electrolytic capacitors with others of higher or lower value. For example if you replace them with 33µF capacitors this will slow down the hee-haw rate, while replacing them with 15µF capacitors this will speed things up and give a more 'urgent' sound.

You might want to house the siren/flasher in a plastic box, to protect it from damage. The board assembly, mini speaker and battery will all fit easily inside a standard UB3 size plastic jiffy box, such as the Jaycar HB-6023 (grey) or HB-6013 (black). The board assembly can be mounted inside the box itself, using four 15mm long M3 machine screws

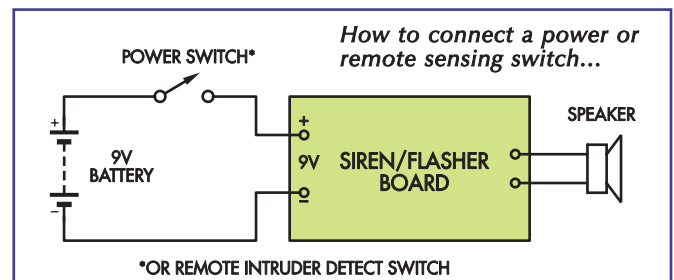
(HP-0406) and nuts (HP-0425), with 9mm metal spacers (HP-0862) between the board and the box rear. The mini speaker can then be glued on the rear of the box lid, behind an array of 8mm holes to let the sound out.

If you do mount the siren/flasher in a box like this, you might also like to fit it with an on-off switch. A simple mini toggle switch is all that's needed, such as the Jaycar ST-0335. It's simply wired in series with one of the battery clip leads.

Of course if you want to use the siren/flasher as an intruder alarm, you'd use a remote door or window switch as its power switch — so when the door or window is opened, the siren 'goes off'. In this case the type of switch you'd use would be something like the Jaycar LA-5066 tamper switch or the SM-1040 microswitch, connected up to the siren via a length of light-duty 'figure 8' cable such as Jaycar's WB-1560 or WB-1702. The switch would be wired so its contacts are 'open' when the door or window is closed, and only close the circuit when the someone opens the door or window.

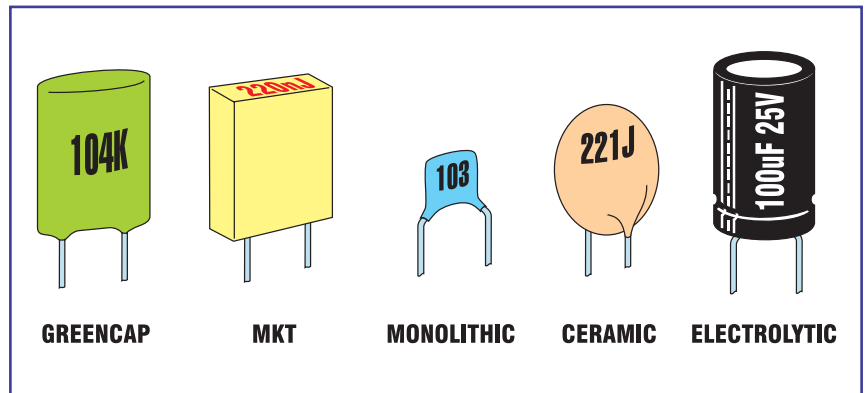
Finally if you'd like the siren to produce a louder sound, the easiest way to do this is to replace the kit's mini speaker with a more efficient horn speaker like the Jaycar AS-3180. In addition you can replace the two 150 ohm resistors with a pair of 82 ohm resistors, so the speaker is able to draw more current. However if you **do** change these resistors, the small 9V battery will have to be replaced with one capable of delivering more current as well. A suitable replacement would be six AA alkaline cells, mounted in a six-cell holder like the Jaycar PH-9206.

By the way, don't lower the output resistors below that suggested lower value of 82 ohms. This would allow the speaker to draw more current than the 555 timer IC can handle, and it would almost certainly be damaged.



# Capacitors & Their Markings

There are five types of capacitor you'll commonly meet in electronics. Most of the differences between them are due to the different kinds of material used for their dielectric (the insulation between the capacitor's two plates).



## Polyester Film caps

One very common type uses a polyester plastic film for the dielectric, with the electrode metal deposited on each side. Once the leads are attached, the resulting **metallised polyester** capacitor is then either dipped in coloured plastic to become a 'greencap' (although these can come in brown and deep red, as well as green) or potted in a small rectangular box of yellowish plastic to become an 'MKT' capacitor. Both versions are good for general electronic work where you want a capacitor in the middle range of values — from about 1nF (1000pF or 0.001uF) to 1uF.

## Multilayer Monolithic ceramics

Another type is the **multilayer monolithic ceramic** type, where very thin layers of ceramic material (like porcelain) are used as the dielectric, between similarly thin layers of metal film. Called 'monolithics' for short, this type is very compact and low in inductance, and very common in digital circuits. Values range from about 10nF (0.01uF) to 220nF (0.22uF). Monolithics are often blue in colour.

## Disc ceramics

For use at high frequencies, and especially where low capacitance values (from say 1pF to 1nF) are needed, the **disc ceramic** type is usually best. These have metal electrodes on either side of a small ceramic disc. As the physical and electrical behaviour of many ceramics tends to vary with temperature, they're available with different types of *temperature coefficient* (or **tempco**). The 'NPO' type varies least with temperature (NPO stands for 'negative-positive-zero').

## Electrolytics

The last main type of capacitor you'll meet are **electrolytics**, often called 'electros' for short. These use a very thin layer of insulating metal oxide as the dielectric, but a small quantity of conducting liquid is used inside to make electrical contact with the surface of the oxide. Electros are not ideal capacitors in terms of performance, but they're the easiest to make in high values (above about 1uF, and up to 10,000uF or more). They're generally found in power supplies.

## Capacitor values and markings

Most types of capacitor are made in a series of nominal or preferred values which are much the same as the E12 series of resistor values (see page 25). That is, within each decade or 1:10 range in values, they are usually available in values such as 1nF, 1.2nF, 1.5nF, 2.2nF and so on.

Unlike resistors, though, capacitors generally have their value printed directly on them in digits, rather than as a

colour code. But it can still be a bit tricky to work out their value, because a coding system is often used. The code most often used is similar to the resistor code, with two value digits followed by a third digit giving the multiplier or 'number of noughts'. So '104' decodes as 10 followed by four digits, or 100,000; and '221' means a value of 220.

When this coding system is used, you can almost always assume that the value is being given in **picofarads** — so '104' means 100,000pF or 100nF, '103' means 10,000pF or 10nF and '221' means 220pF.

Another code uses three digits followed by an 'n'. This usually means that the third digit is just part of the value, and it's all in **nanofarads** rather than picofarads. So '220n' means 220nF (0.22uF), for example.

Low-value ceramic capacitors generally have their full value given in digits — that is, with no coding. The value is in **picofarads**, like '15' (for 15pF) or '47' (for 47pF). They might also have a decimal point — such as '5.6' (for 5.6pF).

Electrolytic capacitors generally have their full value and voltage rating printed on their outer sleeve, without any coding. Because they're polarised they also have a band to indicate either the negative (or positive) electrode lead.

## Other markings

Other letters on a capacitor's body tend to be codes for the **tolerance** (ie, the margin of error around the capacitor's nominal value). For example K means +/-10%, J means +/-5%, G means +/-2% and E means +/-1%.

On ceramic capacitors, a coloured paint stripe is often used as a code for the tempco. For example a black stripe means NPO, while a yellow stripe means N220 (a negative tempco of 220 parts per million, per degree C change in temperature). Similarly a violet stripe means N750, or a tempco of -750ppm (parts per million) per °C. ★

## Nominal Values and Tolerance

When electronic components are being made, there are always small inaccuracies in the manufacturing processes. As a result it simply isn't possible to make any component with a value guaranteed to be EXACTLY the same as its marked or **nominal** value.

Some circuits can only tolerate a small amount of error in the value of certain components, while others are more tolerant. Manufacturers therefore make (or select after manufacture) components with different margins of error or **tolerance** for their components, like capacitors with tolerances of say +/-10% or +/-2%.



## Project 4:

# Mini Strobe Light

How would you like to have one of those fancy (and expensive) strobe lights, with a flashing white light that can be used to 'stop' spinning objects, or produce weird stop-motion effects at dances? Here's how to make one yourself, at very low cost. It only has a low light output, but enough for you to experiment with strobe lighting.

### What does it do?

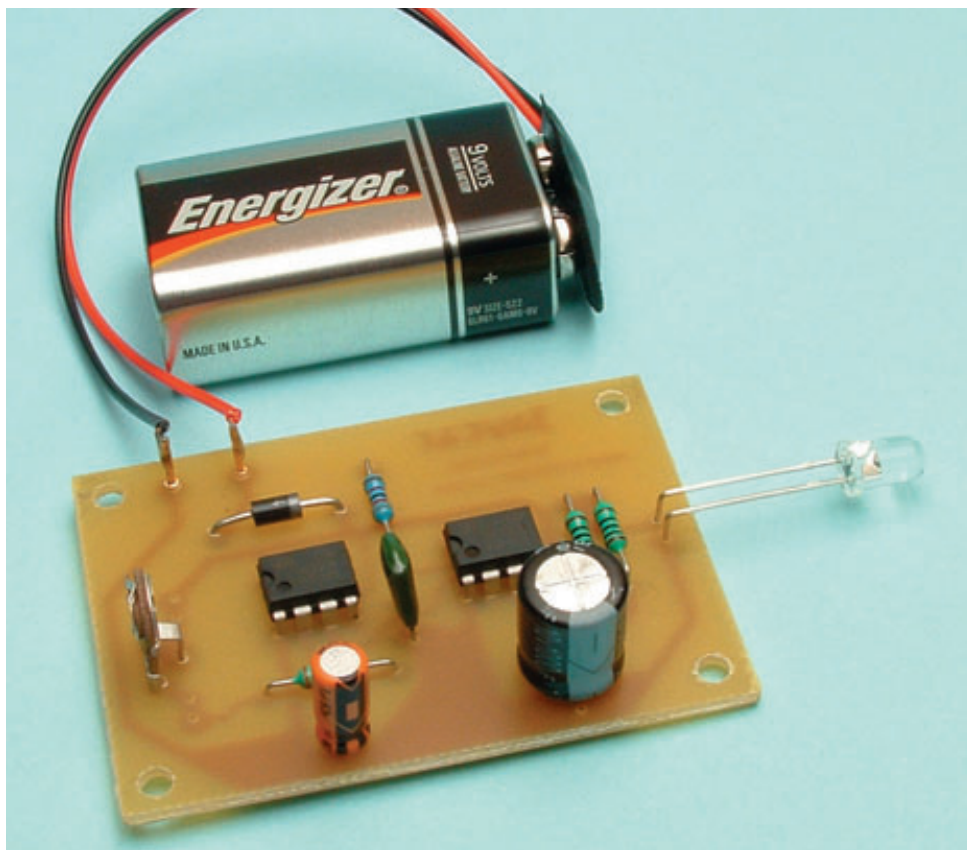
The idea of this project is to make a high efficiency 'bright white' LED produce a string of short light flashes, at an adjustable rate. By adjusting the flash rate to match the speed of a rotating object like a fan blade or the beaters in a food mixer, you can arrange for the flashes to always show the object in the same position, so that it seems to have 'stopped'.

Similarly if you use this kind of flashing light to illuminate people who are moving in the dark (like dancing), you'll only see them at the instants that the light flashes occur, so they'll seem to be flitting from one stationary pose to another without actually moving. This 'stop motion' effect can be quite impressive, and it can also be used to analyse the motion of sports people — like a golfer's swing or a tennis player's serve.

By the way if a strobe light like this one is *calibrated*, so that you know its flashing rate, it can then be used to measure the speed at which objects are rotating or moving. That's because once you know the flashing rate in flashes-per-second, you then also know how far the moving object has moved in the time between flashes. So your Mini Strobe Light can also be used as a **stroboscope**, if you wish. We'll tell you more about this in the What To Do Next section.

### Putting it together

Like all of the other projects in this book, the Mini Strobe Light is built on a compact PC board. This board is coded SHRTC204 and measures only 61 x 45mm. Everything is mounted on the board except the 9V battery, which hooks



up via the usual clip lead.

Before starting construction, open the kit and lay the parts out so you can make sure you have everything. Then give the copper side of the PC board a careful inspection, just in case it has any small manufacturing faults. It probably won't have any, but if it does you'll be able to fix them easily at this stage with your soldering iron.

There are only two terminal pins used in this project, so begin construction by fitting these. They go on the lower left-hand side of the board, where the battery clip lead wires

## The parts you'll need for this project:

- 1 PC board, code SHRTC204, 61 x 45mm
- 2 PCB terminal pins, 1mm dia.
- 1 9V battery, 216 type
- 1 Battery clip lead to suit
- 1 500k vertical trimpot, 5mm open carbon type (VR1)

- 1 Small pack of resin-cored solder

### Semiconductors

- 2 555 timer ICs (IC1, IC2)
- 1 5mm bright white LED (LED1)
- 1 1N4004 diode (D1)

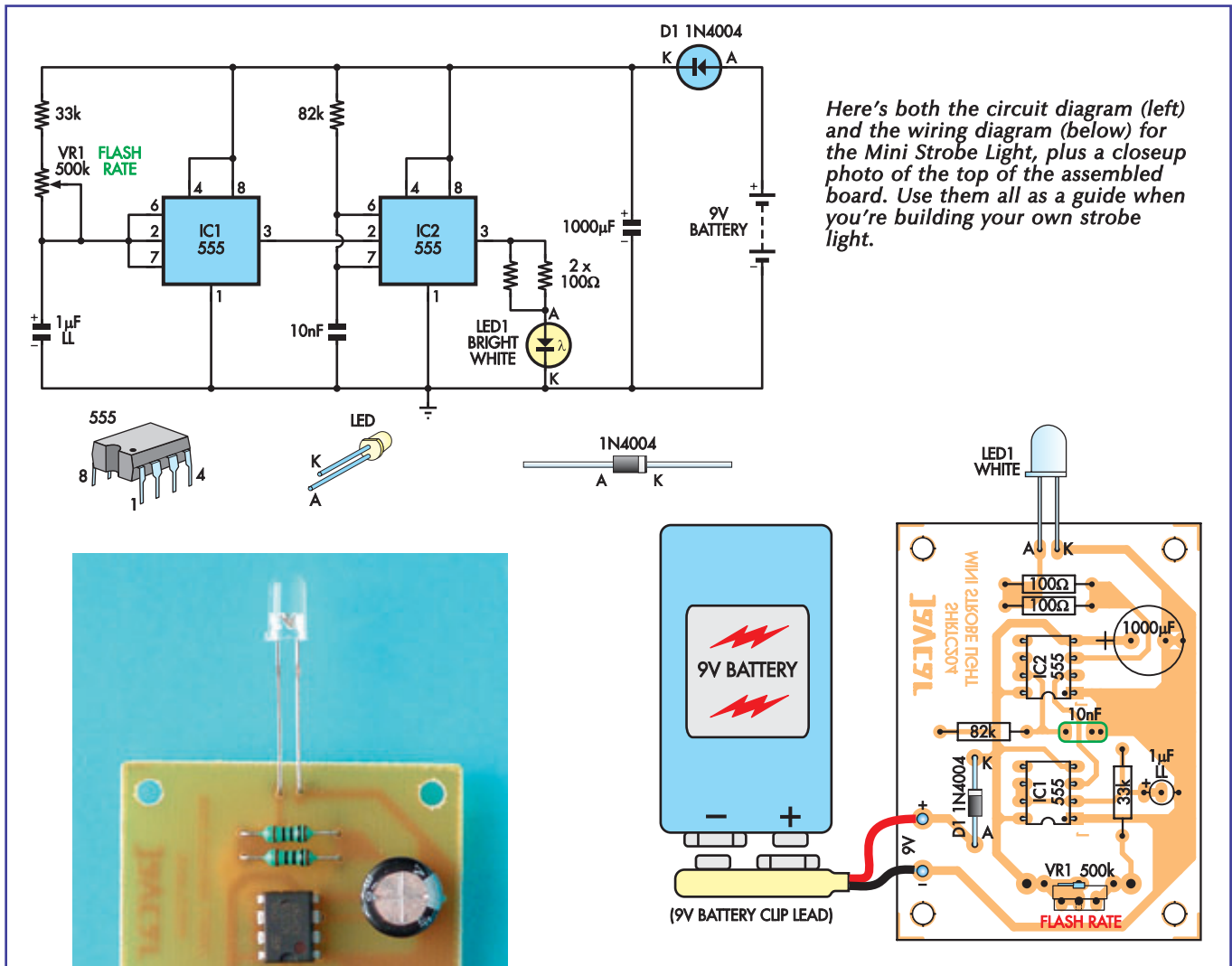
### Capacitors

- 1 1000 $\mu$ F 16V RB electrolytic
- 1 1 $\mu$ F 50V RBLL electrolytic
- 1 10nF greencap

### Resistors (0.25W 1%)

- 1 82k
- 1 33k
- 2 100 ohms





Here's both the circuit diagram (left) and the wiring diagram (below) for the Mini Strobe Light, plus a closeup photo of the top of the assembled board. Use them all as a guide when you're building your own strobe light.

will connect later. You can see this in the photo above.

Now fit the four fixed resistors, taking care to fit each one in the correct position according to its value as shown in the wiring diagram. Note that the two 100 ohm resistors mount side by side near the top of the board.

The 10nF greencap capacitor can be fitted next, using whichever one of the two holes on its right side best matches its lead spacing. Like the resistors the greencap isn't polarised, so you can fit it either way around.

Next fit the trimpot VR1. This isn't electrically polarised, but it will only fit into the board one way around because of the offset in its centre pin. Note that the board also provides mounting holes for larger pots in the same position — more about this later.

Now fit the two electrolytic capacitors. These are polarised, of course, and in this case they both mount with their positive leads towards the left and their negative

'stripe' side towards the right. As usual we have provided an extra hole for both electrolytics, to allow for different lead spacings: there are two for the negative lead of the 1000µF electro, and two for the positive lead of the 1µF low leakage electro. If your 1µF unit has its leads spaced 2.2mm apart, make sure you use the inner hole of the three for its positive lead. The negative lead must use the rightmost hole.

Now you should be ready for the semiconductor parts, so begin this by fitting diode D1. As you can see from the wiring diagram this fits with its cathode band end upwards, towards the 82k resistor.

Then fit the two 555 timer ICs, IC1 and IC2. These both mount with their notch/dimple end downwards, as you can see. Make sure you fit them this way around, because the project won't work if either is connected around the other way. The ICs may be damaged, as well.

The final component to fit is the white LED, and as you can see from the photos this has its leads bent down at 90°, about 6mm from the end of the shorter (cathode) lead. This allows the LED to be mounted with its light output directed upwards, in a plane parallel to the PCB board itself.

The main thing to watch when you're bending the LED's leads is to bend them the right way, so that when you fit them to the board the LED will have its flat side and shorter cathode lead towards the right. This is shown in the wiring diagram, so use this as a guide and you shouldn't go wrong.

To finish building the project, solder the ends of the battery clip lead wires to the terminal pins on the board. The black wire goes to the lower pin, and the red wire to the upper pin. Your Mini Strobe Light should then be

## Tech Talk: How does it work?

We're using not one, but two 555 timer ICs in this project. The first one is used as an oscillator to produce a stream of pulses at the desired flashing rate, while the other 555 is used to convert the pulses from the first IC into very narrow pulses to drive the LED. This allows us to allow the LED to draw a much higher peak current, and produce much brighter light pulses, while at the same time keeping the average current low and as a result not overtaxing either the LED or the battery.

IC1 is used as the basic oscillator, with its frequency of operation controlled by the  $1\mu\text{F}$  capacitor, the 33k resistor and trimpot VR1. Although this circuit is slightly different from the one used in projects 1 and 3, it works in much the same way. The main difference is that instead of connecting the charging resistor back to output pin 3, to get the feedback action, we connect the resistor straight to the +9V supply rail and instead make use of the 555's pin 7.

Inside the IC there's an NPN transistor, connected with its emitter connected to the negative pin 1 and its collector to pin 7. The transistor's base is connected to the internal circuitry so that whenever the IC's output pin 3 switches low, this transistor is switched on too. The transistor is known as the *discharge transistor*, and pin 7 is called the **discharge pin**.

When the battery is first connected, the  $1\mu\text{F}$  capacitor is discharged and has no voltage across it. This low voltage is sensed by pins 2 and 6, and the IC switches its output pin 3 to the higher voltage level (about +9V). It also turns off the discharge transistor, so no current flows into pin 7. As a result, the capacitor begins charging up by drawing current through VR1 and the 33k resistor. And as it charges, the voltage across it begins rising.

When the voltage reaches about +6V, this is sensed by pin 6 of the IC, and it suddenly switches output pin 3 to the low voltage level (about 0V). At the same time it switches on the discharge transistor, which suddenly conducts current into pin 7. This current quickly discharges the  $1\mu\text{F}$  capacitor, so the capacitor voltage drops down to zero again. And when this happens pin 2 of the IC senses that the voltage has dropped, and switches output pin 3 high again. It also switches off the discharge transistor, allowing the capacitor to begin charging once again.

As you can see the circuit switches back and forth repeatedly in this way, charging the capacitor via VR1 and the 33k resistor and then discharging it again via pin 7 and its internal switching transistor. The rate at which this cycle is repeated depends mainly on the  $1\mu\text{F}$

capacitor and VR1, because these control the charging time. The 33k fixed resistor is to set a minimum resistance value, which also sets the maximum flashing rate.

So the output pin 3 of IC1 produces a stream of extremely narrow negative pulses, at the rate we control by setting VR1. But these pulses are too narrow for producing worthwhile current through a LED, so we use IC2 to convert them into 'fatter' positive pulses that are more suitable.

Although it's connected in a very similar manner to IC1, IC2 is used not as an oscillator but as a 'monostable' or **one shot multivibrator**. As you can see its 'input voltage low' sensing pin 2 is connected to pin 3 of IC1, rather than to its own pins 6 and 7. So what happens is that initially the 10nF capacitor charges up via the 82k resistor, and while it does so the IC switches its output pin 3 high. But as soon as the voltage reaches about +6V this is sensed by pin 6, which makes the IC switch its output pin 3 low. It also switches on the discharge transistor, which discharges the 10nF capacitor again via pin 7.

Because pin 2 isn't connected across this capacitor though, IC2 cannot sense that the capacitor voltage has dropped to zero again, and as a result IC2's output pin remains switched to the low voltage level. The discharge transistor also remains on, stopping the 10nF capacitor from charging up again.

This situation continues until the next narrow negative pulse arrives at pin 2 from oscillator IC1. Only then does IC2 switch its output to the high level, and turn off the discharge transistor so that the 10uF capacitor can start to charge up again. Then when the capacitor voltage reaches +6V again, IC2 switches its output low again and turns on the discharge resistor, to end that cycle.

So because pin 2 of IC2 is driven by IC1, IC2 doesn't actually oscillate continuously but instead generates just one short positive output pulse each time a negative pulse arrives from IC1. And the length of these output pulses is set purely by the 10nF capacitor and 82k resistor, because these control how long it takes for the capacitor (and pin 6) voltage to reach +6V, as the capacitor charges up each time. With the values of 10nF and 82k shown, this time is very close to one millisecond (1ms, or one thousandth of a second).

Each time the output of IC2 switches high, the LED is able to draw current through the two 100 ohm resistors. These allow it to draw about 70mA (milliamps) of current, but only for the duration of each 1ms pulse from IC2. So the LED produces a brief but very bright flash of light, each time IC2 produces a pulse.

finished and ready to roll.

Before you try it out, though, it's a good idea to give it a good 'once over' to check that you haven't made any mistakes. Check all the parts against the wiring diagram to make sure you've put them all in the right positions and with the correct orientations, and also inspect all of your solder joints to make sure there are no dry joints or solder bridges.

### Trying it out

Everything look OK? Good, so set the trimpot to about the centre of its adjustment range, using a small screwdriver, and then connect the clip lead to your 9V battery. The LED should immediately begin flashing brightly, at about 5 or 6 flashes per second.

Assuming this happens, try turning the trimpot slowly clockwise. The flashing should get faster and faster, until it becomes so fast that it appears to be glowing continuously. (It isn't, but your eyes make it look that way because of their **persistence of vision** — the same effect that makes movies and TV seem to show smoothly moving pictures, rather than

a succession of still pictures.) The LED should be flashing at about 50 flashes per second when the trimpot is fully clockwise, but your eyes probably won't be able to see this.

Now try turning the trimpot back the other way, so the flashing slows down. By the time you reach the pot's anticlockwise limit, the flashing should have slowed down to about twice or three times a second. You should be easily able to make out each flash, and count them if you wish.

If your Strobe Light does all of this as described, it's working exactly as it should and is now ready for use.

But what if the LED hasn't flashed at all, at any position of the trimpot? Or it's been glowing more or less continuously, with only a small amount of flickering that just varies a bit when you adjust trimpot VR1? Or it just gives once flash when you connect up the battery, but then doesn't flash again? These are really all signs that you've made a mistake in wiring up the project, so disconnect the battery and start looking for the mistake.

For example no sign of flashing at all is usually a sign that you've connected the battery with the wrong polarity, or

alternatively that diode D1 is around the wrong way. These both stop the circuit from working at all. Or you may have got both of these connections right but fitted the LED the wrong way around, so it can't conduct current and flash even though the rest of the circuit may be working correctly.

On the other hand if the LED flashes only once, or seems to be glowing all the time, you've probably connected one of the other components around the wrong way — most likely the 1uF electro or one of the two ICs.

Or you may have made a **dry** soldered joint, or accidentally left a tiny solder bridge between two of the pads or tracks on the PC board. So track down the cause of the problem, and once you find it remove the component concerned and refit it the correct way around. Most of the time this will fix things and your project will spring into life as soon as you reconnect the battery.

## What to do next

There are quite a few things you can do to enhance this project. For example you can replace trimpot VR1 with a larger 16mm or 24mm control pot, and then fit this with a knob so you can adjust the Strobe Light's flashing rate more easily and without a screwdriver. As you've no doubt noticed already, the project's PC board provides mounting holes for both larger sizes of pot as well as those for the trimpot.

You can either use a larger pot with the same value as VR1 (500kΩ), or give it a larger value of 1MΩ. This will give you a larger adjustment range, extending the lower end down to around one flash per second. You can get very suitable pots for this in Jaycar stores, such as the RP-8524 (1MΩ), RP-3522 (500kΩ) or RP-3524 (1MΩ). We can also provide a variety of knobs to match.

If you do decide to replace RV1 with a larger control pot, it's also possible to change the flash range so the Strobe Light can be set to flash faster at the top end. You can do this by replacing the 1uF electro with one of smaller value, like 0.68uF or 0.47uF. Make sure you use a similar low leakage capacitor, though, like the Jaycar RL-6412 or RL-6410. Also don't use a capacitor value any smaller than 0.47uF, because this will make the LED draw too much average current and it could easily be damaged.

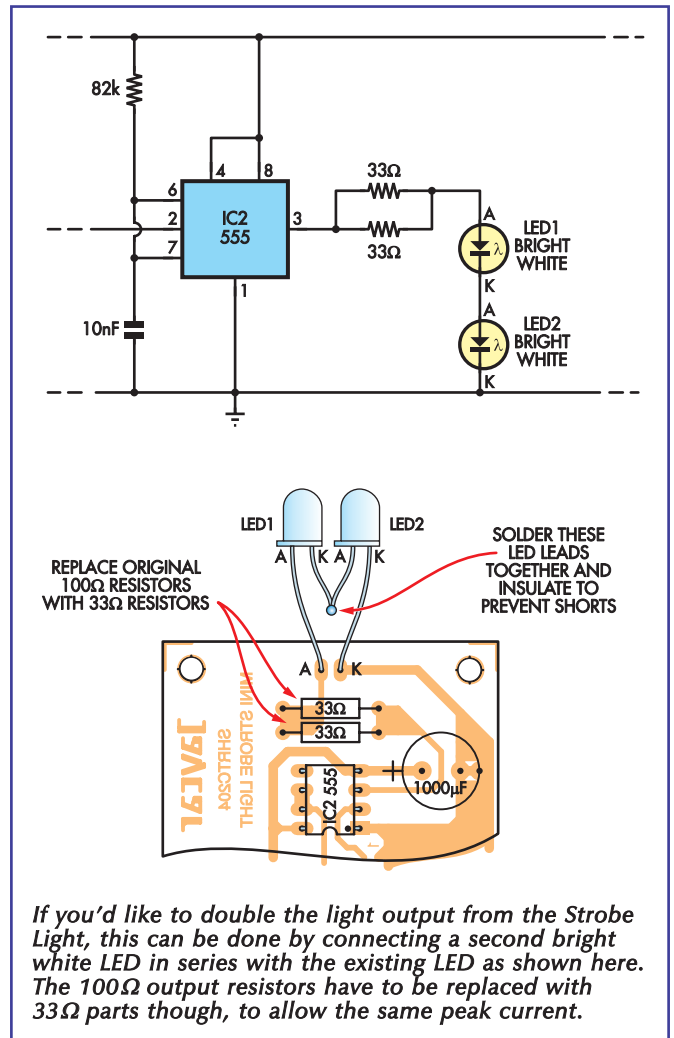
Is it possible to increase the light output from the Strobe Light? Yes, you can actually double the project's light output by connecting a second high-efficiency white LED, wired in series with the existing LED so that they both conduct together. (Jaycar stores can supply extra high efficiency white LEDs as Cat. No. ZD-1997.)

When you do this you also have to replace the two 100 ohm resistors with a pair of smaller value, to allow the two LEDs to still draw the same current as the single original — despite the additional voltage drop of the second LED. This means replacing the resistors with two having a value of 33 ohms.

The small diagram shows how this is done. As you can see the two LEDs are connected to the board in place of the single original one, with the cathode of one joined to the anode of the other in 'midair'. Just cover this joint with heatshrink sleeving or insulating tape, so it can't contact either of the end leads and short out one LED or the other.

Another way you might like to enhance the project is to house the board assembly in a small plastic box, to protect it from damage. It has been designed to fit inside a UB5 size box (83 x 54 x 31mm), and will easily fit even when you use a larger 16mm control pot instead of the trimpot. Use either the HB-6025 (grey) or the HB-6015 (black) boxes from Jaycar, or even the HB-6005 which is moulded in clear plastic so you can see the contents.

One or two 5mm diameter holes cut at one end of the box will allow the LED or LEDs to protrude through and emit their light, while a 6mm diameter hole at the other end will allow the pot spindle to protrude and have the control knob fitted. The board assembly itself can be mounted inside the bottom of the box using four 15mm long M3 machine screws (HP-0406) and nuts (HP-0425), with 6mm long spacers



(HB-0860) used to separate the board and box.

It won't be possible to fit the 9V battery in this size box, because there isn't room. In any case, you'll need to be able to turn the power on and off easily. So this can be done by extending the battery clip lead using a metre or so of light duty figure-8 twin core cable (like Jaycar WH-3078, or WB-1702), bringing the cable out of the box through a 5mm diameter hole. The battery can then be kept in your pocket, and power still turned on and off by clipping or unclipping the clip lead.

Another approach would be to build the Strobe Light into a larger box, such as the UB3 size measuring 130 x 67 x 44mm. Jaycar stores stock these as HB-6023 (grey) or HB-6013 (black). This will allow you to fit the battery into the box as well, so the complete unit is self-contained.

If you do this, you'll have to wire in a power on-off switch as well. This could be simply a miniature toggle switch like the Jaycar ST-0335, mounted on the box lid and connected in series between the red wire of the battery clip lead and the +9V terminal pin on the PC board.

You'll also have to take the control pot off the PC board, and mount it on the box lid like the on-off switch. It would mount in the centre of the lid, with its three connection lugs connected down to the original PC board pads via short lengths of insulated hookup wire.

By mounting the pot in the centre of the lid, you'll also make it easy to provide the pot's knob with a circular dial scale which can be given calibration markings so you can always tell the Strobe Light's flashing rate. Of course to do this you'll need to measure the flashing rate for each pot setting, perhaps by borrowing a frequency counter.



## Project 5:

# On-Off Touch Switch

Sick of fumbling around in the dark to find the switch for your bedside lamp or alarm clock radio? Here's a much more convenient way to control either these or any other low voltage gadgets. Easy to build, it lets you turn things on or off simply by touching a small sensor pad with your finger — or even a toe!

### What does it do?

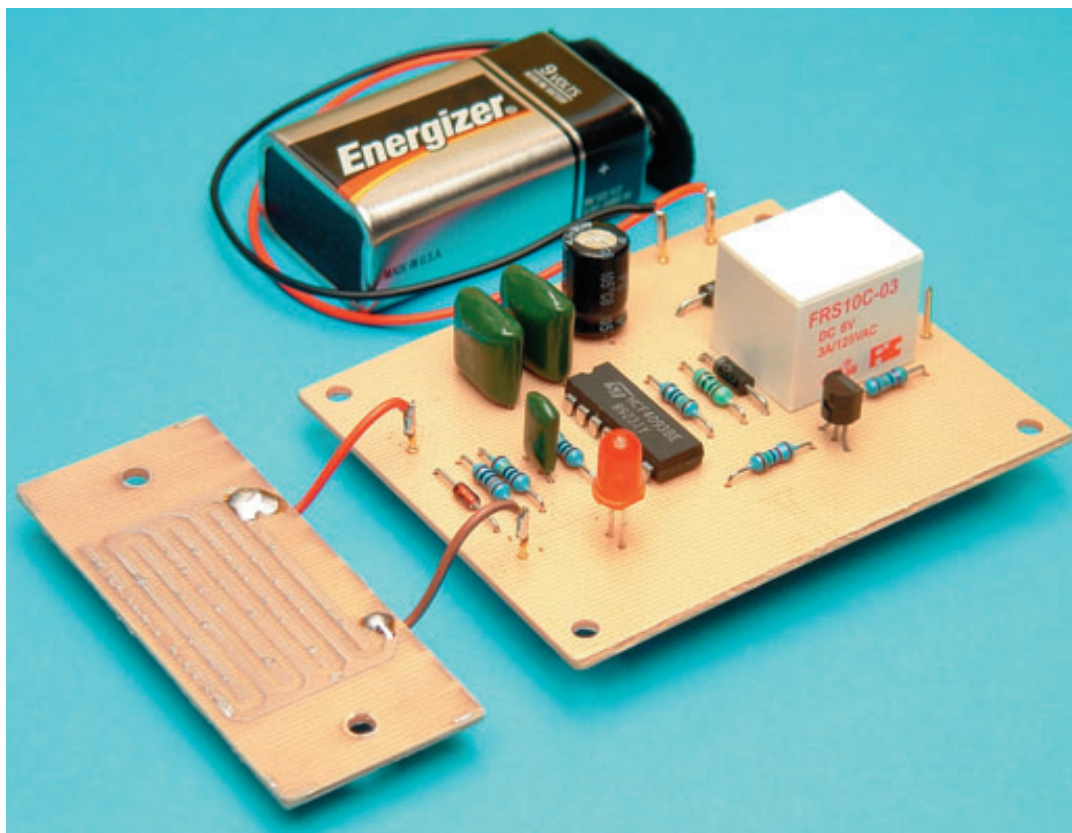
Even in winter, our skin is always slightly moist from a tiny amount of perspiration. That's why when we touch smooth surfaces, we usually leave our fingerprints.

Because perspiration is mainly water, it's also capable of conducting electricity. So when you touch a couple of electrical contacts, your fingertip is quite capable of conducting a tiny amount of current. And although the current may be so small that you're not even aware of it, it can still be enough to be sensed by an integrated circuit.

That's how this On-Off Touch Switch project works. It has a touch sensor pad consisting of a set of copper tracks making up two contacts, with a very low voltage between them.

So when you close the circuit by touching the tracks with your fingertip, a tiny current flows. The IC in the touch switch circuit senses when this tiny current flows, and operates a relay so that your bedlamp, alarm clock or radio is turned either on or off again.

It's as simple as that — fingertouch control, and with complete safety. The current that flows through your fingertip is only about nine microamps (9 $\mu$ A), or nine millionths of an amp. You can't feel such a tiny current, even when it flows through your tongue! (We checked this, just to make sure...)



### Putting it together

Apart from the battery and its clip lead, all of the parts used in the Touch Switch mount on a small PC board measuring 72 x 58mm, and coded SHRTC205. A second smaller board measuring only 58 x 25mm has the interleaved pattern of copper tracks which form the touch sensor itself.

Before starting assembly, open the kit and lay out all of the parts so you can check that everything is there. Then carefully inspect the copper side of both boards, to make sure that there are no manufacturing defects.

There are no wire links needed on either board, so you can begin assembly by fitting the seven PC board terminal pins used for the battery clip lead, sensor lead and relay contact connections on the main board. As you can see from the wiring diagram the first two of these are on the upper left-hand side of the board, the next two go at bottom centre and the remaining three go at top centre.

### The parts you'll need for this project:

- |   |   |                   |                                 |
|---|---|-------------------|---------------------------------|
| 1 | PC board, code SHRTC205, 58 x 100mm (or cut apart)  | 1                 | PN100 transistor (Q1)           |
| 7 | PCB terminal pins, 1mm dia.                         | 1                 | 5mm red LED (LED1)              |
| 1 | 6V mini relay, SPDT (Relay 1)                       | 1                 | 1N4148/1N914 diode (D1)         |
| 1 | 9V battery, 216 type                                | 2                 | 1N4004 diodes (D2,D3)           |
| 1 | Battery clip lead to suit                           | <b>Capacitors</b> |                                 |
| 2 | 100mm lengths of insulated hookup wire (13 x .12mm) | 1                 | 220 $\mu$ F 16V RB electrolytic |
| 1 | Small pack of resin-cored solder                    | 2                 | 220nF greencap                  |

#### Semiconductors

- |   |                                    |
|---|------------------------------------|
| 1 | 4093B quad Schmitt NAND gate (IC1) |
|---|------------------------------------|

#### Resistors (0.25W 1%)

- |   |             |   |              |
|---|-------------|---|--------------|
| 3 | 1M          | 1 | 100k         |
| 1 | 15k         | 1 | 820 $\Omega$ |
| 1 | 47 $\Omega$ |   |              |



## Tech Talk: How does it work?

At the heart of the Touch Switch is the combination of NAND gates IC1b and IC1c, which as you can see are 'cross connected' with one input of each connected to the other gate's output. As a result of this cross coupling the two gates form what is called a bistable or **flipflop**, which has two stable states. One of these is where the output of IC1b is high and that of IC1c is low, and the alternative state is where the output of IC1c is high and that of IC1b is low.

Both of these states are called *stable*, because the flipflop can remain in either state indefinitely. However it can be prompted into flipping from one state to the other by applying a short negative-going or 'low' pulse to the second input of one gate or the other.

As you can see from the circuit diagram, we connect the output of IC1c to the base of transistor Q1 via a 15k resistor, so that the resistor is turned on when IC1c's output is in the high state. And when Q1 is turned on it conducts current through the 47Ω resistor and both the relay coil and the LED (via the 820Ω resistor), so this 'IC1c output high' state of the flipflop is the one where the Touch Switch is ON. Conversely when the output of IC1b is high and IC1c's output is low, Q1 is turned off and this is the OFF state of the Touch Switch, with the LED and relay both off.

We switch the flipflop between these two states by means of short pulses of voltage, generated each time you press your finger against the touch sensor and cause a small current to flow through it. The pulses are 'steered' to one input of the flipflop each time by gates IC1a and IC1d, to make it flip on or off. Here's how this is done:

When the battery is first connected, there is no current path to allow current to flow into the 10nF capacitor, and the capacitor remains discharged. This keeps the input voltage on pins 1 and 12 of IC1a and IC1d low, so the outputs of both of these outputs go high. Because of this and because pins 6 and 10 of the flipflop gates are pulled slightly down by a small current drawn through the 15k base resistor of Q1, the flipflop always 'wakes up' in the OFF state with the output of IC1c low and the output of IC1b high. This also allows the 220nF capacitor connected from pin 13 of the IC to the negative line to charge up via the 1M resistor, so that the voltage on pin 13 rises to almost +9V.

Now when we touch the sensor contacts with a finger,

a small current can flow from the +9V line through our finger and the 100k resistor. This tiny current allows the 10nF capacitor to charge, and as it charges its voltage rises — taking pins 1 and 12 of the IC with it.

As soon as this voltage rises to about +4.5V, IC1d is forced to switch because both of its inputs are now 'high'. So it immediately switches its output low, pulling the pin 9 input of flipflop IC1c low with it. This triggers the flipflop into flipping states, so it switches ON with IC1c's output high and IC1b's output low. This makes Q1 turn the LED and relay both on as well.

Notice that because the output voltage of IC1b goes low, the 220nF capacitor on pin 13 of IC1b is now forced to discharge via the 1M series resistor. So the voltage at pin 13 falls away to zero. On the other hand the 220nF on IC1a's input pin 2 is now able to charge up instead, via its own 1M series resistor connected to the output of IC1c. So the voltage on pin 2 now rises to +9V, instead.

Now if we touch our finger to the sensor contacts again, the tiny current allows the 10nF capacitor to charge up again, taking input pins 1 and 12 of the IC high again. But this time it's gate IC1a that is switched on when the capacitor voltage reaches +4.5V, because its pin 2 is resting at +9V rather than IC1d's pin 13. So now pin 3 switches low, pulling with it input pin 5 of flipflop IC1b. This again triggers the flipflop into flipping states — this time back into the OFF state, with the output of IC1b high and the output of IC1c low. So Q1 turns off, turning off the LED and relay.

Get the idea? Even though we only have a single touch sensor to generate the pulses to trigger the flipflop into switching back and forth, the 220nF capacitors and 1M resistors control gates IC1a and IC1d so that they 'steer' each alternate pulse to the right flipflop input to make it change state. So when the floplop is OFF the next pulse is steered to the input of IC1c to trigger it ON, and when it's ON the next pulse is steered to the input of IC1b to trigger it OFF.

By the way diode D1 is used to make sure the pin 1 and pin 12 inputs of the IC can't be pulled to a more positive voltage than +9V, by any excessive charge that may be on your fingertip when you touch the sensor. Similarly diode D2 protects transistor Q1 from damage due to back-EMF 'spikes' which may be generated in the relay coil when Q1 turns off. And of course diode D3 is to protect all of the components from damage if you should accidentally connect the battery with reversed polarity.

colour codes all read either left-to-right or bottom-to-top, depending on the resistor's orientation.

With the resistors fitted, you can fit the greencap capacitors. The small 10nF capacitor goes in the centre of the board down between two of the 1M resistors, while the two larger 220nF capacitors go on the left. The board is provided with extra holes to suit capacitors with different pin spacings, so you shouldn't need to dress any of their leads.

Next you can fit the first polarised part, the 220μF electrolytic capacitor. This goes just above the two 220nF greencaps, with its positive lead towards the right as shown in the wiring diagram. The board again provides extra holes for its leads, so pick the two whose spacing best matches the capacitor's lead spacing.

With all of the capacitors now in place, you can now add the three diodes. The 1N4148 diode D1 in its smaller glass package goes at the bottom centre of the board, while the larger 1N4004 power diodes D2 and D3 go just above the 820Ω resistor and at upper left respectively. Remember that all diodes are polarised, so check their polarity carefully against the wiring diagram before you solder them in place.

Now you can fit the PN100 transistor Q1. As shown in the

wiring diagram this fits with its flat side upward, but you'll have to crank each of its two outer leads further outwards by about 1.25mm, to match the board hole spacing.

Next the 4093B integrated circuit (IC1) can be fitted, making sure that you fit it to the board with its notch/dimple end towards the left as shown in the wiring diagram. Remember that the 4093B is a CMOS device and susceptible to damage from electrostatic charge, so use an earthed soldering iron and make sure you discharge both yourself and the PC board by touching some earthed metalwork before you handle the IC and fit it into the board. It's also a good idea to solder pins 7 and 14 of the IC to their board pads first, as this helps the IC's own internal circuitry to protect itself.

The last semiconductor device to fit is the LED. As you can see from the wiring diagram, this fits on the lower right hand side of the board with its cathode flat side towards the right and its longer anode lead passing through the leftmost hole. The LED can be fitted with the bottom of its body about 8mm above the board, as shown in the photos.

The very last component of all to fit is also the largest: the relay. This goes near the top centre of the board, and can only be fitted one way around because its five pins are



arranged with two at one end, and the other three at the other end. So it's simply a matter of orientating the relay this way around, pushing the pins through the matching board holes and soldering them to the pads underneath.

Your main board assembly should now be complete, and almost ready for testing. All that remains is connecting up the battery clip lead wires to the terminal pins at upper left, and connecting the small sensor board to the terminal pins at bottom centre using two short lengths of insulated hookup wire. Follow the wiring diagram carefully when you're making these connections, and be particularly careful with the polarity of the battery clip wires. The red wire goes to the upper '+' terminal pin.

Now your Touch Switch should be complete, but before trying it out check all of the component locations and the orientation of all polarised parts to make sure you haven't made any mistakes. Also give your solder joints a quick once over, in case you've forgotten any or made any dry joints.

### Trying it out

Everything check OK? Great, so now you can connect up the battery and see if your Touch Switch works as it should.

When the battery is first connected, nothing should seem to happen and the LED should remain dark. But when you briefly touch the tracks on the sensor board with a finger, the LED should suddenly turn on and there'll be a small click from the relay, as it turns on at the same time.

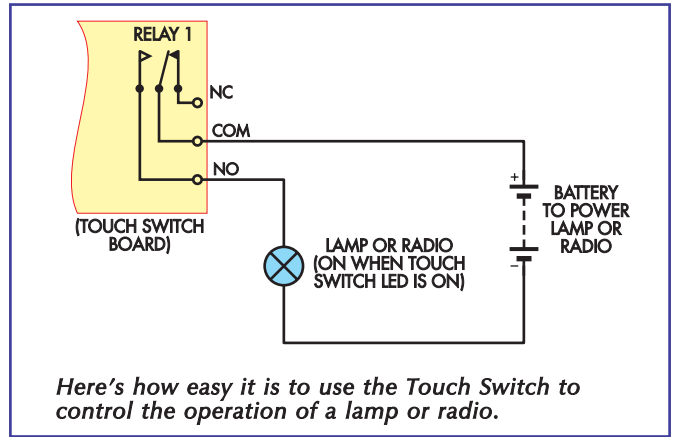
Now try touching the sensor board tracks again. This time the LED and relay should both turn off again, so there should be another small click and the LED will go dark. Touching the sensor board a third time should switch the LED and relay both on once again, and so on. In fact if you keep your finger pressed lightly against the sensor, the LED and relay should turn on and off repeatedly at about twice a second.

If everything happens as we've just described, your Touch Switch is finished and working exactly as it should. So it's ready to be put to use, by connecting up the relay contacts as a switch to control your low voltage bedlamp or radio.

But what if it **doesn't** work as we've described? Ah, that will be because you've made a mistake of some kind in wiring it up. So you'll now have the job of disconnecting the battery and tracking down the cause of the problem.

If nothing happens at all, even when you touch the sensor board a number of times, chances are that you've made a mistake in wiring up the battery clip lead wires, or in fitting one of the diodes (such as D2 or D3). Or you may have fitted either Q1 or IC1 the wrong way around.

If the LED and relay turn on as soon as you connect the



battery, and stay on regardless of you touching the sensor board, you may have connected in diode D1 the wrong way around.

These are probably the main kinds of mistake you might make that will prevent the Touch Switch working properly. So checking for each of these mistakes will very likely show up the one you've made, and then let you fix it.

### What to do next

It's quite easy to use the Touch Switch relay contacts to switch the power to a lamp, radio or other low voltage device. This is done simply by connecting wires to the COM and NO (normally open) relay, and wiring them in series with one battery lead to the lamp or radio. This is shown in the small diagram.

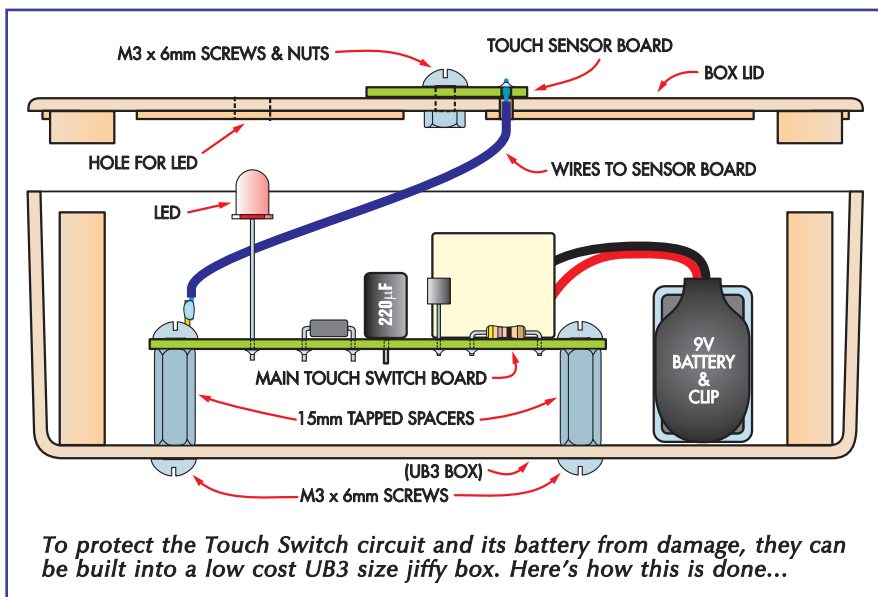
Alternatively you could use the Touch Switch to mute (silence) your radio while you answer the phone, by connecting the relay's COM and NC (normally closed) contacts in series with one of the radio's battery leads instead. This means that the radio will be turned off when the Touch Switch's LED is on, and vice-versa.

Because the Touch Switch is so handy, you might want to house it in a small plastic utility box so it's neater and easier to use. This is quite easy to do, as the PC board has been designed to fit easily inside a standard low cost UB3 size (130 x 67 x 44mm) jiffy box. The Jaycar HB-6023 (grey) or HB-6013 boxes are ideal.

The main board can be mounted inside the bottom of the box using eight M3 x 6mm machine screws (HP-0400), with four 15mm long M3 tapped spacers (HP-0904) to space them apart and allow the LED to protrude through a 5mm hole in the lid when it's fitted. The touch sensor board can be mounted on the top of the lid, using a pair of M3 x 6mm machine screws and nuts to attach it and with the connection wires passing through to the inside of the box via a pair of 2mm diameter holes immediately behind the connection pads.

You don't even need to fit the Touch Switch with its own On-Off switch when it's housed in a box like this, because when the LED and relay are both off the circuit draws almost no current from the battery. In fact the battery drain is less than one microamp (1µA) in this 'waiting' state, so there's simply no need to disconnect the battery to extend its life.

**Finally, an important note: Don't try to use this Touch Switch project to control mains powered devices. The insulation on the PC board is not designed to withstand high voltage, and there would be a serious risk of a potentially fatal electric shock.**



## Project 6:

# A Wet/Dry Moisture Alarm

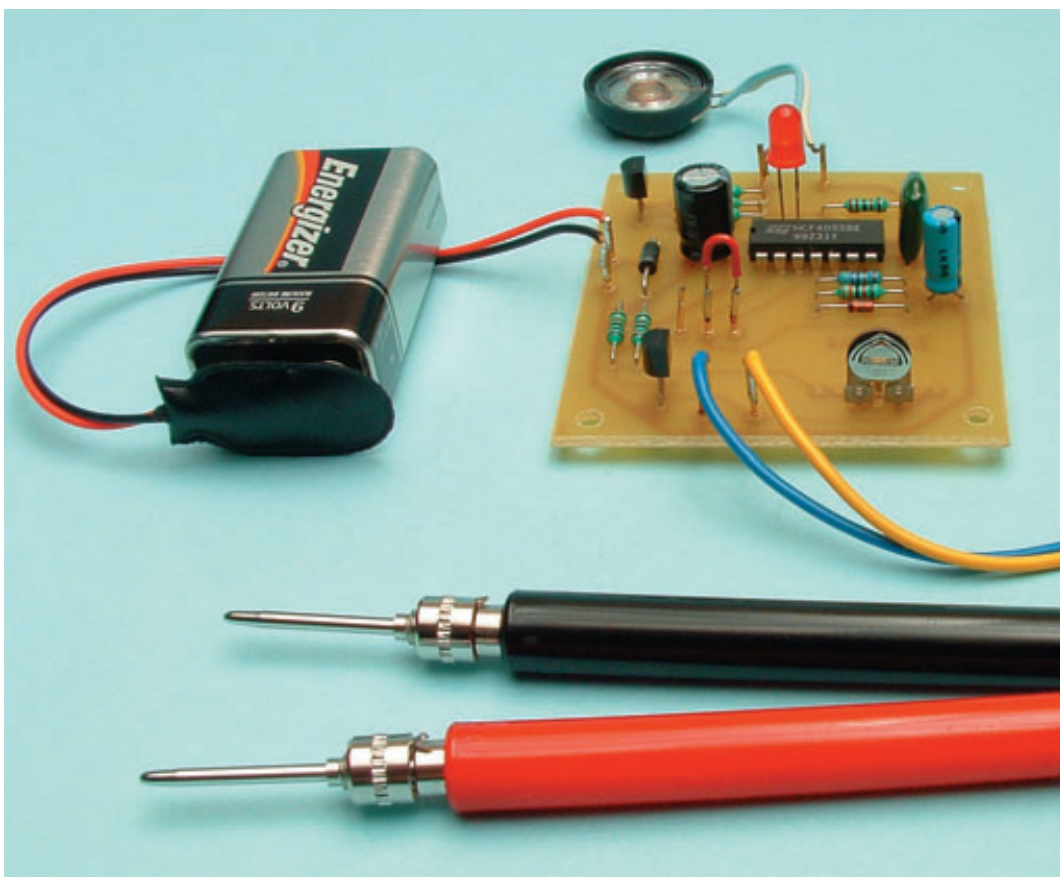
Do mum's pot plants die because no-one remembers to water them often enough? You can be a hero by building up this neat wet or dry alarm, which lets you know when the soil has dried out and needs more water. It can alternatively be used to let you know when soil has become too moist, or the water level in your pool has risen too far...

### What does it do?

This project has many uses, because it senses the amount of moisture present between two metal electrodes or 'probes', and sounds a small alarm siren when the moisture level is either too low or too high — depending on what you want. It even provides a **sensitivity** control, so you can adjust exactly how far the moisture level can go up or down before the alarm will sound.

It can sense the amount of moisture present because just about all kinds of water conduct electricity. (The only exception is distilled water.) So the amount of current that flows between the alarm's sensing probes is a good guide to the amount of water that's present between them.

By setting the Alarm's wire link for 'DRY' detection, it will monitor the small current that flows between the two probes and sound the alarm when the current falls to too low a level. So in this mode, the alarm can be used to keep track of the moisture level in the soil of pot plants, rose gardens or whatever. It can even be used to monitor the water level in a rainwater or fish tank, and sound the alarm



### The parts you'll need for this project:

- 1 PC board, code SHRTC206, 57 x 63mm
- 1 21mm mini speaker
- 1 9V battery, 216 type
- 1 9V battery clip lead to suit
- 1 1M vertical trimpot, 5mm open carbon type
- 9 PCB terminal pins, 1mm dia.
- 1 2m length insulated wire
- 1 Small pack of resin-cored solder

#### Semiconductors

- 1 4093B quad Schmitt NAND gate (IC1)
- 1 PN100 NPN transistor (Q1)

- 1 PN200 PNP transistor (Q2)
- 1 5mm red LED (LED1)
- 1 1N4148/1N914 diode (D1)
- 1 1N4004 diode (D2)

#### Capacitors

- 1 330 $\mu$ F 16V RB electrolytic
- 1 2.2 $\mu$ F 50V RBLL electrolytic
- 1 47nF greencap

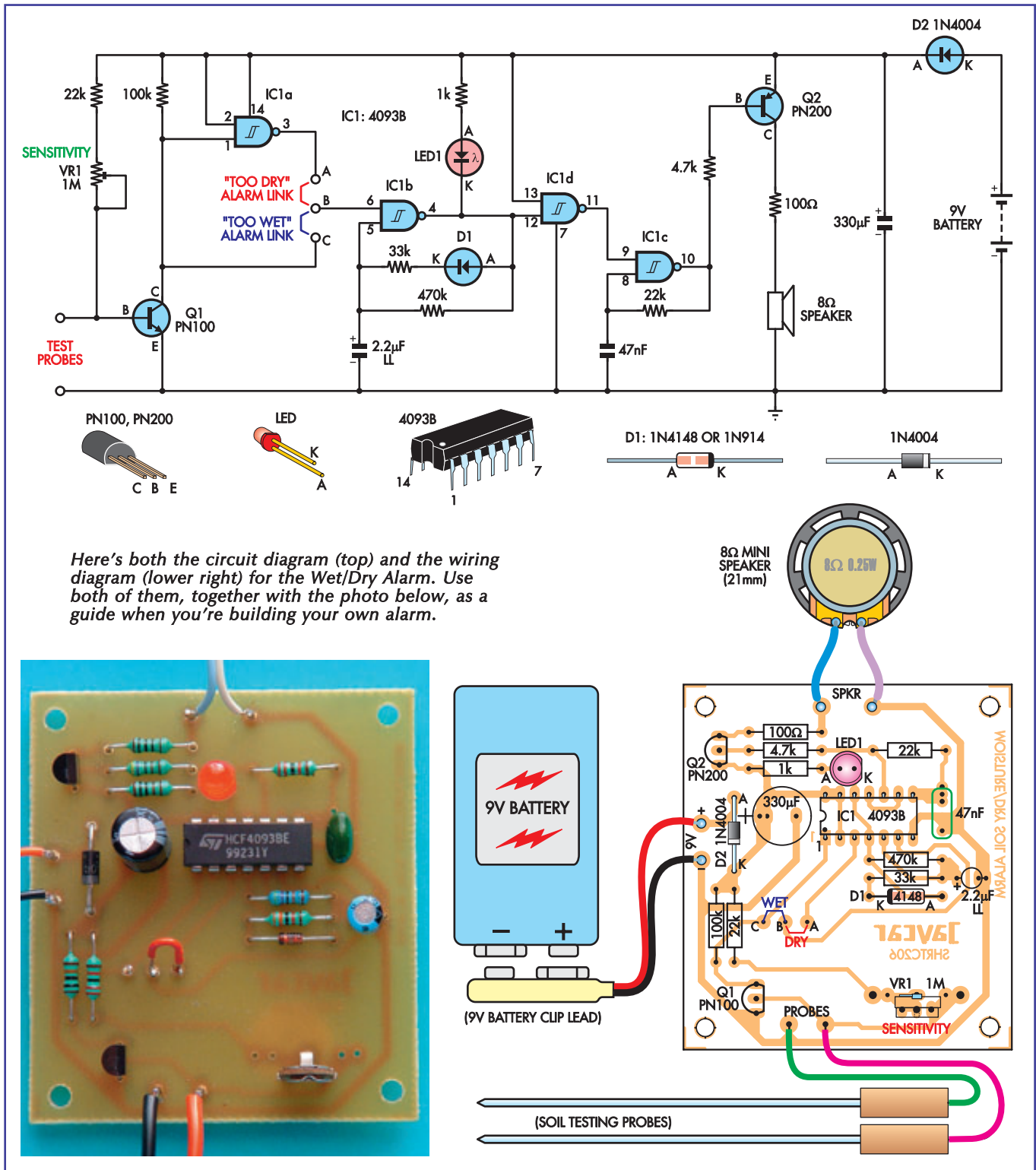
#### Resistors (0.25W 1%)

- |            |        |
|------------|--------|
| 1 470k     | 1 100k |
| 1 33k      | 2 22k  |
| 1 4.7k     | 1 1k   |
| 1 100 ohms |        |

when the level drops below the electrodes.

On the other hand by setting the Alarm's wire link for 'WET' detection, it will monitor the two probes and sound the alarm when a current flows between them of more than the 'threshold' level you've set. That means that in this mode, the alarm can be used to warn you when the soil in pot-plants or gardens has become too moist, or 'waterlogged'. Another use would be in monitoring the water level in a pool (or spa, or bath) and warning you when the level rises too high so it's in danger of overflowing.

The Wet/Dry Alarm does all of these jobs with complete safety, because the voltage between the moisture sensing probes is always less than one volt. The maximum current that can flow between them is also extremely small: less than half a milliamp (0.5mA).



## Putting it together

The Wet/Dry Alarm is very easy to build. That's because apart from the 9V battery and a tiny speaker used to produce the Alarm's beeping siren sound — and of course the test probes — everything fits on a compact PC board coded SHR2C206 and measuring only 63 x 57mm.

Although there are no wire links needed on this board, it does need some PC board terminal pins. In fact there are nine of these, six for the various off-board connections and three for the WET or DRY mode selection link connection.

Before starting construction, open up your kit and lay out

the parts on your work area so you can make sure you have everything. Then check the copper side of the board carefully, to make sure it has no manufacturing defects. Now is the time to fix them, in the unlikely event that it does.

Begin the construction by fitting the PC board terminal pins, in the positions shown in the wiring diagram and the photos. Don't forget to solder them all to their pads under the board.

Now you can fit the fixed resistors. There are eight of these, and only two have the same value (22k). So it's a good idea to fit these two first, to avoid errors. Then fit the others, still taking care to fit each one in the correct position



## Tech Talk: How does it work?

As you can see from the circuit, the test probes are connected directly between the base and emitter of transistor Q1. A very small forward bias current can also be supplied to the transistor's base, via trimpot VR1 and the 22k resistor connected to the +9V line. So if there's no external conductive path between the two probes (because the soil is very dry), all of this bias current can flow into the base and turn the transistor on.

If there **is** a conductive path between the two probes, though, some or all of the bias current will flow through this external path rather than through the transistor's base-emitter junction. The transistor will therefore tend to turn off, especially if we have already set VR1 so that the initial bias current was only just enough to turn the transistor on.

It's this simple input stage which does the basic job of sensing the external resistance between the two test probes. When that resistance is high, transistor Q1 is turned on and conducts current through the 100k collector resistor, so its collector voltage drops to zero. On the other hand when the external resistance between the probes drops below a certain value (adjusted by using VR1), Q1 turns off and its collector voltage rises up to very nearly +9V.

The rest of the circuit is designed to respond to this behaviour of the input stage, and make the LED flash and the mini speaker beep if it detects one of these states or the other. If the mode link is wired between pins B and C, for example, the LED flashes and the speaker beeps if the collector voltage of Q1 is **high** — which corresponds to Q1 being off, because the bias current is being drained away through the probes. In this mode the Alarm works when the soil resistance is too low — i.e., it's too wet.

Gate IC1a is connected as an inverter, so we can choose the alternative mode of operation. Because of the gate's inversion, its output voltage is high whenever the collector voltage of Q1 is low, and vice-versa. By connecting the mode link between pins B and A, the Alarm will flash its LED and produce beeps from the speaker whenever the collector of Q1 is **low**. This

corresponds to the transistor being turned on, because most of the bias current is flowing into its base rather than through the test probes. This means the Alarm works when the soil resistance is too high — i.e., it's too dry.

We produce the LED flashing and beeping in the following way. Gate IC1b is connected as an oscillator, because of the two resistors and diode D1 connected between output pin 4 and input pin 5, and also the 2.2µF capacitor connected from pin 5 to the negative line. This allows the gate to oscillate at about 2Hz (two cycles per second), but only when the second input pin 6 is raised to the high (+9V) level. So when the voltage on pin 6 is pulled high by the input circuit, the output of IC1b starts flicking up and down twice per second.

Now as you can see LED1 is connected between this output pin and the +9V line, via a 1k series resistor. So each time the output of IC1b goes low, the LED glows and produces a brief flash of light.

Input pin 12 of IC1d is also connected to the output of IC1b and as you can see, this gate too is connected as an inverter. So whenever the output of IC1b goes low, the output of IC1d goes high. And this output in turn is used to gate another oscillator, using gate IC1c. When this second oscillator is gated on, it oscillates at a frequency of around 1kHz. The output of this oscillator is used to control the conduction of transistor Q2, which therefore gets turned on and off at this frequency.

When Q2 conducts, it allows a short pulse of current to flow through the 100Ω resistor to the speaker. So whenever the IC1c oscillator is gated on, the speaker emits a sound tone of about 1kHz.

But because IC1c is only gated on when the output of IC1b is low, and this happens only twice a second — at the same time as the LED is flashing — this means that the speaker only produces the 1kHz tone in short beeps, at the same rate.

Why do we make the LED flash and the speaker produce short beeps of sound? Simply because this uses less battery power than if the LED and tone were made to stay 'on' continuously. At the same time the flashing and beeping are actually better at attracting your attention, because of their cyclical changing.

as shown in the wiring diagram. They're not polarised, but if you fit them with their colour codes reading left-to-right or bottom-to-top this will make troubleshooting easier if it's needed later on.

Next you can fit the 47nF greencap capacitor, which goes at upper right and just to the right of where the IC will be fitted. This capacitor isn't polarised, but the board does have some additional holes to allow you to fit components with different lead spacing.

Now you can fit the two electrolytic capacitors — the larger 330µF unit and the smaller 2.2µF low leakage unit. These are both polarised, of course, and in this case they both mount with their positive leads towards the left. Again we've provided extra holes on the board to allow you to fit caps with different pin spacing.

The last passive component to fit is VR1, the 1M trimpot which is used to adjust the Alarm's sensitivity. As you can see from the wiring diagram this mounts vertically at lower right on the board. You'll also notice that there are additional holes around the trimpot's position — these are provided so that you can replace it with a larger control pot, if you wish. We'll tell you more about this later, in the What To Do Next section.

Right, now it's time to fit the semiconductor devices. Start by fitting the two diodes, and note that D1 is a 1N4148 in a small glass package while D2 is a 1N4004 in a larger plastic package. They're both polarised, so they each have to be fitted to the board with the correct orientation as shown in

the wiring diagram. Next fit the LED, which goes at the top centre of the board just below the terminal pins for the mini speaker. It also fits with its cathode flat side towards the right, and its longer anode lead in the leftmost of the two board holes. Solder its leads with the body of the LED about 10mm above the board, unless you're going to fit the Alarm inside a UB3 size box as described later. In that case, leave the LED leads at their full length.

The two transistors Q1 and Q2 are fitted next, taking care not to mix them up. Q1 is the PN100, and Q2 the PN200. They both fit on the board with their flat side towards the right, but as usual you'll have to crank their outer leads further away from the inner lead so they'll all pass through the board holes without strain.

The last component to fit is IC1, the 4093B. As you can see this fits between the 330µF electro and the 47nF greencap, with its notch/dimple end to the left. You may need to dress the pins on each side of the IC inwards slightly, so they all pass through the PC board holes without strain.

Don't forget that the 4093B is a CMOS device, and these can be damaged by electrostatic charge. Use an earthed soldering iron, and discharge both yourself and the Alarm PC board's copper by touching some earthed metalwork before you handle the IC and solder its pins to the board pads. It's also a good idea to solder pins 7 and 14 of the IC first, as this allows its internal protection to begin working.

Your Wet/Dry Alarm's board assembly should now be

complete, so to finish off the project you only need to add the various off-board connections and the short wire link used to select either wet or dry alarm mode.

After you decide which alarm mode you want, fit the wire link to join the centre of the three terminal pins to either of the two outer pins — using the wiring diagram as a guide. (The photos also show the link fitted for a DRY mode alarm.)

Now connect the battery clip lead wires to the pins on the left-hand side of the board, with the red wire going to the upper pin. Then connect the mini speaker to the two pins on the top of the board, using the wiring diagram as a guide again.

Next solder a couple of lengths of insulated hookup wire to the two PROBE pins on the bottom of the board, between Q1 and the trimpot VR1. These wires will be used to connect up the Alarm's moisture sensing probes — more about them later.

Your Wet/Dry Alarm should now be complete and ready to try out. But just before you do this, give it a careful check to make sure you've fitted all components in their correct positions and with their correct orientation. Also make sure you've made all of the solder joints properly, and not accidentally left any slivers of solder to cause short circuits.

### Trying it out

If everything checks out OK, set trimpot VR1 to the middle of its range and connect up the 9V battery. What happens next will depend on the mode you've set with your wire link.

With the link in the DRY position, the LED should immediately begin to blink on and off, and the speaker should emit a beeping sound at the same time. This is assuming that the ends of your two sensor probe wires are not touching, by the way — if they are touching, you'll get no flashing or beeping. In fact you should be able to stop the activity in both the LED and speaker by touching the two wire ends together.

On the other hand if your link has been fitted in the WET position, you shouldn't get any blinking or beeping when the battery is first connected. Instead you'll only get this activity when you touch the ends of the probe wires together, to allow a current to flow between them.

If your Wet/Dry Alarm behaves in either of these ways, depending on the position of your mode link, it's working exactly as it should. You'll now be able to add a couple of sensor probes to the ends of the wires, and put it to use.

For the probes themselves you can use a couple of 200mm lengths of stout wire — perhaps salvaged from an old wire coathanger. There's no need to use fancy multimeter-type test probes like those shown in the photo, although these

would be nice if you can afford them.

The easiest way to find the best setting for the sensitivity trimpot VR1 is by placing the probes in a small pot of soil. If you make the soil just slightly moist, so that it represents the driest you want your plant's soil to get, trimpot VR1 can then be set so that there's no activity from the LED and speaker. Then when the soil dries out just a little bit more, they'll sound the alarm.

Of course if you will be using the Alarm in WET mode, you'll need to make the soil in your testing pot as wet as you want your plant soil to get, before the plants get waterlogged. Then adjust trimpot VR1 so that the LED and speaker are just starting to flash and beep.

If you're going to use the Alarm to warn you about the water level in a tank, pool or bath, you don't even have to use a pot of soil to find the correct setting for VR1. Just use a glass or jar of water, or even the water in the tank or pool itself.

### What to do next

If you want to use your Wet/Dry Alarm to check the moisture levels in a number of different pot plants or gardens, you might want to replace trimpot VR1 with a larger 16mm or 24mm control pot, fitted with a knob so the Alarm's sensitivity can be adjusted more easily. This is easy to do, as the PC board has extra holes to take the pins of either of these larger pot sizes.

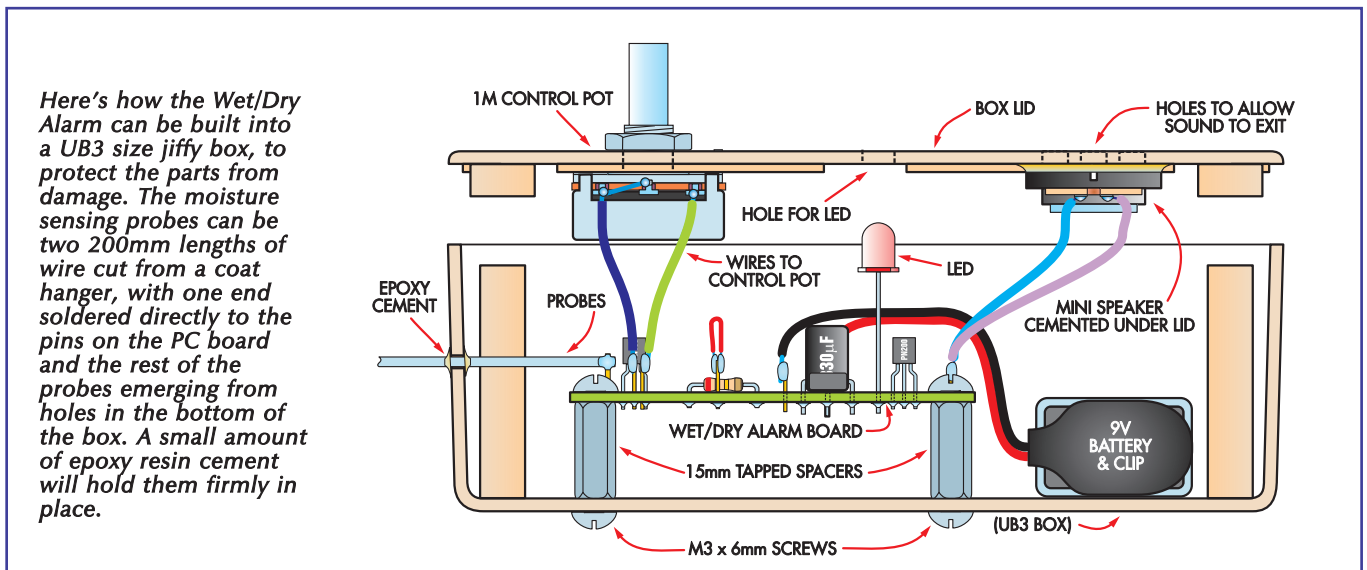
The larger pot you fit should have the same value as shown for VR1 — i.e., 1M $\Omega$ . Jaycar stores can provide the RP-7524 (16mm) or the RP-3524 (24mm), either of which would be fine for the job. They can also provide a selection of control knobs to match.

There's no real need to fit the Alarm with an On/Off power switch, because the current drawn from the battery when the Alarm is not flashing and beeping is very low — less than 40 microamps (40 $\mu$ A), and typically only about 17 $\mu$ A. So the battery can be kept connected all the time.

Need a louder beeping sound from the Alarm? You can get a louder sound by replacing the kit's min speaker with a larger and more efficient speaker, such as the low cost 90 x 50mm oval type available in Jaycar stores as AS-3025. Or you could use a small horn speaker for even higher efficiency — such as the Jaycar AS-3180.

If the sound still isn't loud enough for you, you can replace the 100 $\Omega$  resistor with a 33 $\Omega$  resistor (1W rating, like the Jaycar RR-2538), to allow more current to flow through the speaker. But if you do this you'll also need to replace the 4.7k base resistor with a 3.3k resistor (such as Jaycar's RR-0536), so Q2 can switch the higher current.

You'll also need to replace the 216-type 9V battery with a



larger battery, capable of supplying the higher current. A good choice would be six AA alkaline cells (SB-2382 + SB-2383), fitted in a six-cell holder like the Jaycar PH-9206.

You might also like to house the Wet/Dry Alarm 'works' in a plastic utility box, to protect it from damage. The board will easily fit in a standard UB3 box like the Jaycar HB-6023 (grey) or HB-6013 (black), with the mini speaker glued to the rear of the box lid behind a small array of 5mm holes to let the sound pass through.

The board itself is mounted in the bottom of the box using four 15mm long M3 tapped spacers, and eight 6mm long M3 machine screws as shown in the small diagram. The leads of the LED are left long, so it can protrude through a 5mm hole in the lid.

If you house the Alarm in a box like this, you'll probably also want to replace trimpot RV1 with a larger control pot as mentioned earlier. In this case the larger pot would not be fitted directly to the board, though, but mounted on the lid

so it can be adjusted even when the box is closed. This is also shown in the diagram.

You might also want to connect a small toggle switch to the three terminal pins on the board, so you can also change the Alarm between DRY and WET mode without having to open the box. The switch (such as Jaycar's ST-0335) would be mounted on the lid alongside the pot, with short insulated wires running down to the board pins.

Fitting everything into a UB3 box like this would also allow you to make the two test probes a permanent part of it as well. If you use a pair of 200mm long lengths of coat-hanger wire, these can be passed through a pair of 2.5mm holes in the bottom end of the box, and soldered to the pins on the bottom of the PC board assembly. A small blob of epoxy resin cement can be used to seal each probe wire to the box, so there's no strain on the solder joints when the probes are pushed into soil. The diagram also shows how this can be done.

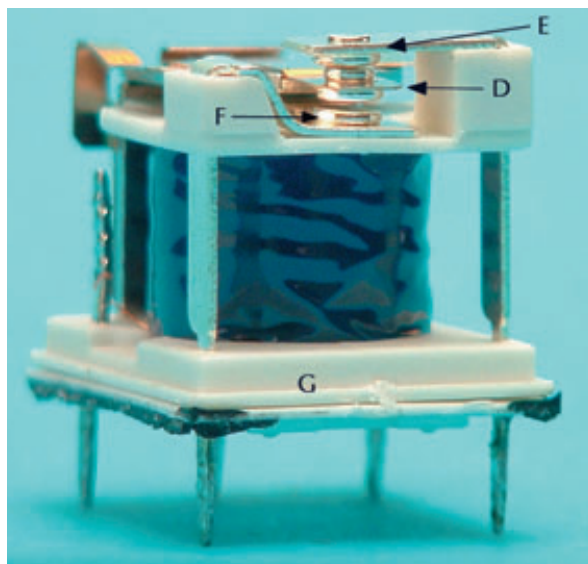
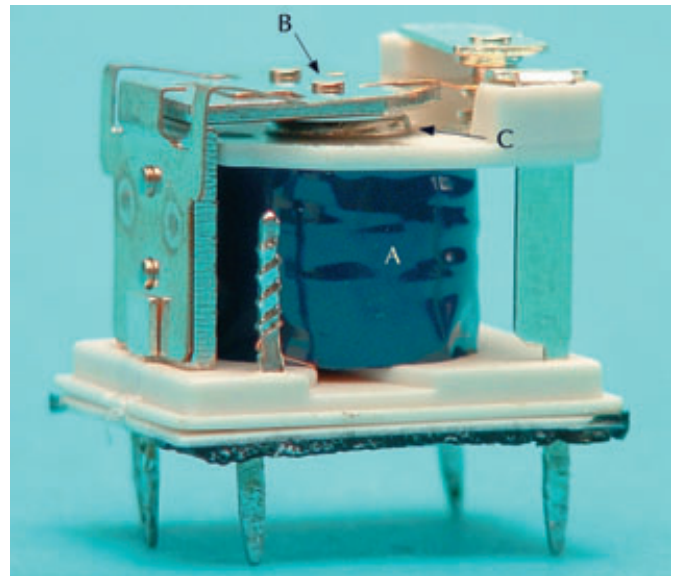
## How Relays Work, & How to Use Them

Two of the projects in this book make use of a relay, so you may want to learn more about these interesting and useful components. Here's an easy to follow explanation of the way they work, and also how they're used.

A relay is basically just a switch that is operated by a small electric current, instead of manually like a pushbutton or toggle switch. As a result relays make it possible for one electrical or electronic circuit to control whether or not a current flows in another circuit — or to select which of two circuit paths a current flows through in that second circuit. This makes relays very handy components.

A relay has one or more sets of switch contacts, just like any other kind of mechanical switch. But the big difference is that instead of being operated by you pressing a button or flipping a toggle lever, in a relay the switch contacts are made to operate by passing a relatively small current through the coil of an electromagnet. As a result of this current flow the electromagnet pulls a small pivoting metal **armature** towards its pole piece, and this movement operates the switch contacts.

Sometimes the end of the moving armature operates the switch contacts through a small lever of insulating material. This makes doubly sure that there is no electrical connection between the **controlling** circuit which is operating the relay and the **controlled** circuit which is connected to the switch contacts. However in many very compact relays, especially



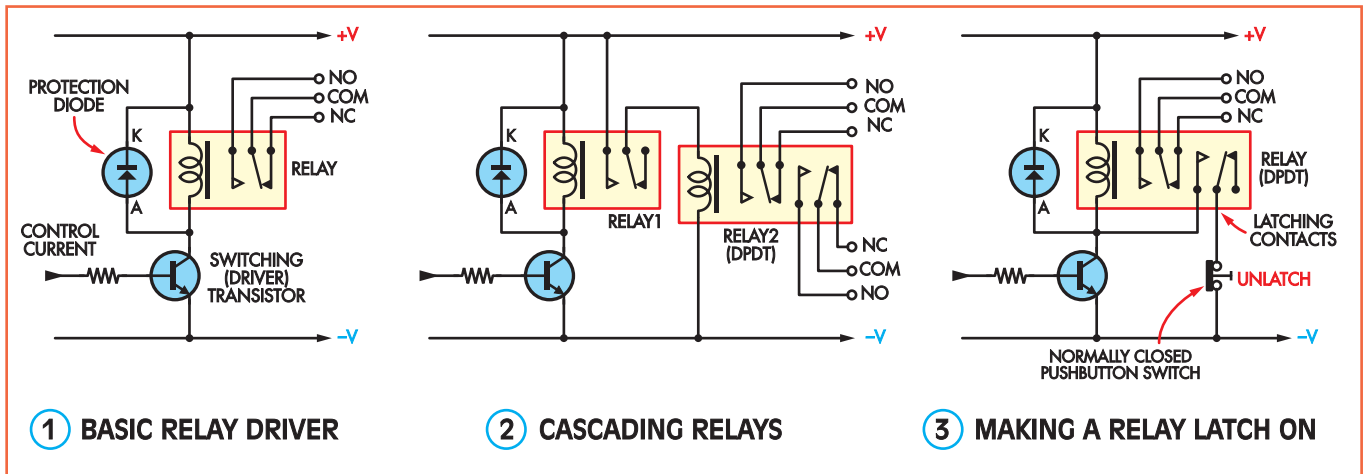
*You can see above the relay's electromagnet coil A and its pivoting armature B, just above the pole piece C. The moving switch contact D is at the right-hand end of the armature, and is better seen in the end photo at left. Here you can also see the upper and lower fixed contacts E and F, and their connections passing down through the base G.*

those with just a single set of switch contacts and intended to switch only low voltages, the end of the moving armature itself is used as the moving switch contact.

Even where this is done, there can still be a high degree of electrical insulation between the controlling and controlled circuits — because only the electromagnet coil is connected to the controlling circuit, and the armature and switch contacts never make electrical contact with the coil.

The photos show what's inside the kind of compact relay used in projects 2 and 5 in this book. As you can see the electromagnet has a small cylindrical coil wound on a vertical soft iron pole piece, with the coil connections brought out to two of the pins which emerge from the base of the relay. An L-shaped piece of sheet iron provides a





1 BASIC RELAY DRIVER

2 CASCADING RELAYS

3 MAKING A RELAY LATCH ON

magnetic path from the bottom of the electromagnet pole piece up the side of the coil (on the left in the upper photo), and another small piece of soft iron pivots on the top of this L-piece, to become the moving armature.

An L-shaped stamping of phosphor-bronze foil forms the pivot 'hinge', and also acts as a spring to push the armature away from the electromagnet pole when the coil isn't passing any current (and therefore isn't energised). And the end of the spring extends past the end of the iron armature (visible in the second photo), where it forms the moving contact. Tiny silver-plated contacts attached to its end touch either an upper fixed contact when the relay isn't energised, or a lower fixed contact when it is energised. Needless to say the connections to all three contacts are brought out of the relay via more pins which emerge from the bottom. You can see the two fixed contact pins quite clearly in the second photo — the upper ('normally closed') contact pin on the right, and the lower ('normally open') contact pin on the left.

Normally all of the relay's works are enclosed in a small plastic cover, to protect them from dust and moisture. We removed this cover to take the photos. Notice that the relay shown has only a single set of 'changeover' contacts — ie, it's an SPDT (single pole, double throw) relay.

Now in order to move the relay's armature and thus operate the switch contacts, the electromagnet must provide a specific amount of magnetic 'pull'. How much pull it provides depends mainly on two things: the number of turns of wire in the coil and the current we arrange to flow through them. So the relay manufacturer can make a relay which needs only a small coil current by winding the coil with a large number of turns (using very fine wire). Conversely by winding the coil with a smaller number of turns (using larger diameter wire), the manufacturer can produce a relay which needs more coil current to operate (but quite possibly from a lower voltage). This is how they make relays which are designed to operate from different controlling circuit voltages — 6V, 9V, 12V and so on.

By the way, a relay needs more coil current to pull its armature against the pole piece, than it needs to **hold** the armature in that 'energised' position. That's why relays often have two coil current ratings — the 'pull-in' current level and the 'holding' current level. The holding current level may be 30% lower than the pull-in current.

Note that the voltage required to produce the relay's pull-in current in the coil is largely determined by the coil resistance. But relays also have another set of voltage and current ratings: the voltage and current that the relay's **contacts** are able to handle and switch safely. For example the small relays used in projects 2 and 5 have contacts which can switch currents of up to 3A and voltages of up to 125V AC (not necessarily at the same time). This means that they're fine for switching quite reasonable currents in low voltage circuits, but they're definitely NOT suitable for switching even small currents in 240V AC mains circuits.

To switch high currents and/or currents in high voltage

circuits, you need to use relays which are designed for these jobs. Some special 'heavy duty' relays have very large contact sets which can handle hundreds of amps, while 'high voltage' relays have better insulation and contacts designed to switch high voltage without creating an arc.

### Driving relays

Often the simplest way to operate a relay is to connect its coil in series with a small transistor, as we've done in projects 2 and 5. The transistor is then used to switch the coil current on and off, to energise the relay or turn it off — and hence operate its contacts, controlling whatever circuit is connected to them. The basic idea is shown above in diagram 1.

So if the relay coil needs say 30mA of pull-in current to operate it, the transistor only needs to switch this kind of current. Since most transistors have a current gain of at least 30, this means that less than 1mA of base current is needed to control the transistor and relay combination.

Why is there almost always a diode connected across the relay coil, with its anode connected to the join between the coil and the driver transistor? That's to protect the transistor from the high voltage 'spike' which is induced in the relay coil when the transistor turns off (to de-energise the relay). The coil generates this voltage spike when its magnetic field collapses, to try and keep the current flowing. If the diode isn't connected as shown, this high voltage spike can damage the transistor. But with the diode fitted, it conducts when the spike occurs and turns this returned energy into heat.

### Cascading relays

What if you want to control high currents or voltages, or control a number of different circuits, from a circuit fitted with only a small low power relay with one set of contacts — like Project 5 in this book? This isn't all that hard to do, by using the small relay to control a larger one that IS rated for switching higher currents or voltages.

Using one relay to control another is known as **cascading** relays. It's illustrated in diagram 2 above.

### Making a relay latch

In some circuits, we may need a relay to latch itself (hold itself on), after it has been turned on by the controlling circuit. This isn't hard to do either, providing it has an extra set of contacts. The extra contacts are simply used to make another connection from the relay's coil to its supply voltage (see diagram 3 above). So when the relay has been turned on by another relay or a transistor, it closes these contacts to keep itself turned on.

But how do you turn this kind of latching relay off again? By using another switch or normally-closed pushbutton to break the connection between its latching contacts and the supply voltage. This is also shown in diagram 3. It's easy when you know how! ★

## Project 7:

# LED Audio Level Display

Have you admired those fancy volume level displays on DJ mixing desks and recording consoles, with columns of light that dance up and down with the music? Here's how to make one for yourself, which can be hooked up to the output of a CD or tape player — or even a transistor radio. If you build two of them, they can be used for level displays on your stereo hifi system.

### What does it do?

When you're listening to a music CD or tape, the electrical signals which the player feeds into your amplifier or headphones are called 'audio' signals because they ultimately get turned back into *audible* sounds: the music. You won't be surprised to learn that these audio signals consist of a mixture of varying AC voltages, each voltage representing the sound from one particular instrument or singer's voice. The sum of all these AC voltages varies up and down in level as the sound volume itself goes up and down.

What this LED Level Display does is convert this varying audio AC signal into a varying DC voltage, whose voltage at each instant still represents the overall audio volume level. Then it feeds this varying DC voltage into a special 'LED driver' integrated circuit (IC) which controls the current drawn by each LED in a vertical column of 10. The IC checks the varying DC input voltage every instant, and depending on the exact voltage level, it turns on a proportional number of the LEDs, starting from the bottom.

For example only one or no LEDs may get turned on when the audio level is quite low, but as the level rises more and more of the LEDs are turned on. That's why the LEDs provide a 'dancing column of light' in time with the music.

DJs and recording engineers use these displays so they can get an accurate indication of the volume level at all times. This allows them to make sure they are playing or recording the music at a high enough level to keep noise inaudible, yet at the same time not having the volume too high — because this produces **overload** and

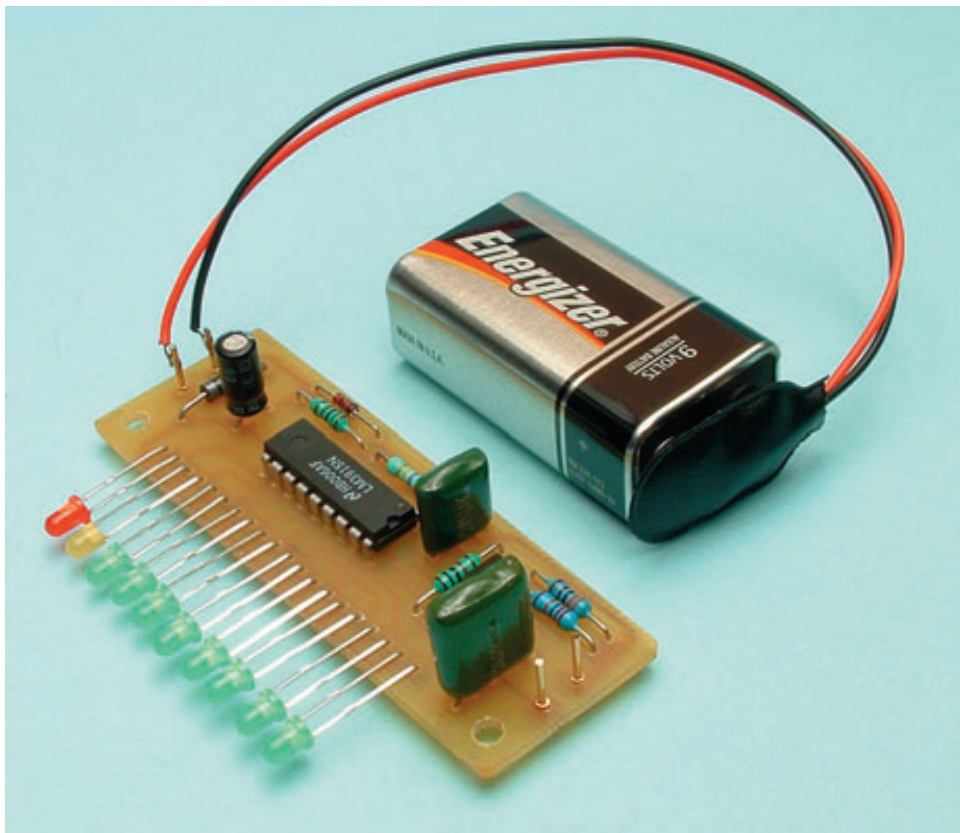
makes the music become distorted and 'rough'.

The LED driver IC in this LED Level Display does provide an accurate display of the input signal volume, and it's also provided with orange and red LEDs in the two top positions to show when the volume is approaching overload level.

Both of these features mean that the project is quite suitable for 'serious' volume indication work if you want to use for this. But it's so easy to build and so low in cost that it's just as suitable for use as a dancing light display just to impress your friends.

One of the reasons why it is so low in cost is that we've made it capable of displaying only a single audio signal channel. This means that if you do want a two-channel display for stereo signals, you'll have to build a second one for the other channel.

Of course if you really *must* have a six-channel display for showing off home theatre surround sound signals, you'll have to build one for each of the six channels. This kind of display won't be



### The parts you'll need for this project:

|   |                                    |   |                         |
|---|------------------------------------|---|-------------------------|
| 1 | PC board, code SHRTC207, 26 x 75mm | 1 | 3mm red LED (LED10)     |
| 1 | 9V battery, 216 type               | 1 | 1N4148/1N914 diode (D1) |
| 1 | Battery clip lead to suit          | 1 | 1N4004 diode (D2)       |
| 4 | PCB terminal pins, 1mm dia.        |   |                         |
| 1 | Small pack of resin-cored solder   |   |                         |

#### Semiconductors

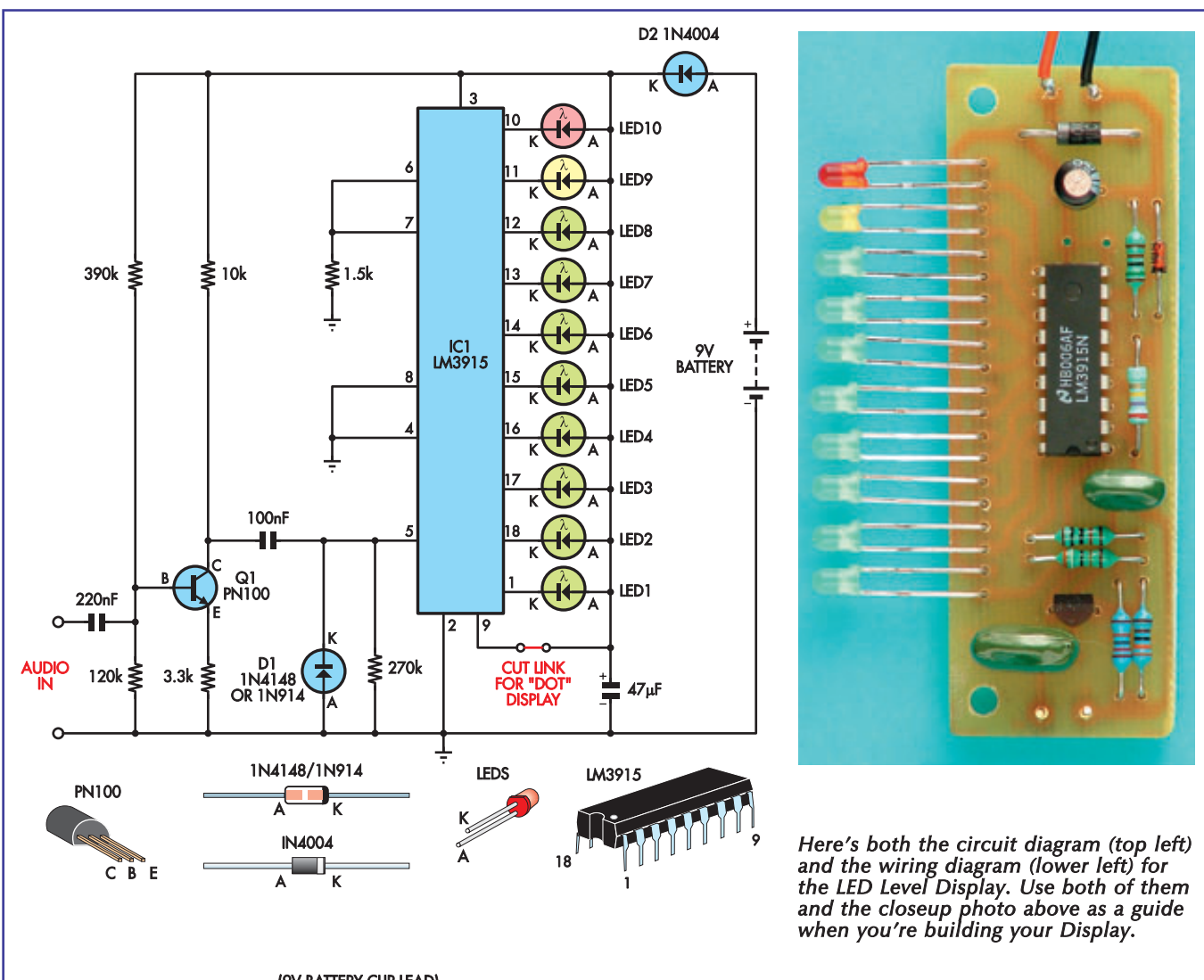
|   |                           |
|---|---------------------------|
| 1 | LM3915 LED driver (IC1)   |
| 1 | PN100 NPN transistor (Q1) |
| 8 | 3mm green LEDs (LEDs 1-8) |
| 1 | 3mm orange LED (LED9)     |

#### Capacitors

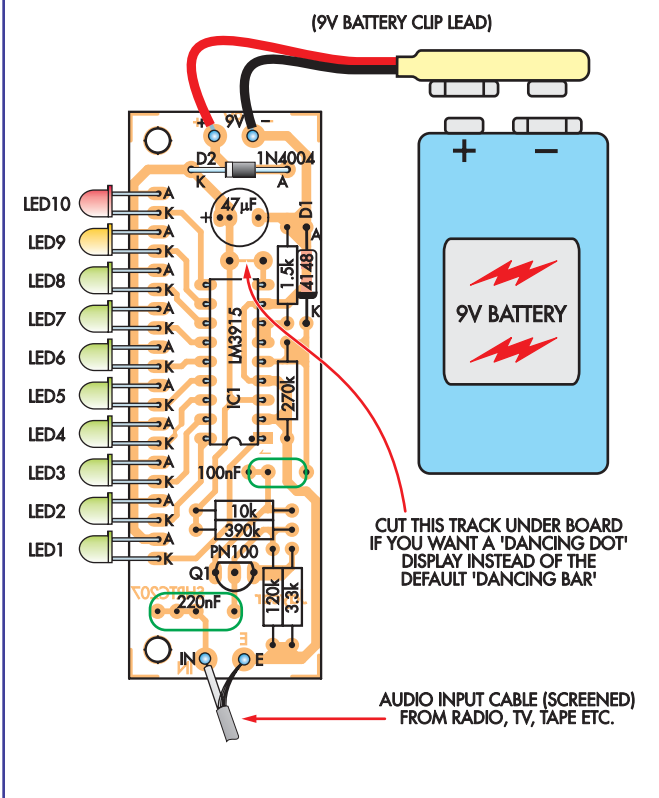
|   |                          |
|---|--------------------------|
| 1 | 47µF 16V RB electrolytic |
| 1 | 220nF greencap           |
| 1 | 100nF greencap           |

#### Resistors (0.25W 1%)

|   |      |   |      |
|---|------|---|------|
| 1 | 390k | 1 | 270k |
| 1 | 120k | 1 | 10k  |
| 1 | 3.3k | 1 | 1.5k |



Here's both the circuit diagram (top left) and the wiring diagram (lower left) for the LED Level Display. Use both of them and the closeup photo above as a guide when you're building your Display.



all that cheap, but it's probably still the cheapest way to get a six channel surround sound display to dazzle your friends and relatives!

### Putting it together

Apart from the battery, all of the parts used in the LED Level Display fit on a very small PC board coded SHRTC207 and measuring only 75 x 26mm. The column of LEDs are mounted on one of the longer sides, so the board can be mounted vertically behind a front panel with the LEDs protruding through a column of holes. Two or more boards can be mounted this way spaced only 18mm apart, for multi-channel displays.

Before you start assembling the kit, open it up and lay out the components so you can make sure you have everything. Then inspect the copper side of the PC board carefully, to make sure there are no minor faults needing to be fixed.

There are no wire links to worry about in this project, so you can begin assembly by fitting the four PC board terminal pins. There are two of these at the top of the board for the 9V battery clip lead connections, and the other two at the bottom for the audio input signal connections.

Next you can fit the resistors. There are only six of these, but they all have different values — so take care not to mix them up. If you follow the wiring diagram and also use the photos as a guide, you shouldn't go wrong.

The two greencap capacitors can be fitted next, with the larger 220nF cap going down near the bottom of the board. Note that the board provides extra holes for both capacitors,



## Tech Talk: How does it work?

You can think of the LED Level Display circuit as having three main sections: an input amplifier stage, a signal rectifier and the LED display section itself.

The input amplifier stage uses transistor Q1 to boost the incoming audio signals by about three times. As you can see the transistor is connected as a common emitter amplifier, with the signals fed into its base via the 220nF coupling capacitor and the amplified signals appearing at the collector. The 390k and 120k resistors provide the transistor with base bias, while the ratio of the 3.3k emitter resistor and 10k collector resistor sets the transistor's amplification factor or **gain** to three times.

The amplified audio signal that appears at the collector of Q1 is coupled through to diode D1 via the 100nF capacitor — which lets through AC while blocking DC, of course. But the combination of D1, the 100nF capacitor and the 270k resistor also forms a signal rectifier, so a DC voltage is generated across the 270k resistor with a value that is directly proportional to the negative signal peaks of the audio signal. It's this varying DC voltage that we feed into LED driver IC1, via pin 5.

IC1 is a fairly complex device, but its operation isn't too hard to understand. Inside it there are 10 **comparator** circuits — circuits which compare two voltages, and produce an output voltage which is either high or low depending on which of the two voltages is

greater. In this case all of the comparators have one input connected to IC1's input pin 5, while the other input of each one is connected to a 'tap' on a series string of resistors connected as a voltage divider between a reference voltage and the negative supply line (earth). As a result each comparator compares the input voltage on pin 5 with a different voltage level, and these voltage levels increase in steps from one comparator to the next.

The outputs of the 10 comparators are brought out to pins 1 and 10-18 of the IC, and as you can see we connect each of the 10 LEDs between the +9V line and one of these output pins. So when each comparator finds that the input voltage on pin 5 is greater than its particular reference voltage, its output pin drops down to a low voltage and this makes the LED connected to that output draw current, and glow.

The number of LEDs that glow at any instant therefore depends on how many of the comparators find the input voltage is greater than their particular reference voltage level. As the input voltage varies up and down, the number of LEDs glowing varies with it.

We've chosen the values of Q1's collector resistor and the 270k resistor across diode D1 so that the DC voltage generated by the rectifier circuit is quite fast in building up when there are sudden peaks in the audio signal level, but slower to fall away again when the volume drops. This gives the LED Level Display a 'fast attack, slow decay' performance, which recording engineers find gives a more accurate indication of audio signal level.

so that it should be easy to fit them whatever their lead spacing. This is also the case with the next component, which is the 47µF electrolytic. As you can see this goes up near the top of the board, with its positive lead towards the left (front) and its negative lead toward the right/back.

Now fit diodes D1 and D2. The first of these is a 1N4148 type in a small glass package, while D2 is a 1N4004 in a larger plastic package. They're both polarised of course, so follow the wiring diagram carefully to fit them with the correct orientation.

Transistor Q1 is fitted next, just above the 220nF greencap and with its flat side upwards. As usual you'll have to crank its two outer leads further away from the centre lead carefully, so they'll all pass through the holes in the board without strain.

The LM3915 IC is next, and as you can see this is fitted with its notch/dimple end downwards. You'll very likely have to bend its two rows of pins towards each other slightly, before they'll all pass through the board holes without strain. The LM3915 isn't a CMOS device, so you don't have to be unduly worried about it getting damaged from electrostatic charge.

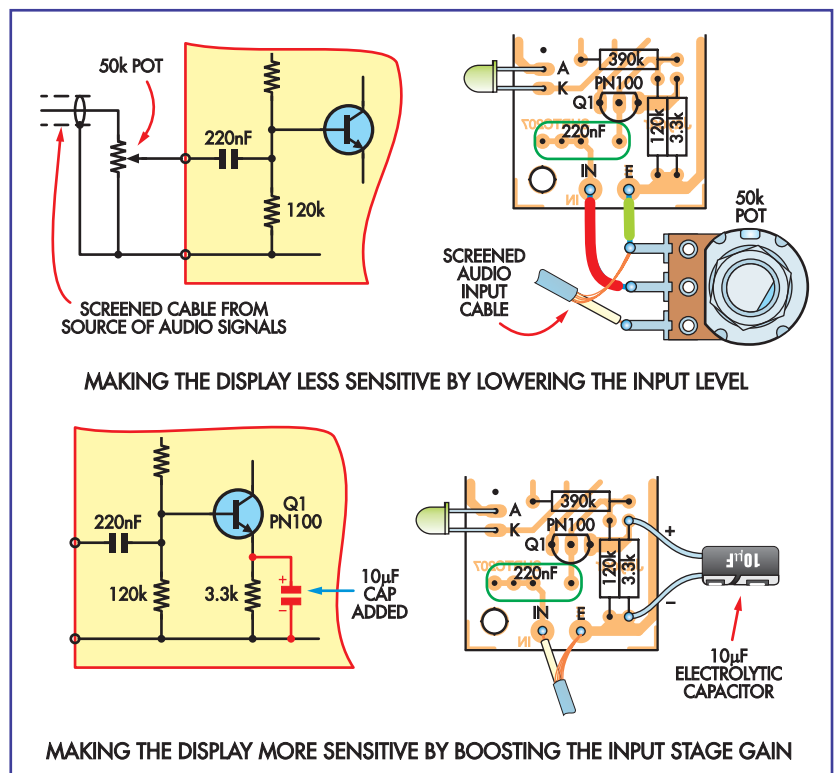
It's a good idea to leave the LEDs until last, because there are 10 of them and each one needs to have its leads carefully bent down at right angles before soldering to the board.

To bend each LED's leads, hold it in front of you with its body towards the left and its leads towards the right. It should also be orientated so that the flat side of its body is downwards, and its longer anode lead uppermost. Then grip both leads with your long nose pliers (held vertically), at a point 14mm from the body of the LED. Then bend the free ends of the LED leads away from you, through an angle of 90°.

Bend each LED's leads in this way before you fit it to the board, and they should then all line up when they're fitted. Note that the

green LEDs are fitted in the eight lowest positions 1-8, the orange/yellow LED in position 9 and the red LED in the top position 10.

The final step in building the project is to connect the battery clip lead wires to the terminal pins at the top of the board, and a length of screened audio cable to the bottom terminal pins for bringing in the audio signals you want to display. Note that the red battery clip wire connects to the top left terminal pin, while the 'inner' wire of the screened audio lead connects to the bottom left-hand pin. These are



both shown clearly in the wiring diagram.

One more point about building the LED Level Display: you may have noticed, while fitting everything to the board, that there are two small holes close together between IC1 and the 47 $\mu$ F electrolytic. These are not there to take any extra component, and in fact their pads are already connected together under the board via a thin copper track. So what are they for?

Well, the LM3915 IC is very flexible and can operate in either of **two** display modes. As well as the 'dancing light bar' mode that the Display works in when you build it up as we've just described, the IC can also work in 'dancing dot of light' mode — where only one LED glows at any instant, the one corresponding to the audio level at that instant.

Which mode the LM3915 works in is controlled by the connection to pin 9 of the IC. If this pin is connected to the +9V line it operates in 'light bar' mode, but if the pin is disconnected and left 'floating' the IC operates in 'dancing dot' mode. As light bar mode is the one usually wanted in a volume level display, we've made the PC board link pin 9 to the positive line. However we've done this via a narrow track, so you can easily cut the link under the board if you want dot mode instead. And to make it easier for you to reconnect pin 9 again if you change your mind later, there's also two pads and holes so you can fit a wire link...

Your LED Level Display should now be complete, and ready to go. But before you try it out, give it a quick once over to make sure you've fitted everything in the right place and with the correct orientation. Check all of your solder joints as well, to ensure you haven't made any dry joints or left solder slivers to short-circuit between tracks.

## Trying it out

If everything seems OK, connect a 9V battery to the cliplead. As you do, you'll probably see the LEDs flash briefly in turn, from LED10 down to LED1. Then they'll all go dark, at least until you feed in some audio signals via the screened lead.

So now try connecting the end wires of the screened lead to the 'line' or headphone output of your CD or tape player, or across the headphone output of your transistor radio — or even a TV. The LEDs should now begin to flash in time with the music or singing, giving you the familiar dancing bar of light display.

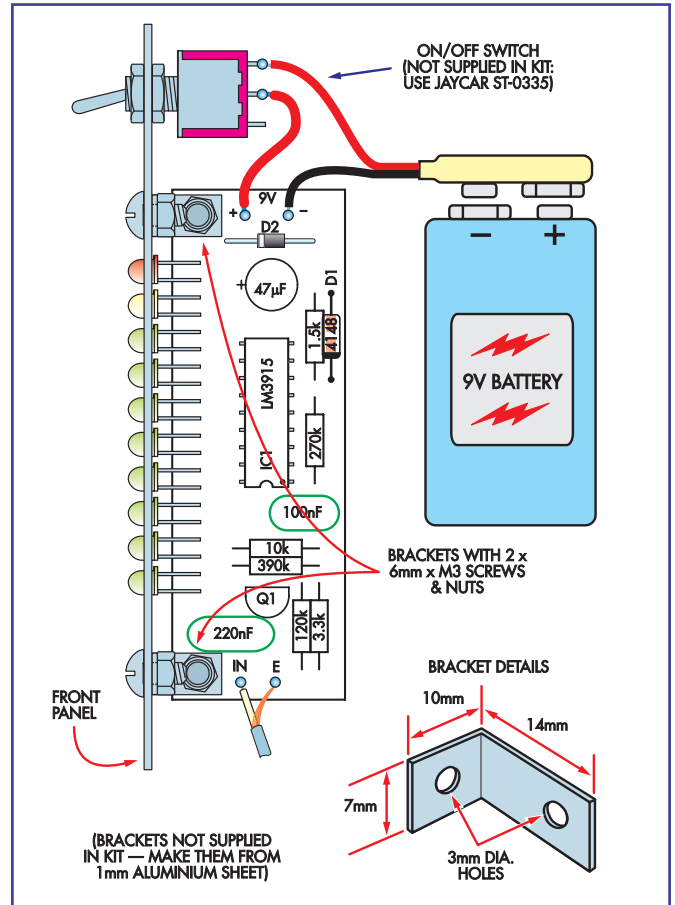
But what if none of your LEDs glow, even when you do feed in some audio signals? That will probably mean that you've made a mistake in wiring up the project. You may have connected the battery lead wires the wrong way around, or fitted one of the diodes the wrong way, or fitted the 47 $\mu$ F electrolytic capacitor the wrong way. These are the most likely causes of 'no glow', although another possibility is that your 9V battery may be flat.

## What to do next

When you build it up as described, the basic sensitivity of the LED Level Display is about 420mV peak (a bit less than half a volt). That is, audio input signals with this level are needed to make all of the LEDs glow. This should be fine to give a good display of typical audio signals available at the line or headphone outputs of tape players and transistor radios. However it may be too sensitive for some sources of higher-level audio signals, or not sensitive enough for other sources of lower level signals.

If the signals you want to display are too high in level, many of the LEDs will be glowing for most of the time and you won't get a good display of the full range of signal levels. On the other hand if the signals are very low in level, only the lowest LEDs will ever glow at all and you again won't get a good display. So you might want to correct either of these problems.

The easiest way to get a better display of high level signals is to reduce them in level before feeding them into the LED Level Display, using a 50k pot connected as a simple 'volume control'. The pot can be either a screwdriver-adjusted trimpot like the Jaycar RT-4020, or a larger control



pot like the RP-7516 or RP-3516. The small diagram opposite shows how it's connected to the input of the LED Level Display.

On the other hand if you want to be able to display much lower level audio signals, this can be done by increasing the amplification or **gain** of transistor Q1 in the LED Level Display. The easiest way to do this is to connect a 10 $\mu$ F electrolytic capacitor (like the Jaycar RE-6066) across the 3.3k resistor in series with the transistor's emitter, so it 'bypasses' the resistor for most AC frequencies. The small diagram also shows how this is done — but note that the positive lead of the added 10 $\mu$ F capacitor must connect to the emitter of Q1, and the negative lead to the earthy negative line. Adding this capacitor will make the Display very much more sensitive, and all LEDs will now glow for signal levels of only 7mV (millivolts). If you find this is too sensitive, you'll need to add a pot at the input to allow the input signals to be reduced down to this level.

You might also want to mount the LED Level Display behind a panel, so all that can be seen are the display LEDs. This is easily done by making up two small right-angle brackets from 1mm sheet aluminium, with a 3mm hole drilled in the centre of each of their 'legs'. Then the brackets can be used to mount the Display board behind the panel with 6mm x M3 machine screws and nuts, as shown in the diagram above. Needless to say you'll have to drill a row of ten 3mm diameter holes in the panel to allow the LEDs to poke through, and also a couple of further 3mm holes to take the bracket mounting screws.

If you do decide to mount one or more of the LED Level Displays behind a panel in this way, you'll probably also want to add a small on/off switch so you can control the Display's operation without having to clip and unclip the battery lead. A miniature toggle switch like the Jaycar ST-0335 would be ideal for this, and can be mounted on the panel just above the Display itself. It's simply connected in series with the positive wire of the battery clip lead, as shown in the diagram above.

## Project 8:

# Mini Electronic Organ

How do you rate as a musician? Here's a snazzy little keyboard instrument you probably haven't played yet. It's a miniature electronic organ, which you play by touching a small stylus or probe against its printed-circuit 'keys'. It has a range of two full octaves, and even sports a vibrato effect you can switch on or off to give the music more 'life'.

### What does it do?

You can use this baby electronic organ much like its full-size relatives, to play whatever kind of music takes your fancy. Although it's 'monophonic' and can only produce one note at a time, it has a range of two full octaves plus a vibrato effect you can use to make the sound more lively. You'll be surprised how easy it is to play its small printed-circuit 'keyboard' with a stylus, too.

In short, this must be about the simplest and easiest electronic musical instrument it's possible to build. So why not put one together and have some fun?

### Putting it together

Apart from the battery and its speaker, all of the parts used in the Mini Organ fit on two very small PC boards with the code SHRTC208. The smaller 'main' board measures 131 x 30mm and fits most of the organ's circuitry including the vibrato on/off switch, while the larger board measures 131 x 50mm and



### The parts you'll need for this project:

|                       |  |                             |                               |   |      |
|-----------------------|--|-----------------------------|-------------------------------|---|------|
| 1                     | PC board, code SHRTC208, 131 x 81mm (or cut into two, 131 x 30mm & 131 x 50mm) | 1                           | 470µF 16V RB electrolytic     |   |      |
| 1                     | Mini slider switch, SPDT PC board mounting                                     | 1                           | 47µF 16V RBLL electrolytic    |   |      |
| 7                     | PCB terminal pins, 1mm dia.  | 2                           | 2.2µF 16V RBLL electrolytic   |   |      |
| 1                     | 57mm mini speaker  | 1                           | 10nF greencap                 |   |      |
| 1                     | 9V battery, 216 type   | <b>Resistors (0.25W 1%)</b> |                               |   |      |
| 1                     | Battery clip lead to suit  | 4                           | 100k                          | 1 | 51k  |
| 1                     | Small pack of resin-cored solder   | 1                           | 47k                           | 2 | 11k  |
| <b>Semiconductors</b> |  | 2                           | 10k                           | 1 | 9.1k |
| 1                     | 555 timer (IC1)  | 2                           | 8.2k                          | 2 | 7.5k |
| 2                     | PN100 NPN transistor (Q1,2)  | 1                           | 6.8k                          | 2 | 6.2k |
| 1                     | PN200 PNP transistor (Q3)  | 2                           | 5.6k                          | 1 | 5.1k |
| 1                     | 1N4004 diode (D1)  | 4                           | 4.7k                          | 1 | 4.3k |
| <b>Capacitors</b>     |  | 2                           | 3.9k                          | 1 | 3.6k |
| 1                     | 1000µF 16V RB electrolytic   | 2                           | 3.3k                          | 1 | 3.0k |
|                       |  | 1                           | 150 ohms                      |   |      |
|                       |  | 1                           | 100k horizontal trimpot (VR1) |   |      |

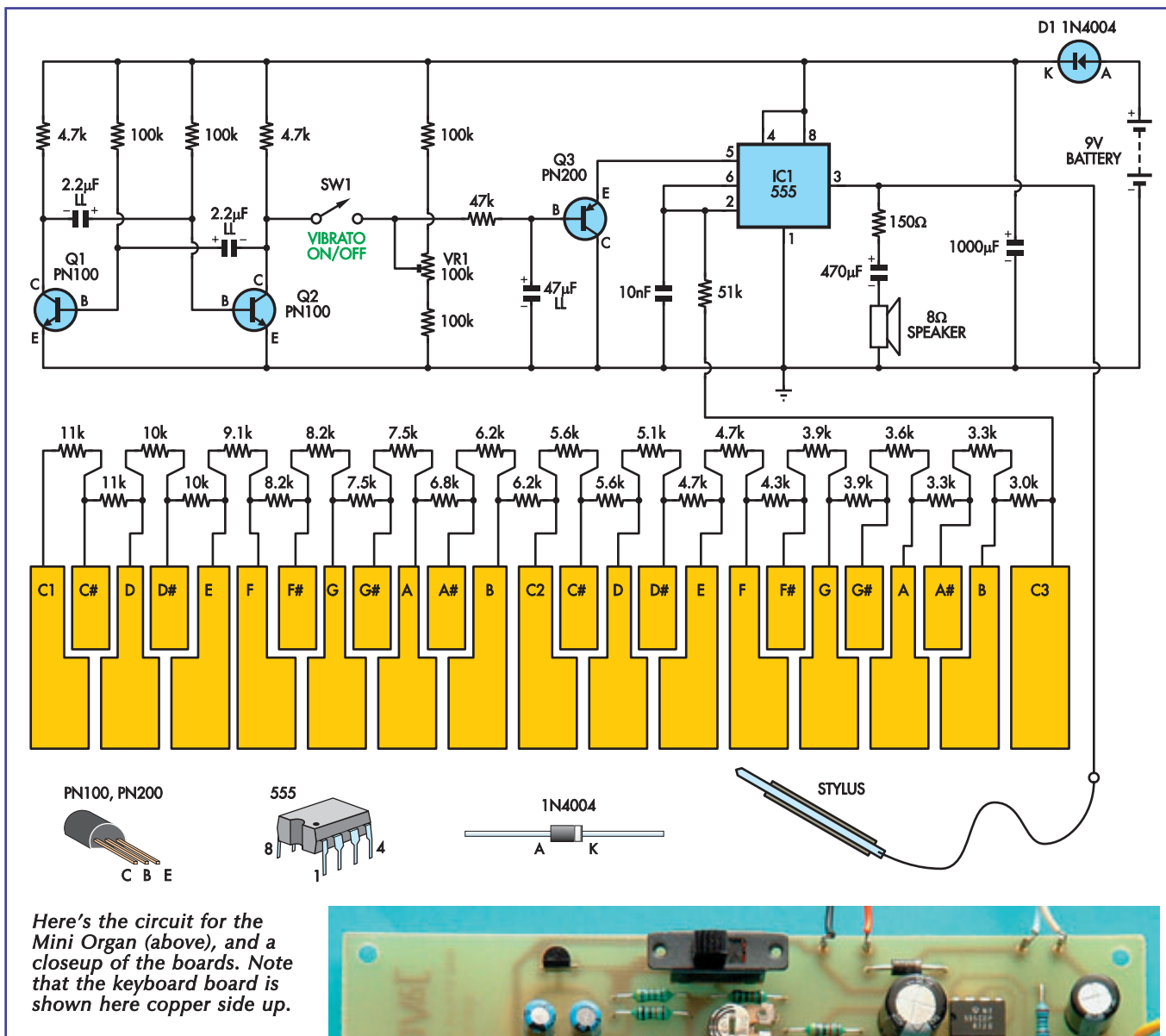
provides the organ's keyboard plus the resistors which set its notes.

As usual, before you start putting the organ together it's a good idea to open up the kit and lay out all of the components to make sure you have everything. Then check the copper side of both boards (after cutting them apart carefully with a hacksaw if they arrived together as a single board). Make sure that there are no hairline cracks in any of the copper tracks, and no tiny threads of copper forming short circuits between them.

There are no wire links needed on either board, so you can begin assembly by fitting the six PC board terminal pins to the main board. As you can see from the wiring diagram four of these go along the top edge for the battery and speaker connections, while the other two go down near the right-hand corner for the keyboard and stylus connections.

With the pins fitted, you can start on the resistors. There are eight of these

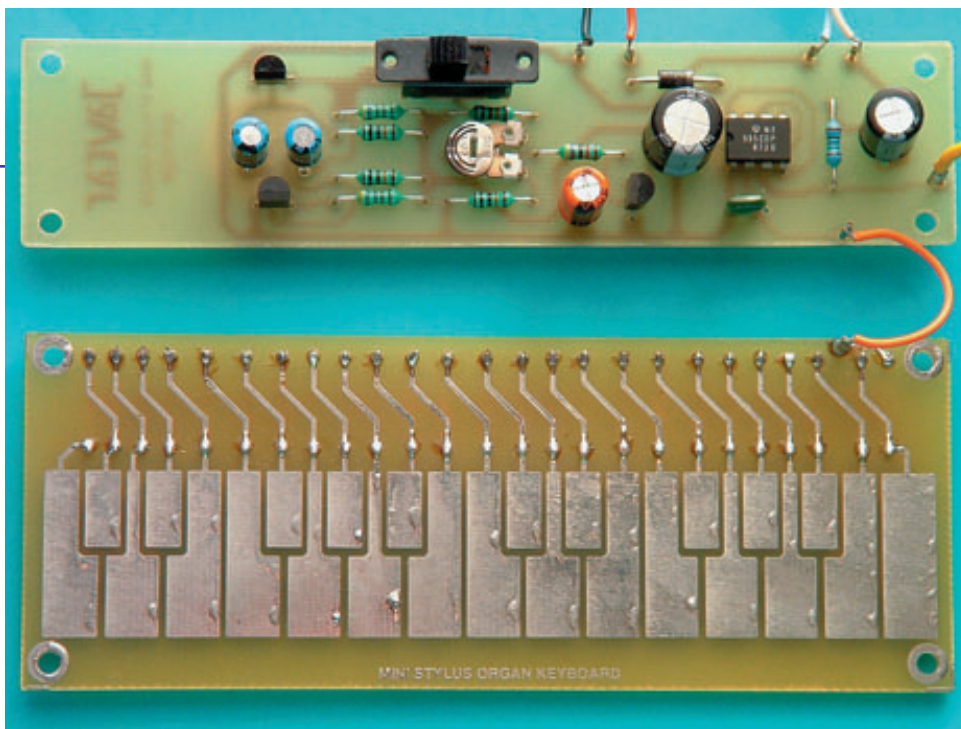




on the main board, and 25 on the keyboard board. Notice that there are four with a value of 100k to go on the main board, and also two with a value of 4.7k. It's a good idea to fit these first to help prevent mistakes. Also be very careful to fit all of the keyboard resistors in their correct positions, as otherwise your keyboard will have notes that are 'out of tune'.

As you can see, apart from the first resistor with a value of 51k, all of the other resistors for the keyboard have values which gradually increase in value from 3.0k to 11k. So one way of making sure you fit these resistors in their correct sequence is to identify them all and lay them out in ascending order first, before fitting them.

Once the resistors are all fitted, you can fit the 10nF greencap and the five polarised electrolytic caps. These all



fit with their positive leads towards the rear of the board, and their negative stripes towards the front. The board provides extra holes for most of the electros, to cope with

## Tech Talk: How does it work?

The heart of this Mini Organ is IC1, a multi-purpose 555 timer IC which is used here as an oscillator to produce the notes. But it only oscillates when the stylus is touching one of the key pads, because the oscillator's feedback path is from IC1's output pin 3 back to input sensing pins 2 and 6, via the stylus, the 51k series resistor and whichever other resistors are in series with the keypad you touch.

Because the oscillator's frequency is set by this feedback resistance and the 10nF capacitor connected from pins 2 and 6 to the negative line, that's why we can vary the organ's note simply by touching the stylus to each of the various key pads. If you work out the total feedback resistance for each of the key pads, you'll find that the resistance decreases from left to right by almost exactly the same factor (1.0595), from one note to the next. This makes the frequency or pitch of the notes increase by the same factor, which happens to be the ratio between notes for modern 'equal temperament' musical scales.

Because the speaker is also connected between IC1's output pin 3 and the negative line, via the 100Ω series resistor (to limit the current) and the 470μF electro (to block DC), some of the IC's output is fed to the speaker. As a result the speaker produces sound whenever the oscillator is working, and at the oscillation frequency.

We produce the vibrato effect by using transistors Q1 and Q2 in another oscillator circuit, to generate a very low frequency (about 0.5Hz). This is then used to vary the frequency of note oscillator IC1, so that the note

'wavers' at this rate. That's what vibrato means.

As you can see Q1 and Q2 are connected in a cross-coupled **multivibrator** circuit, where the base of each one is connected to the other's collector. This means that they both can't conduct at the same time, but instead flip back and forth — with first one conducting and then the other, and so on. The frequency they oscillate at is set mainly by the two 2.2μF electros and the 100k base resistors. The oscillator produces a **square wave** signal at the collector of Q2, which switches back and forth between +9V and 0V.

If we were to feed this square wave signal directly to IC1, it would not produce a musical vibrato effect but simply sound as if each note had been separated into two. So instead, when SW1 is closed, we first feed the signal through a simple 'low pass' filter circuit formed by the 47k resistor and 47μF electrolytic capacitor. This removes most of the 'sudden changes' (harmonics) from the vibrato signal, leaving a voltage which still varies up and down at the 0.5Hz rate, but now does so quite smoothly.

This smoothed vibrato signal is then fed through transistor Q3 and into the control voltage input (pin 5) of IC1, so it can vary the note frequency up and down by a small amount. *Voila* — a nice vibrato effect!

When switch SW1 is opened to turn off the vibrato, we instead feed a small DC voltage from trimpot VR1 through the filter and Q3 into IC1. VR1 is used to adjust this substitute DC voltage so that it matches the average DC level of the vibrato signal, to make sure that IC1's note frequencies are the same whether the vibrato is turned on or off.

various lead spacings.

Next you can fit trimpot VR1, which goes in almost the exact centre of the main board. Follow this with the mini slider switch SW1, which can go either way around. You may have to enlarge the board holes slightly with a small round ('rat tail') file before the switch lugs will pass through easily, as these are relatively wide.

Now you're up to the semiconductor parts, the first of which is diode D1. This fits just behind the 1000μF electro, but it's polarised, so make sure you orientate it correctly as shown in the wiring diagram.

Next fit the three transistors, taking care to fit the two

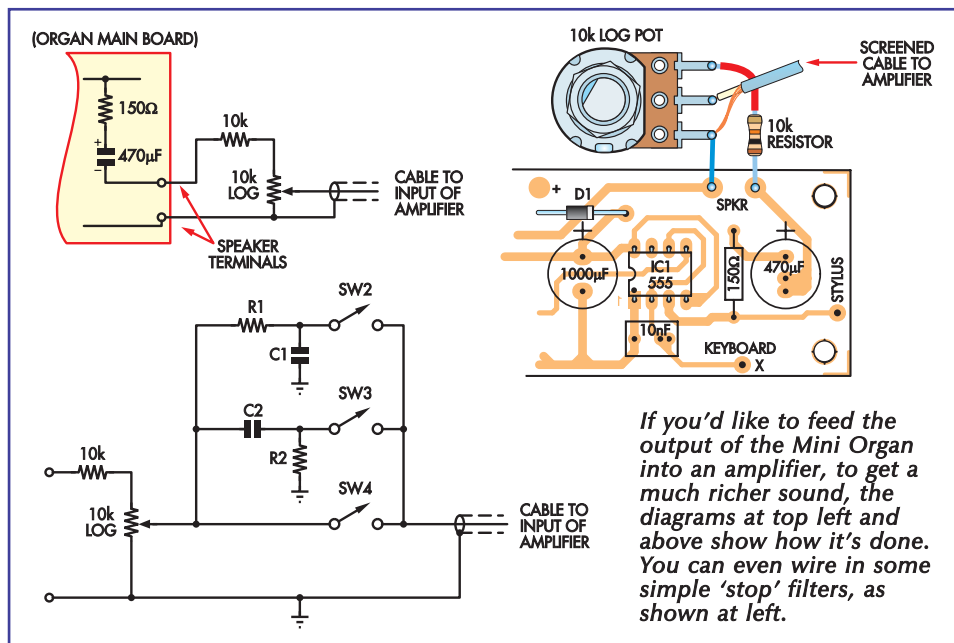
PN100s in the Q1 and Q2 positions, and the PN200 in the Q3 position. All three will need their outer leads cranked out carefully to make their spacing match the board holes, and they should all be orientated as shown in the wiring diagram.

The last component to fit is 555 timer IC1. As you can see this fits with its notch/dimple end towards the left and the 1000μF electro. You may need to bend its two rows of pins slightly inward and towards each other, so they'll pass through the board holes easily.

Your two board assemblies should now be complete, and all that remains is to make the various off-board

connections. So connect the ends of the battery clip lead wires to the two terminal pins of the centre rear of the main board, and then connect the speaker to the other pair of rear pins via a couple of lengths of insulated hookup wire. Then use another short length of the same wire to connect the main board's X terminal pin to the keyboard, and finally connect a longer length of the same wire to the main board's STYLUS terminal pin, on the right-hand end.

At the other end of this last wire you can connect whatever you're going to use as a playing stylus. This can be as simple as a 150mm length of stout wire salvaged from a wire coat hanger, if you wish, or perhaps an old ballpoint pen with the ink tube removed and the end of the connection wire run down the inside of the body and soldered to the rear of the metal point. But if you'd like a more professional looking stylus, you



can use a multimeter test probe as we've shown in the photo. These are available from Jaycar as Cat. No. PP-0425, but they're only sold as pairs so you'll end up with a second one — for your second Mini Organ, perhaps?

Another advantage of these probes is that you don't have to solder them to the end of the wire. You simply bare about 6mm at the end of the wire and poke in down inside the plastic handle until it protrudes from a small hole in the side of the tip. Then you tighten up the clamping ring, to make a good contact and fasten the wire in place.

Once the stylus is fitted, your Mini Organ should be finished and ready to go. But before trying it out, give it a quick once over to make sure you've fitted everything in the right place and the right way around. Check your solder joints too, to make sure they're all up to scratch.

### Trying it out

If everything seems in order, connect a 9V battery to the cliplead and flick slider switch SW1 over to the right. Also set the slider of trimpot VR1 to the middle of its range. Then touch the stylus to any of the 'note' pads on the keyboard, and you should be rewarded by the speaker sounding a steady note, which lasts as long as you keep the stylus in contact. Touching the stylus against any of the other key pads should give other notes, and straight away you should be able to play a tune.

Now try flicking the slider switch to the left, and then playing some notes again. This time they shouldn't be steady, but should 'waver' noticeably to give what musicians call a

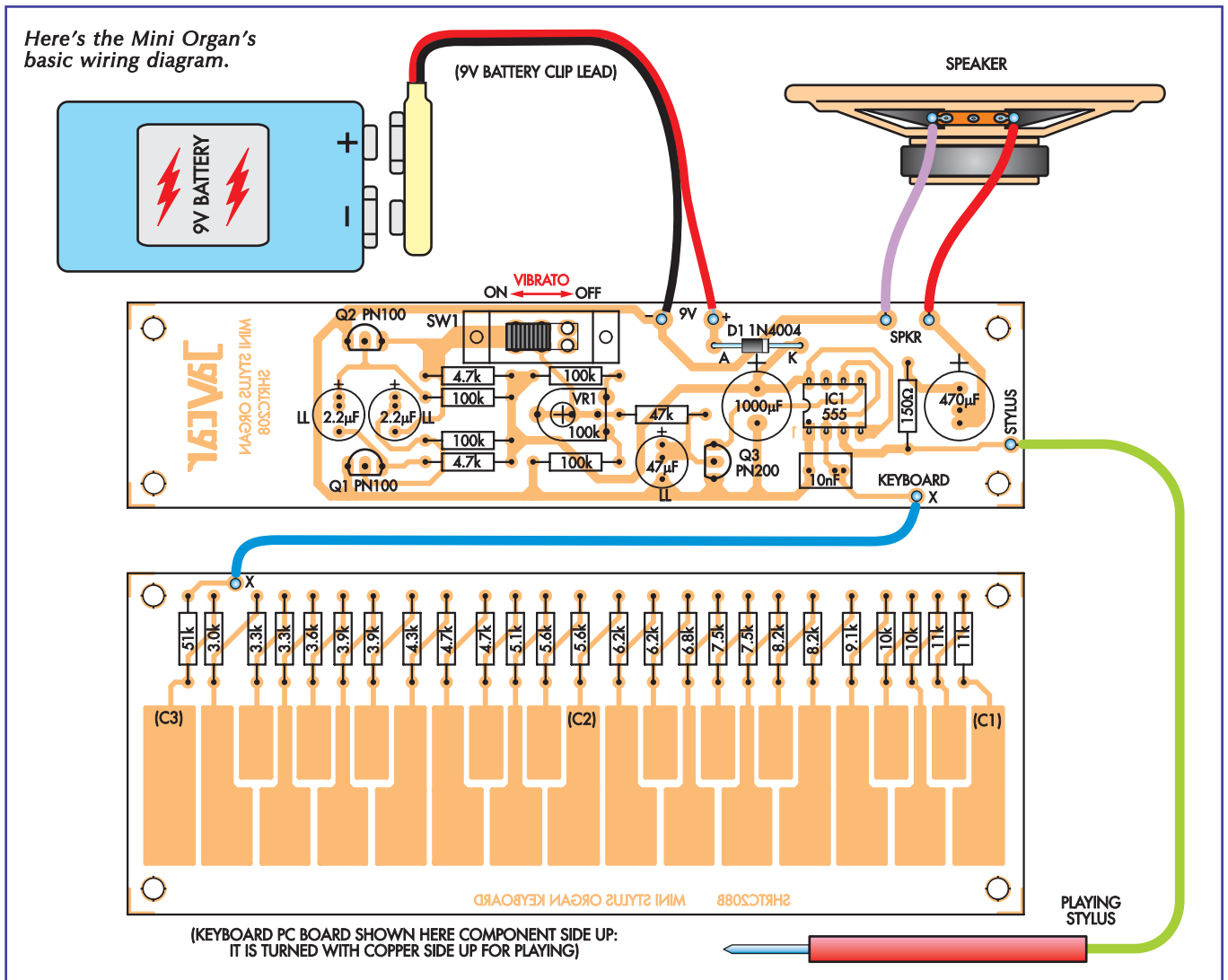
vibrato effect. You'll probably want to leave SW1 in this position, because most people seem to find the notes sound more 'alive' with the vibrato.

But what if *your* organ doesn't produce any notes at all when you touch the stylus to the key pads — just sits there, stubbornly silent? That will be almost certainly because you've made some kind of mistake in wiring up the organ boards. You might have accidentally fitted diode D1 the wrong way around, for example, or reversed the connections of the battery cliplead wires to the terminal pins. Or perhaps you've fitted one of the electrolytic caps the wrong way around, or even one of the transistors, or IC1. You might even have forgotten to solder one of the component leads to its copper pad on the PC board.

So to track down the problem, it's a matter of checking all of these possibilities in a methodical fashion, and then fixing whatever is the problem when you find it.

Even if your organ seems to produce all of the notes, there might still be a minor problem. You might find that one or more of the notes seems to be out of tune, for example. This will be a sign that you have made a mistake with the resistors on the keyboard, so you'll need to disconnect the battery and check them all carefully. Then you'll need to remove the resistors that are in the wrong positions, and replace them in their correct places.

Another possibility is that you get all the right notes, but nothing happens when you flick switch SW1 to the left — i.e., there's no vibrato effect. If this happens it will probably be because you've made a mistake in fitting one of the components to the left of the switch. You might have





reversed Q1 and Q2, or one of the 2.2 $\mu$ F electros.

By the way, if you notice that the organ's notes all change in pitch when you operate switch SW1, this can be remedied by adjusting trimpot VR1 one way or the other. This is because VR1 is effectively a 'fine tune' control for the notes when SW1 is open and has disconnected the vibrato oscillator.

The way to make this adjustment is to sound a note (any note) with the vibrato turned on (SW1 to the left), and then turn the vibrato off (SW1 to the right) and adjust VR1 until the note sounds the same in pitch (frequency). If you're not quite sure you have the setting right, flick the switch back and forth again to compare the note's pitch in both positions. Just remember that RV1 really only adjusts the pitch of the note when the vibrato is **off** (SW1 to the right).

### What to do next

If you'd like the Mini Organ to produce deeper notes, this can be done fairly easily by replacing the 10nF greencap with one of larger value. For example if you replace it with a 22nF greencap (like the Jaycar RG-5085), this will move all of the Organ's notes down by just over an octave. Or you can replace it with a 39nF capacitor (RG-5100), which will move them down by almost two octaves.

It's also possible to shift the notes upward in pitch by replacing the same capacitor with a 4.7nF greencap (RG-5047), but you might not want to do this because the notes are fairly high in pitch already. However you might want to change the vibrato rate, to make it either faster or slower than 0.5Hz. This is also quite easily done.

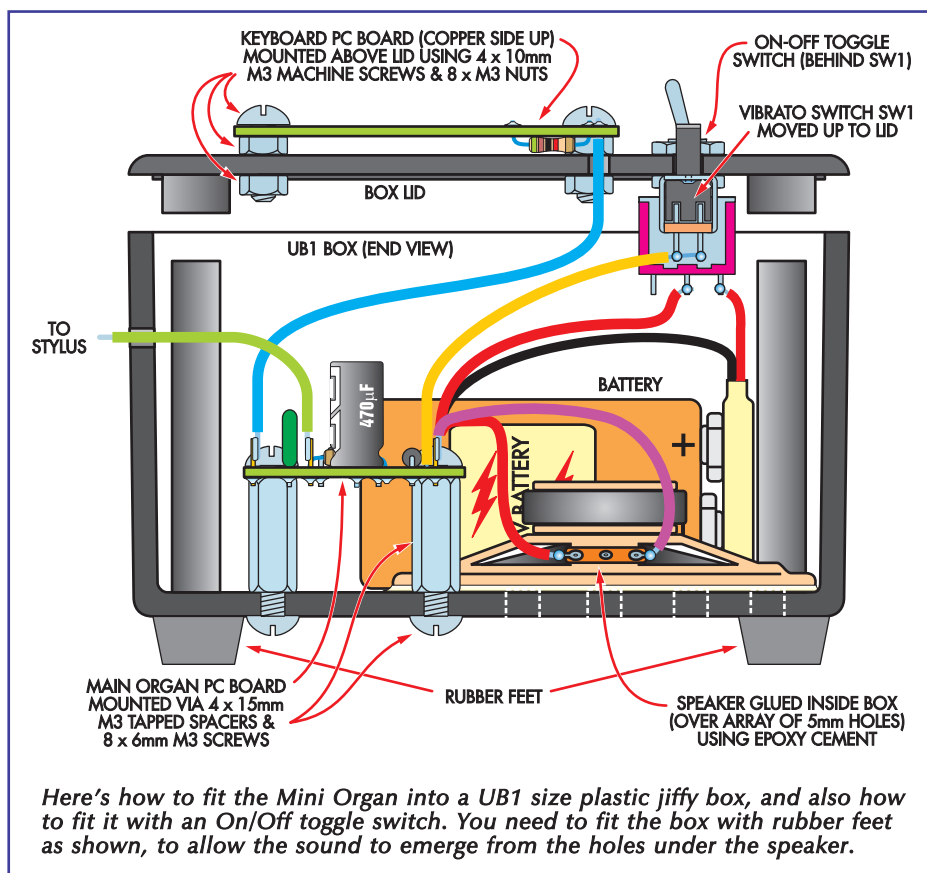
To speed up the vibrato, you merely replace the two 2.2 $\mu$ F electrolytic caps with a pair of lower value — say 1.5 $\mu$ F (RL-6418). On the other hand if you replace the capacitors with a pair of higher value like 3.3 $\mu$ F (RL-6422), this will slow the vibrato down.

What about feeding the output of the Mini Organ into an external amplifier (like the family hifi amp), so that you can have its music at a much higher volume and with a richer tone? Yes, that's quite easy too, and at the same time you can change the quote of the notes using either the amplifier's tone controls or some simple filters in between the two.

The easiest way to feed the organ's output signal to an external amplifier is to disconnect the speaker, and instead connect up a series resistor and a 10k log pot (RP-7610 or RP-3610) as shown in the small diagram. The pot allows you to adjust the output level, and hence the organ's volume through the amplifier.

As you can see, the organ's output signal is taken to the input of your amplifier via a length of screened audio cable. In most cases you'll need to fit the other end of this cable with what's called an **RCA** or 'phono' plug, because most family 'hifi' amplifiers use RCA/phono sockets for their external input connections. Jaycar can supply many different kinds of RCA plug, from the low cost plastic PP-0242 (black) or PP-0240 (red) plugs to more elaborate metal ones.

Be careful to connect the organ's cable to the right kind of input on the amplifier, though. The kind of input to use is one of the amplifier's *line level* inputs, which are usually marked 'Line', 'Aux', 'Tuner' or 'CD'. But if the amplifier has inputs marked 'Phono', DON'T try feeding the organ's signal



*Here's how to fit the Mini Organ into a UB1 size plastic jiffy box, and also how to fit it with an On/Off toggle switch. You need to fit the box with rubber feet as shown, to allow the sound to emerge from the holes under the speaker.*

into one of these because this will drive the amplifier into overload and make the sound very distorted. It might even damage either the amplifier or your speakers.

In any case, when you plug the organ's output cable into an amplifier input to try things out, make sure you turn the amplifier's main volume control right down before you turn it on. Then turn the volume up very slowly, while you're touching the organ's stylus to one of its notes to make a signal for checking the volume. Only turn the amplifier volume up far enough to make a comfortable listening level, so you don't risk damage.

If you'd also like to experiment with changing the organ's sound, this can be done by adding the filter components shown in the diagram. As you can see a low-pass filter like the one using R1 and C1 (via SW2) will give the notes a smoother or 'more flutey' sound, while a high-pass filter like that using R2 and C2 (via SW3) will give the notes a thinner or 'more reedy' sound. The 'straight through' path through SW4 will leave the notes unchanged, of course.

Connecting in some filters and switches like this will give your organ some simple 'stops', and allow you to change its sound very easily with the flick of a switch or two.

There's lots of experimentation possible here, by changing the values of the filter resistors and capacitors. We suggest you start by giving R1 a value of 100k, C1 a value of 1nF, C2 a value of 47nF and R2 a value of 10k. You can also try other kinds of filter, like one using a small inductor as well as a resistor and capacitor.

Finally, you might like to build the organ into a plastic utility box, to make it neater and protect the 'works' from damage. It can be built quite easily into a standard UB1 size (158 x 95 x 53mm) jiffy box, like the Jaycar HB-6011.

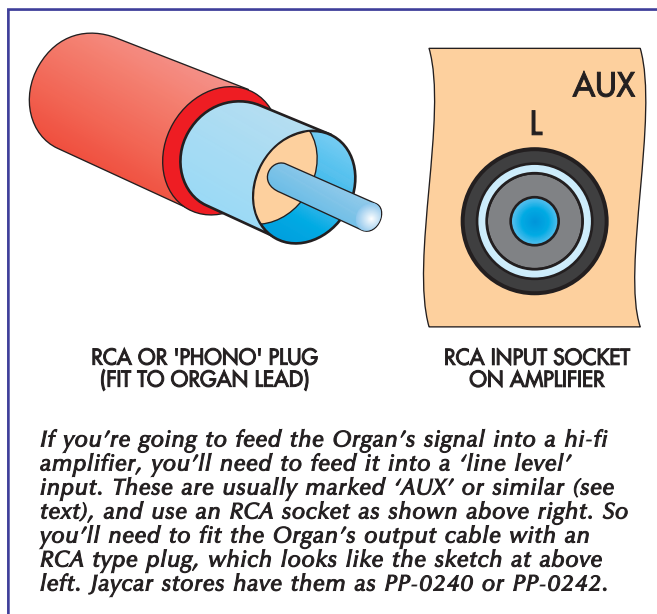
As you can see from the diagram above, the speaker can be glued into the bottom of the box, above an array of 5mm holes to allow the sound out. The organ's main PC board is also mounted on the bottom of the box, using four 15mm long M3 tapped spacers and eight 6mm x M3 screws. The organ's keyboard board is mounted on the top of the lid,

attached with four 10mm x M3 screws and eight nuts — four used as spacers, to shift the board up and clear the resistors. A 2.5mm hole drilled just below the 'X' pad allows the connection wire from the main board to be brought through the lid and soldered to the keyboard. Another 2.5mm hole drilled in the side of the box will let the stylus lead emerge, as you can see above.

When the organ is built into a UB1 box in this way, the slider switch SW1 can be removed from the main board and mounted on the lid instead using a pair of M2 machine screws (which mate with the tapped holes in the switch end tabs). The switch lugs are then connected to the main board via two short lengths of insulated hookup wire.

You'll probably also want to add an on-off switch to the organ when it's built into a box, to save having to open it up and use the battery clip lead each time. The switch to use would be a small toggle type like the Jaycar ST-0335, mounted on the lid and with its centre lug and one outer lug connected in series with the battery clip lead's red wire.

So that the sound can emerge easily from the holes in the bottom of the box, you'll also need to fit the box with four rubber feet to lift it up from the table you sit it on. Jaycar stores can provide 12 x 12mm stick-on rubber feet, sold in packs of four as HP-0815. These would be just the shot, as they lift the box up by about 6mm.



## Meet the Pioneers of Electronics:

# Alessandro Volta

Alessandro Volta was born in Como, Italy in 1745, and grew up to become a physics teacher in the local high school. He was fascinated by static electricity, like the 'charge' that built up on a rubber or ebonite rod when it was rubbed with a silk cloth.

In 1775 he developed the electrophorus, a device which could be used to store static electricity. Then in 1794 he discovered that he could generate continuous electrical energy by placing rods of two different metals in a dish of salt solution: the first **electrochemical cell**. By 1800 he had made a battery of these cells by assembling stacks of copper and zinc discs, interspersed with cardboard discs soaked in salt water. These simple batteries became known as **Volta's piles**, and were used to provide the first electrical currents. They were the ancestors of the dry batteries we still use to power personal radios, CD players and so on.

Before he died in 1827, Volta received many awards for his pioneering work. Napoleon Bonaparte awarded him the Legion of Honour and made him a count, but history has honoured him even more by using his name to derive the standard unit for potential difference and EMF: the **volt**.



# Andre-Marie Ampere

Born in 1775 in a small village in France, Andre-Marie Ampere became a leading physicist and mathematician. He was the first to explain why a current flowing in a wire would make a compass needle deflect – because it generates a magnetic field around the wire. He demonstrated this in a classic experiment where two wires suspended alongside each other would attract each other when they were both carrying current in the same direction, and repel each other if they carried current in different directions – like permanent magnets.

He was convinced that there was an important link between electricity and magnetism, and in 1823 he published a paper which proposed that the magnetic field around a permanent magnet was due to tiny electrical currents flowing inside it. When the electron was discovered about 60 years later, he was shown to be correct.

Ampere's life and work are honoured by using his name as the standard unit of electrical current: the **ampere** (or 'amp' for short).

## Project 9:

# Compact Audio Amplifier

Want more volume and a better sound from your personal transistor radio, CD or tape player? That's exactly what you can get by building this neat little amplifier. It can drive a speaker to give you more volume from any of these gadgets — and also from the Mini Organ of Project 8, if you want.

### What does it do?

As the name suggests, an amplifier makes weak signals stronger. In this case the amplifier handles *audio* signals, which are the low frequency signals corresponding to sound waves — music, singing, talking and so on. In fact signals are described as 'audio' when they contain frequencies which are within the range from about 30Hz — 20kHz, which is about the maximum that we humans can hear.

This compact little audio amp has a maximum **gain** of 32 times, meaning that it can amplify small audio input voltages and produce output signals up to 32 times larger. So you can feed quite weak signals into it, and it can boost them enough to drive a speaker and produce more sound.

Although it can't produce a huge amount of audio power when it's running from a 9V battery, there's still enough to produce a good listening volume when you feed the output into a speaker. In fact if you have an efficient large speaker in a reasonably sized box or enclosure, you'll be surprised just how much sound you can get.

There are also ways to get more output from the amplifier, as we'll explain in the What to Do Next section.

### Putting it together

All of the components used in the amplifier fit on a small PC board, apart from the battery. The PC board is coded



SHRTC209, and measures just 64 x 57mm.

As usual, it's a good idea to check your kit over carefully before you begin assembly. Open up the kit and lay the parts out on the bench, so you can make sure you have everything. Also inspect the copper side of the PC board, just in case there are any minor defects like hairline cracks or bridges between tracks or pads.

If everything seems OK, start the assembly by fitting the six PC board terminal pins. Two of these go down at the front of the board and the other four go at the back, as you can see from the wiring diagram. The front two are for the audio input, while the other pairs are for the 9V battery cliplead and the speaker connections respectively.

## The parts you'll need for this project:

- 1 PC board, code SHRTC209, 57 x 64mm
- 1 9V battery, 216 type
- 1 Battery clip lead to suit
- 1 57mm mini speaker
- 6 PCB terminal pins, 1mm dia.
- 1 Length of 2-core speaker lead
- 1 Small pack of resin-cored solder

### Semiconductors

- 1 BC549 NPN transistor (Q1)
- 1 PN200 PNP transistor (Q2)

- 1 PN100 NPN transistor (Q3)
- 1 BD135 or BD139 NPN medium power transistor (Q4)
- 1 BD136 or BD140 PNP medium power transistor (Q5)
- 1 1N4004 diode (D1)

### Capacitors

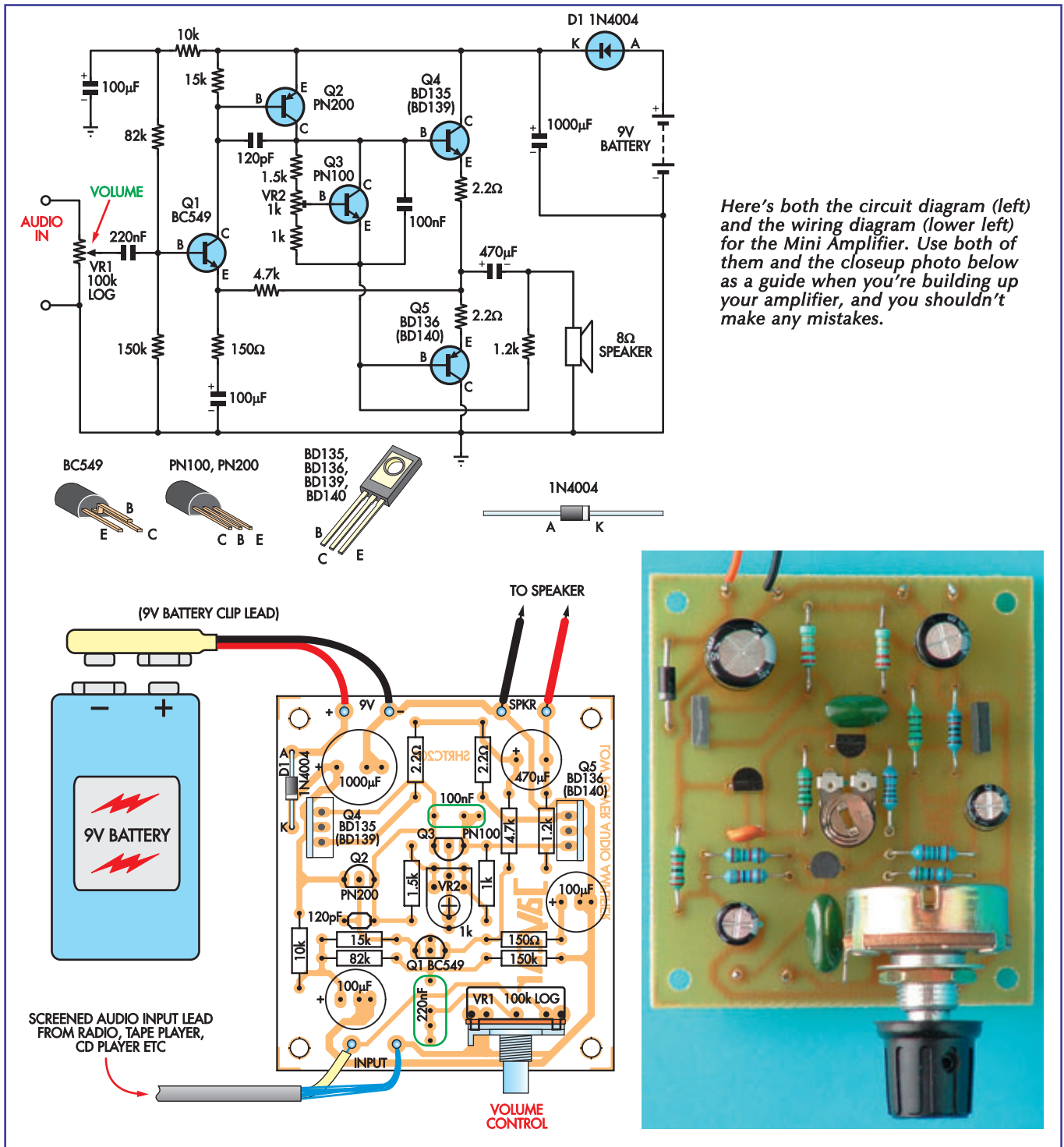
- 1 1000 $\mu$ F 16V RB electrolytic
- 1 470 $\mu$ F 16V RB electrolytic
- 2 100 $\mu$ F 16V RB electrolytic
- 1 220nF greencap

- 1 100nF greencap
- 1 120pF ceramic

### Resistors (0.25W 1%)

- |                                 |            |
|---------------------------------|------------|
| 1 150k                          | 1 82k      |
| 1 15k                           | 1 10k      |
| 1 4.7k                          | 1 1.5k     |
| 1 1.2k                          | 1 1k       |
| 1 150 ohms                      | 2 2.2 ohms |
| 1 100k log potentiometer, (VR1) |            |
| 1 1k horizontal trimpot (VR2)   |            |





Here's both the circuit diagram (left) and the wiring diagram (lower left) for the Mini Amplifier. Use both of them and the closeup photo below as a guide when you're building up your amplifier, and you shouldn't make any mistakes.

Next fit the fixed resistors. There are 11 resistors in this project, and only two have the same value: the two 2.2 ohm resistors which go at the centre rear of the board. We suggest that you fit these first to help prevent errors, and then fit the others carefully — making sure you fit each one in the right position. Then fit the trimpot VR2, which goes in the very centre of the board. (But not the larger control pot VR1; this is fitted last.)

After this fit the 120pF ceramic cap and the two greencap capacitors. Note that we've provided extra holes on the board in these positions, to let you fit greencaps with different lead spacings without having to crank their leads.

Next fit the four electrolytic caps. These all fit with their positive leads towards the left and the negative 'stripe' leads to the right, as you can see from the wiring diagram and

photos. Again there are extra holes in the board for most of these electros, to suit different lead spacings.

Now you can fit diode D1, making sure you fit it the right way around as shown in the wiring diagram. This can be followed by the three small transistors Q1, Q2 and Q3 — but make sure you fit each one in its correct position on the board, and the right way around.

You'll probably have to crank the outer leads of all three transistors outward so they'll pass through the board holes, but there shouldn't be any need to dress the centre lead of the BC549 (Q1) because we've provided two holes for it. This is to suit devices with the centre lead either straight or bent out towards the rounded side of the body.

With these transistors in place it's time to fit the two

## Tech Talk: How does it work?

The Compact Amplifier uses a circuit configuration that looks a little complicated, but is really quite simple. At the heart of the amplifier are output transistors Q4 and Q5, both of which are connected as common collector or **emitter follower** stages where they provide no voltage gain, only current gain. Because Q4 is an NPN transistor and Q5 is a PNP, and Q5 is connected as a kind of mirror image of Q4, the combination is also known as a **complementary symmetry** output stage.

As you can see the amplifier's output is taken from the two emitters via the 2.2Ω current limiting resistors, and then fed through the 470μF output coupling capacitor into the speaker.

The voltage amplification of the amplifier is provided by input transistor Q1 and driver transistor Q2, both of which are connected as common emitter stages. The input signals are fed to the base of Q1 via the 220nF coupling capacitor, after passing through volume control VR1. The amplified signals at the collector of Q1 are then fed directly to the base of Q2, where they're amplified further. The larger signals which then appear at the collector of Q2 are then fed directly to the base of Q4, as you can see, and also to the base of Q5 via the 100nF capacitor.

You're probably wondering why so far we haven't mentioned transistor Q3. That's because this transistor isn't directly involved in amplifying the AC audio signals. Instead it's used as an 'amplified diode', to allow us to control the small amount of DC forward bias voltage between the bases of Q4 and Q5. The voltage drop across Q3 can be adjusted using trimpot VR2, and we use this to set the operating current in Q4 and Q5 so they can deliver the audio output we want without distortion. At the same time the voltage drop across Q3 also depends inversely on its temperature, so when we provide thermal coupling between it and transistors Q4 and Q5, we can use it to protect them against 'thermal runaway'.

Most of the collector load resistance for driver transistor Q2 is provided by the 1.2k resistor. You might expect this resistor to connect directly down to the earthed negative line, because it's the collector resistor for a PNP amplifier transistor. But as you can see, it connects instead to the top of the speaker — and then to the negative line through the speaker. Can you guess why this is done?

It's just a protection system, to help make sure the amplifier isn't damaged if the speaker becomes disconnected or goes open circuited. When this happens, there is no DC circuit through the 1.2k resistor and as a result there is no forward bias for transistor Q5. So it turns off, and this stops Q4 from conducting any current as well. As a result the complete amplifier effectively 'shuts down', protecting itself from damage.

But what about that 4.7k resistor connected from the output transistor emitters back to the emitter of input transistor Q1, which also has the 100Ω resistor and 100μF capacitor connected down to earth? Ah, these parts provide the amplifier with **negative feedback**, because they feed some of the amplifier's output back to Q1, but with the opposite polarity to the input signals fed to its base.

Doesn't this mean that the feedback signals tend to cancel the effect of the input signals, and reduce the gain of the amplifier? Yes, that's right. But at the same time the feedback reduces any distortion that may be generated in the amplifier, and also makes it amplify signals of different frequencies much more evenly. So the amplifier has a flatter and more extended frequency response, from less than 30Hz to well above 20kHz.

By the way the negative feedback circuit also sets the final gain or amplification factor of the amplifier. That's why the final gain of this amplifier is 32, because the voltage divider formed by the 4.7k and 150Ω resistors feeds back  $150/(4700 + 150)$  or near enough to 1/32 of the output voltage, to partially cancel the input signals at the base of Q1. The gain is simply the inverse of this feedback division factor.

power transistors Q4 and Q5. These both come in identical looking TO-126 (TO225) cases, but they are quite different: one is a BD135 (or BD139) NPN transistor, the other a BD136 (or BD140) PNP transistor. So check them carefully to identify them, and make sure you fit them in the right positions as shown in the wiring diagram. Also make sure you fit them both with their metal tab sides facing outwards — i.e., away from each other.

The board holes for Q4 and Q5 are already spaced 2.5mm apart, to suit the standard lead spacing for TO-126 devices, so you shouldn't need to dress their leads. Fit them vertically and shown in the photos, with their bodies only about 3-4mm from the top of the board.

Now that all of the smaller parts are in place you can fit control pot VR1, which will become the amplifier's gain or volume control. But before you fit it into the board, it's a good idea to cut the pot's spindle to the length you'll need to fit a knob.

If you're going to be building the amp into a box as described later, cut the spindle a little longer — say about 24mm. If you don't plan to build it into a box the spindle can be cut shorter, say 12mm long.

In either case, saw the spindle with a hacksaw or jeweller's saw, and smooth off any burrs with a small file. Then you can fit the pot to the amplifier PC board, which has holes to suit either 16mm or 24mm size control pots.

Your audio amp should now be almost complete. All that should remain is connecting the battery clip lead wires to the '9V' terminal pins at the left rear of the board (red wire to the + terminal pin), and the speaker lead wires to the pair of pins at the right rear. You can also connect a

screened audio cable to the input pins at the front of the board, of course, so you can feed in the audio signals to be amplified. As you can see in the wiring diagram the cable's centre wire goes to the pin on the left, and the outer screening wires go to the pin on the right.

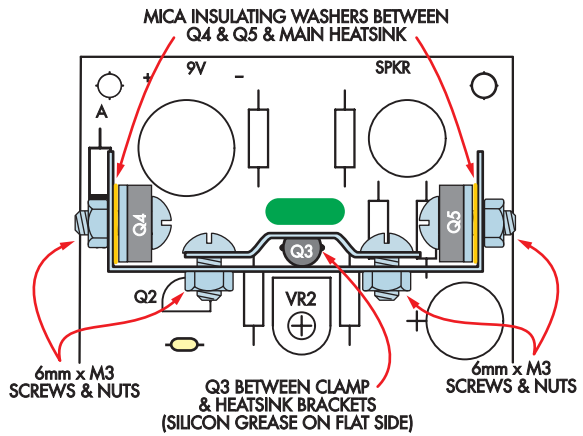
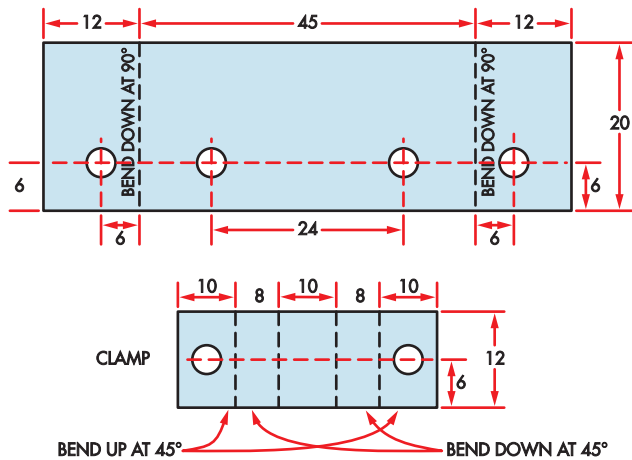
The amp should now be ready to try out, but just before you do this it's a good idea to give everything a quick once over. Make sure you have all parts in their correct positions on the board, and orientated correctly. Check that you haven't forgotten to solder any of the component leads, and that all of your solder joints are well made. If there are any dry joints or solder whiskers shorting pads together now is the time to fix them, before they cause trouble.

### Trying it out

Assuming everything seems to be OK, turn trimpot VR2 to the centre of its adjustment range and also set volume control VR1 fully anticlockwise. Then connect the cliplead to a 9V battery, and slowly turn up the volume. If your screened input cable is connected to the headphone output of a radio, or a CD or tape player, or to a similar source of audio signals, you should start to hear these signals. They should also become louder as you turn up the volume.

You should be able to turn up the volume until the sound is quite loud, while at the same time it's still quite clear and undistorted. But if you notice any distortion such as an 'edginess' creeping into the sound before it gets loud enough, you'll need to turn trimpot VR2 anticlockwise a small amount — not much, just enough to remove the distortion.

If you don't get any sound at all even when the volume



ALL DIMENSIONS IN MILLIMETRES, ALL HOLES 3.5mm DIAMETER

*If you decide to run the amplifier from 12 volts to get more output, you'll need to fit output transistors Q4 and Q5 with a small heatsink made from 1mm thick aluminium sheet. It's also a good idea to clamp transistor Q3 to the heatsink, so it can sense when Q4 and Q5 are getting hot. Here's how the heatsink and clamp are made and used.*

control is turned up fully clockwise, this will be almost certainly because you've made some kind of mistake in wiring the amplifier up. So disconnect the battery straight away, and start looking for the cause of the problem. You might have fitted diode D1 the wrong way around, or reversed the battery cliplead connections. Or you might have put some of the transistors in the wrong positions, or the wrong way around. When you've found the mistake it's a matter of removing the part or parts concerned, and re-fitting them the right way again.

Another possibility is that you might get some sound from the speaker, but it's quite distorted even at very low volume levels. Again this is most likely the result of a wiring mistake, like having output transistors Q4 and Q5 swapped around — or Q2 and Q3 swapped. Or you might have fitted one of the electrolytic caps the wrong way around.

Otherwise, your Compact Audio Amplifier should be finished and ready for use.

**What to do next**

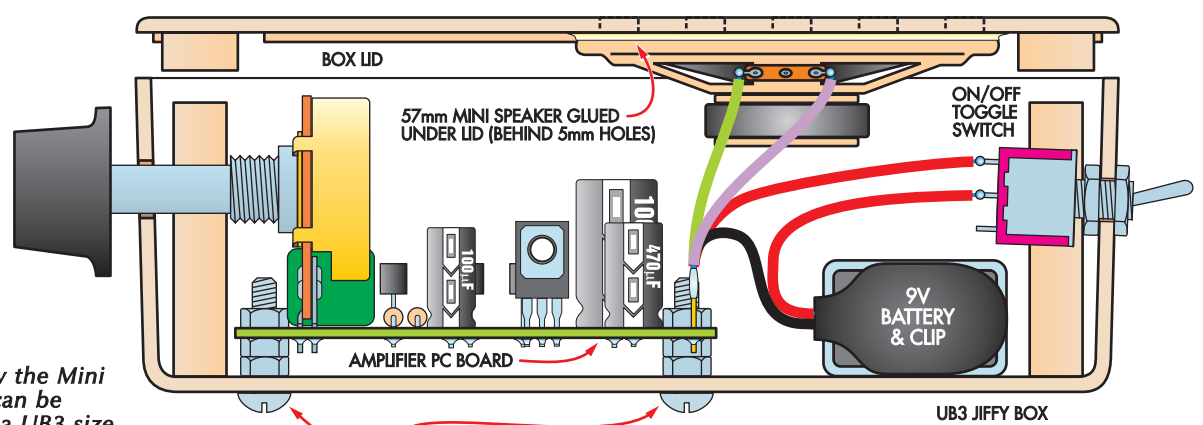
The Compact Amp can produce quite a good level of sound from the 57mm mini speaker supplied, especially when they're built into a UB3 size jiffy box as we describe shortly. However you'll get an even louder and richer sound if you feed the output of the Amp into a larger speaker that is mounted in a larger box.

So if you have a larger 200mm (or 250mm or 300mm) speaker from an old radio or stereo system, try hooking it up to the Amp instead of the 57mm mini speaker. You'll probably be surprised at how much better the sound is, especially if the larger speaker is in a suitably sized box or enclosure. That's because larger speakers have stronger magnets than small ones, and this makes them more efficient. The larger box helps as well.

Ideally the larger speaker you use should have an impedance of 8 ohms (8Ω), but this isn't too critical.

If you still can't get as much volume as you'd like, even using a larger speaker, you can try running the Amplifier from a 12V battery or regulated DC power supply instead of the 9V battery supplied. You could power it from eight alkaline AA cells, for example, fitted into a holder like the Jaycar PH-9209.

When you do power the Amp from 12V, you'll need to turn trimpot VR2 anticlockwise by a small amount, to prevent the output becoming distorted at higher levels. It's also a good idea to fit the output transistors Q4 and Q5 with a heatsink bracket made from a small strip of 1mm aluminium sheet, which makes a good thermal (heat) contact with transistor Q3 as well. The diagram above shows how to make such a heatsink, and how it's fitted to the transistors. By doing this you'll be making sure that the Amp can deliver more audio power without getting output transistors Q4 and



*Here's how the Mini Amplifier can be fitted into a UB3 size jiffy box, to make it neat and tidy.*

BOARD MOUNTED IN BOX USING 4 x 15mm LONG M3 SCREWS AND NUTS, WITH TWO ADDITIONAL NUTS ON EACH SCREW FOR SPACING



Q5 too hot and bothered.

As we mentioned earlier, it's fairly easy to build the Compact Amplifier into a UB3 jiffy box if you'd like to make it neater and protect the parts from damage. Either of these Jaycar boxes would be suitable: the HB-6013 (black) or the HB-6023 (grey).

The second diagram shows how the Amp and mini speaker can be built into this size of box, along with the 9V battery. As you can see the Amplifier board assembly is mounted in the bottom of the box via four 15mm long M3 machine screws and M3 nuts, with each screw also passing through a pair of additional M3 nuts to space the board about 4mm above the box bottom. This allows the top of volume control pot VR1 to just clear the bottom of the box lid, when it's all assembled.

The volume control spindle emerges from the end of the box via a 7mm hole, and has the control knob fitted. You can also drill a 6mm hole in the same box end, and mount a

3.5mm jack socket (like the Jaycar PS-0120 or PS0122) in this hole to allow you to plug in the screened audio input cable. The socket is connected to the audio input pins on the front of the Amp board, of course.

The speaker can be cemented on the inside of the box lid, behind the usual array of 5mm holes to let the sound out. As you can see the battery fits in the bottom of the box alongside the Amp board, perhaps held down using some double-sided adhesive tape or a strip of 'gaffer' tape.

With the battery inside the case, you won't want to open the case every time you want to turn the amplifier on or off. So you'll also want to fit an On/Off switch, connected in series with the positive (red) clip lead. The easiest type of switch to use is the mini toggle type, such as the Jaycar ST-0335. This can be fitted into the opposite end of the box to the pot spindle and the input jack, as shown in the diagram. All you need to do is drill a 6.5mm hole in the centre of the box end and mount the switch in this hole.

## How a Microwave Oven Works

Did you realise that your humble microwave oven is electronic? It sure is, and inside it there's one of the few 'radio valves' still in common use: the magnetron. Here's a quick look inside to explain how they both work.

Microwave ovens were first developed in about 1962. They're basically just a power supply and a magnetron valve which turn electrical power from the mains into microwave radio energy — plus a metal box into which the radio energy is beamed to heat the food you've placed inside. It's like a radio transmitter with its output waves all directed inside a 'tin', to heat up your cup of coffee or cook your chook, leg of lamb or whatever.

In all except the cheapest models there's also a microcomputer which is used to pulse the magnetron on and off to control its average power level, and also control the overall cooking time. Cheap models have just a mechanical or simple electronic timer.

But why do these 'radio ovens' work at microwave frequencies? Basically because the higher the frequency of the radio waves, the faster they heat the food up. Concentrated radio waves heat food because their strong alternating electromagnetic field distorts electrically charged food molecules first one way, and then in the reverse

direction. This alternate tugging in opposite directions generates frictional heat, and the faster the field reversals take place, the more heat is generated. The only complication is that if the frequency is increased too far, the radio waves can't penetrate very far into the food, and heating tends to be concentrated in the outer layer.

In fact the best frequency turns out to be around 2,450MHz (2.45GHz), in the microwave spectrum. This happens to be just the right frequency for optimum heating of molecules of water — and water is of course a major part of most food. So most microwave ovens operate at this frequency.

By the way, microwave energy tends to cause heat to be generated inside the actual food itself. This makes a microwave oven very efficient; it doesn't waste a lot of energy heating up the oven, dishes and whatever. Most of the energy is directed right into the food itself.

Modern microwave ovens still use a magnetron valve to generate the required amount of 2.45GHz radio energy, just like the first models of 1962. That's because a magnetron is still the simplest and most reliable way to generate the required 400 to 900 watts of continuous microwave energy. That power level is equivalent to the output from quite a husky microwave transmitter or radar set. And magnetron valves were developed in the 1940s, specifically for this kind of job. So in a sense, a modern microwave oven effectively combines a radar transmitter and a computer, both with the sole job of heating up your tucker!

### The magnetron

But back to the magnetron. How does it work? Essentially it's a fancy kind of diode valve — the simplest valve of all. Just a heated cathode, boiling off electrons in a vacuum, and with a cylindrical metal anode placed around it, with a positive voltage on it to attract the electrons...

Well, not quite. In a magnetron the anode is in the form of a cylinder with internal fins, as shown in Fig.1 (left). And the fins are carefully arranged so that the little cavities between them form **resonant** chambers at the magnetron's operating frequency — in this case, 2.45GHz. In other words, the inductance of the fins and the capacitance between the walls of the cavities interact, just as in a normal tuned circuit, producing a natural tendency for the chambers to oscillate at this frequency.

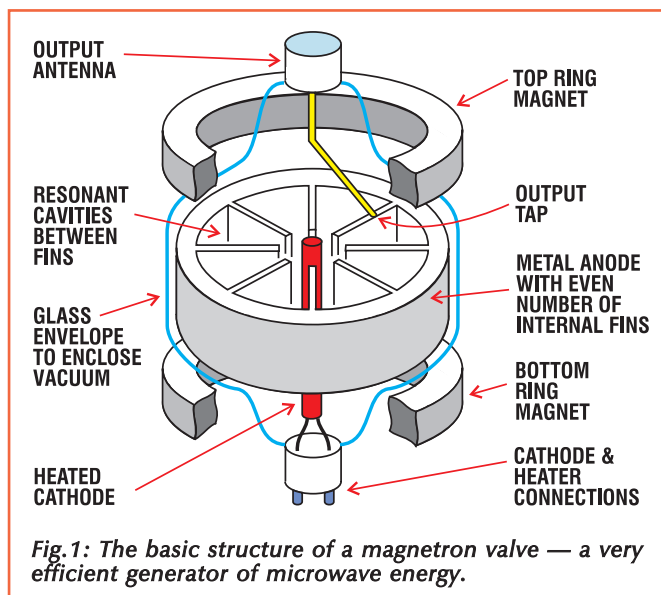


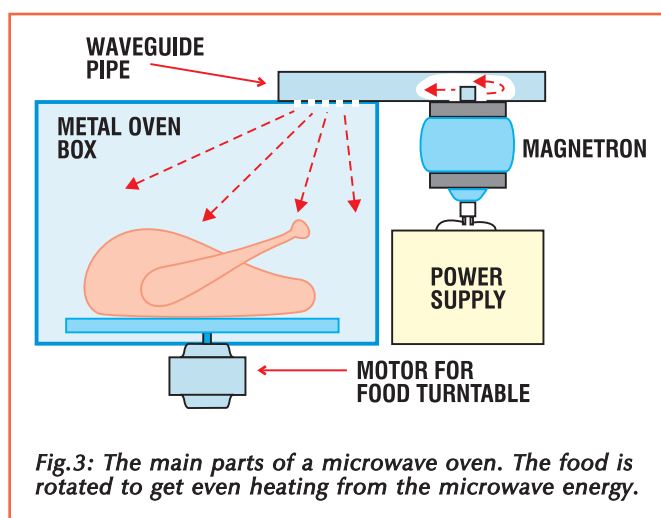
Fig.1: The basic structure of a magnetron valve — a very efficient generator of microwave energy.

As well as that, ring-shaped *permanent magnets* are placed at top and bottom of the magnetron, so that there's a strong magnetic field passing down through the valve axially, in a direction parallel to the cathode. It's this magnetic field that gives the valve its name, of course.

The anode and its fins are typically about 4000V positive with respect to the cathode, so electrons leaving the cathode tend to be accelerated towards one of the fins by the strong electric field. However once they're moving, they become influenced by the axial magnetic field, which tends to deflect them around in a circular path.

The result of this interaction is that the electrons tend to be swung back towards the cathode. However in swinging around, their electrical charges distort the electric field in the gaps *between* the fins, and this in turn tends to excite the fields inside the cavities — so they begin oscillating, at their resonant frequency. And in giving some of their energy to the electric field, to excite this oscillation, the electrons are slowed down. This reduces the influence on them of the magnetic field, so they tend to move outwards again towards the fins.

The ratio of the two fields is carefully adjusted so that the electrons do gradually move outwards and eventually reach one of the fins, but they do so in *cycloidal* paths, in the process donating most of their energy to the oscillations in



**Fig.3: The main parts of a microwave oven. The food is rotated to get even heating from the microwave energy.**

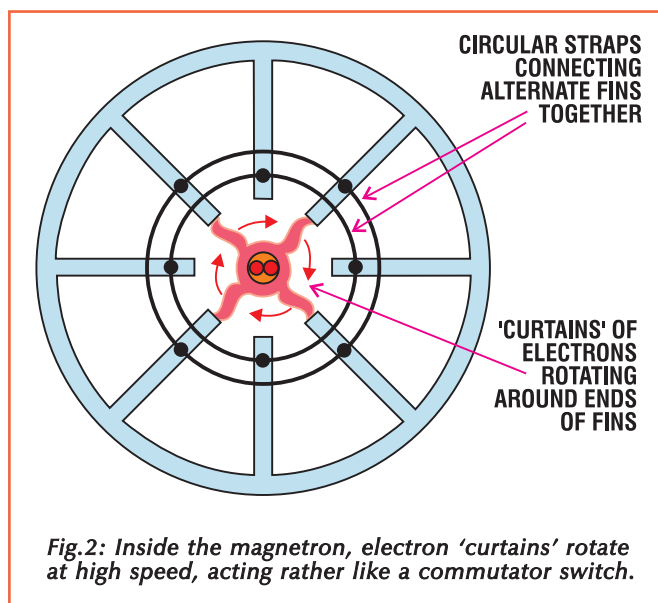
the cavities. As a result, the inner ends of the fins tend to develop a strong AC voltage at 2.45GHz, superimposed on the DC voltage. When one fin is more positive, the next fin is more negative and so on.

This in turn causes the electrons to 'bunch together', in a relatively small number of radial streams or 'curtains' of electric charge, which rotate around inside the valve — rather like the poles of a rotary switch, or commutator. And the curtains rotate at a speed synchronised with the oscillations of the cavities, so that they move from one fin to the next in one half of a cycle at the magnetron's resonant frequency.

If the magnetron has say eight fins (and therefore eight cavities), there will be four of these space charge curtains rotating around inside, moving between one fin and the next in about 0.2 nanoseconds (the time for one half-cycle at 2.45GHz). This is shown in Fig.2. Each curtain makes a full revolution every 1.63ns.

So the magnetron effectively works like a very rapidly rotating multi-pole switch, switching DC electrical power into the oscillating cavities — and potentially generating large amounts of microwave power in the process. It's a very compact and quite efficient power converter.

Actually to ensure that everything happens as just described, there's one little detail inside the magnetron that we haven't mentioned yet. This is that there are circular



**Fig.2: Inside the magnetron, electron 'curtains' rotate at high speed, acting rather like a commutator switch.**

straps used at each end of the magnetron's fins, to connect every alternate fin together (Fig.2). The straps make sure that the oscillations of the various cavities are all synchronised together, and change polarities at the same time.

The microwave power is extracted from the magnetron by connecting a tapping near the outer end of one anode fin. Generally the tapping lead comes out of the magnetron at the opposite end to the cathode heater leads. Its end forms a very short microwave transmitting antenna, used to couple the microwave energy into a *waveguide*. This is the microwave equivalent of a transmission line cable — at these frequencies, it becomes purely a rectangular metal pipe leading the microwaves to their destination. In the case of a microwave oven the destination is the metal oven cavity itself, containing the food to be heated. Needless to say the oven cavity itself is also carefully designed to be resonant at 2.45GHz.

The basic physical arrangement of a microwave oven is therefore as shown in Fig.3. A power supply provides energy to the magnetron, which converts it into microwave energy. This is then led by the waveguide along and into the oven cavity, to heat the food.

Although the magnetron is relatively efficient in converting the input DC power into microwave energy, it is not perfect. The remaining power is dissipated as heat, in the magnetron itself. As a result the magnetron is usually mounted in a finned heatsink enclosure, with a small fan used to blow cooling air through the fins. It's this fan that generates most of the 'rushing air' noise you hear when a microwave oven is operating.

### **Danger: don't open it up!**

Although the power supply inside a microwave oven is essentially fairly simple, be aware that it's designed to deliver around a **kilowatt** of power to the magnetron at about 4000 volts. This makes it **very** dangerous. In fact a microwave oven's power supply is far and away the most dangerous of any item of domestic electronic equipment — bar none.

**So never underestimate the danger lurking inside a microwave oven's power supply. It won't just give you a nasty shock and throw you across the room, like a TV set's EHT supply. It can kill you!**

Leave the repairing of your microwave oven to the manufacturer's service department. They're trained to work on them safely, and they also have the specialised test gear to ensure that the oven isn't leaking microwave energy — another potential danger. Don't even think of opening up the oven yourself, even for a 'quick look'. ★

## Project 10:

# A Two-Station Intercom

Intercoms aren't just for business people to talk to each other between offices. You can use this low cost intercom for easy two-way communication between a home office and the kitchen, or between the kitchen and front door. It can also be used as a 'baby minder', to let Mum listen for the baby's crying while she gets on with her work.

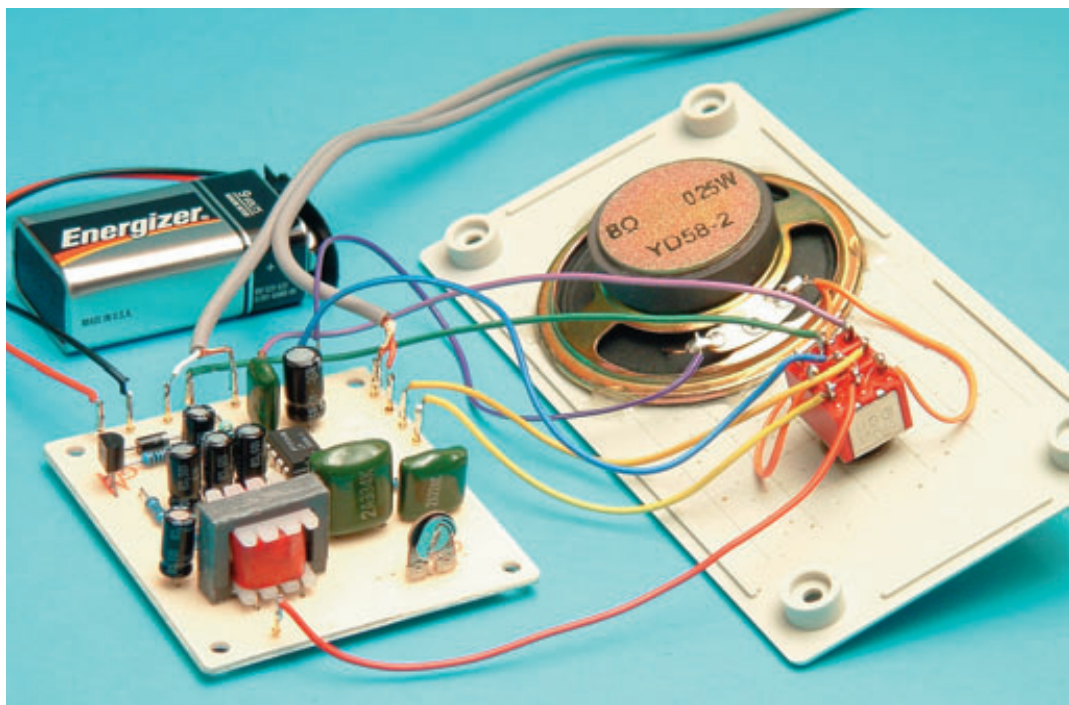
### What does it do?

Intercoms are basically a small audio amplifier with speakers connected to both input and output. The speaker connected to the input of the amp acts like a microphone: the sound signals it picks up are amplified and then fed to the speaker at the other end, so it reproduces the original sounds.

We use two speakers rather than a microphone and a speaker, because the intercom is designed to allow communication in either direction simply by reversing the roles of the two speakers. So for communication one way, speaker A picks up the sounds while speaker B reproduces them at the other end; then for communication back the other way, speaker B picks up the sounds and speaker A now reproduces them at its end.

The roles of the two speakers can be swapped around as you want, by means of switching. Usually there's a switch or pushbutton at each end or 'station', which is pressed whenever the person at that end wants to talk. Not surprisingly, the switch is usually known as the **Press to Talk** or PTT switch. The action of each PTT switch is not only to turn on the power for the intercom's amplifier, but also to operate the speaker switching so that the speaker at that end becomes the microphone. The speaker at the other end then becomes the active speaker by default.

This intercom project has only a small amplifier and uses a 57mm mini speaker at each end, but it works surprisingly



well over cables as long as 10 or 12 metres. So it's just the shot for setting up a link between your kitchen and home office, or the kitchen and the garden shed or workshop. Or the remote station can be fitted near the front door, so you can identify visitors without having to walk there yourself.

That's not all you can use it for, though. By adding another low-cost switch the intercom can also be used as a 'baby minder', with the intercom's main station able to listen continuously to sounds picked up by the remote station. This can allow Mum or Dad to listen for when the baby wakes up and starts to cry, while they work away elsewhere.

## The parts you'll need for this project:

- 1 PC board, code SHRTC210, 57 x 63mm
- 1 Audio transformer, 1k:8Ω (T1)
- 13 PCB terminal pins, 1mm dia.
- 1 9V battery, 216 type
- 1 Battery clip lead to suit
- 2 57mm mini speakers
- 1 6m length of figure-8 (stereo) screened audio cable
- 1 Mini toggle switch 3PDT
- 1 Mini pushbutton switch (NO)

- 1 Small pack of resin-cored solder

### Semiconductors

- 1 LM386 audio amplifier (IC1)
- 1 PN100 NPN transistor (Q1)
- 1 PN200 PNP transistor (Q2)
- 1 1N4004 diode (D1)

### Capacitors

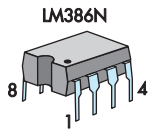
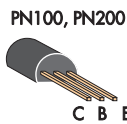
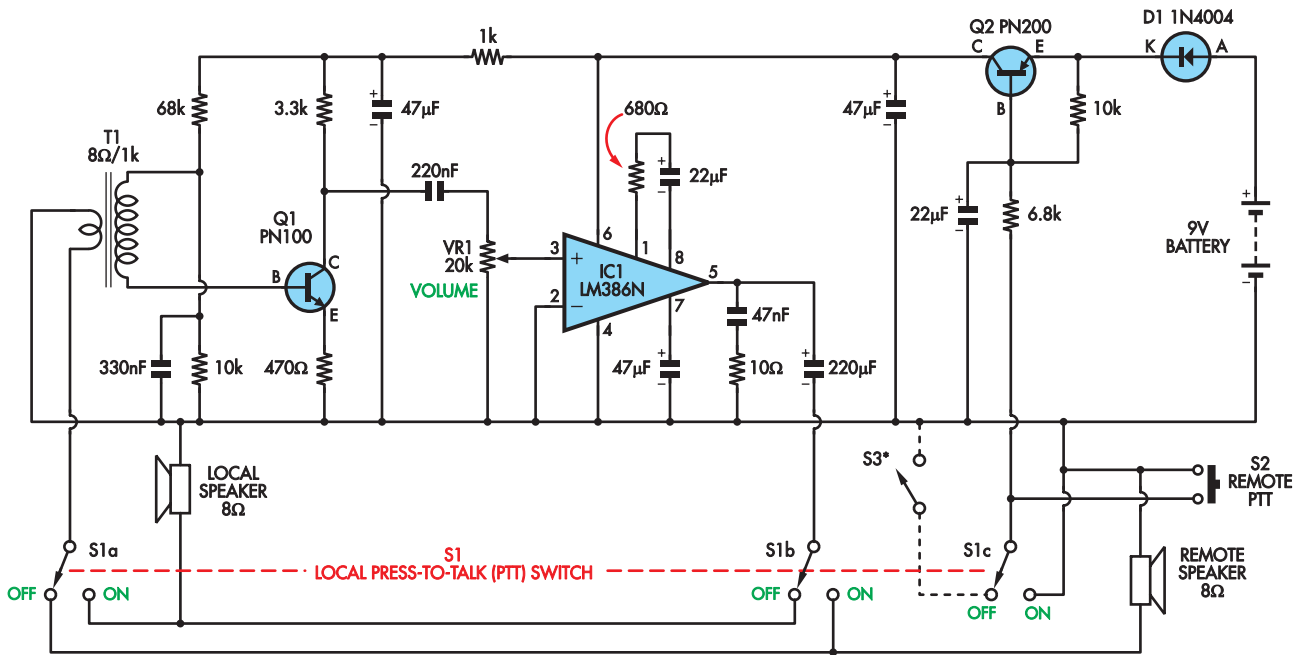
- 1 220μF 16V RB electrolytic
- 3 47μF 16V RB electrolytic
- 2 22μF 16V RB electrolytic

- 1 330nF greencap
- 1 220nF greencap
- 1 47nF greencap

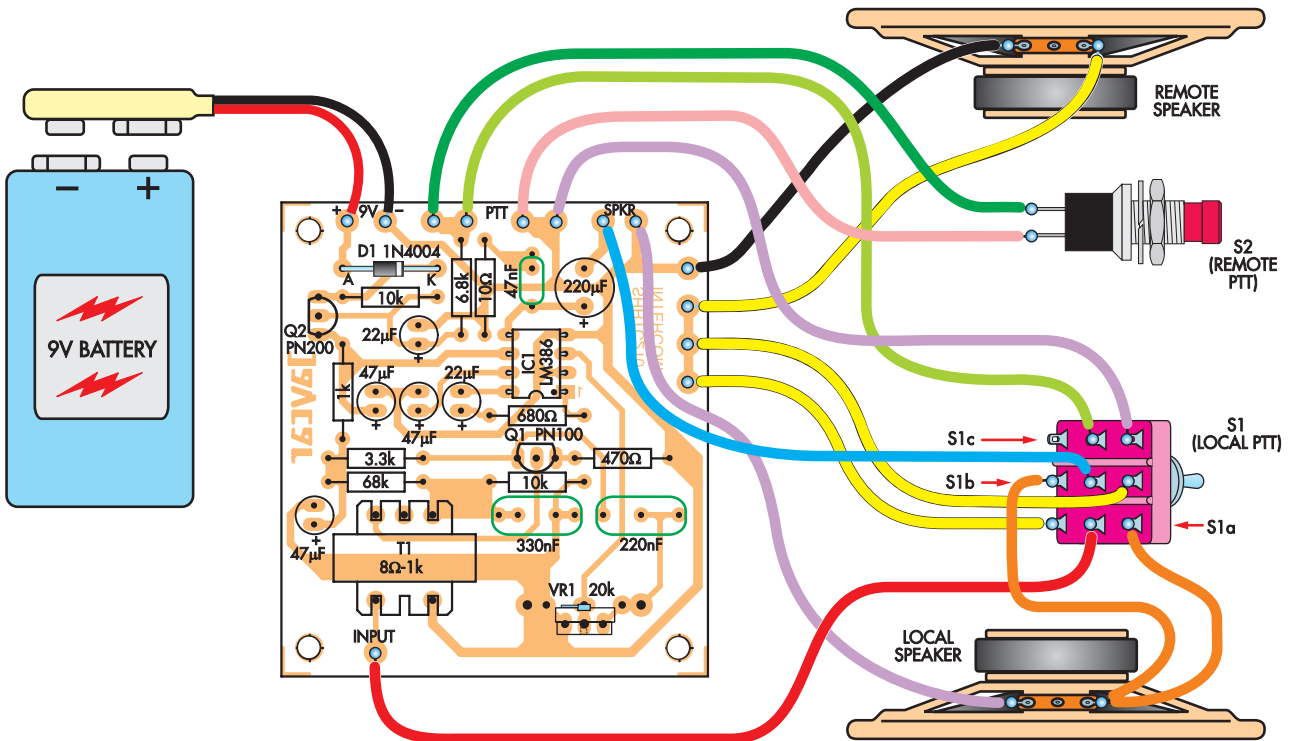
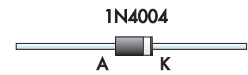
### Resistors (0.25W 1%)

- |                              |        |
|------------------------------|--------|
| 1 68k                        | 2 10k  |
| 1 6.8k                       | 1 3.3k |
| 1 1k                         | 1 680Ω |
| 1 470Ω                       | 1 10Ω  |
| 1 20k vertical trimpot (VR1) |        |





\*OPTIONAL 'BABY MINDER' SWITCH



Here's both the circuit diagram (top) and the wiring diagram (above) for the Intercom. Use both of them and also the photos, as a guide when you're building your Intercom.

So the Intercom is a very handy little device, with a lot of practical uses.

## Putting it together

Apart from the speakers, the PTT switches and the 9V battery that powers the intercom, all of the components fit

directly onto a compact PC board. The intercom board is coded SHRTC210 and measures only 63 x 57mm.

Before starting to assemble the project, open up the kit and lay out all of the parts so you can check that you have everything. Carefully inspect the copper side of the PC board as well to make sure there are no hairline cracks in

## Tech Talk: How does it work?

Because the voice coil of a speaker is only a few turns of wire, its audio output signal is very tiny when it's used as a microphone. That's why the Intercom uses a small audio transformer T1 to step up the signals from whichever speaker's voice coil is being used as a microphone. The transformer steps up the voice coil signals by about 125 times. This still isn't enough though, so we then pass them through transistor Q1. This is connected as a common-emitter amplifier stage, giving a further gain of about seven times.

Forward bias for the base of Q1 is derived by the voltage divider using the 68k and 10k resistors, and fed to the base through the secondary winding of T1.

From the output of Q1, the now much stronger signals are then fed into our main amplifier IC1 via the 220nF coupling capacitor and volume control VR1. IC1 is a power amplifier device, and provides a further voltage gain of about 100 times as well as the current gain needed to drive either speaker from its output — via the 220 $\mu$ F coupling capacitor.

So the circuitry around T1, Q1 and IC1 makes up the Intercom's audio amplifier section, to amplify the signals picked up by one speaker and feed them to the other speaker. Which speaker is connected to the amplifier's input and which speaker to its output is controlled by local PTT switch S1. As you can see section S1a selects which speaker is connected to the input, while section S1b selects which one is connected to the output. When S1 is in the 'Off' position as shown in the circuit diagram, S1a connects the remote speaker to the input and S1b connects the local speaker to the output.

The power for the Intercom's amplifier is controlled by transistor Q2, which is connected as an electronic on-off switch. When neither S1 nor S2 is switched on, Q2 cannot conduct because it has no forward bias on the base. The base is simply connected back to its emitter via the 10k resistor.

But if either of the PTT switches S1 or S2 is switched on, this allows current to flow from Q2's base to the negative line via the 6.8k resistor. So Q2 is now forward biased, and turns on — connecting the 9V battery to the Intercom's amplifier.

Notice that it's the S1c section of S1 which does this switching in the Intercom's local station, turning on the Intercom when S1 is in the On position. At the same time S1a and S1b connect the local speaker to the Intercom amp's input and the remote speaker to its output. These are the connections for the local station to talk to the remote station, of course.

On the other hand when S1 is in the Off position and remote PTT switch S2 is pushed instead, power is applied to the Intercom amp with S1 still connecting the remote speaker to the input, and the local speaker to the output. So all the connections are set for the remote station to talk to the local station.

When additional switch S3 is added to the circuit, it simply allows power to be applied to the Intercom when S1 is in the Off position — where the remote speaker is connected to the input and the local speaker to the output. This is very much like pressing S2 and keeping it pressed, so the local station is able to listen to the remote station as long as S3 is turned on. This allows the Intercom to function as a baby minder. To turn the baby minder off, you simply turn off S3.

the tracks or tiny 'bridges' shorting between pads.

There are no wire links needed on this board, but there are 13 PCB terminal pins to be fitted — seven along the rear, four at upper right and two at the front. Fit these all first, so you don't forget them. You should be able to see where they go quite clearly from the wiring diagram.

Next fit the fixed resistors. There are nine of these, and

only two have the same value (10k). So fit these first to help avoid mistakes. The resistors are not polarised of course, but as usual you should try to fit each one so its colour code reads either left-to-right or front-to-back, depending on the resistor's alignment. This makes things easier in the future if you ever have to faultfind in the project.

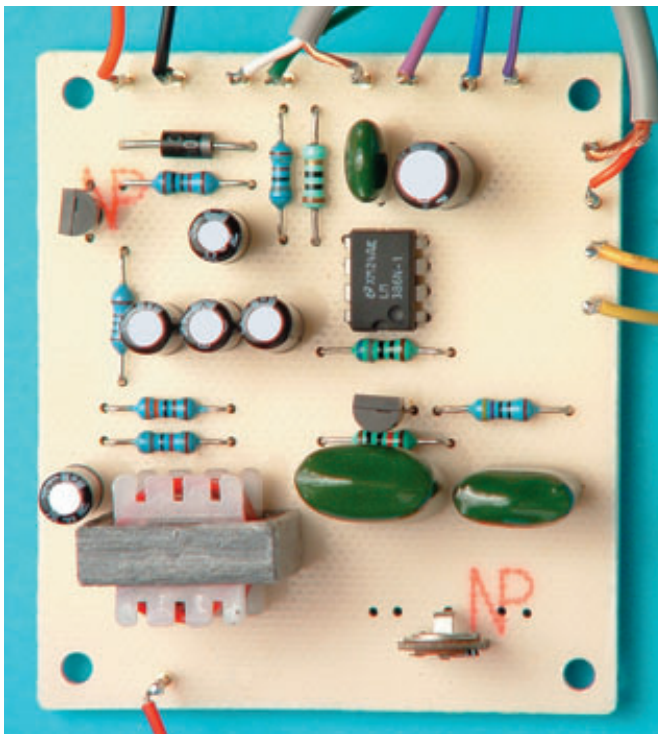
Now you can fit trimpot VR1, which goes down in the front right-hand corner of the board. You'll notice that the board also has holes for mounting a larger control pot in the same position, but don't worry about this at present. We'll talk about this later in the What To Do Next section.

Next fit the three greencap capacitors. The two larger caps go down at lower right, just above the trimpot, while the small 47nF cap goes at upper right just to the right of the 10 $\Omega$  resistor. Notice that the PC board provides additional holes for each of the two larger greencaps, to suit different lead spacings. The greencaps are not polarised, so you don't have to worry about fitting them the right way around — just in the right positions.

After the greencaps are fitted you can fit the electrolytic caps. There are six of them in this project and they are all polarised, so follow the wiring diagram carefully when you're fitting each one. As you can see all six are fitted with their positive leads towards the front/bottom of the board. Be careful to place each one in the correct position though. Notice that there are three electros with a value of 47 $\mu$ F and two of 22 $\mu$ F, plus the largest 220 $\mu$ F which goes at upper right. You might have to dress the leads of this electro so they'll pass through the board holes easily.

Next fit diode D1, which as you can see goes at upper left with its cathode band end towards the right. This is followed by transistors Q1 and Q2, but take care that you fit these in their correct positions: Q1 is the PN100, while Q2 is the PN200. Their correct orientations are shown in the wiring

*Here's a closeup of the top of the Intercom board, to guide you when you're wiring up your own board.*



diagram, but you'll have to crank their outer leads so they'll pass through the board holes without strain.

Now you can fit IC1, which is an LM386 amplifier IC in an eight-pin package. Notice that this needs to be fitted with its notch/dimple end downwards (towards the front of the board), but you might need to bend the rows of pins on each side gently inwards towards each other, so they'll all pass through the board holes without strain.

The final component to fit on the board is input transformer T1, which is left until last because it's the largest. You'll find that it has three wires emerging from the bottom of one side of the bobbin and two wires from the other. These may all need to be straightened and dressed so they're all parallel, before the transformer can be fitted by passing them through the board holes. Needless to say the two-wire side goes towards the bottom of the board.

Push the body of the transformer down against the board, with all five wires passing through the board holes as far as they'll go. Then bend them all over at about 45° to hold the transformer in place while you solder the wires to the pads. After soldering you can then trim off the excess wires. (The transformer is actually held in place by the soldered wires, but this is OK because it's fairly light.)

Your intercom board assembly should now be complete, and ready to make the connections to the battery, speakers and PTT switches. All of these off-board connections are shown in the wiring diagram, including the wiring details for the switches. Notice, though, that this diagram shows **both** of the speakers and PTT switches quite near the PC board assembly, to make the connections as clear as possible. In reality both the 'remote' speaker and its PTT pushbutton S2 need to be connected to the rest of the circuit via a length of screened two-core (figure 8) audio cable, as shown in the diagram above.

Once you have hooked everything up, you're just about ready to try out the Intercom. Before you do this, give the board assembly a quick inspection to make sure you've fitted all of the parts in their correct positions, and the polarised parts with their correct orientations. Check the copper side of the board too, in case you've forgotten to make any of the solder joints. And finally check your off-board connections against the wiring diagram, to make sure you haven't made any mistakes.

## Trying it out

If all seems well, turn trimpot VR1 fully anticlockwise (as viewed from the bottom/front of the board) and check that the local PTT switch S1 is in its Off position — with the lever towards the right, viewed from the rear as shown in the wiring diagram. Then connect a 9V battery to the cliplead. At this stage there should be no sound from either speaker.

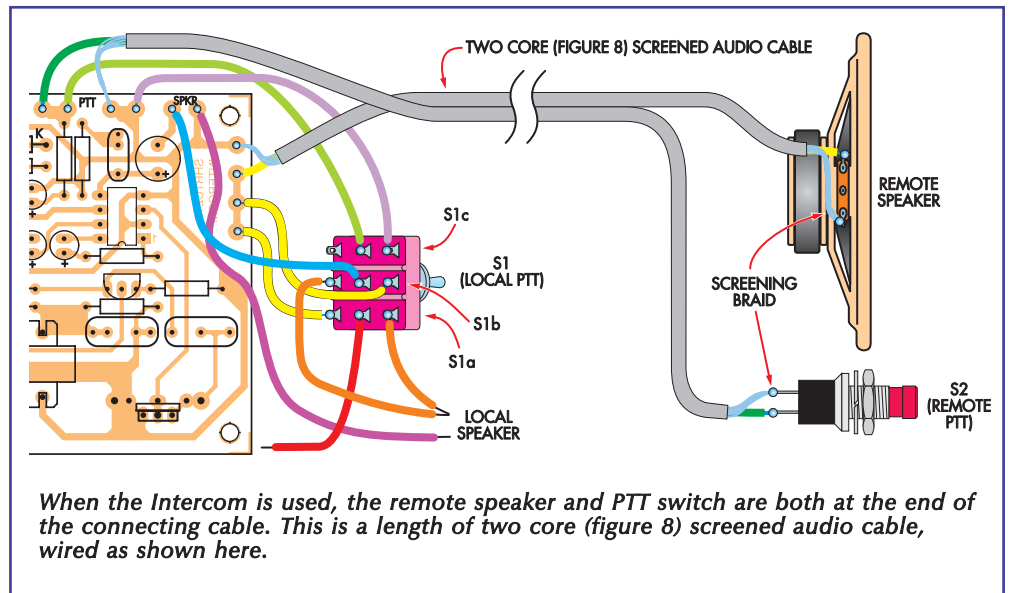
Now try turning up trimpot VR1 to about the middle of its range (12 o'clock), and try pressing the remote PTT button S2. If you or someone else speaks a few words into the remote speaker while you or they keep this button pressed, your voice should also emerge quite clearly from the local speaker.

If this does happen as it should, try releasing S2 and using local PTT switch S1 instead. This time if you speak into the local speaker, your voice should emerge from the remote speaker.

If you have to speak too closely into the Intercom speakers to be heard clearly at the other end, you'll need to turn trimpot VR1 up (clockwise) a little to increase the gain. On the other hand if the gain is already so high that the sound that emerges from either speaker is too loud and distorted, VR1 needs to be turned down (anticlockwise) a little instead.

You'll also need to turn down the gain if the Intercom tends to whistle or 'howl', which can happen when the speaker being used as a microphone is able to pick up the sounds from the other speaker. This positive feedback signal is then amplified, making the Intercom oscillate — just like a public address system where the microphone can pick up some of the sound from the speakers.

But what if your Intercom doesn't seem to be working at all, with no sound emerging from either speaker even when the trimpot is turned fully clockwise, and regardless of



whether you have either PTT switch turned on? You guessed it — that will be because you've made some kind of mistake in wiring up the intercom. So you'll need to disconnect the battery again, and track down the cause of the problem.

You might have fitted diode D1 the wrong way around, for example, or connected the wires from the battery cliplead to the wrong terminal pins. Or you might have accidentally swapped the two transistors, fitting the PN100 as Q2 and the PN200 as Q1. Any of these things can stop the Intercom from working at all.

If the Intercom works after a fashion but the output sound is very weak and distorted, there are other possibilities. You might have fitted IC1 the wrong way around, or one of the electrolytic caps instead. Or you might have accidentally swapped a couple of resistors.

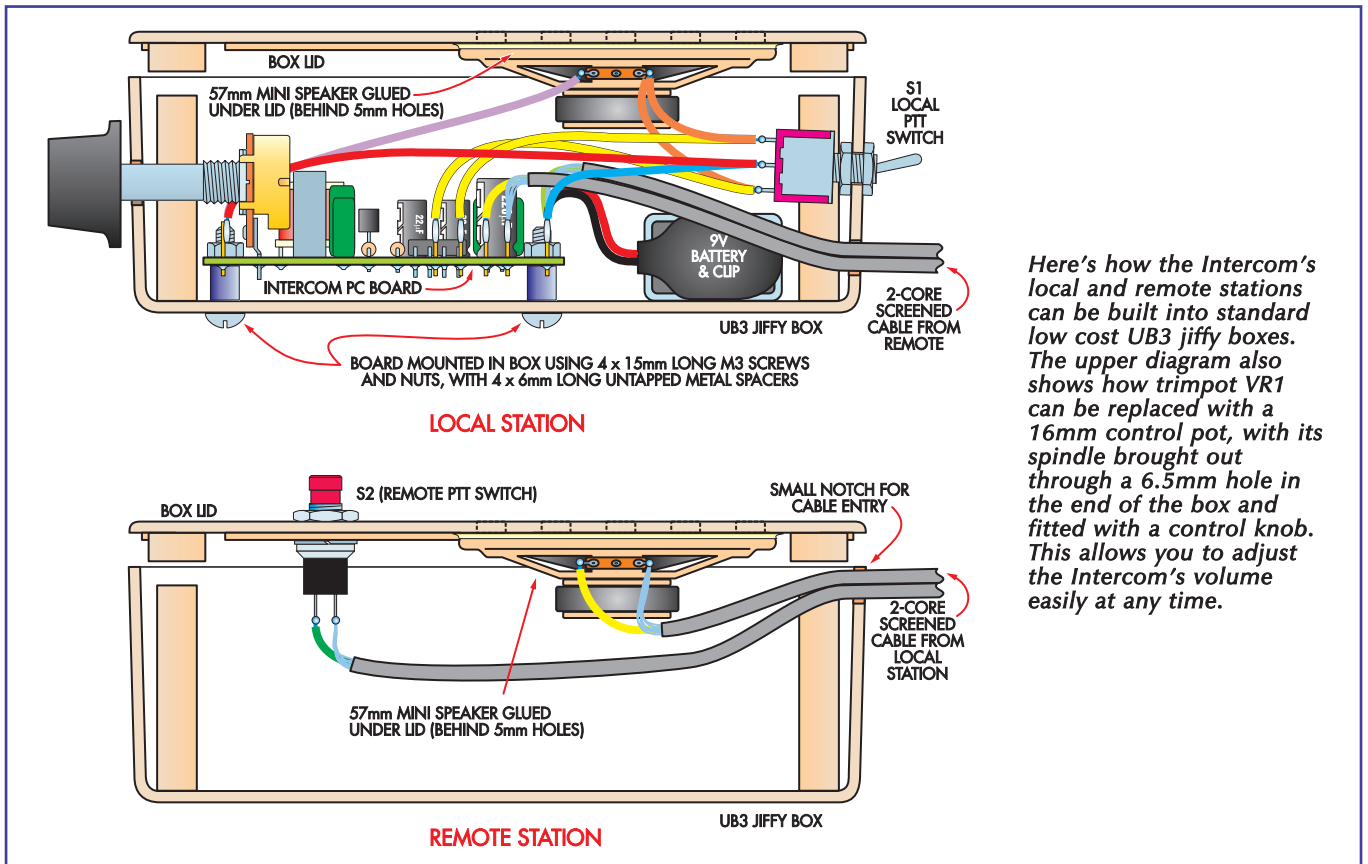
If you check through all of these possible mistakes carefully and methodically, the odds are that you'll find your mistake and be able to fix the problem fairly quickly.

## What to do next

You'll want to fit the Intercom into a couple of plastic boxes, not only to protect the components from damage but also to make the Intercom much tidier and easier to use.

The PC board has been designed for easy mounting in a standard UB3 size jiffy box, along with the local speaker and PTT switch S1, and of course the battery. It's even easier to fit the remote speaker and its PTT pushbutton in another UB3 jiffy box, as they can both be mounted on the lid. So you're going to need two UB3 size boxes, such as the Jaycar HB-6013 (black) or HB-6023 (grey).





*Here's how the Intercom's local and remote stations can be built into standard low cost UB3 jiffy boxes. The upper diagram also shows how trimpot VR1 can be replaced with a 16mm control pot, with its spindle brought out through a 6.5mm hole in the end of the box and fitted with a control knob. This allows you to adjust the Intercom's volume easily at any time.*

The diagram shows how things are fitted in both boxes. As you can see the PC board assembly is mounted in the bottom of its box near one end, using four 15mm long M3 machine screws and nuts and with 6mm untapped metal spacers (Jaycar HP-0860) for spacing. A 3.5mm hole can be drilled in that end of the box opposite the adjustment slot for VR1, if you wish, to allow the gain to be adjusted using a small screwdriver even when the box is screwed together.

The 'local' speaker is mounted on the underside of the box lid, behind a small array of 5mm holes which allow the sound to get in and out. Because the speaker is quite light it can be held in place quite securely using epoxy cement.

The local PTT switch can be fitted into the end of the box as shown — all it needs is a 6.5mm hole. Mount it so that the intercom power is turned off when the switch toggle is in the up position. Then you simply have to press it down to talk from the local end.

The battery can lie in the bottom of the local station box, between the PCB assembly and the PTT switch. It can be held in place by a short length of 'gaffer' tape.

In the remote station box the speaker and PTT pushbutton are simply mounted on the lid, as you can see. All that's needed to prepare the bottom of the box is file a small notch at the top of one end, allow the entry of the cable from the local station. Make sure to remove any sharp burrs from the notch though, so they don't gradually cut through the cable.

The Intercom doesn't need a separate On/Off switch when

it's built into boxes, because there is no significant current drawn from the battery when neither PTT switch is pressed on. But you might want to replace trimpot VR1 with a larger control pot (fitted with a knob), so the intercom gain/volume can be adjusted at any time without having to use a screwdriver. The control pot to use for this is of the 16mm log type, either the RP-7610 (10k) or RP-7616 (50k) from Jaycar would be suitable.

When you use the larger pot all you need to do is drill and ream out a 6.5mm hole in the end of the local station box to allow the pot spindle to pass through, and then fit the spindle with a suitable control knob.

One further thing you might want to do with the Intercom is add an additional switch to the local station so the Intercom can be used as a baby minder. The wiring for this additional switch (S2) is shown in dashed lines on the circuit diagram. As you can see it connects from the otherwise unused lug of S1c to the Intercom's negative line — such as one of the PTT terminal pins just above the 47nF greencap, or the topmost pin on the right-hand side of the PC board.

You can use almost any small SPST or SPDT switch for S3, but we suggest the ST-0335 from Jaycar's range. It can be mounted on the end of the box alongside S1 if you wish, for easy use.

If you find the Intercom's gain isn't quite enough when it's used as a baby minder, the gain can be increased quite easily by removing the 680Ω resistor between IC1 and Q1 on the PC board, and replacing it with a wire link.

# The Story of Radar

The development of radar is one of the biggest success stories in the history of electronics, and also one of its most interesting. Here's how radar came into being, and also a quick rundown on how it works.

Back in 1886, Hertz noticed that radio waves could be reflected from metal and other objects. Then in 1922, Marconi suggested to the American Institute of Electrical Engineers that one day, radio waves would be used for locating and measuring the range of ships and aircraft. But this didn't actually happen until the late 1930s. It was the looming threat of war that finally prompted scientists to develop radio direction finding and ranging technology, which was soon dubbed 'radar' for short.

In 1925, British scientists Breit and Tuve had used short radio pulses to measure the height of reflecting layers in the upper atmosphere. They transmitted pulses of radio energy only one millisecond long vertically upwards, and then received the weak pulses reflected back by the upper atmosphere using a receiver alongside the transmitter. Then by comparing the time difference between the transmitted and received pulses, and knowing that the radio waves travelled at the speed of light (300,000km per second), they could work out the total 'up and down' distance and hence the altitude of the reflecting layers.

Early in 1935, with another war looming, Britain became nervous about their vulnerability to attacks by enemy aircraft. A committee of scientists was set up by Sir Henry Tizard, to investigate how the country could be best defended. They decided that unless there was at least 20 minutes warning of the approach of enemy aircraft, most forms of defence were almost useless. Based on his knowledge of the Breit and Tuve work, and also on some experiments of radio waves reflected from aircraft, scientist Robert Watson Watt led a team of scientists to try and develop an 'early warning' and ranging system based on the reflection of radio waves. By June 1935 they had successfully received echoes of pulsed signals from a distant aircraft.

It was soon realised, though, that in order to work really well they would need to transmit radio pulses of quite high power — and at a very high frequency. At that time they had no technology to achieve high power levels at such high frequencies, so a group of scientists at Birmingham University began working on this aspect. They worked in a lab run by Marcus Oliphant, who later moved to Australia.

Meanwhile another group including Arnold Wilkins and Welsh scientist Edward 'Taffy' Bowen (later head of CSIRO Radiophysics in Australia) worked on a continuous wave radio direction finding (RDF) system, at a remote base in Orfordness. By 1939 they had achieved results that were promising enough to gain approval for the building of a chain of RDF stations down the east coast of England, which could detect approaching aircraft when they were about 170 miles away. This was the 'Chain Home' (CH) system.

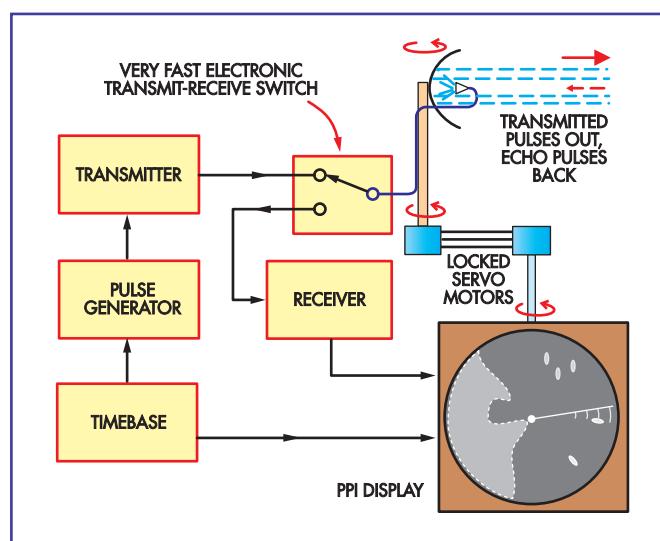
Bowen had also been working on a small radar system that could be built into aircraft, and in 1939 this too was working well enough for the Airforce to order 30 sets to be installed in their Blenheim fighters.

Another momentous development came in early 1940, when scientists John Randall and Henry Boot developed the first **cavity magnetron** in their lab at Birmingham University. This was a development from the magnetron diode valve which had been invented in 1920 by Albert Hull, at the General Electric Research Laboratory in Schenectady, New York. Randall and Boot soon realised that their development was capable of generating enormous amounts of microwave radio energy, especially as pulses. This made it ideal for radar, of course, and Randall and Boot's achievement breathed new life into the British radar effort.

Similar work had been going on in the USA, at the Naval

Research Laboratory in Anacostia, DC and also in the Radiation Laboratory which had been set up at Massachusetts Institute of Technology. In August 1940, Winston Churchill realised that Britain would not be able to develop microwave radar fast enough by themselves to win the war, so he agreed to send a secret mission to the USA to negotiate a full exchange of scientific information on radar.

Sir Henry Tizard and John Cockcroft led the mission, which also included Taffy Bowen carrying a sample of the new top-secret cavity magnetron. The Tizard mission met with US scientists at the Bell Laboratories, and an agreement was soon reached to pool their knowledge and accelerate radar development. The rest is history, with microwave radar helping to win the Battle of Britain and the war as well.



## How Radar works

Radar is easy to understand. A transmitter produces short pulses of very high power microwave radio energy, which are transmitted outwards as a narrow beam from a parabolic antenna. As soon as each pulse has been transmitted, the antenna is then switched to the input of a sensitive receiver, which 'listens' for any echo pulses reflected from objects such as an aircraft or ship. The time between the transmitted and echo pulses is then used to calculate the **range** of the reflecting object — ie, how far it is from the transmitter.

At first the antenna was rotated manually to 'scan' the sky, and both the transmitted and echo pulses were displayed on a simple oscilloscope with the scanning beam of the 'scope deflected horizontally at a known rate so the distance between the two 'blips' could be measured directly in microseconds and then quickly converted into miles or kilometres. This early type of radar display was known as the **A scan**, and could only show the target's range.

Soon, though, the antenna was rotated by an electric servo system and the information on its exact direction at any instant was used to rotate the axis of the display 'scope in a matching circle. This produced a two-dimensional 'map' type of radar display, showing the target's compass bearing as well as its range. This is the 'pulse position indicator' or **PPI radar display** which has been used right up to the present day, in one form or another. ★

## Project 11:

# 'Skeet Shoot' Game

How good is your hand-eye coordination? Rifle enthusiasts test theirs by trying to shoot down 'skeets' or clay targets, hurled up into the air by a catapult or trap. Here's a much less dangerous way to check your own coordination, with a simple electronic version of skeet shooting.

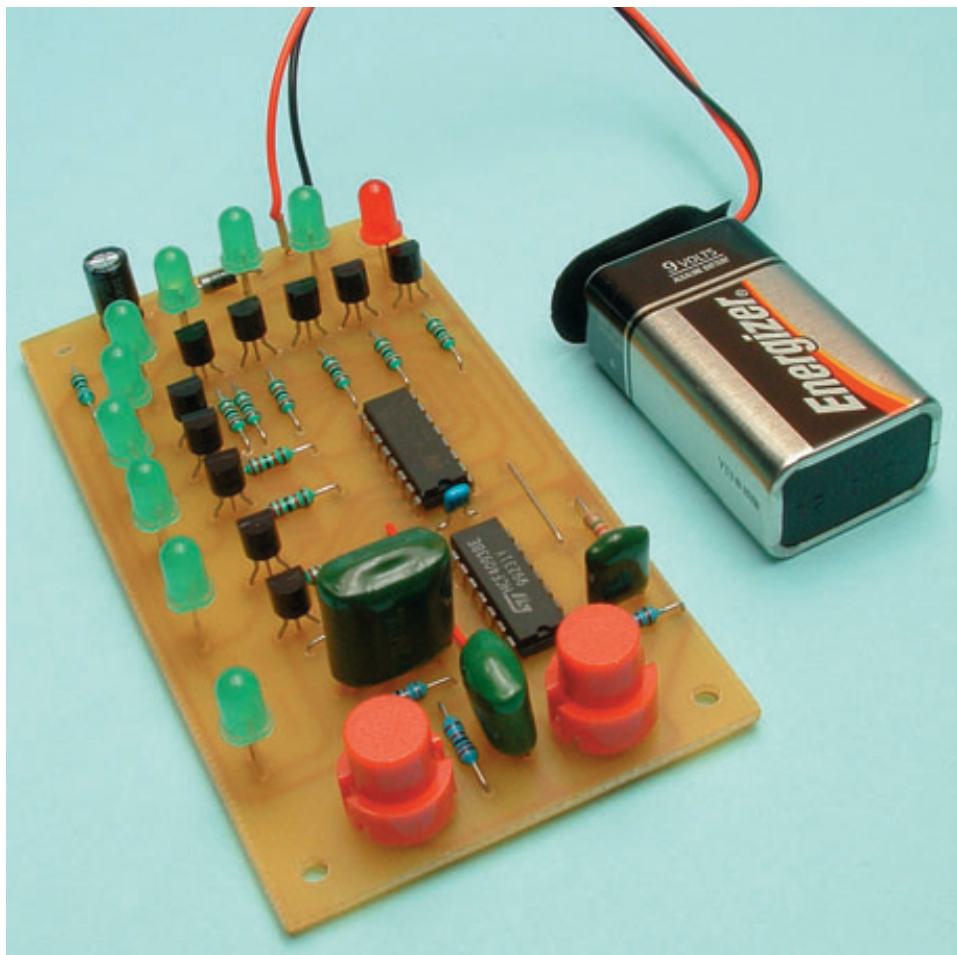
### What does it do?

Trying to shoot down a fast-moving clay target or skeet is a real test of hand-eye coordination, because you have to move your rifle to anticipate the skeet's movement, and then press the trigger at exactly the right instant to make sure the bullet and skeet will arrive at the same place at the same time. It might sound easy, but it sure isn't!

Building this game will give you a much less dangerous way to test your own coordination, because it's a simple electronic version of skeet shooting. The game sends a burst-of-light 'skeet' up along a string of LEDs, and you have to try to 'hit' it by pressing a FIRE push-button at exactly the same time as it reaches the red LED at the end. This isn't as easy as it looks either. Most of the time you miss and the game simply keeps on firing more skeets.

When you do 'hit' the skeet, though, the game stops with the end LED glowing. After gloating over your 'hit' or writing down your score, you can then make the game start up again by pressing the RESET button.

It's fun to play and it's also a very good way to improve your coordination, as well as testing it.



### The parts you'll need for this project:

- 1 PC board, code SHRTC211, 57 x 107mm
- 2 Mini pushbutton switches, PC board mounting (S1,S2)
- 1 9V battery, 216 type
- 1 Battery clip lead to suit
- 2 PCB terminal pins, 1mm dia.
- 1 Small pack of resin-cored solder

#### Semiconductors

- 1 4093B quad Schmitt NAND gate (IC1)
- 1 4017B decade counter (IC2)
- 10 PN100 NPN transistor (Q1-10)

- 9 5mm green LED (LED1- 9)
- 1 5mm red LED (LED10)
- 1 1N4004 diode (D1)

#### Capacitors

- 1 100µF 16V RB electrolytic
- 1 470nF greencap
- 1 100nF greencap
- 1 100nF multilayer monolithic
- 1 47nF greencap

#### Resistors (0.25W 1%)

- 1 2.2M
- 1 220k
- 11 22k
- 1 2.2k
- 1 680Ω

### Putting it together

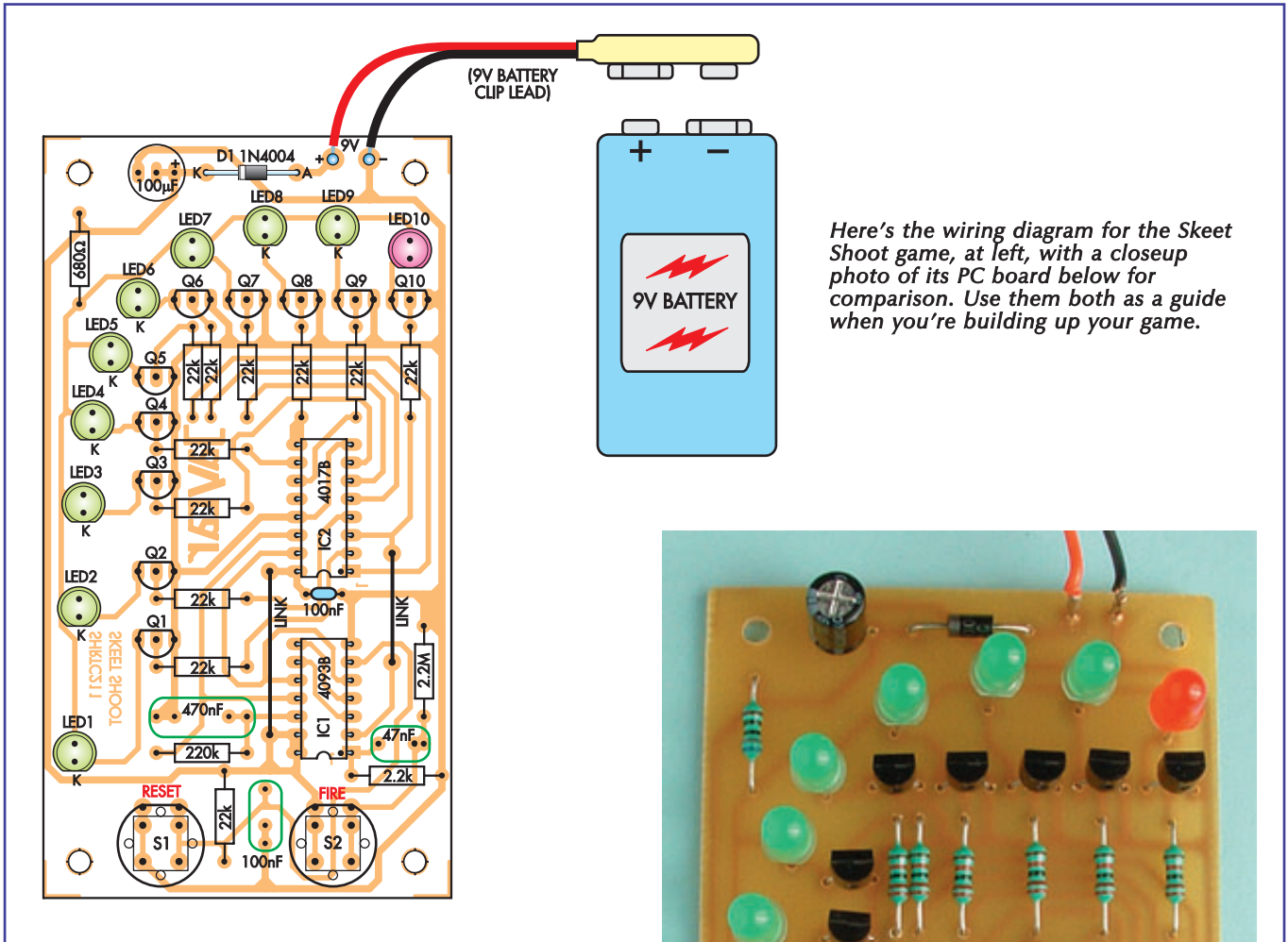
Apart from the 9V alkaline battery which provides its power, all of the parts used in the Skeet Shoot game mount directly on a compact PC board. This is coded SHRTC211 and measures only 107 x 57mm.

As usual, it's a good idea to open your kit and check that you've got everything before starting the assembly. At the same time you can quickly check the PC board for undrilled holes, hairline cracks and bridges between pads. These can all be fixed much more easily at this stage, compared with after the components have been fitted.

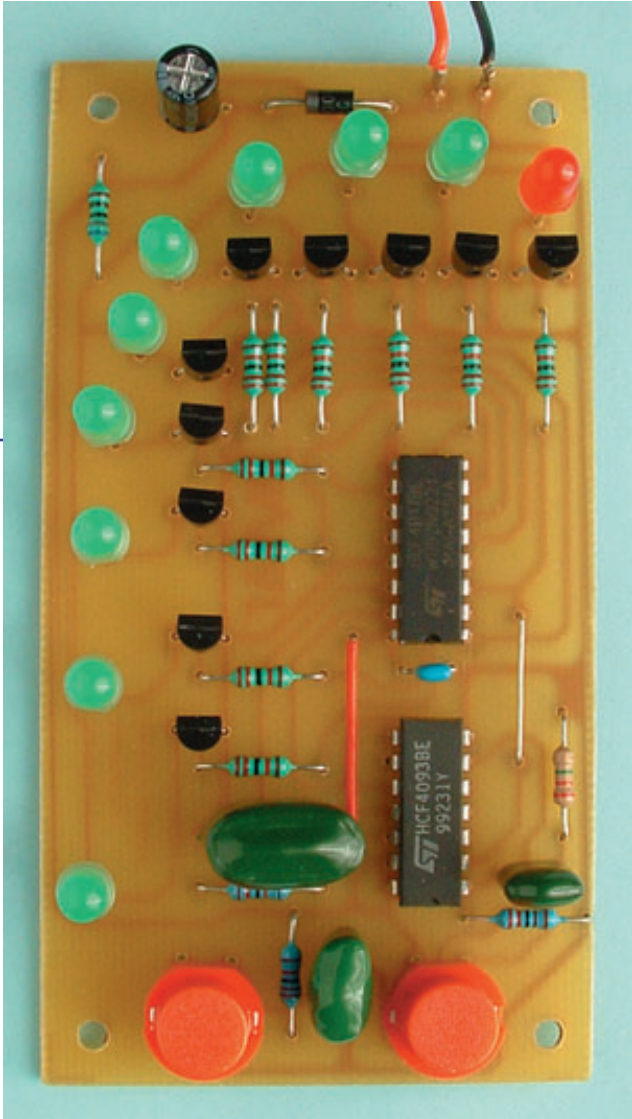
There are two wire links needed on the board. As you can see from the







Here's the wiring diagram for the Skeet Shoot game, at left, with a closeup photo of its PC board below for comparison. Use them both as a guide when you're building up your game.



positions. But you will need to crank their outer leads away from the centre lead to match their spacing to the board holes, and you should also make sure to fit each one the correct way around. In this case it shouldn't be hard, since they all fit with their flat side uppermost.

Next we suggest you fit the two ICs. The 14-pin 4093 device goes in the IC1 position just above FIRE button S2, while the 16-pin 4017 device goes in the IC2 position just above the 100nF monolithic cap. Both ICs fit with their notch/dimple end downwards (i.e., towards the front), but you might need to bend their rows of pins inwards and towards each other so they'll all pass easily through the board holes.

When you're handling the ICs, though, remember that they are both CMOS devices and therefore vulnerable to damage from electrostatic charge. So it's a good idea to remove any charge you've acquired by touching some earthed metalwork, before you handle the ICs. Make sure your soldering iron is earthed too, before you solder their pins into the board. Also try to solder their main supply pins (pins 7 and 14 for the 4093, pins 8 and 16 for the 4017) before you solder the others, so their internal protection can begin working.

The last components to fit into the board are the LEDs. There are 10 of these in all, nine of them green (LEDs 1-9) and the last one red (LED10). They are all of the larger 5mm size, and they all mount vertically with their cathode lead downwards — i.e, with their flat side towards the front. Mount all the LEDs with the bottom of their bodies about 8mm above the board as shown in the photos.

All that remains now is to connect the two wires of the battery cliplead to the terminal pins at the top right of the board, and your Skeet Shoot game should be finished and ready to try out. Before you do, though, give everything a

final check in case you've made a mistake. Make sure you've placed each component in the right position and the right way around in the case of the polarised parts (including S1 and S2). Check under the board too, just in case you've forgotten to solder any component leads — or made a dry joint, or perhaps left a solder bridge short circuiting between two pads.

## Tech Talk: How does it work?

Although the circuit for the Skeet Shoot game might look a bit daunting, it's really quite easy to understand.

Because of the 220k feedback resistor and the 470nF capacitor connecting from its input pin 12 to the negative line (ground), gate IC1d works as an astable oscillator running at about 10Hz. This means that it feeds one pulse every 1/10th of a second into one of the clock pulse inputs (pin 14) of IC2, a 4017 decade counter. The other clock pulse input (pin 13) of IC2 is not used, but tied to the negative line instead.

So when the battery is first connected to the circuit, IC1d starts feeding pulses into IC2, which begins counting them. As it does, its outputs go 'high' in turn: first O1 (pin 2), then O2 (pin 4) and so on.

Because each of the counter's outputs is connected to the base of a switching transistor via a 22k series resistor, this means that when each output goes high it turns on that transistor. And when each transistor is turned on, it draws current through the LED connected between its collector and the +9V line, via the 680 ohm resistor. So as IC2 counts the pulses from IC1d, the LEDs flash on in sequence — from LED1 up to LED10. This is how the 'skeet' flies up the LEDs, when the game is running.

After the counter's O10 output has gone high briefly, turning on LED10, the next pulse to arrive from IC1d causes the counter to start again from scratch. So the counting sequence and the LEDs flashing in turn repeats itself, with new 'skeets' moving up the LEDs at a rate of about once every second.

Of course so far we've been assuming that this counting can continue because you haven't tried pressing the FIRE pushbutton S2. So let's now see how this counting sequence can be controlled.

First of all, notice that gates IC1c and IC1b are connected as a simple **flipflop**, with each gate's output connected to one input of the other gate. As a result of this 'cross coupling', the flipflop is able to remain in either of two stable states: one with the output of IC1c high and that of IC1b low, and the other state with IC1b's output high and that of IC1c low. That's why this kind of circuit is called a flipflop or **bistable**.

The flipflop tends to stay in either of these states unless one of the two inputs that aren't cross coupled is pulled down to the negative line (ground) briefly. In fact if the flipflop is in the state where IC1b's output is high, it can only be 'triggered' into flipping into the other state by briefly pulling down pin 9 — the second input of IC1d. Conversely when it's in the state where the output of IC1c is high, it can only be triggered into switching back to the other state by briefly pulling down IC1b's input pin 6.

Now notice that IC1c's input pin 9 is connected up to the +9V line via a 22k resistor, and also connected down to the negative line via a 100nF capacitor. So when we first apply 9V to the circuit, when the game is turned on, pin 9 of IC1c starts off by being pulled down to the negative line by the capacitor, before it charges up via the 22k resistor. As a result the flipflop is always switched into the state where the output of IC1c is high and the output of IC1b low, when the battery is first connected.

Notice too that the output of IC1b (pin 4) is connected

to pin 15 of counter IC2, as well as to pin 8 of IC1c. This input of IC2 is the counter's *master reset* (MR) input, which makes the counter stop counting when it's taken to the logic high level (i.e., +9V). But when the flipflop turns on and switches into the state where the output of IC1c is high and that of IC1b is low, this of course pulls the MR input of IC2 low as well. As a result the counter can start counting straight away, and sending the 'skeets' up the string of LEDs.

But how does the circuit tell when you have pressed S2 at exactly the same time as a 'skeet' has reached LED10, and then stop the counter? Well, as you can see the output of gate IC1a is connected to the pin 6 input of the second flipflop gate IC1b. One input pin (2) of IC1a is also connected to pin 3 of IC2, which is the O10 output. So each time the counter reaches '10' and sends this output pin high to turn on Q10 and LED10, it also pulls pin 2 of IC1a high as well.

Now notice that FIRE pushbutton S2 is connected between the +9V line and a 47nF capacitor which connects to the second input (pin 1) of IC1a. Both ends of the capacitor are also connected down to the negative line, so that until S2 is pressed, both sides of the capacitor are pulled down to this low voltage level. This also means that pin 1 of IC1a is pulled low, and its output will remain high even when pin 2 is pulled high each time the counter reaches '10'.

When you press S2, this connects the junction of the 4nF capacitor and the 2.2M resistor to +9V. As a result the 47nF capacitor is able to charge up quickly, via the 2.2k resistor connecting to the +9V line. And as the capacitor charges, it draws a short 'blip' of current through the 2.2k resistor. This produces a short pulse of positive voltage drop across the resistor, pulling up pin 1 of IC1a at the same time.

So the effect of pressing S2 is to produce a very short 'high' pulse on pin 1 of IC1a. This pulse is very short, only lasting for about 100µs (microseconds) even if you keep the button pressed. In fact S2 can't cause another pulse to be produced until you first release it and then allow the 47nF capacitor to discharge again via both the 2.2M and 2.2k resistors, which takes about 1/10th of a second (100 milliseconds).

Of course the brief high (positive) pulse on pin 1 of IC1a won't have any effect **unless** pin 2 happens to be pulled high at exactly the same time. This will only happen if you've pressed S2 at exactly the same time as IC2's O10 output has gone high, to make LED10 glow. So this is how the circuit can tell if you've pressed S2 at the right time.

When you do press S2 at the same instant as IC2's O10 output has gone high, this of course makes both inputs of NAND gate IC1a high at the same time, so the output (pin 3) will go low. This in turn will pull down input pin 6 of IC1b, which makes the flipflop switch states. Pin 4 of IC1b will flip high, pulling pin 15 of IC2 high as well and immediately stopping the counter with LED10 glowing to register a 'hit'.

The circuit will stay in this state until you either disconnect the battery, or else press RESET button S1. As you can see, pressing S1 simply connects pin 9 of IC1c to the negative line, making the flipflop switch back into its original state with pin 10 high and pin 4 low. So this removes the high from IC2's reset pin, and allows it to start counting again.

## Trying it out

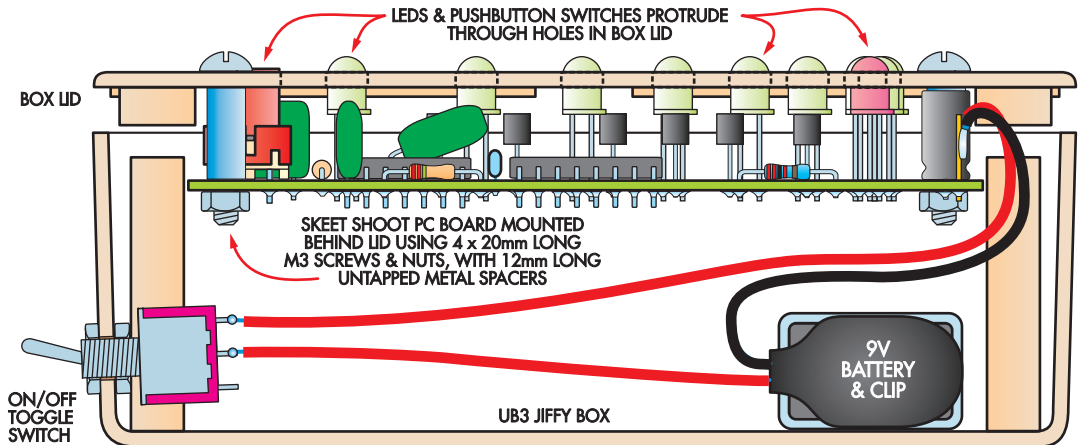
If everything seems to be in order, try connecting a 9V alkaline battery up to the cliplead. You should be immediately rewarded by seeing a small flash of light 'travel' up the string of LEDs, starting with LED1 at lower left and going through each LED in turn until it reaches the red

LED10 at top right. Then another 'light skeet' should follow it up the LEDs and so on, at about one per second.

Now it's time to see if you can press the FIRE button (S2, on the right), at the exact time that one of these light skeets reaches LED10. This may take quite a while to achieve, because they're travelling up the LEDs quite quickly. But



Here's how the Skeet Shoot game can be built inside a UB3 size jiffy box to make it neater and more robust. The large 470nF greencap may need to be mounted 'leaning over' as shown, so it will fit in the 12mm space between the board and the box lid.



when you do get the timing for your button press right, all movement will stop and LED10 will stay glowing steadily to confirm that you've had a 'hit'.

After congratulating yourself, you can then restart the game by pressing the RESET button (S1, on the left). One of your friends can then see if they can hit the 'skeet' this time, in fewer tries than you needed to do it. Or you can try again yourself, of course.

OK, what if *none* of your LEDs glows at all, when you first connect the battery to *your* Skeet Shoot game? You guessed it, that will be because you've made some kind of mistake in wiring it up. You might have reversed the connections of the battery cliplead wires to the terminal pins for example, or fitted diode D1 the wrong way around.

Another possibility is that you've accidentally connected all of the LEDs the wrong way around, or all of the transistors instead. Or you might have fitted one of the ICs the wrong way around.

If most of the LEDs do seem to be passing the 'skeet' up the chain, except for one or two, that will be almost certainly because you've fitted the dark LEDs the wrong way around. Either that, or you've reversed their driver transistor instead. An even more remote possibility is that if only one LED stays dark, you may have swapped that transistor's 22k base resistor with the 2.2M resistor, so the transistor can't be turned on when it should.

If all your LEDs seem to be glowing all the time, instead of in sequence once a second, this is likely to be because you've accidentally swapped the 220k resistor with one of the 22k resistors, or even with the 2.2k resistor. This would make the game run so fast that the LEDs seem to be glowing continuously. On the other hand if the game seems to be working, but the 'skeets' are moving up the LED string much more slowly than one per second, you've probably swapped the 220k resistor with the 2.2M resistor.

In short, whichever of these problems you may have, it's a matter of deducing what must have happened from the symptoms, tracking down the cause and fixing it. Then, when you connect the battery again, your Skeet Shoot game should spring into life just as we've described.

## What to do next

If your hand-eye coordination is so good that you find it's too easy to hit the skeets, their movement can be speeded up to make the job more difficult. The easiest way to do this is to replace the 470nF greencap with one of smaller value, like 390nF (Jaycar RG-5159) or even 330nF (RG-5153).

The only other improvement you might want to make is to build the game into a plastic utility box, to protect it from damage and also make it much neater looking.

The board assembly has been designed to fit in a standard UB3 size jiffy box, such as the Jaycar HB-6013 (black) or HB-6023 (grey). The complete board assembly can be mounted up behind the lid of the box, using four 20mm long M3 machine screws and nuts, and with four 12mm long untapped metal spacers (HP-0864) to space them apart. The lid has ten 5.5mm holes drilled in it to allow the LEDs to protrude through and be seen, and also two 9mm holes for the pushbutton actuators to be pressed. The diagram above shows how it all goes together.

There may be a small complication with fitting this project into a box, though, if the higher-value greencaps in your kit are more than 12mm high. This means if they're mounted in the normal 'upright' position they won't fit in the 12mm gap between the board and the box lid. This may well be the case with the 470nF greencap for example, as these are often about 18mm high like the one visible in the photos. The 100nF and 47nF greencaps might also measure a whisker over 12mm high.

You should be able to fix the problem with the 100nF and 47nF greencaps by simply mounting them 'leaning over' sideways a little, so their effective height becomes less than 12mm. But with the 470nF greencap you may have to fit it leaning right over at 90°, either above two of the 22k resistors or else under the board on the copper side.

As usual the battery can be held in the bottom of the box using a strip of gaffer tape or similar. You'll also want to fit a small switch in the end of the box, to let you turn the game on and off without having to open it up. The switch to use is Jaycar's ST-0335 miniature toggle, wired in series with the positive (red) cliplead wire as shown.

# How a 555 Timer IC Works

Many of the projects described in this book make use of the 555, a low cost IC which is usually described simply as a 'timer'. In reality it's an extremely versatile device, which can be made to operate in a surprising number of different ways. Here we explain two of the most common ways it's used: as an astable or oscillator, and as a monostable or 'one-shot'.

## Astable operation

A 555 can be made to oscillate over a very wide frequency range, delivering a continuous stream of pulses varying from seconds or even minutes per cycle right up to about 100kHz (100,000 pulses per second) or more. This, together with its wide operating voltage range and low cost, has made it a very popular device.

Looking at the diagrams below you can see several similarities between the basic astable circuit (on the left) and the way the 555 is used as an oscillator in a number of the projects in this book.

When power is first applied, capacitor C1 starts to charge towards the supply voltage Vcc via resistors R1 and R2. At this stage the voltage on the 555's output pin 3 is 'high' (very close to Vcc).

C1 continues to charge until its voltage reaches two thirds of the supply voltage Vcc. Pin 6 (the threshold input) senses when the capacitor voltage reaches this level, and tells the 555 to switch the output low (i.e., around 0V). At the same time, pin 7 also goes low and this causes the capacitor to begin discharging again via R2 and the IC itself.

Pin 2 (the trigger input) detects when the capacitor voltage drops to one third of the supply voltage, at which point it triggers the 555 into action again. Output pin 3 switches high again, as does discharge pin 7 — allowing C1 to start charging once again.

This process repeats itself for as long as power is applied, or something else is done to stop it. The ratio of the two resistors R1 and R2, and the values of R1, R2 and C1 normally determine both the frequency of oscillation and the **duty cycle** — the ratio between the time in each cycle that the output pin 3 is high, and the time that it's low. The expressions are:

$$\text{Output high time (t1)} = 0.693 \times (R1 + R2) \times C1$$

$$\text{Output low time (t2)} = 0.693 \times R2 \times C1$$

$$\text{Oscillation frequency} = 1.44 / ((R1 + 2 \times R2) \times C1)$$

where R is in ohms, C is in farads and times t1 and t2 are in seconds.

You may have noticed that in one or two of the projects in this book, we use slightly different versions of this astable oscillator circuit — which shows how flexible the 555 really is. For example in the LED flasher (Project 1), we leave out resistor R2 and also ignore pin 7 of the IC, connecting the top of R1 (in this case 100k) around to output pin 3 instead of to the supply line. This variation works in much the same way, though, except that the charging and discharging times t1 and t2 are now virtually

identical — because they both involve only R1 and C1.

Another variation of the astable circuit is used in the oscillator stage of the Mini Strobe (Project 4), around IC1. Here the top of R1 (in this case a 33k resistor and a 500k pot in series) is still taken to the positive supply line, but resistor R2 is left out and pins 7, 6 and 2 are simply connected together. This variation still works in much the same way, except that the charging time t1 is slightly shorter (because it only involves R1 and C1), and the discharging time t2 is **much** shorter — because it involves only C1 and the IC's internal resistance at pin 7.

So this variation of the 555 astable circuit is good for generating a stream of narrow negative-going pulses.

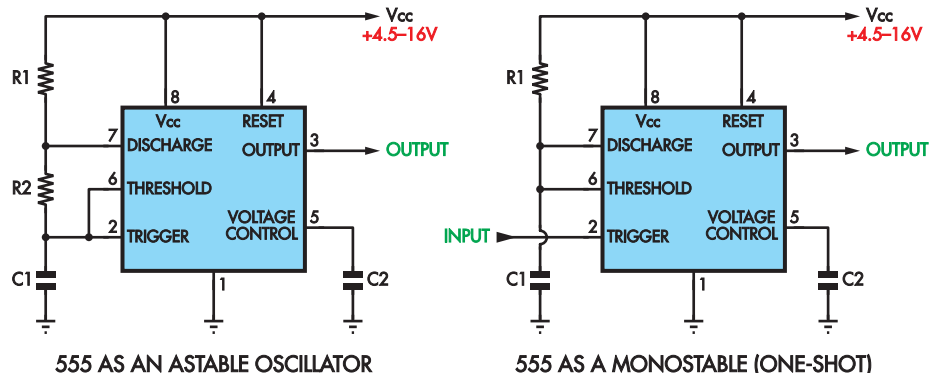
## Monostable operation

A monostable or one-shot doesn't produce pulses continuously, but only produces a single pulse each time it's triggered into doing so. One of the main uses for this type of circuit is to stretch pulses. The 555 is very good at this, enabling very short duration pulses to be lengthened so that slower circuitry can handle them.

The basic monostable circuit shown delivers a single pulse at output pin 3 each time a trigger pulse is applied to the pin 2 input. At the same time, the design of the 555 allows it to be used to **invert** the pulse if the circuit calls for this — that is, a negative-going pulse can be used to produce a positive-going pulse. It can also be used to produce an output pulse which is effectively **delayed** by a certain period of time after the input trigger pulse.

Again, the IC uses the one-third and two-thirds supply voltage levels as its trigger points. The external components are chosen to give the required output pulse length or delay time, as the external capacitor (C1) charges and discharges through these levels. Output pulse widths or time delays ranging from microseconds to seconds are possible.

As you can see, the second 555 used in project 4 (IC2) is used as a monostable, to produce a positive-going output pulse 1ms long each time it's triggered by one of the very narrow negative-going pulses from IC1. ★



Here are the two most common ways of using the 555 'timer' IC, in their basic forms. Variations of these are used in some of the projects described in this book.

## Project 12:

# FM Radio Microphone

Want to be able to hear when the baby wakes up and starts to cry — without having to run an intercom cable between rooms? Here's a low power radio microphone that's ideal for this kind of job. It's easy to build and get going, and puts out a signal that can be received on virtually any standard FM radio.

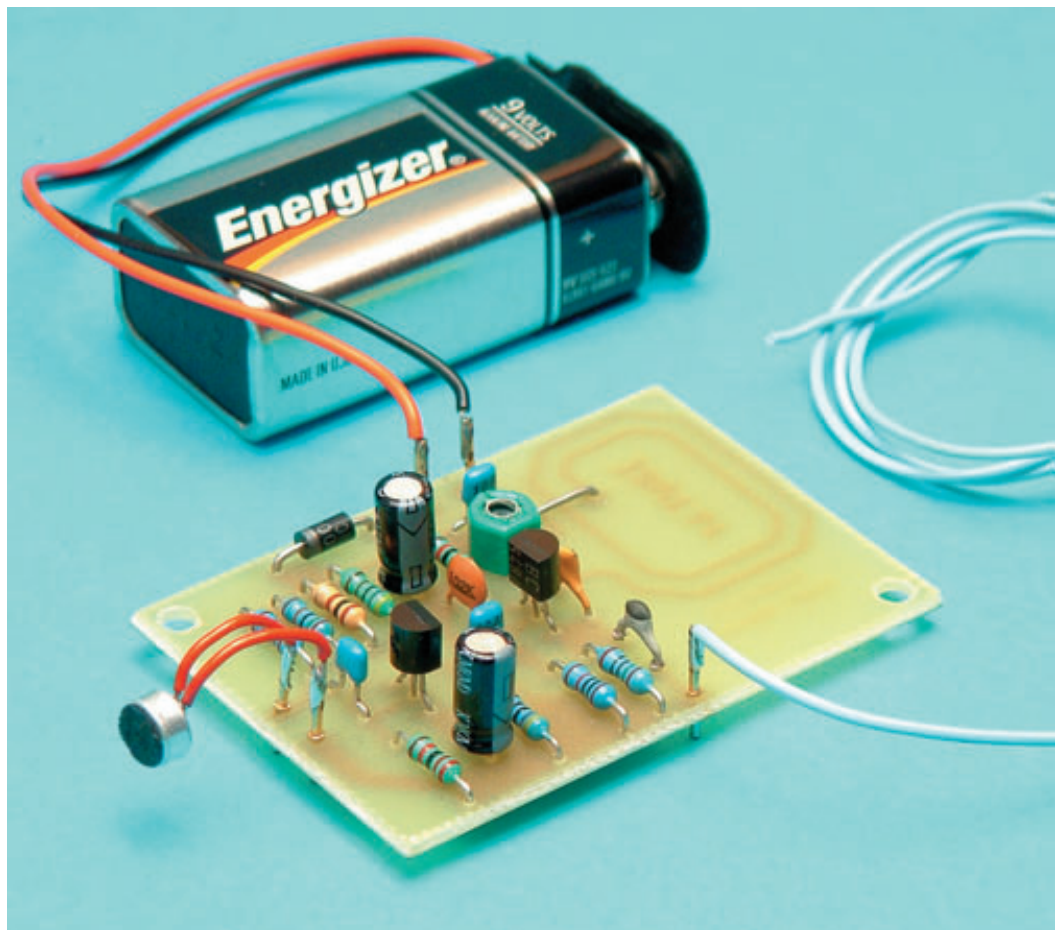
### What does it do?

An FM radio mic is basically a very simple low power FM transmitter — like a 'bonsai' version of an FM radio station. It has an oscillator which produces a VHF (very high frequency) radio signal, with a frequency in the 88 - 108MHz band used for FM broadcasting.

There's also a microphone to pick up the sound you want to transmit, of course, and a small audio amplifier to boost the microphone's output. The output of the amplifier is then used to vary or **modulate** the frequency of the oscillator, so it produces an FM (frequency modulated) signal which can be received on a normal FM radio.

In this FM radio mic the output power from the oscillator is kept very low, so that it doesn't cause interference with your neighbours' reception of the normal FM stations. However by feeding the oscillator's output into a short length of wire used as a transmitting antenna, the signal can be received by any FM radio within about 10 metres of the radio mike itself.

This makes the radio mic very suitable for use as a baby minder. All you have to do is put it in the nursery near the baby's bassinet or cot, and then tune in its signal



### The parts you'll need for this project:

- 1 PC board, code SHRTC212, 59 x 41mm
- 1 Mini electret mic insert
- 1 9V battery, 216 type
- 1 Battery clip lead to suit
- 5 PCB terminal pins, 1mm dia.
- 1 750mm length of insulated hookup wire
- 1 50mm length of 2-core lead
- 1 Small pack of resin-cored solder

#### Semiconductors

- 1 PN100 NPN transistor (Q1)
- 1 BC548 NPN transistor (Q2)
- 1 1N4004 diode (D1)

#### Capacitors

- 2 10 $\mu$ F 16V RB electrolytic
- 3 100nF multilayer monolithic
- 1 1nF disc ceramic
- 1 6.8pF NPO ceramic
- 1 3.9pF NPO ceramic
- 1 6.2-30pF trimcap (VC1, green)

#### Resistors (0.25W 1%)

- |                |                |
|----------------|----------------|
| 1 150k         | 1 33k          |
| 1 22k          | 1 10k          |
| 1 4.7k         | 1 470 $\Omega$ |
| 1 150 $\Omega$ | 1 100 $\Omega$ |
|                | 1 430k         |

with an FM radio wherever you are in another room. This allows you to listen for any crying, without having to keep walking into the nursery — and also without having to go to a lot of trouble running a cable between the rooms.

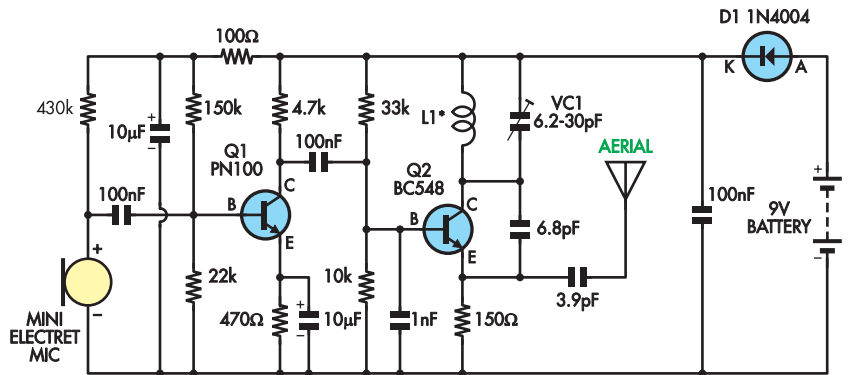
Radio microphones have many other uses too, of course. For example secret service 'spooks' use them for listening to people they suspect may be planning terrorism, and private investigators use them for eavesdropping on people suspected of cheating on their partners, or stealing from their employers, etc.

### Putting it together

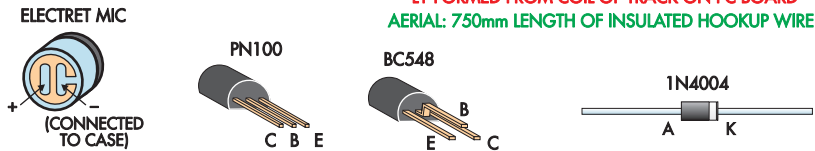
Except for the 9V battery that provides its power, and the wire used for its antenna, all of the parts used in the FM Radio Mic are mounted directly on a small PC board. The board is coded



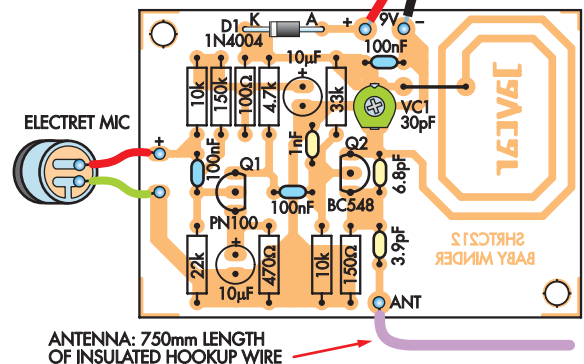
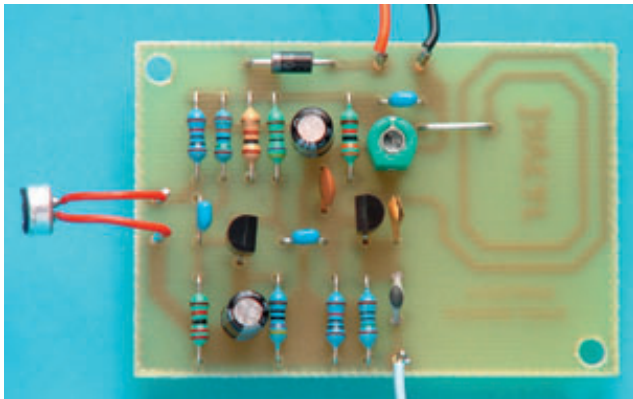
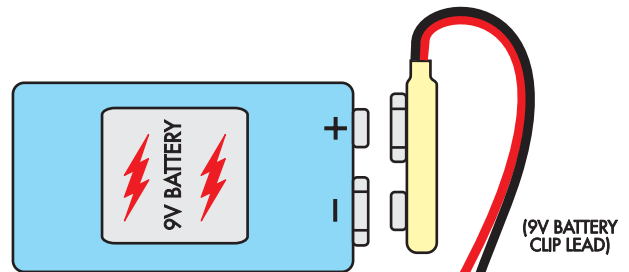
Here's the circuit diagram (right) for the FM Radio Mic. It uses only two transistors – one to amplify the audio signals from the electret mic (Q1), and the other to oscillate at a frequency in the VHF FM band (Q2).



\*L1 FORMED FROM COIL OF TRACK ON PC BOARD  
AERIAL: 750mm LENGTH OF INSULATED HOOKUP WIRE



To help you in assembling your own FM Radio Mic, here's the wiring diagram (right) and a closeup photo of the finished board assembly showing it very close to actual size. Use them both as a guide and you shouldn't go wrong, because there isn't even a coil to wind!



SHR2C12 and although its tracks provide the oscillator's resonating coil as well as making the circuit connections, it still measures only 59 x 41mm.

Before starting to assemble the project, it's a good idea to open up the kit and lay out the parts so you can check that you have everything. At the same time you should inspect the PC board to make sure all of the holes have been drilled, there are no hairline cracks in any of the tracks and no accidental 'bridges' left between pads.

If everything is present and correct, the first assembly step is fitting the wire link. This goes up near the top of the board and just to the right of its centre, as you can see from the wiring diagram. It can be made from a 15mm length of either tinned copper wire or an offcut from a resistor lead, because there's no need for it to be insulated.

Next you can fit the five PCB terminal pins. Two of these go at top centre of the board, for the battery cliplead connections, while another pair go at the left-hand end of the board for the microphone insert connections. The remaining pin goes at bottom centre of the board, for the

antenna wire connection.

With the link and pins fitted, the next components to fit are the fixed resistors. There are nine of these in this project, and they all mount in the usual horizontal manner. Only two of them have the same value though, (10k), so if you identify these and fit them into the board first this will help avoid mistakes. In any case use the wiring diagram to make sure you fit each of the resistors in their correct places. If you also fit all of the resistors so their colour code bands read in the same direction (like 'south' to 'north'), this will also make it easier if you ever need to troubleshoot the project down the track.

Next fit the unpolarised capacitors. There are six of these and they're all quite small, so be very careful when you're identifying them — and also when you're dressing their leads so they're spaced to fit into the board holes. Notice that the three 100nF capacitors are all of the multilayer monolithic ceramic type, which have a shiny body and are usually blue in colour. The other three low value capacitors are of the equally small ceramic disc type, with a matt-finish body and

## Tech Talk: How does it work?

The heart of the FM Radio Mic is transistor Q2, which is connected as a VHF oscillator. It oscillates because of the 6.8pF capacitor providing feedback between the transistor's collector and emitter, and its frequency of oscillation is set by the tuned circuit formed by trimcap VC1 and inductor L1.

In this case inductor L1 isn't the usual coil of wire, but a small spiral of copper track on the PC board itself. We've done this so that you don't have the hassle of winding a coil — just fit the short wire link which connects one end of the 'printed' coil. We've also made L1 just the right size so that the oscillator's frequency can be set to anywhere in the 88-108MHz FM broadcasting band, simply by adjusting VC1.

As you can see we pick off a small amount of the oscillator's RF energy from the emitter of Q2, and feed it to the antenna wire via a 3.9pF coupling capacitor.

The weak audio signals from the electret microphone insert are first fed to the base of transistor Q1, which is connected as a common emitter audio amplifier. The stronger audio signals which appear at the collector of Q1 are then fed to the base of the oscillator transistor Q2, via the 100nF coupling capacitor.

Although the base of Q2 is bypassed to the negative line via the 1nF capacitor, and therefore has no RF signal on it, the bypass capacitor has quite a high impedance for audio frequencies. So the audio signals from Q1 are able to vary the base bias on Q2, and this varies the transistor's internal capacitance. As a result its oscillating frequency is varied a small amount as well, producing the frequency modulation we want.

usually either grey or light beige in colour.

Now you can fit the small trimcap VC1, which goes just above the centre of the board. Make sure you fit it with its flat side facing downwards, towards the 6.8pF fixed capacitor.

Next fit the two small 10µF electrolytic caps, which both fit with their negative 'stripe side' leads towards the bottom of the board. Although the board doesn't provide any extra holes for these electros, this shouldn't be a problem because just about all 10µF electros of the PC board mounting type come with their leads already spaced 2.5mm apart — and that's just the hole spacing we've provided for them on the board.

The next component to fit is D1, the 1N4004 diode. This

mounts up at the top of the board, just to the left of the terminal pins for the battery cliplead. Make sure you follow the wiring diagram and fit it with its cathode band end towards the left.

Next fit the two transistors Q1 and Q2. Make sure you fit the PN100 transistor in the Q1 position, and the BC548 in the Q2 position. Notice that the two are fitted so their flat sides are facing each other.

The final component to fit is the mini electret mic insert, which as you can see connects to the terminal pins on the left-hand end of the board. But don't try to solder its rear connection pads directly to the terminal pins, because this would require too much heating and risk damaging the mic's internal circuitry. We recommend that you prepare two short lengths of insulated hookup wire, say about 30mm long.

Bare about 4mm at each end, and carefully tin them with your soldering iron. Then carefully solder one end of each wire to the pads on the rear of the mic, doing this as quickly as you can to avoid trouble. Then you can hold the mic insert while you solder the other end of each wire to the PCB terminal pins. Just make sure that you solder the wire that connects to the mic's 'connected to the case' pad to the terminal pin marked '-', because the mic insert is polarised. It won't work the other way around.

Your FM Radio Mic should now be just about complete. All that remains is to solder one end of the antenna wire to the 'ANT' pin at the bottom of the board, and also solder the battery cliplead wires to the 9V pins at the top of the board. Make sure you get the polarity of the cliplead wires right, though: the red wire goes to the '+' pin on the left, nearer diode D1.

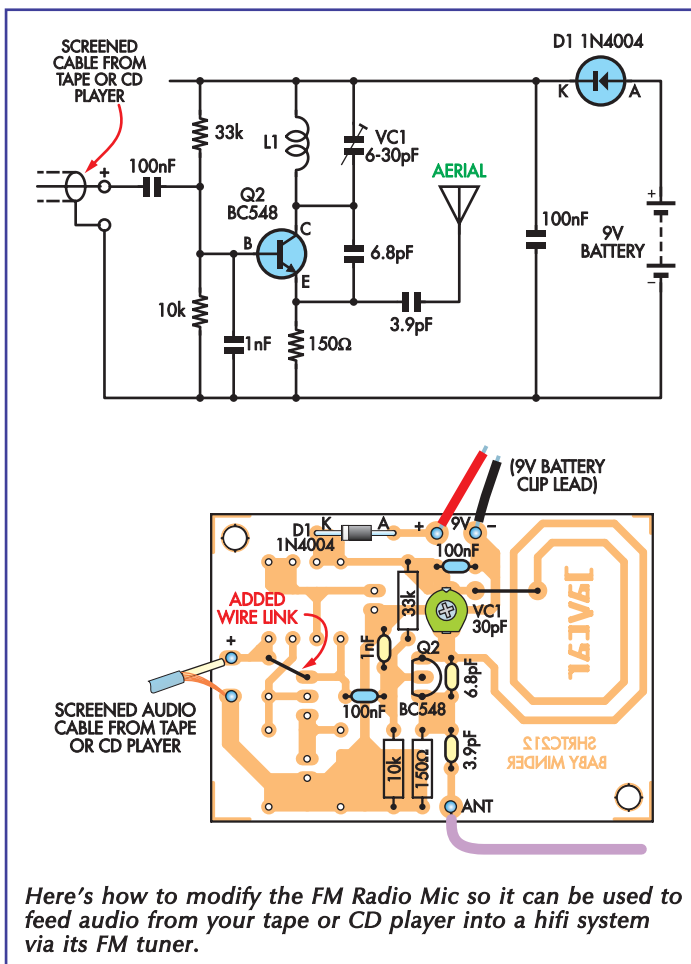
There's just one last job to do before you can try out the FM Radio Mic, and you can probably guess what it is. That's right: check the board carefully to make sure you're fitted all of the components in their right position, and the right way around in the case of the polarised parts. It's also a good idea to give the underside of the board a quick inspection too, in case you've forgotten to make one of the solder joints — or left a dry joint or solder bridge shorting between pads.

### Trying it out

If everything checks OK, it's time to grab a 9V battery and a small jeweller's screwdriver or mini alignment tool for adjusting trimcap VC1. Then take these and the FM Radio Mic to a spot within a couple of metres of an FM radio — or bring the radio near your workbench, if that's easier.

Now turn on the FM radio, and tune it carefully until you find a spot on the dial where there are no FM stations which can be received in your area.

Next connect the 9V battery to the Radio Mic's cliplead, and then very slowly turn trimcap VC1 with the mini screwdriver or alignment tool. VC1 is the Radio Mic's tuning control, so before long you should match the Mic's



Here's how to modify the FM Radio Mic so it can be used to feed audio from your tape or CD player into a hifi system via its FM tuner.

output signal frequency to the radio's tuning frequency. You'll probably hear a feedback 'howl' as this occurs, because the Radio Mic will be picking up the sound of its own signal from the radio's speaker.

To make sure you get the Radio Mic's tuning exactly 'spot on', you may have to turn down the radio's volume control — and/or move the radio further away. The best idea is to get someone else to listen to the radio in another room, and let you know when you set VC1 to give the loudest and clearest 'transmission' of your voice.

But what if you can't detect any signal on the FM radio, with any setting of the Radio Mic's trimcap? You guessed it again, that will probably be because your Radio Mic isn't working. And if it isn't working, that'll be almost certainly because you've made some kind of mistake in wiring it up. So disconnect the battery and start looking for the problem.

Perhaps you've connected the battery cliplead wires the wrong way around to the terminal pins, or else fitted diode D1 to the board around the wrong way. Or you may have swapped the PN100 and BC548 transistors, or connected one of the other polarised parts the wrong way around — one of the 10 $\mu$ F electros perhaps.

If you seem to be able to receive a 'silent signal' on the radio with one setting of VC1, but there's no sign of any sound picked up by the electret mic, this will probably be because you've accidentally reversed the connections to the mic insert.

Once you do track down your mistake and fix it, your FM Radio Mic should be complete and ready for use.

## What to do next

With a few small modifications, you can adapt the FM Radio Mic so it can be used as a radio sound link — to feed audio signals from your personal tape or CD player into a hifi stereo system, via the FM radio tuner. In fact it's easy to modify it for this type of use, because the modification mainly involves removing all of the components used for the electret mic and the audio amplifier stage around Q1. Or not fitting them in the first place, if you prefer.

The components you don't need for this are the electret mic insert, the 150k, 22k, 4.7k, 470 $\Omega$  and 100 $\Omega$  resistors and also the 10k resistor at upper left on the board. In fact you can also leave out transistor Q1, both of the 10 $\mu$ F electros and the 100nF monolithic cap that normally fits to the left of Q1.

With these components removed all you need do is fit a wire link to the board as shown in the small diagram on the page opposite. Then a screened audio input cable can be connected to the pins usually used to connect the electret mic. This cable can be connected to the headphone or 'line' output of your tape or CD player, to bring in the signals to be transmitted.

It's quite easy, as you can see.

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## Meet the Pioneers of Electronics:

# Michael Faraday

Born in London in 1791, Michael Faraday grew up in a very poor family and began work as an apprentice bookbinder. But he was fascinated by science, and went to lectures at the Royal Institution by the great Humphry Davy. Davy offered him a job as his assistant, and soon Faraday was experimenting with magnets, batteries and coils of wire.

Faraday was the first to discover the principles of **electromagnetic induction** – how a changing magnetic field through a coil of wire can induce a voltage into it. In other words, he discovered that magnetism could produce electricity just as electricity could produce magnetism. This discovery set the stage for the invention of both electrical generators and transformers. In fact he built the first crude electric motor and dynamo (generator), and also produced the first simple instrument to indicate electric charge: the **electroscope**.

Faraday was also the first to properly analyse electrolysis – what happens when an electric current passes through a conducting liquid. This provided the understanding needed for many future industries, like electroplating and electrolytic metal refining.



# Georg Simon Ohm

Born in Erlangen, Germany in 1787, Georg Ohm was the son of a mechanical engineer who taught him a wide range of mechanical skills. But the family was quite poor, and he didn't have the opportunity to go to university for a full scientific education. Instead he found a job teaching in a local school, and experimented with electricity as a hobby. Using the skills learned from his father, he made most of his equipment himself – including batteries he made when he learned of the work of Volta, and a sensitive galvanometer he could use to measure very small currents.

When he learned that the 'flow' of heat energy from one point to another depended directly on the temperature difference between them and inversely on how unwilling the material between them was to conduct heat, Ohm guessed that similar factors probably controlled the flow of electric currents. He then carried out many experiments which showed in 1827 that this was indeed true: the flow of current through a conductor is directly proportional to the voltage difference across it, and inversely proportional to the resistance of the conductor itself. This turned out to be a fundamental law of electricity, named **Ohm's Law** in his honour.



## Project 13:

# Metronome With Beat LED

Here's a neat little electronic metronome that produces an adjustable 'tick' sound to help you play your music at just the right speed. It also flashes a LED once per bar, to help you get the music's rhythm right as well.

### What does it do?

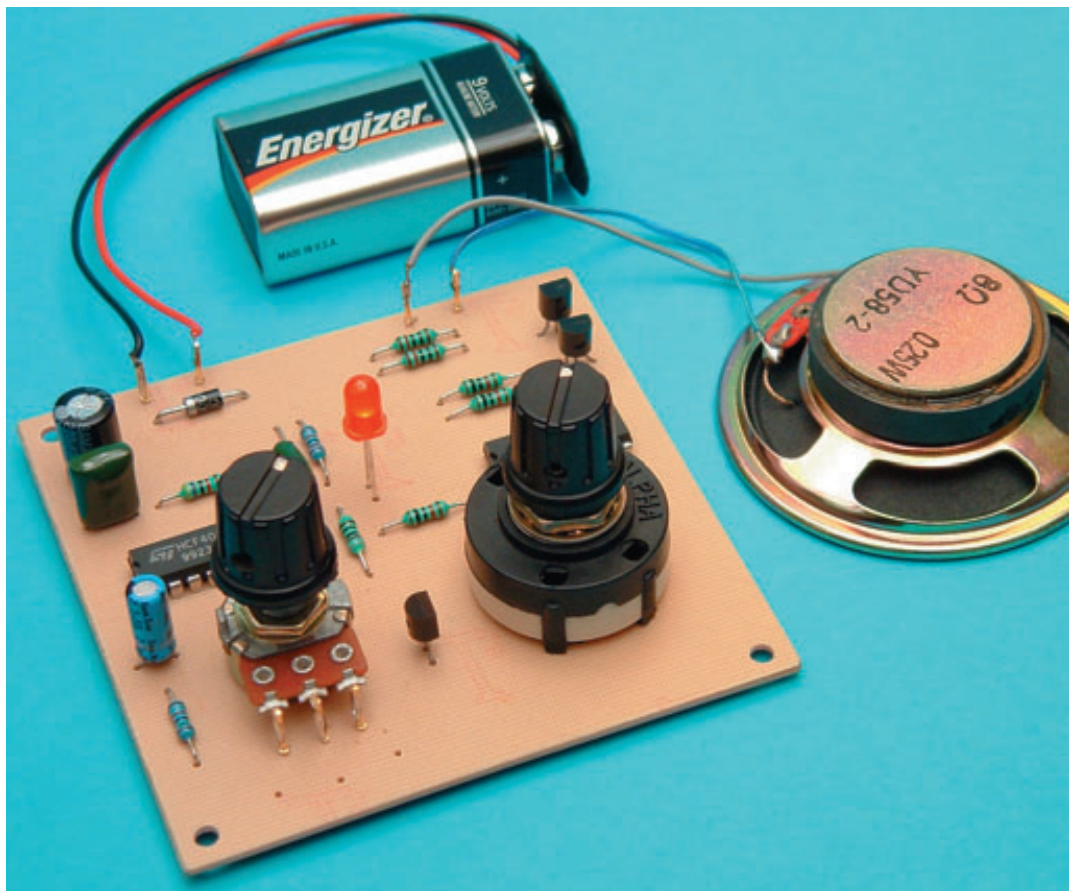
When you're learning to play a musical instrument, playing the right notes in the right order is only part of the story. Many people actually find it harder to get the **timing** right, especially when it comes to accenting the right beats to get the correct rhythms. That's why, many years ago, some smart music teacher came up with the traditional 'metronome'.

You've probably seen one: a small pyramid shaped wind-up gizmo with a weight near the top of a small lever, which waves from side to side at an adjustable rate and makes a ticking sound at the same time. The ticking is just loud enough to give you a guide for timing your music.

Nowadays these old clockwork metronomes are very expensive, so it makes much more sense to use a cheaper electronic version. If you want to save even more money you can even build one yourself, from the design described here.

Like one of the old metronomes it produces a not-too-loud ticking or beeping sound, which you can easily adjust to give any music timing rate between about 30 and 200 beats per minute. In addition it has a LED which can be set to flash briefly every two, three or four beats, to guide you in timing the bar rhythms.

In short, it does everything that a traditional metronome can do — and more. It's also much lower in cost, and very easy to build.



### Putting it together

Apart from the 9V battery and the mini speaker and the mini speaker used to produce the ticking sound, all of the other components used in the Metronome fit on a PC board coded SHRTC213 and measuring 82mm square.

## The parts you'll need for this project:

- 1 PC board, code SHRTC213, 82 x 82mm
- 1 57mm mini speaker
- 1 1 pole (or 2 pole) 3-position rotary switch, PCB mount
- 1 1M linear pot, 24mm or 16mm (VR1)
- 2 Knobs to suit switch and pot
- 1 9V battery, 216 type
- 1 Battery clip lead to suit
- 7 PCB terminal pins, 1mm dia.

- 1 Small pack of resin-cored solder
- 1 Short length of speaker cable

### Semiconductors

- 1 4093B quad Schmitt NAND gate (IC1)
- 1 4017B Johnson counter (IC2)
- 3 PN100 NPN transistors Q1–Q3)
- 1 5mm red LED (LED1)
- 1 1N4148/1N914 diode (D1)
- 1 1N4004 diode (D2)

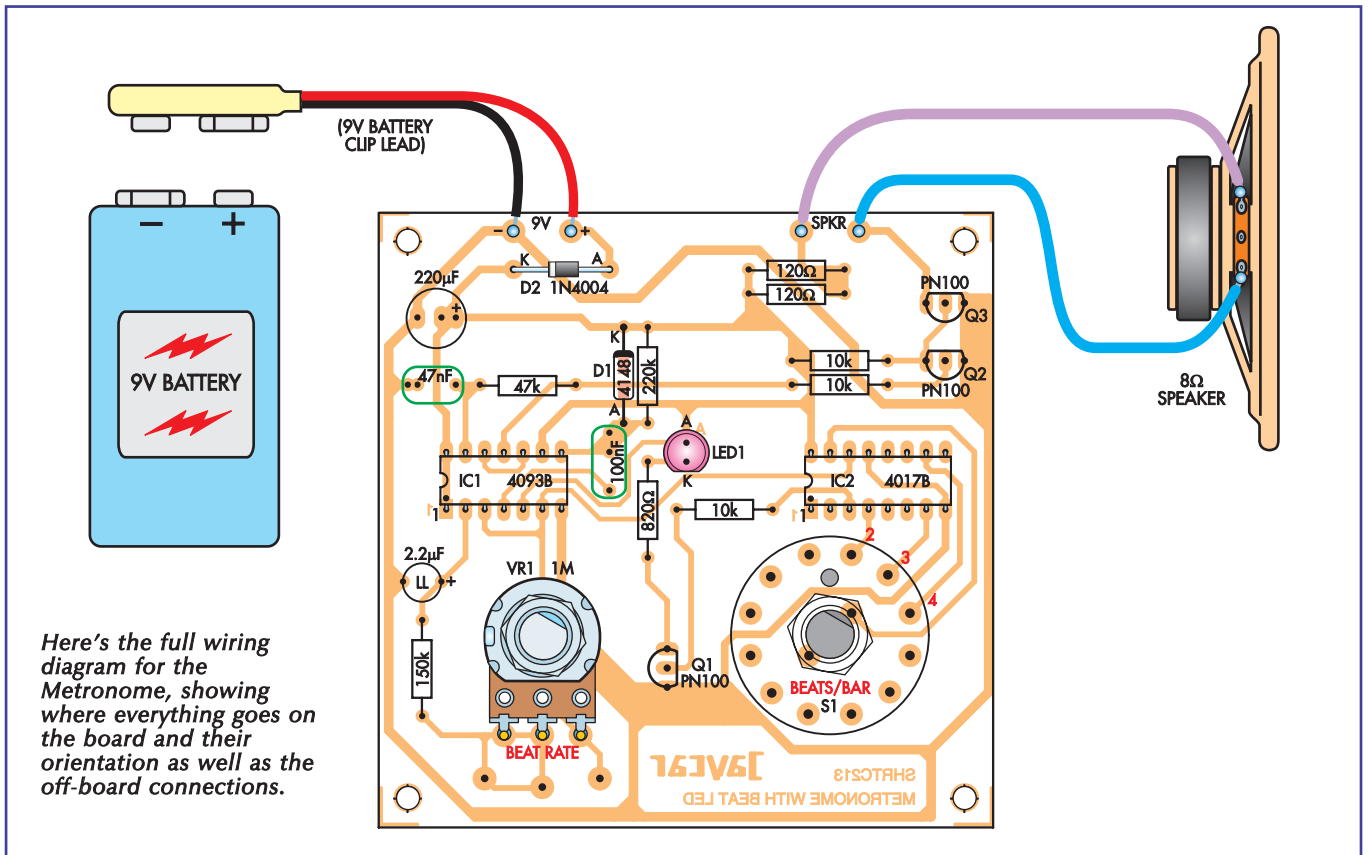
### Capacitors

- 1 220 $\mu$ F 16V RB electrolytic
- 1 2.2 $\mu$ F 50V RBLL electrolytic
- 1 100nF greencap
- 1 47nF greencap

### Resistors (0.25W 1%)

- |                |                |
|----------------|----------------|
| 1 220k         | 1 150k         |
| 1 47k          | 3 10k          |
| 1 820 $\Omega$ | 2 120 $\Omega$ |





fit horizontally — i.e., 'lying down'. Use the wiring diagram as a guide when you're placing them, of course.

Notice that there are two 120Ω resistors, which go at the rear of the board just in front of the speaker terminal pins. There are also three 10k resistors, two of which go at upper right and the third one just in front of the centre of the board. The resistors are not polarised, of course, but it's still a good idea to fit them so their colour codes all read in the same direction: either 'west to east' or 'south to north' as the case may be. This makes it easier if you ever have to troubleshoot the circuit some time in the future.

Next you can fit the greencap capacitors. There are only two of these, one with a value of 100nF which goes just to the left of the board's centre and the other of 47nF which goes at upper left.

The polarised electros are next. There are only two of these and they both go on the left-hand side of the board with their negative leads towards the left. The 2.2µF low leakage (RBLL) electro goes toward the front and the 100µF electro at the rear. You'll find that the board has an extra hole for the positive lead of the 100µF electro, to suit different lead spacings. Be careful that you place the electro's negative lead in the leftmost of the three holes, though.

Now you can fit the diodes. There's a 1N4148 glass-body diode (D1) which fits just behind the 100nF greencap with its cathode bar end towards the rear, and a 1N4004 power diode (D2) which fits at the rear of the board with its cathode bar end towards the left.

Next fit the three transistors. These are all PN100 devices, so you don't have to worry about mixing them up. One of them (Q1) goes in the centre of the board near the front, while the other two (Q2 and Q3) go on the right hand side of the board near the back. As usual you'll need to crank the outer leads of each transistor away from its centre lead, so they'll all pass through the holes without strain. Make sure you fit all three transistors the correct way around, using the wiring diagram as a guide.

Next fit the two ICs. These both go with their notch/

dimple end towards the left, as you can see from the wiring diagram. The 14-pin 4093B goes on the left of the board as IC1, while the 16-pin 4017B goes on the right as IC2.

You may have to bend each row of pins on each IC inwards towards the other row slightly, so they all go through the board holes easily. Just take care when you're doing this, as both devices are of the CMOS type and can be easily damaged by electrostatic charge. It's a good idea to touch some earthed metalwork to discharge yourself before handling the ICs, and also to use an earthed soldering iron when you solder their pins to the board pads. Soldering their supply pins (pins 4 and 14 for the 4093, pins 8 and 16 for the 4017) first is a good idea too, as this allows their internal protection circuits to begin working.

Now you should be ready to fit the rotary switch S1. This fits directly to the board, with its rear connection pins passing through the matching holes and soldered to the pads underneath. But before you do try fitting it to the board, you should shorten its spindle to a length of 10mm from the end of the threaded bush. Cut off the excess with a hacksaw or jeweller's saw, and then smooth off the burrs with a small file. This will make sure you'll be able to fit a control knob more easily later.

You may need to straighten some of the switch contact pins slightly before they'll all pass through the board holes without strain. Also make sure you fit the switch the correct way around, with its front locating spigot towards the rear of the board as shown in the wiring diagram.

Once the switch is fitted, it's a good idea to unscrew and remove its top nut and lockwasher. This allows you to check that the programming stop-pin washer underneath is positioned correctly to give the switch only three working positions.

The washer's stop pin should be passing down into the slot between the '3' and '4' figures moulded into the plastic. If this isn't so in your switch, prize up the washer with a small screwdriver and then turn the switch's control spindle anti-clockwise as far as it will go (without undue force). Then refit the stop washer so that now the pin does go in the



## Tech Talk: How does it work?

The AC timing signals that make most of the Metronome circuit work are all generated by gate IC1a, which is part of a 4093B quad NAND gate. In this circuit IC1a has the 150k resistor and pot VR1 connected between its output and one input (pin 2), and also the 2.2 $\mu$ F capacitor connected between the same input and ground (the negative line). These components provide the gate with positive feedback, and turn it into an **astable** or free-running oscillator. So its output pin (3) provides a continuous low frequency square wave AC signal, whose frequency can be varied between about 0.5Hz and 3.3Hz by adjusting pot VR1.

We use this low frequency AC signal in two ways: one to produce the clicks from the speaker, and the other to make the LED flash less often. We'll look first at how the signal is used to produce the clicks.

As you can see the output of IC1a is connected to one input (pin 6) of gate IC1b, which is used as an inverting buffer. So our low frequency AC signal appears at the output (pin 4) of IC1b, simply reversed in polarity.

The output of IC1b then connects to one input (pin 8) of IC1c — not directly, but via the 100nF capacitor. Pin 8 is also connected to the positive supply line (+9V) via the 220k resistor, but as the gate input doesn't draw any current this means that there's normally no voltage drop in the resistor. It therefore tends to pull the gate input up to +9V, at least when the output of IC1b is also at the high level.

When the AC signal from IC1a pulls the input of IC1b high, though, the output of IC1b switches to the low level. This in turn pulls that end of the 100nF capacitor down to the negative supply line (i.e., ground), and because the capacitor is initially uncharged, it pulls the input of IC1c down as well. But not for long, because the capacitor soon charges up through the 220k resistor. As it charges the voltage on pin 8 rises again, and within about 25ms (milliseconds) the voltage is back up very close to +9V again.

So what we do with gate IC1b, the 100nF capacitor and 220k resistor is pull down the input of gate IC1c very briefly, each time the output of IC1a goes high. Of course since IC1a's output does this repeatedly, we get as a result a series of narrow (about 25ms wide) negative pulses at the pin 8 input of IC1c.

(Wondering what diode D1 does? Ah, that's interesting. Just as the capacitor and resistor produce a narrow negative pulse at the input of IC1c when the output of IC1b switches *low*, they also tend to produce a narrow positive pulse at the same input when IC1b's output switches *high* again. This is because the capacitor is now charged, and has to discharge. The diode is there to insure that the capacitor is discharged very quickly, and also to protect the input of IC1c by making sure it can't be taken much more positive than +9V.)

Right, now we have short negative pulses pulling pin 8 of IC1c briefly down to ground, once for every oscillation cycle of IC1a. As you can see IC1c is also connected as an inverting buffer, which means that its output pin 10 will switch high whenever pin 8 is pulled low. As a result we now get a series of positive pulses appearing at the output of IC1c.

If you look closely you'll see that the remaining gate of IC1 (IC1d) is connected as another oscillator, just like IC1a. Only this time the feedback resistor and input

capacitor have much smaller values — 47k and 47nF. As a result this oscillator tends to work at a much higher frequency, of about 2kHz. But it can only oscillate when the second input (pin 12) of IC1d is pulled high, to let the gate work as an inverter.

See what we're doing? Because the pin 12 input of IC1d is connected to the pin 10 output of IC1c, this means that the oscillator can only work when each narrow positive pulse appears at pin 10. As a result the oscillator doesn't generate a continuous 2kHz AC signal, but a series of short bursts instead.

It's these short bursts (about 25ms long) of 2kHz oscillation which become our 'clicks', as you've probably guessed. We feed them to the base of transistor Q2 via a 10k resistor, and then from the collector of Q2 to the base of Q3. This results in Q3 being switched firmly on and off at 2kHz, in short bursts which only last for 25ms.

As you can see the speaker is connected between the collector of Q3 and the +9V line, via the two 120 $\Omega$  resistors (which are there to limit the current). So whenever Q3 conducts, current flows through the speaker. The end result is that the speaker produces short bursts of 2kHz sound — our beeps or clicks.

But how do we make the LED flash? That's where IC2 and Q1 come into the picture. IC2 is a 4017 decade counter, and as you can see we connect the output of IC1a not only to IC1b, but also to the CP0 input (pin 14) of IC2. As a result IC2 counts the low frequency AC cycles from oscillator IC1a, and as it counts them its outputs at pins 3, 2, 4, 7, 10 and so on go to the 'high' voltage level in turn.

IC2 would normally count right up to 10 of course, with its last output O9 going high before the count returns to 1 (O0 high), before starting over again. However in this circuit we force it to count by a smaller number, by using switch S1 to feed the signal from one of the higher outputs back to the counter's master reset (MR) input. This means that the counter is forced to reset and return to 1 as soon as it reaches the count where the output selected by S1 goes high.

For example when S1 is switched to the '2' position, the counter is reset as soon as output O2 goes high — which is on the second AC cycle to arrive from IC1a. Similarly when the switch is set to '3', the counter gets reset as soon as O3 goes high (i.e., after the third AC cycle); and when S1 is set to the '4' position, the counter is reset when O4 goes high.

So depending on the setting of switch S1, IC2 is reset with its O0 output high on every second, third or fourth AC cycle from IC1a. It no longer counts in decades (10 times), but in either 2's, 3's or 4's depending on the setting of S1.

As you can see we connect output O0 of the counter to the base of transistor Q1, via the 10k resistor. So whenever the counter resets and output O0 does go high, Q1 is turned on. And the collector of Q1 is connected up to the +9V line via the LED and its 820 $\Omega$  current limiting resistor, so whenever Q1 is turned on current flows through the LED and it produces a flash.

Get the idea? LED1 glows whenever the counter is reset, with its O0 output switched high. And this happens on every second, third or fourth AC cycle from IC1a, depending on the setting of S1. So we get a flash of light on every second, third or fourth click from the speaker, which can indicate the start of each two-beat, three-beat or four-beat musical bar.

correct slot. After this you can replace the lockwasher and screw the nut on again, to hold everything in place. Then when you try turning the switch spindle, it should only be able to click through a total of three positions.

Next after the switch comes the 1M $\Omega$  pot VR1, and as we

mentioned earlier this can be of either the 24mm or 16mm size. Regardless of which size it is, you'll need to shorten its spindle to match that of the switch, when it's resting on the top of the board. So mark the point on the spindle that is exactly 33mm from the BACK of the pot, and cut the spindle

off at this point with a hacksaw or jeweller's saw. Then smooth off the burrs with a small file, so you won't have any problems fitting a knob.

Next bend each of the pot's three contact lugs carefully down at 90°, fairly close to the point where it narrows down. Then you should be able to sit the pot on the top of the board with its spindle upwards and in line with the switch spindle, with all three bent-down lugs just behind and very close to their terminal pins. The lugs can then be soldered to the pins, to hold the pot in place as well as making its connections.

The last component to fit is the LED, which as you can see goes just behind the very centre of the board with its flat side and cathode lead towards the front. It can be fitted with its body about 15mm above the board, as shown in the photos.

Your board assembly should now be complete, with all that remains being to connect the battery cliplead and speaker wires to the terminal pins at the rear. Notice that the cliplead's red wire connects to the terminal pin on the right of that pair of pins, and the black wire to the left pin.

Use two short lengths of insulated hookup wire to connect the mini speaker to the other two pins, baring just 5mm or so at each end of both wires to make the solder connections. The polarity of the speaker's connections isn't important in this project — either way around is fine.

It might also be a good idea to fit the control knobs to the spindles of pot VR1 and switch S1 at this stage, so your Metronome should really be ready to try out. But just before you do try it out, give it a careful inspection in case you've fitted any of the components in the wrong positions or the wrong way around. Check the copper side of the board as well, in case you've forgotten to solder any of the leads, left a dry joint or even a bridge of solder shorting between pads.

## Trying it out

If (or when) everything seems in order, turn the control knob fully clockwise and also turn the switch knob so it's in the most clockwise of its three positions. Then connect a 9V alkaline battery to the cliplead, and you should be greeted by a series of 'click' or 'beep' sounds emerging from the speaker, at the rate of a little over three per second. The LED should also flash in time with every fourth click.

If you now turn the knob of pot VR1 gently anticlockwise, the click rate should slow down — and the LED flashing rate with it. By the time you have turned the pot fully anticlockwise, the clicking should have slowed down to only

about one click every two seconds, and the flash rate to once every eight seconds (i.e., still only one for every fourth click).

Now try turning switch S1 to its centre position. Here the LED should flash on every third click, rather than on every fourth. Finally if you turn the switch to its third and most anticlockwise position, the LED should flash on every second click. This is obviously the '2 beats to the bar' setting.

But what if *your* Metronome doesn't produce any clicks or flashes at all, and just sits there as dead as a dodo? You can probably guess what that means. Yep, you must have made some kind of mistake in wiring it up. So quickly disconnect the battery again and start searching for the problem.

A completely 'dead' circuit is usually caused by something fairly easy to find, like connecting the battery cliplead wires the wrong way around or fitting diode D2 the wrong way instead. Other less likely possibilities are fitting the 100µF or 2.2µF electrolytics the wrong way around, or even having a totally 'flat' battery.

Perhaps your Metronome does produce the clicks alright, but there are no flashes from the LED. In this case you've probably fitted the LED the wrong way around, or perhaps transistor Q1 or IC2.

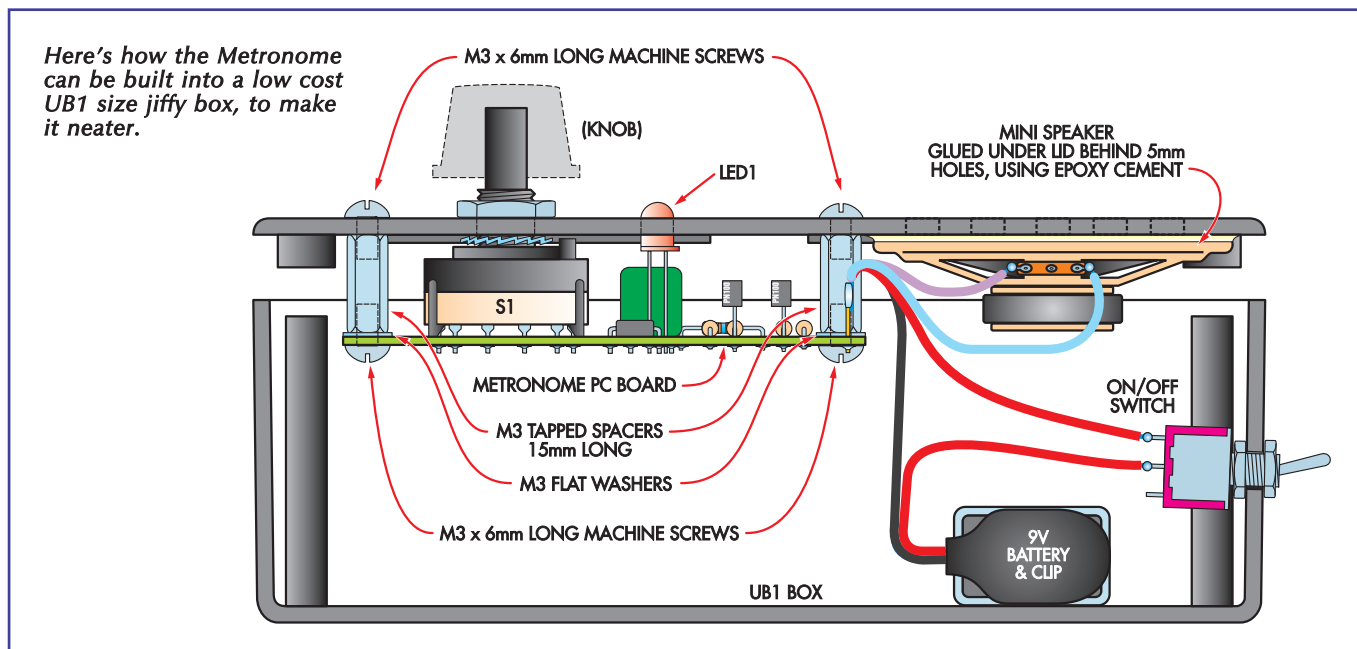
On the other hand your LED might be flashing OK, but there are no clicks from the speaker. The cause here is likely to be that you've fitted either Q2 or Q3 the wrong way around, or perhaps diode D1.

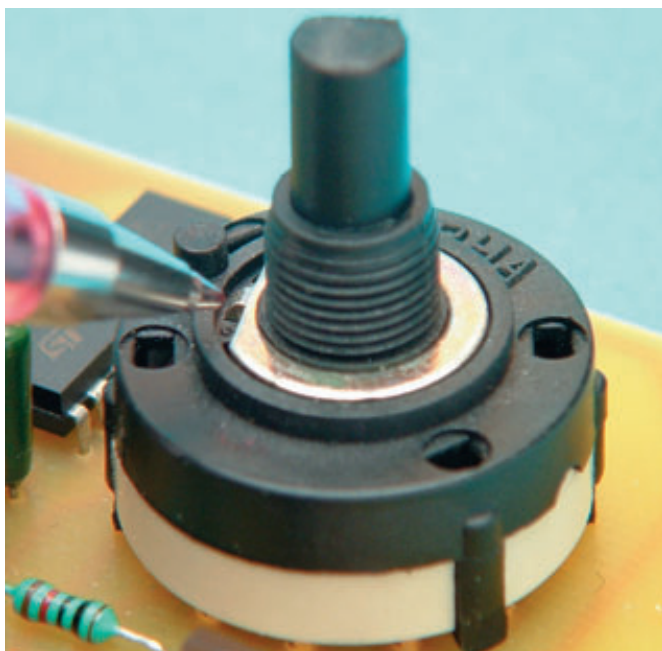
## What to do next

It's fairly easy to change various aspects of the Metronome's behaviour, if you're not entirely happy with the way it's working. This is done by replacing some of the components with others of different value.

For example if you'd like to change the sound of the beat 'clicks', this is easily done by replacing the 47k resistor with one of higher or lower value. If you replace it with a 39k or 33k resistor this will make the clicks *higher* in pitch. On the other hand replacing it with a 56k or 68k resistor will make the clicks *lower* in pitch.

If you'd like the clicks to be a little shorter, this can be done by replacing the 100nF greencap with one of lower value — like 47nF. This will also make them sound quieter. However if you find the clicks are still too loud, this can be easily fixed by removing one of the 120Ω resistors in series with the speaker. Or you can replace it with a resistor of say 150Ω or 180Ω.





*To make sure that your rotary switch is set for only three positions, remove the nut and lockwasher from its threaded bush. This reveals a flat washer with the programming stop pin, pointed out in this photo. To set the switch for three positions, it should be in the small slot between the '3' and '4' moulded into the plastic. If it isn't, prize up the washer and refit it with the pin in the right slot. Then fit the lockwasher and nut again to hold everything in place.*

Replacing both 120Ω resistors with a pair of 100Ω resistors will have the opposite effect, making the clicks louder but also reducing the life of the battery. It's also not a good idea to reduce the value of these resistors below 100Ω, as this can stress transistor Q3 and it may fail.

If control pot VR1 doesn't quite allow you to make the click rate fast enough at its clockwise limit, you can replace the 150k resistor to the left of the pot with one of smaller value, like 120k or 100k. On the other hand if the click rate isn't quite slow enough for you at the pot's anticlockwise

limit, you can replace the 2.2μF electro with one of higher value — like 3.3μF (Jaycar RL-6422) or 4.7μF (RL-6424). Just make sure the replacement electro is of the same low leakage (RBLL) type.

If you find the LED flashes a little too brightly, this can be easily fixed by replacing the 820Ω resistor with one of higher value, like 1k or 1.2k. Or if you'd like the LED to flash a little *more* brightly, you can replace this resistor with one of 680Ω. Don't reduce the value any further though, as this would shorten the battery life and also cause stress for transistor Q1.

Finally, you might want to build the Metronome into a plastic utility box to make it a lot neater and protect it from damage. This is also quite easy to do, as you can see from the diagram on the opposite page.

The Metronome has been designed so that it will fit into one of the larger standard jiffy boxes — the UB1 size, which measures 158 x 95 x 53mm. This is available from Jaycar stockists in black as the HB-6011, and would make an excellent housing for the project.

As you can see the board assembly is mounted under the lid of the box, held there securely by the switch mounting nut as well as by eight 6mm long M3 machine screws (HP-0400) and four 15mm long M3 tapped spacers (HP-0904). A flat washer also needs to be fitted between each spacer and the PC board as shown, to match the spacing to the length of the switch body and its lockwasher.

The box lid needs to have a 10mm diameter hole drilled and reamed in it to allow the threaded bush of S1 to pass through, and also a 6.5mm hole for the spindle of pot VR1. You'll also need to drill a 5.5mm hole for the beat LED, so it can protrude through and be seen.

The mini speaker can be cemented under the other end of the box lid as shown, behind an array of 5mm holes to 'let the clicks out'. You'll also have to drill four 3mm holes to take the upper mounting screws for the Metronome PC board, of course.

The battery can be fitted into the bottom of the box as shown, held in place with a length of gaffer tape. But when you fit it inside the box like this you'll also want to fit the Metronome with a switch, so it can be turned on and off without having to open up the box. The easiest switch to use is the Jaycar ST-0335 mini toggle, which mounts in a single 6.5mm hole. We suggest you drill this hole in the end of the box as shown, and connect two of its lugs in series with the positive (red) battery clelead wire.

## Meet the Pioneers of Electronics:



# Heinrich Hertz

Born in Hamburg, Germany in 1857, Heinrich Hertz trained as an engineer but then changed over to physics at the suggestion of the famous scientist Ferdinand von Helmholtz. In 1883 he was appointed to an academic post at the University of Kiel, where he began research into the theory of electromagnetism which had been worked out by Scottish mathematician James Clerk Maxwell a short time earlier.

A year or two later the Berlin Academy of Science offered an attractive prize for impressive work on the behaviour of oscillating electric currents, and Hertz was encouraged to enter the competition. This led to him performing experiments in 1888 which showed clearly that oscillating currents resulted in the emission of electromagnetic radiation – just as Maxwell had predicted. Hertz had demonstrated how radio waves could be transmitted and received, setting the stage for the development of radio communication and future radio and television broadcasting.

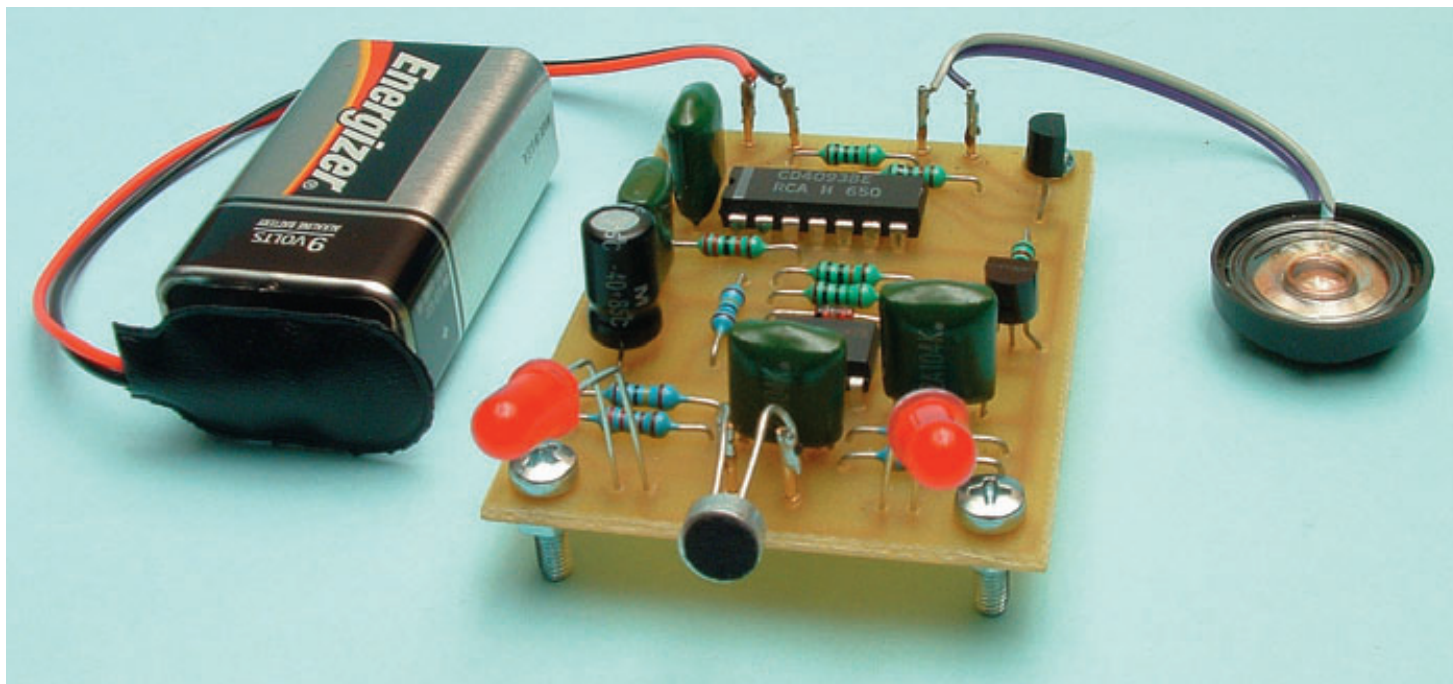
Unfortunately Hertz died before he could use his discovery to develop practical radio transmitters and receivers. However the very year he died (1894), the Italian engineer Guglielmo Marconi achieved the first radio transmissions. In honour of Hertz's pioneering work, we use his name for the standard unit of frequency: the **hertz**, equal to one oscillation cycle or wavelength per second.



## Project 14:

# An Electronic 'Cricket'

Here's an intriguing little novelty project to build: an electronic gizmo that sits there doing nothing — until you make a sound near it. Then it suddenly starts making a chirping sound like a cricket, and flashes its LED 'eyes' at the same time. Your friends will wonder how it works!



### What does it do?

This project doesn't do anything useful at all! It's just a novelty gadget, designed to attract people's interest and curiosity...

It doesn't do anything at all until it picks up a sound with its microphone 'ear'. But then it springs into action, making a chirping sound via its mini speaker — very much like a cricket. At the same time its two LED 'eyes' flash away, to show you that it's on the ball.

It mightn't seem like much, but many people find this kind of electronic novelty gizmo quite cute and amusing. So why not build one up and impress them?

### Putting it together

Almost all of the components used in the Electronic Cricket fit on a very small PC board, which is coded SHRTC214 and measures only 61 x 45mm. The only items that don't mount on the board are the 9V battery and the tiny mini speaker which produces its chirping sound.

Before you start assembling the project, it's a good idea to open the kit and lay out the parts so you can make sure you have everything. At the same time you can give the PC board a quick inspection, to check that all of the holes have been drilled and that there are no etching problems.

If everything seems in order, begin putting the project together by fitting the six PCB terminal pins to the board. Two pairs of pins go at the back of the board for the battery and speaker connections, while the third pair goes at the front of the board for the microphone connections.

Next fit the resistors. There are 12 of these, and they all fit on the board in the horizontal or 'lying down'

## The parts you'll need for this project:

- |   |                                    |   |                         |
|---|------------------------------------|---|-------------------------|
| 1 | PC board, code SHRTC214, 45 x 61mm | 2 | 5mm red LED (LED1,LED2) |
| 1 | 21mm mini speaker                  | 1 | 1N4148/1N914 diode (D1) |
| 1 | Mini electret microphone           | 1 | 1N4004 diode (D2)       |

- |   |                                  |
|---|----------------------------------|
| 1 | 9V battery, 216 type             |
| 1 | Battery clip lead to suit        |
| 6 | PCB terminal pins, 1mm dia.      |
| 1 | Short length of speaker cable    |
| 1 | Small pack of resin-cored solder |

### Semiconductors

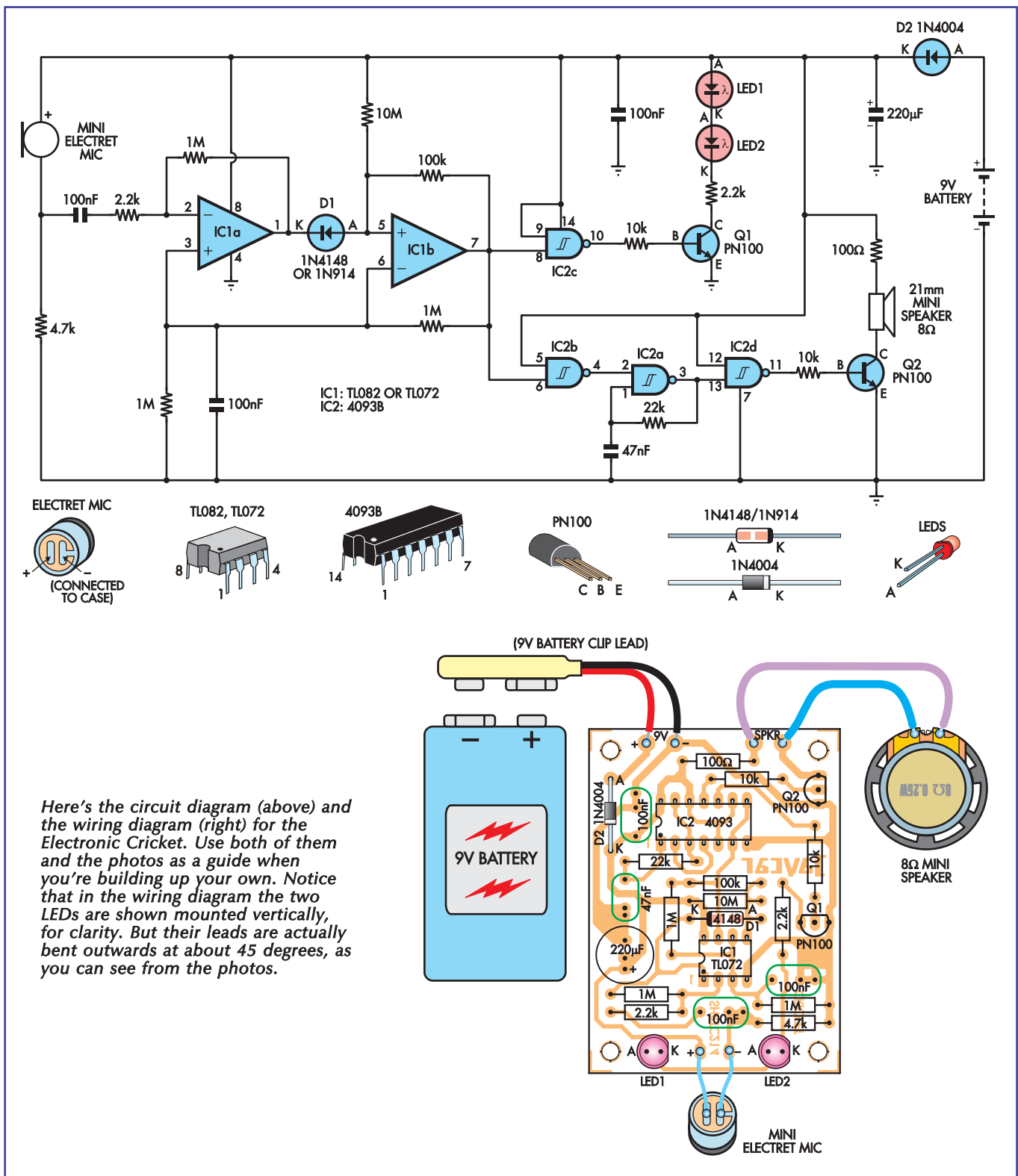
- |   |                               |
|---|-------------------------------|
| 1 | TL082/TL072 dual op-amp (IC1) |
| 1 | 4093B quad Schmitt NAND (IC2) |
| 2 | PN100 NPN transistor (Q1,Q2)  |

### Capacitors

- |   |                                 |
|---|---------------------------------|
| 1 | 220 $\mu$ F 16V RB electrolytic |
| 3 | 100nF greencap                  |
| 1 | 47nF greencap                   |

### Resistors (0.25W 1%)

- |   |      |   |              |
|---|------|---|--------------|
| 1 | 10M  | 3 | 1M           |
| 1 | 100k | 1 | 22k          |
| 2 | 10k  | 1 | 4.7k         |
| 2 | 2.2k | 1 | 100 $\Omega$ |



Here's the circuit diagram (above) and the wiring diagram (right) for the Electronic Cricket. Use both of them and the photos as a guide when you're building up your own. Notice that in the wiring diagram the two LEDs are shown mounted vertically, for clarity. But their leads are actually bent outwards at about 45 degrees, as you can see from the photos.

position as you can see from the photos. Notice that there are three of them with a value of 1MΩ, so it's a good idea to fit these first to help avoid mistakes. The resistors are not polarised, but as usual it still makes sense to fit them so their colour code bands all read in the same east-west or south-north direction to make troubleshooting easier if this is ever needed in the future.

Now you can fit the greencap capacitors. There are four of these, three with a value of 100nF and one of 47nF. Make sure you follow the wiring diagram carefully and fit the 47nF greencap in the centre at the left of the board, just to the

front of one of the 100nF greencaps. The other two go down near the front right-hand corner.

Next fit this project's one and only electrolytic capacitor. This has a value of 220μF and, as you can see, it mounts on the left-hand side of the board just to the front of the 47nF greencap. But don't forget that it's polarised — so make sure you fit it the correct way around. Its positive lead goes towards the front of the board, and the board has an extra hole to suit different lead spacings. Don't let this confuse you: the electro's negative lead must go through the hole nearer the 47nF greencap and the back of the board.

Next you can fit the diodes. There's one smaller 1N4148 in a glass package (D1), and this goes in the centre of the board. The other diode D2 is a 1N4004 in a plastic package, and this goes on the left-hand side near the back. They're both polarised of course, so make sure you fit them with their cathode band ends as shown in the wiring diagram.

After the diodes, it's time to fit the two transistors Q1 and Q2. These are both PN100 devices, so there's no worry about confusing them. You will have to crank out their outer leads away from their centre lead, though, to match their spacing to the board holes. Also make sure you fit each one the correct way around, as shown in the wiring diagram. D1 fits with its flat side towards the back, while Q2 fits with its flat side facing out to the right.

Next fit the two integrated circuits. IC1 is the TL082 (or TL072), which comes in the smaller 8-pin package and goes near the front centre of the board. IC2 is the 4093B in the larger 14-pin package, and this goes near the back of the board. Both of them go with their notch/dimple ends

towards the left, as shown in the wiring diagram. As usual you may need to bend their two rows of pins slightly inward towards each other, so they'll all pass through the board holes without strain.

Both of these ICs are vulnerable to damage from electrostatic charge though, so be careful. Touch some earthed metalwork to discharge yourself before handling them, and use an earthed soldering iron. Also try to solder their supply pins to the board pads first (pins 4 and 8 of IC1, pins 7 and 14 of IC2), so their internal protection circuits begin working as soon as possible.

Next fit the mini electret microphone. This goes at the front centre of the board, with its negative pad (connected to the case) connecting to the right-hand terminal pin. The microphone pads aren't soldered directly to the board's terminal pins though, because it's too hard to do this without damaging the mic by overheating. It's better to solder two short lengths (say 15mm) of tinned copper wire (or resistor lead offcuts) quickly to the mic pads first, and

## Tech Talk: How does it work?

Although the circuit of the Electronic Cricket may look fairly simple, it's actually a bit complicated — especially when it comes to the circuitry around IC1. So we're only going to explain the basic way this part of the Cricket works.

As you can see IC1a is half of a TL082 dual op-amp (operational amplifier) IC. Here it works as a high gain preamplifier which amplifies the weak AC signals from the mic insert when it picks up any sounds. The signals are fed into IC1a through the 100nF coupling capacitor, and the op-amp amplifies them by about 500 times because of the ratio between its 1M feedback resistor (from pin 1 to pin 2) and the 2.2k input resistor.

The preamplifier gets its forward bias from the output of IC1b, the second half of the same IC. When the Cricket is 'waiting' for any sounds to be heard, the output of IC1b is switched up to very close to +9V. This provides a bias voltage of about +4.5V at the positive input (pin 2) of IC1a, because of the voltage divider formed by the two 1M resistors connected between pin 7 and ground (the negative line). The output (pin 1) of IC1a rests at very close to the same voltage, because of the way the amplifier works.

At the same time the negative input of IC1b (pin 6) is also held at +4.5V, because it's connected to the same divider. But the positive input of IC1b is held slightly higher in voltage (about +5V), because of the voltage drop in diode D1. That's why the output of IC1b rests at very close to +9V, because this amplifier acts as a comparator and in this situation its positive input is more positive than its negative input.

When the microphone picks up some sound, though, IC1a amplifies the AC signals from the mic and its output voltage swings up and down with the amplified AC. When the voltage swings negative, this also pulls down the voltage at pin 5 of IC1b, via D1. As a result the output of comparator IC1b suddenly switches low, which removes the +9V from the top of the voltage divider feeding pins 3 and 6. So the bias voltage for both IC1a and IC1b starts dropping, as the 100nF capacitor across the lower 1M resistor starts discharging, and the preamp stops working.

But this situation doesn't remain for long, though. The fine details are quite complex, but essentially what happens is that IC1a and IC1b together form a low frequency oscillator, and a series of short pulses appear at the output of IC1b before it flies back up to +9V again.

Everything returns to the original 'waiting' state, if the sounds that were picked up by the mic have stopped.

However if the mic picks up some more sounds when IC1a begins working again as a preamplifier, the whole process starts again. So we can summarise the behaviour of this 'front end' of the Cricket's circuit like this: when there's no sound picked up by the mic, the output of IC1b (pin 7) rests at a voltage of very close to +9V. But when sounds are picked up, this pin switches low for a short time and then pulses up and down half a dozen times before returning to the +9V level.

The rest of the Cricket's circuit senses these changes in the voltage at IC1b's pin7, and uses them to generate the Cricket's chirps and make its LED 'eyes' flash.

As you can see gate IC2b is connected as an inverter, with input pin 6 connected to the output of IC1b. So when the output of IC1b is 'waiting' at +9V, the output of IC2b is switched down to 0V. But when the output of IC1b switches low, the output of IC2b switches up to +9V instead.

Now gate IC2a has a 22k resistor connected from its output back to its pin 1 input, and a 47nF capacitor connected from the same input to ground (0V). This provides positive feedback around the gate, which therefore tends to oscillate at about 2kHz. But it can only oscillate when its second input (pin 2) is pulled up to +9V. When the second input is held low the gate's output is switched high and the gate can't oscillate.

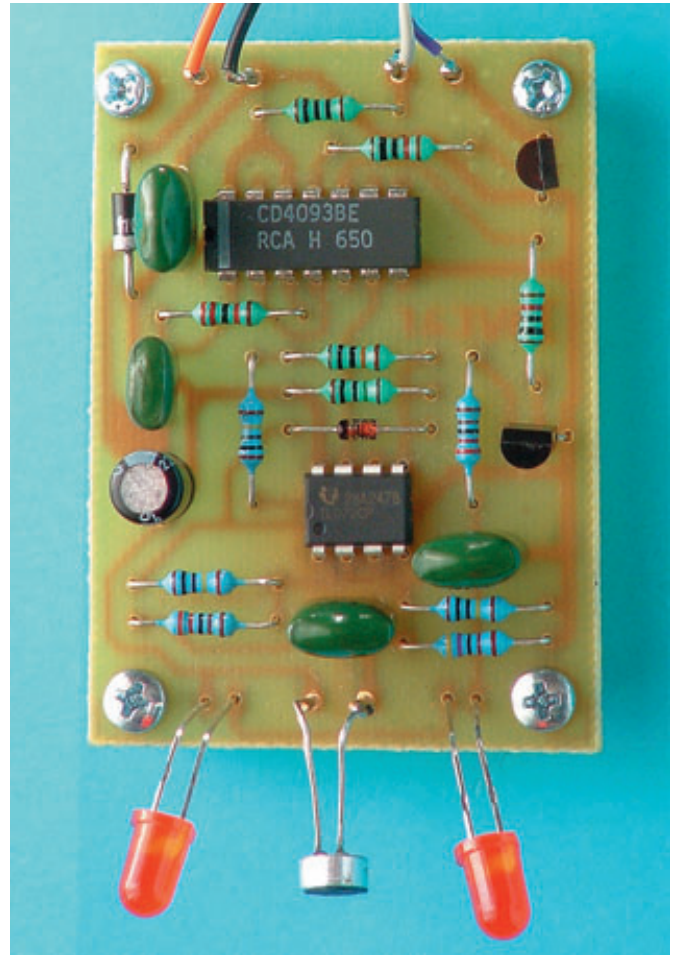
When the output of IC1b pulses low in response to a sound being picked up by the mic, though, this causes the output of IC2b to pulse high. Each time it pulses high this allows IC2a to oscillate, producing bursts of 2kHz square wave signals at its output (pin 3). The bursts of square wave signal are then fed through IC2d, used here as an inverting buffer, and then fed to the base of transistor Q2 via a 10k resistor.

As a result Q2 is turned on and off in bursts, at a rate of 2kHz. And since the mini speaker is connected from the collector of Q2 to the +9V line, via the 100Ω resistor, this causes bursts of current pulsing at 2kHz to pass through the speaker. So that's how we produce the Cricket's chirps.

The output of IC1b is also connected to the pin 8 input of gate IC2c, which as you can see is again used as an inverter — just like IC2b. So when the output of IC1b pulses low in response to sounds being picked up by the mic, the output of IC2c pulses high. Since this output is connected to the base of transistor Q1, via another 10k resistor, this means that Q1 is turned on during each pulse. And the LEDs are connected in series between the collector of Q1 and the +9V line, via a 2.2k current limiting resistor, so as Q1 conducts it allows pulses of current to flow through the LEDs. That's how the Cricket's LEDs flash at the same time as it is chirping.



*Here's a closeup top view of the Cricket's PC board assembly, to help you when you're wiring up yours. Notice the way the LED leads are bent outwards so the LEDs look a bit like the Cricket's eyes. The two wires connecting the microphone are also bent so it looks a bit like a snout — even though it's really the Cricket's 'ear'...*



then solder the other ends of the wires to the terminal pins.

When the wires have been soldered to the pins, you can then carefully bend the connection wires so that the front of the mic insert is pointing in front of the board, as shown in the photos. It then looks a bit like the cricket's snout, as well as pointing in the right direction to pick up sounds coming from the front.

The final components to fit are the LEDs, which in this project become the cricket's eyes. Their leads are left at their full length, but are bent by about 45° roughly 10mm from the body, so the LEDs will 'point' outwards towards the front of the board when the ends of the leads are soldered into the board. You can see this in the photos. Just make sure you fit both LEDs with their longer anode leads in the left-hand holes, and the flat side of each LED's body towards the right.

Now you should be able to connect the battery cliplead wires to the terminal pins at the back left of the board, with the red wire going to the leftmost '+' pin. Similarly you can connect the mini speaker to the two remaining terminal pins, using a couple of short lengths (say 75mm) of insulated hookup wire. Don't worry about the speaker polarity, though. In this project it can be connected either way around.

Your Electronic Cricket should now be finished and ready to try out. But before you do this, give the assembly a quick once-over to make sure you haven't fitted any of the parts in the wrong locations, or with the wrong orientation. Also inspect the copper side of the board carefully, just in case you've forgotten to solder one of the component leads, or left a dry joint.

## Trying it out

Assuming everything seems to be OK, try connecting a 9V alkaline battery to the cliplead. The Cricket's eye LEDs should flash briefly, and the speaker may give a brief chirp. But then all activity should cease, at least if you don't talk or make any other sound yourself.

Now try speaking a few words, or whistling, or even clicking your fingers near the Cricket's microphone. It should immediately start chirping, and its LED 'eyes' should begin flashing in time with the chirps. Then when you stop talking or whistling or making any sounds yourself, it too should stop and 'go back to sleep'.

But what if *your* Cricket doesn't respond to any sounds like this, and stubbornly sits there sulking? You guessed it, that will be almost certainly because you've made some kind of mistake in wiring up the project. So you'll need to disconnect the battery again, and start searching for the mistake.

If the Cricket seems to be completely dead, the most likely causes are that you've reversed the battery lead connections or fitted diode D2 the wrong way around. Or you might have fitted diode D1 the wrong way around, or either of the ICs.

Perhaps your Cricket chirps as it should, but the LED eyes don't flash. This will probably be due to your having fitted the two LEDs the wrong way around, so they can't draw current.

On the other hand if the LEDs flash but there's no chirping, this may be because you've fitted transistor Q2 the

wrong way around. Or you may have accidentally swapped over a couple of the resistors. Or one of the ICs may have been fitted the wrong way around.

If you use a methodical approach in looking for the cause of the problem, you should be able to track it down and fix it in short order. Then your Cricket should spring to life as soon as you hook up the battery again.

## What to do next

There's not much you can alter in the Cricket to make it do anything else. You can change the sound of its chirps a little though, by replacing the 22k resistor with a resistor of higher or lower value. For example if you replace it with a 33k resistor, the Cricket will produce chirps that are lower in pitch — like an old 'grandpa' cricket. Or if you replace it with a 15k resistor, the chirps will be higher in pitch — like a small youngster who's just learned how to do it.

It's not really feasible to put the Cricket in a plastic box, and in any case this is one project that is better left 'naked' so its works are in full view. But you might like to fit an M3 machine screw and nut at each corner of the board as shown in the photos, to give it 'legs'.

If you do this with M3 screws that are 25mm long, this will lift the board up far enough to let you mount the battery and mini speaker underneath, to make the Cricket neater and more compact. The mini speaker can be stuck under the rear of the board using a piece of double-sided adhesive tape (attached to its rear magnet backing disk), while the battery can be wrapped in some sheet plastic and held under the front of the board using a strip of gaffer tape.

## Project 15:

# The 'Bionic Ear'

Sensitive directional microphones are used by movie makers to capture conversations from a distance. They're also used by bird call collectors — and by spies for eavesdropping, of course. Here's how to make one of these 'bionic ears' for yourself.

### What does it do?

The Bionic Ear combines a tiny microphone with a small but high gain audio amplifier, to make up a very sensitive microphone which is able to drive either stereo headphones or a cassette tape recorder.

When the microphone itself is mounted in the centre of a plastic dish or laminated wooden salad bowl, the dish/bowl acts as a sound collector and reflector. This greatly increases the microphone's sensitivity again in the forward direction, so it becomes very **directional**. As a result it's very well suited for listening to sounds quite a distance away, and recording them as well if you want to.

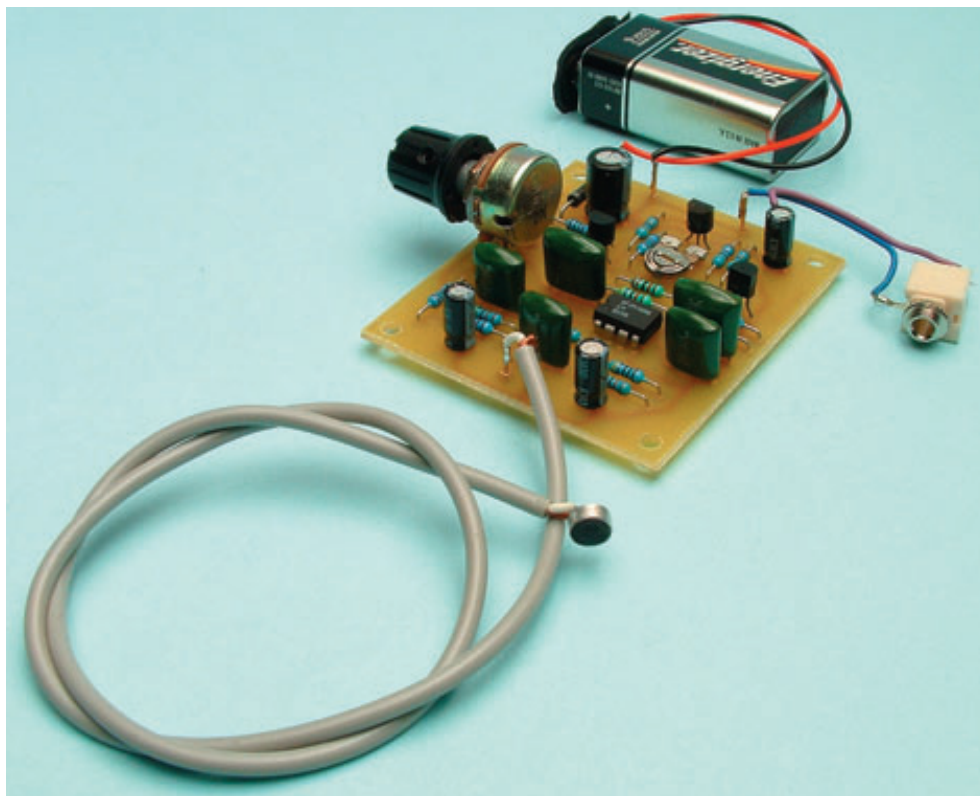
So if you're a movie maker or a collector of bird calls, you'll want to build up the Bionic Ear and take advantage of its high sensitivity and directionality.

### Putting it together

Apart from the microphone insert and the battery which supplies its power, all of the parts for the Bionic Ear mount on a compact PC board. This is coded SHRTC215 and measures 63 x 57mm.

Before you start to assemble the kit though, it's a good idea to open it up and lay out all of the components so you can check that everything is there. At the same time you can give the copper side of the PC board a quick inspection, to make sure that all of the holes have been drilled and there are no hairline cracks in tracks or solder bridges between pads.

If everything seems OK, you can start putting it together. There are no wire links needed on the board, so you can begin by fitting the six PCB terminal pins. One pair of these



goes at the centre front of the board for the mic connections, while the other two pairs go at the back of the board for the battery and output socket connections.

Once the pins are soldered into place, you can fit the fixed resistors. There are 15 of these, five of them with a value of 10k and two each with values of 220k, 47k and 47Ω. To help avoid mistakes it's a good idea to fit all the 10k resistors first, then the 220k, 47k and 47Ω resistors and

## The parts you'll need for this project:

- 1 PC board, code SHRTC215, 57 x 63mm
- 1 Mini electret mic insert
- 1 10k log potentiometer, 24mm or 16mm (VR1)
- 1 Knob to suit VR1
- 1 9V battery, 216 type
- 1 Battery clip lead to suit
- 6 PCB terminal pins, 1mm dia.
- 1 3.5mm stereo jack
- 1 300mm length of single screened audio cable

- 1 100mm length 2-core lead
- 1 Small pack of resin-cored solder

### Semiconductors

- 1 LM833 dual low noise op-amp (IC1)
- 2 PN100 NPN transistors (Q1,Q2)
- 1 PN200 PNP transistor (Q3)
- 1 1N4004 diode (D1)

### Capacitors

- 1 220μF 16V RB electrolytic

- 1 47μF 16V RB electrolytic
- 1 10μF 16V RB electrolytic
- 1 10μF 50V RBLL electrolytic
- 2 220nF greencap
- 3 100nF greencap

### Resistors (0.25W 1%)

- |                                |        |
|--------------------------------|--------|
| 2 220k                         | 1 150k |
| 1 68k                          | 2 47k  |
| 1 22k                          | 5 10k  |
| 1 470W                         | 2 47W  |
| 1 10k horizontal trimpot (VR2) |        |





## Tech Talk: How does it work?

When the electret mic insert picks up sounds, it produces weak audio signals at its positive terminal. These are coupled into the positive input of IC1a via the 100nF capacitor, which blocks DC but lets the small AC signals through. IC1a is one half of an LM833 dual low noise op-amp (operational amplifier), which is used here as a high gain preamplifier.

The gain or amplification of the preamp is set by the ratio of the resistors in its feedback divider, which as you can see are 220k and 470Ω. These give a gain of about 470 (220,000/470), so the signals that appear at output pin 1 are about 470 times stronger than those coming from the mic.

The stronger signals are fed via the second 100nF capacitor to volume control VR1, which adjusts what proportion of them are fed to the rest of the circuit — via the 220nF capacitor.

The remaining part of the circuit is basically another amplifier, using IC1b and transistors Q2 and Q3. IC1b

forms an inverting voltage amplifier, whose output is fed to the bases of the two transistors. These provide no voltage amplification but current amplification instead, so that the amplifier can drive headphones or the input of a tape recorder via a long cable.

Transistor Q1 is not really part of the amplifier, but is used as an 'amplified diode', to allow us to adjust the forward bias voltage applied to the bases of Q2 and Q3 (via trimpot VR2), and hence their quiescent current.

The voltage gain of this output amplifier is about 3 times, being set by the ratio of its 68k negative feedback resistor and the 22k input resistor. The two 47k resistors connected to the positive input of IC1b (pin 5) form a voltage divider, which provides the amplifier with a bias voltage of about 4.5V. The 220nF capacitor connected from the same input to ground (the negative supply line) makes sure that this input is tied down to ground as far as AC signals are concerned.

Finally, the output of the amplifier is coupled from the emitters of Q2 and Q3 to the output socket via the 10μF electrolytic cap, which passes the AC signals but again blocks the DC.

the left. The largest is a 220μF electro which goes near the back of the board on the left. Notice that the board provides extra holes for both the positive and negative leads of this electro, to suit different spacings.

The 47μF electro goes at the front of the board on the left. The other two electros both have a value of 10μF, but notice that these are slightly different. The 'LL' (low leakage) 10μF electro goes at the front of the board on the right, while the other 10μF (16V) electro goes up in the back right-hand corner.

Next comes the trimpot, VR2. This has a value of 1k and should be a small 'open' horizontal mounting unit. It mounts just to the back of the 22k fixed resistor. The board has extra holes to suit a trimpot of the smaller sealed type, though, so if your kit has one of these instead it will be just as easy to mount it.

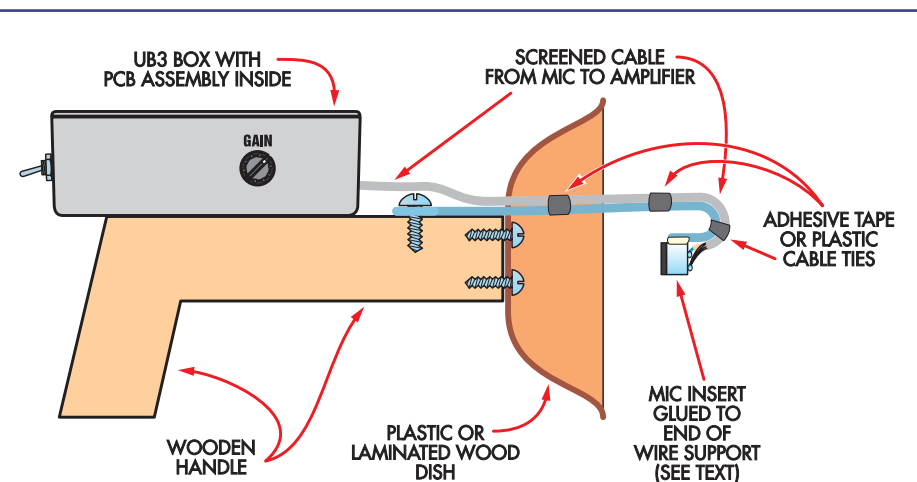
Now you can fit the Bionic Ear's volume or gain control pot, VR1. This has a value of 10kΩ with a 'log' or 'B' taper, and will probably come in the kit as the smaller 16mm size. However if your kit comes with one of the larger 24mm types, don't panic because the board again has the additional holes to suit that size as well.

Before you actually fit the pot to the board, it's a good idea to cut its control spindle at a point about 10mm from the threaded bush. Do this with a hacksaw or small jeweller's saw, and smooth off the burrs with a small file. It's a lot easier doing this before the pot is fitted to the board.

Once the pot lugs are soldered into the board you can start with the semiconductor parts. Diode D1 is first, and as you can see from the wiring diagram this fits at rear left with its cathode band end towards the front of the board.

The transistors come next. Notice that there are two PN100s, which go in the Q1 and Q2 positions, and only one PN200 which becomes Q3. Be careful not to mix them up, because this will cause all kinds of problems. Notice too that Q1 and Q2 are fitted with their flat sides towards the rear of the board, while Q3 is fitted the other way around (flat side towards the front). As usual you'll need to crank the outer leads of each transistor away from the centre lead, so they'll all pass through the board holes without strain.

The last component to fit is IC1, an LM833 device in an 8-pin DIL (dual inline) package. This fits with its notch/dimple end towards the left side of the board, as you can see from the wiring diagram. You may have to bend the two rows of pins inwards towards each other carefully, so they'll all go through the board holes without strain.



*How you can use a laminated wood bowl or a plastic dish as a reflector, to make the Bionic Ear's microphone really sensitive and directional. The mic is glued to the end of some 2.5mm diameter wire, cut from an old coat hanger and bent into a 'J' shape. It's screwed to the wooden handle through a loop at the other end. The dish itself is screwed to the end of the handle, as you can see.*

Your Bionic Ear board assembly should now be complete, apart from the off-board connections. So connect the battery cliplead wires to the two rear terminal pins on the left, making sure to connect the positive (red) wire to the leftmost pin. Then connect the 3.5mm jack socket to the two output pins at the back right of the board, using two short (say 60mm) lengths of insulated hookup wire, using the wiring diagram as a guide for the connections.

The final step is to connect the mini electret mic insert to the two pins at the front of the board, using the 300mm length of screened audio cable. Again use the wiring diagram as a guide for the connections, and notice that the cable's screening braid connects to the mic pad that's also connected to its case. At the other end the screening braid

*Here's a closeup view showing how the electret mic insert is glued to the wire support, and also how the screened lead is taped to the wire as well. The dish itself is screwed to the end of the wooden handle, as you can see.*



connects to the PCB terminal pin on the right. Don't make any mistakes here as the mic won't work if you reverse its connections.

Just before you relax and decide you're ready to try out the Bionic Ear, give everything a quick 'final inspection' to make sure you've fitted everything in the right position and with the right orientation. Do this by comparing them with the wiring diagram and the photos. Also turn the board over and check that you haven't forgotten to solder any of the component leads or pins, or left any dry joints or solder bridges.

### Trying it out

Assuming everything seems OK, adjust the rotor of trimpot VR2 (using a small screwdriver) so it's at the centre of its range. Also adjust gain control VR1 so its rotor is in the fully anticlockwise position. Then plug a pair of headphones (mono or stereo) into the 3.5mm socket, and put on the 'phones so you'll be able to hear their sound output. After this connect up a 9V alkaline battery to the cliplead, and you should hear a small 'plop' in the headphones — followed by silence, or at most a very faint hissing.

Now slowly turn the spindle of VR1 clockwise, to increase the amplifier's gain. The hissing will increase by a small amount, but you should also start hearing an amplified version of any sounds being picked up by the microphone. In fact if you start talking quietly, you should hear your own voice quite loudly once the gain is turned up.

Your voice should be quite clear, and without any distortion or 'edgyness'. If it does sound weak and a bit distorted, try turning the rotor of trimpot VR2 anticlockwise by a small amount. This will increase the quiescent current of the two output transistors Q2 and Q3, and the distortion should disappear. Don't turn VR2 any further than the point where the distortion goes, though — because this will shorten the battery life.

If everything happens as described, your Bionic Ear's electronics is finished and working properly. All that remains should be to mount the microphone in a plastic dish or laminated wooden salad bowl, to make it really sensitive and directional.

What if *your* Bionic Ear doesn't seem to work though, and just sits there in stony silence? You can probably guess the reason for this. Yep, it's a sign that you've made a mistake of some kind in wiring up the board. You might have swapped

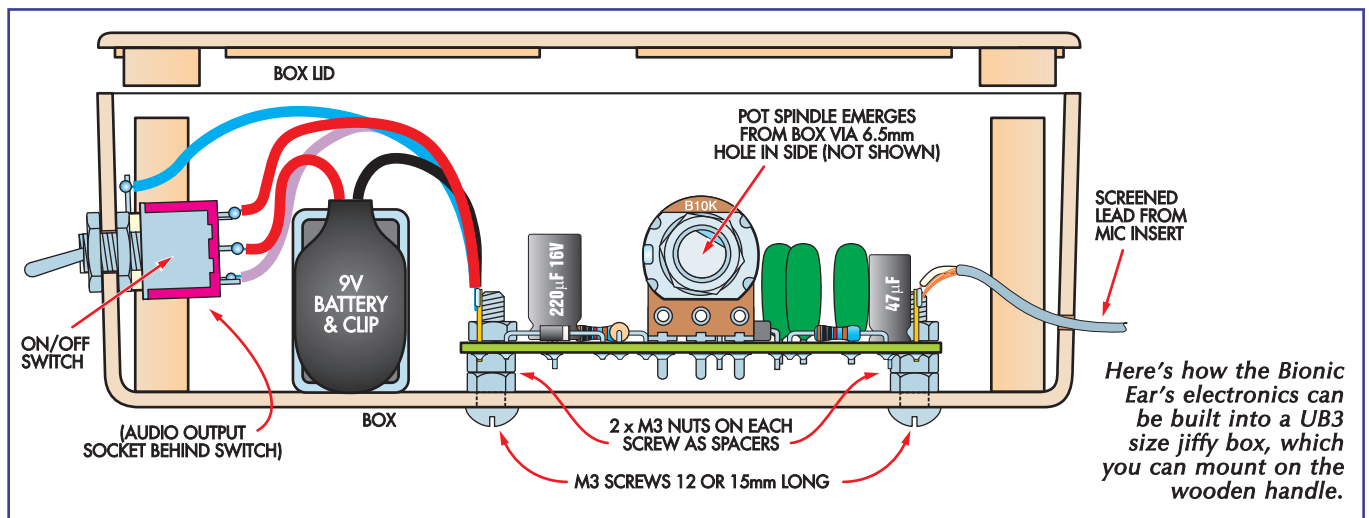
the battery cliplead wires for example, or fitted diode D1 the wrong way around. Maybe you've connected the electret mic the wrong way around. Or you've put the PN200 transistor in the Q1 or Q2 positions, instead of in the Q3 position. Or you've accidentally fitted some of the resistors in the wrong positions, or perhaps reversed one or more of the electrolytic capacitors.

Any of these mistakes could cause the Bionic Ear to either not work at all, or else only work in a very weak and distorted fashion. So it's a matter of disconnecting the battery and checking for each of these possible causes of trouble. Once you track down the mistake and correct it, the Bionic Ear should finally spring into life as soon as you reconnect the battery.

### What to do next

Before you can use it for any serious eavesdropping, listening to wildlife or moviemaking, you'll need to mount the electret mic insert in a sound reflector dish so it becomes fully sensitive and directional.

Ideally, the reflector dish should be as large as possible and with a 'parabolic' shape (i.e., with a cross-section



shaped according to what mathematicians call a **parabola**). But a really large dish with a truly parabolic shape will cost you a lot of money, and will be quite unwieldy as well.

Luckily you can still get quite good results from a dish that doesn't have a truly parabolic shape, and also one that isn't really large either. Just bear in mind that the closer your dish is to a parabola, and also the larger it is, the better the results you'll get. But the larger it is the more awkward it will be to use as well, so you'll probably have to compromise.

As you can see from the photo, we made a reflector from a small laminated wood salad bowl which measures about 155mm in diameter. It's vaguely parabolic in shape, but with a flattened centre. The results with this dish were quite good, although you'd undoubtedly do better with the next-larger size of the same bowl — which measures about 255mm in diameter. These bowls cost only a few dollars in bargain stores, so they'd be well worth considering.

You could also use a plastic washing dish, perhaps one about 300mm in diameter if you don't find this too big.

Whichever dish or bowl you use, it'll need to be mounted on the end of a wooden handle which is cut into a broadly 'pistol' shape (see diagram). This will allow you to hold up the dish and microphone, and point them in the direction of the sounds you want to pick up. We screwed the bowl to the end of the wooden handle using a couple of 12mm long self-tapping screws.

The mic insert itself has to be supported in the centre of the dish, facing inwards. Ideally it should be located at the 'focal point' of the dish parabola, so any sound waves captured by the dish are reflected into it. However since your dish isn't likely to be a true parabola, you don't need to worry too much about the mic's exact spacing. We suggest that you support it at a point that's roughly half the bowl's diameter out from the centre of the dish.

As you can see from the photo and diagram, we bent a piece of 2.5mm wire cut from a coat hanger into a 'J' shape and cemented the mic insert to the end of the shorter leg of the 'J' using epoxy cement (such as *Araldite*). Then we drilled a 2.5mm hole in the reflector bowl just above the top of the wooden handle, so the longer leg of the wire mic support could be passed through and bent into a small loop.

It was then screwed to the wood, with the mic spaced at the right distance in front of the bowl. Another hole of 3mm diameter was drilled in the bowl just near the wire hole, to take the screened cable running from the mic back to the Bionic Ear PC board. After the cable was soldered to the pads on the back of the mic insert and run through the hole in the dish, it was then taped to the support wire using three narrow strips of gaffer tape.

If you build the Bionic Ear's electronics into a small plastic utility box, this can be attached to the top of the 'back end' of the wooden microphone/dish handle to make the whole project much neater and easier to use. The PC board has been designed to go in a standard UB3 size jiffy box, measuring 130 x 67 x 44mm. The grey Jaycar HB-6023 box would be a good choice, or you could go for the HB-6013 if you'd prefer the box to be black.

It's quite easy to mount the board assembly inside a UB3 box, as you can see from the drawing. The board is mounted in the bottom of the box, using four 12mm (or 15mm) long M3 machine screws and nuts. An additional pair of nuts can be threaded on each screw before the board itself, to space the board about 4mm above the bottom. A 6.5mm hole drilled in the side of the box allows the spindle of gain control pot VR1 to pass through, so it can be fitted with a small knob.

Similarly a 3mm hole is drilled in the front of the box, to allow the screened microphone lead to enter. The battery can be fitted inside the box to the rear of the board, held down by a strip of gaffer tape. But if you do this you'll also want to fit the Bionic Ear with an on/off switch. So if you drill a pair of 6.5mm holes in the other end of the box as well, this will let you mount the 3.5mm headphone socket and a small on/off toggle switch (like the Jaycar ST-0335) side by side.

You can mount the finished box of electronics on the top of the mic's wooden handle, where it'll be easy to use. It can either be attached using epoxy cement, or using a couple of woodscrews passing through holes drilled in the bottom of the box. If you use screws though, the box will need to be screwed to the handle before the electronics is actually fitted into it, because the mounting screws will be under the PC board.

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## Meet the Pioneers of Electronics:

# Guglielmo Marconi

Born in Bologna, Italy in 1874, Guglielmo Marconi was the son of a wealthy landowner and an Irish mother. When he was 12 he attended the Cavallero Institute for tuition in physics and chemistry, and then studied electrophysics at Leghorn Technical Institute.

Hearing of the discovery of radio waves by Hertz in 1887, he began experimenting with simple radio equipment on the family estate in Bologna. By 1895 he succeeded in transmitting and receiving telegraphic (Morse code) messages over a distance of two miles. The following year he and his mother went to England, where he received backing and encouragement from the Post Office to set up a series of 'wireless' stations around the UK for communication with ships at sea, and also one in France for communications across the Channel.

In 1897 Marconi received a British patent for his invention of practical radio communication. Then in 1901 he succeeded in transmitting messages across the Atlantic, and was granted another patent (No.7777) for his selective tuning system. He set up a world-wide company with transmitting and receiving stations in many countries for marine and intercontinental communications.

When the liner *Titanic* sank in the Atlantic in 1912, Marconi's radio system allowed 703 survivors to be saved by other vessels. He was knighted that year, but also lost one eye in a car accident while visiting Italy. In 1914 he began experiments with shortwave radio communications, and was made a Senator of Italy. In 1922 he presented a paper at the American Institute of Electrical Engineers foreseeing the use of radio waves for detecting and measuring the range of ships and aircraft (i.e., radar). In 1934, three years before he died, he was working on microwave beacons for direction finding and navigation.





## Project 16:

# An Electronic Die

People have used dice for centuries as a simple way to generate random numbers. Here's how to build a hi-tech replacement, with seven LEDs to indicate the number that comes up when you 'roll it'. It even turns off the power automatically after you've had about six seconds to check the number, so the battery lasts as long as possible.

### What does it do?

The Electronic Die is a simple random number generator, just like an old fashioned die: those familiar little cubes of wood or plastic with engraved dots on each side to indicate the numbers from 1 to 6. In this case there are seven LEDs, arranged in a square array. When you 'roll' the die by pressing a button, all of the LEDs blink away rapidly. Then the blinking slows down and stops, with anywhere between one and six of the LEDs glowing to indicate the number you've obtained from the roll. The LED pattern for each number even matches the dot pattern on an old type die, so you can recognise them quickly.

Then about six seconds after the rolling stops, the LEDs stop glowing and the circuit effectively turns itself off. This is to make sure you get the longest possible life from the 9V battery which powers the Electronic Die. In fact it should last for just about the normal 'shelf life'.

Incidentally 'die' is the singular term for the more commonly used 'dice', which is really the plural term.

### Putting it together

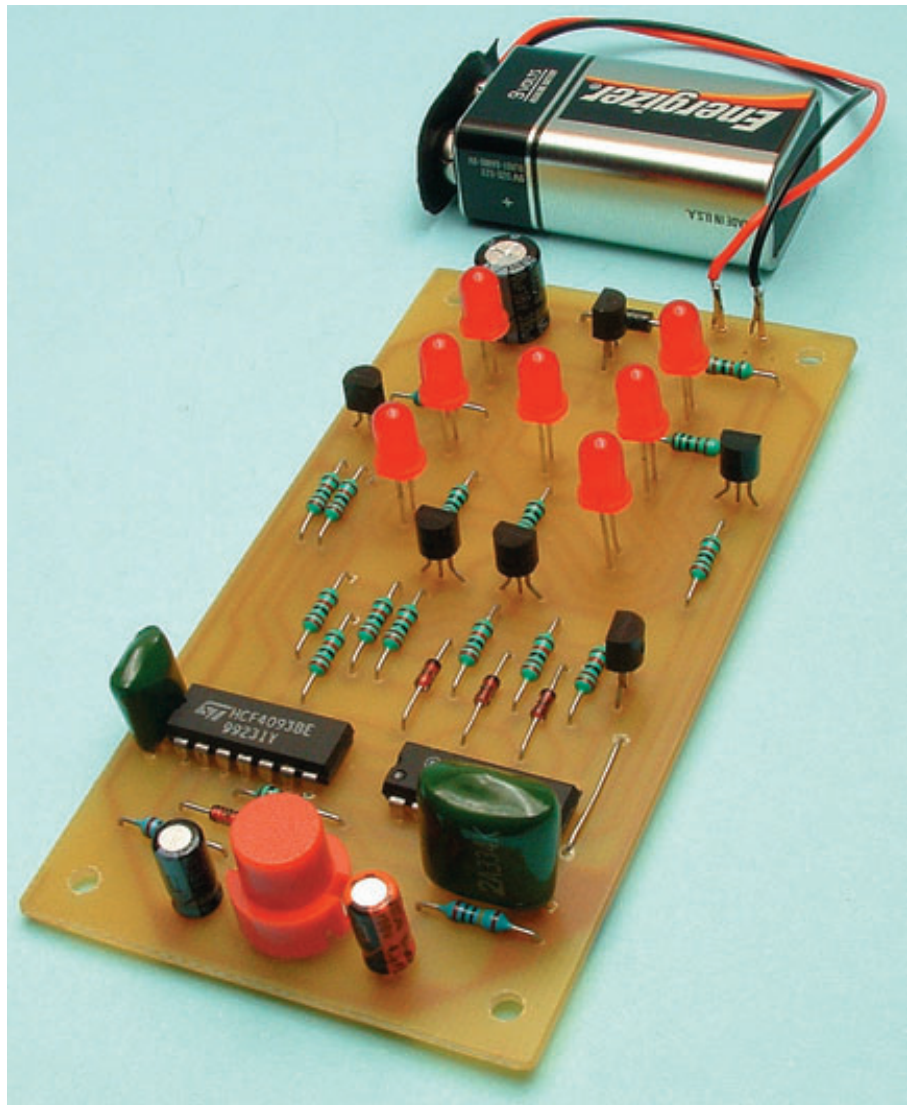
Apart from the battery, all of the parts used to make the Electronic Die's circuitry are mounted on a small PC board. The board is coded SHRTC216 and measures just 107 x 57mm.

Before you start assembling the parts on the board, though, it's a good idea to unpack the kit and lay out all of the parts so you can make sure you have everything. At the same time you can carefully inspect the copper side of the PC board, checking that all of the holes have been drilled and that there are no etching 'glitches' like breaks in tracks or tiny bridges between pads.

If everything seems OK, start the assembly by fitting this project's one wire link. This goes on the right-hand side of the board about 2/3rds of the way down, as you can see from the wiring diagram and photos. You can use either tinned copper wire or an offcut from a resistor lead for this link, as it doesn't need to be insulated.

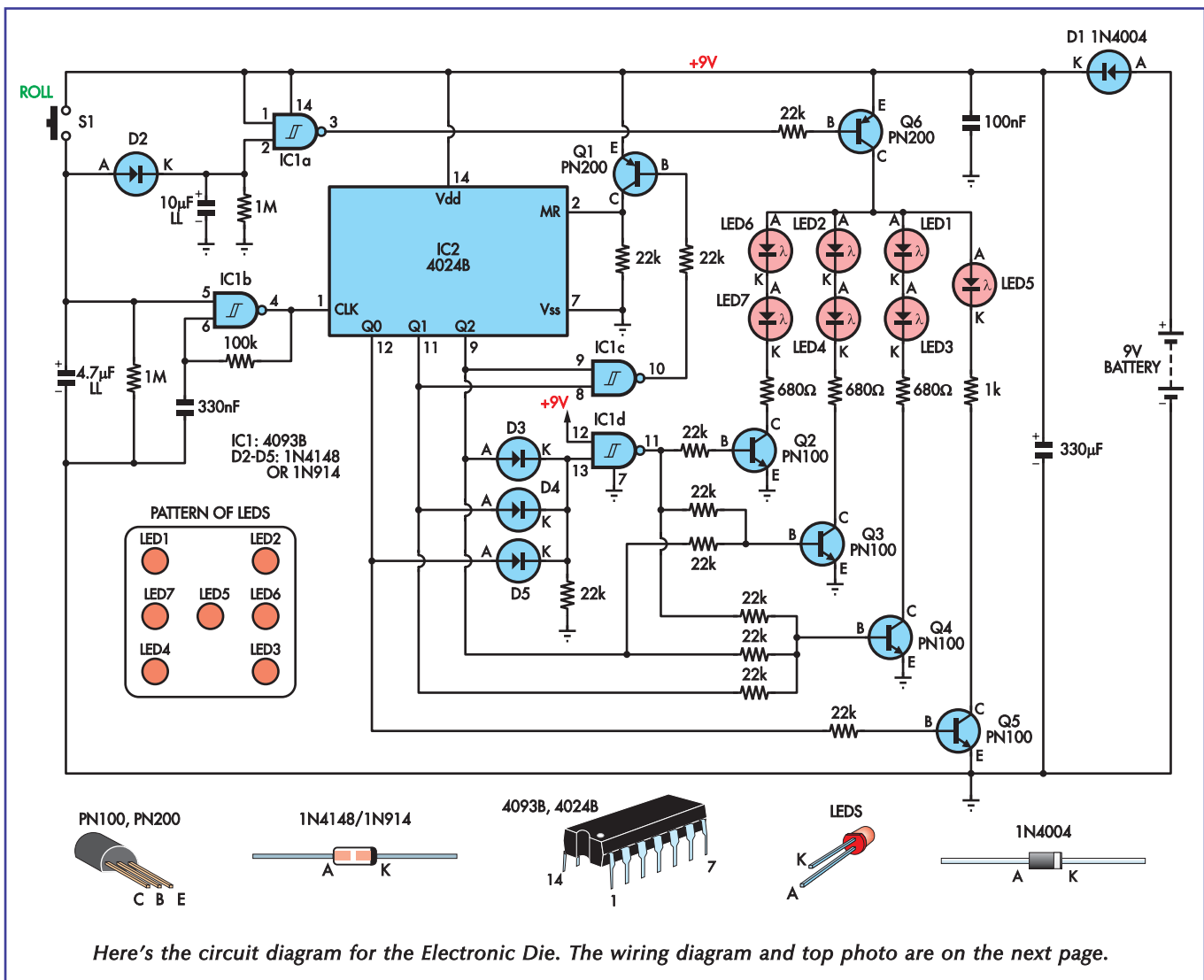
After the wire link you can fit the two PCB terminal pins, which go at the top of the board and over on the right, for the battery clip lead connections.

After the pins, fit the resistors. There are 18 of these in this project, and they all mount horizontally — i.e., lying down on the board. As 11 of the resistors have the same



value (22k), it's a good idea to pick these out and fit them first to help avoid mixups. Then pick out the three 680Ω resistors and fit these next, followed by the two 1M resistors and finally the 100k and 1k 'singles'.

Once the resistors have all been soldered in place, you can fit the two greencap capacitors — or at least the smaller one (100nF). This one goes over on the left, near the front of the board. You can fit the larger 330nF greencap as well if you're not going to build the Electronic Die into a box, as we describe in the What To Do Next section. It goes at front right, as you can see from the wiring diagram. But if you **do** plan to build the Die into a box, leave this greencap out until you've fitted the ICs — because it will need to be fitted 'leaning over' IC2, for reduced height.



Notice that the board provides an extra hole for each of the greencaps, to suit different lead spacings.

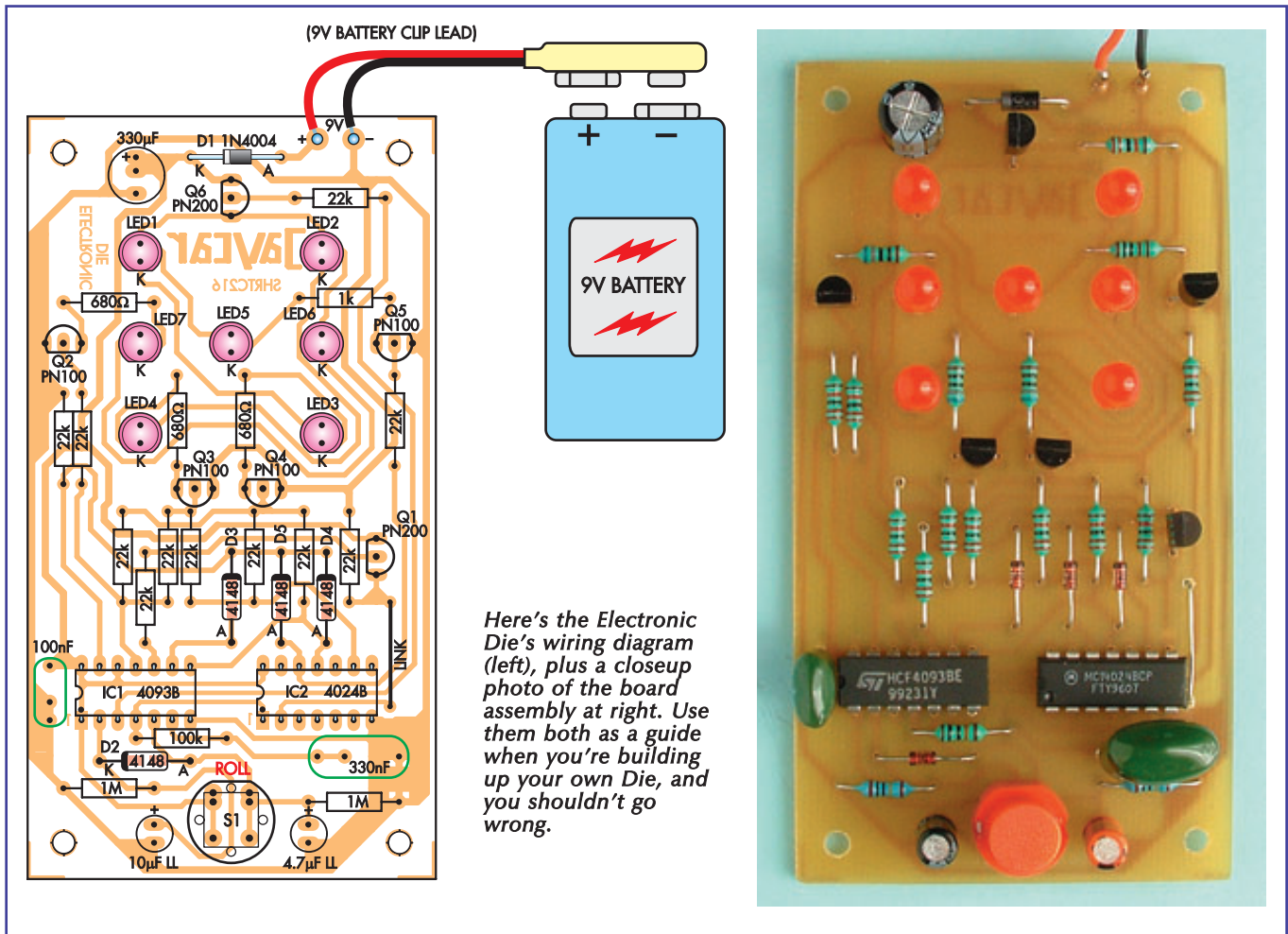
Next fit the three electrolytic caps, remembering that they're polarised so you need to follow the wiring diagram carefully with regard to their orientation. In this project all three electros are positioned so that their positive lead is towards the top (rear) of the board. The smaller 10µF and 4.7µF RBLL (low leakage) electros go down at the front of the board, while the larger 330µF electro goes at the back on the left. The board also provides an extra hole for this last electro, to cope with different lead spacings. Just make sure you always fit the electro's negative lead through the hole furthest from the back of the board.

Now fit the diodes. There are five of these in all, and they're all polarised of course. So make sure you position each one with its cathode band end orientated as shown in the wiring diagram and photos. The single 1N4004 diode in a plastic package goes at the centre rear of the board as D1. The remaining four diodes are of the 1N4148 (or 1N914) in a smaller glass package, and these go much nearer the front of the board as D2 and D3-D5.

## The parts you'll need for this project:

- |                       |   |                             |                             |   |      |
|-----------------------|---|-----------------------------|-----------------------------|---|------|
| 1                     | PC board, code SHRTC216, 57 x 107mm       | 7                           | Red LEDs, 5mm (LEDs 1-7)    |   |      |
| 1                     | 9V battery, 216 type                      | 1                           | 1N4004 diode (D1)           |   |      |
| 1                     | Battery clip lead to suit                 | 4                           | 1N4148/1N914 diodes (D2-D5) |   |      |
| 1                     | Pushbutton switch, PC board mounting (S1) | <b>Capacitors</b>           |                             |   |      |
| 2                     | PCB terminal pins, 1mm dia.               | 1                           | 330µF 16V RB electrolytic   |   |      |
| 1                     | Small pack of resin-cored solder          | 1                           | 10µF 50V RBLL electrolytic  |   |      |
| <b>Semiconductors</b> |   | 1                           | 4.7µF 50V RBLL electrolytic |   |      |
| 1                     | 4093B quad Schmitt NAND gate (IC1)        | 1                           | 330nF greencap              |   |      |
| 1                     | 4024B binary counter (IC2)                | 1                           | 100nF greencap              |   |      |
| 2                     | PN200 PNP transistor (Q1, Q6)             | <b>Resistors (0.25W 1%)</b> |                             |   |      |
| 4                     | PN100 NPN transistor (Q2-Q5)              | 2                           | 1M                          | 1 | 100k |
|                       |   | 11                          | 22k                         | 1 | 1k   |
|                       |   | 3                           | 680Ω                        |   |      |

Next fit the transistors. There are two PN200 (PNP) transistors, which go in the Q1 and Q6 positions, and four PN100 (NPN) transistors which go in the Q2-Q5 positions. Make sure you don't confuse them and swap them around. You'll need to crank the outer leads of each transistor away from the centre lead, so they'll go through the board holes without strain. Follow the wiring diagram carefully when



Here's the Electronic Die's wiring diagram (left), plus a closeup photo of the board assembly at right. Use them both as a guide when you're building up your own Die, and you shouldn't go wrong.

you're fitting each transistor, so you orientate it the right way around.

Next fit pushbutton switch S1, which becomes the Die's Roll button. This has four pins in a square pattern, but as they're connected together in pairs inside the switch, make sure you fit the switch the right way around. As you can see from the wiring diagram and top photo, it should be orientated with its 'flat' side towards the back of the board.

Now it's time to fit the two ICs. These are both 14-pin devices, so don't confuse them. The 4093B goes on the left as IC1, while the 4024B goes on the right as IC2. They're both orientated with their notch/dimple end towards the left though, as you can see from the wiring diagram. You may need to bend their two rows of pins slightly inwards towards each other, so they'll all go through the board holes without strain.

As both ICs are CMOS devices, they are susceptible to damage from electrostatic charge. So it's a good idea to touch some earthed metalwork to discharge yourself before handling the ICs, and use an earthed soldering iron of course. Another thing that helps protect the ICs from damage is to solder their supply pins (pins 7 and 14) before you solder the others, so their internal protection circuitry can begin operating straight away.

The final components to fit are the seven LEDs. As you can see from the photos and wiring diagram these all fit with their 'flat' side (cathode lead) towards the front of the board, with their body about 10mm above the board.

Your Electronic Die PC board assembly should now be complete and almost ready to try out. All that remains is to connect the battery cliplead's wires to the terminal pins at the back of the board, making sure that you connect the red wire to the left pin and the black wire to the right pin. Then give everything a final inspection, to make sure you've

placed each component in the right position and with the correct orientation. While you're at it, check the copper side of the board as well to make sure all of your solder joints have been made and that none of them is 'dry'.

### Trying it out

Once everything checks OK, you can connect up the cliplead to a 9V battery. Don't be surprised if nothing seems to happen when you do this, though. That's because nothing *should* happen until you press the Roll button S1.

When you do press S1, the LEDs should all begin blinking rapidly. They should continue to do this for a few seconds after you stop pressing the button, but should then 'slow down' and finally stop with the LEDs displaying one of the numbers from 1-6.

They should keep displaying this number for about six seconds, and then turn off again to save the battery.

What if nothing happens with *your* Die, even when you do press the button? Or something else doesn't happen? You guessed it, that will be almost certainly because you've made some kind of mistake in wiring up the board. So disconnect the battery again, and search for the cause of the trouble.

You might have forgotten to solder one of the component leads under the board, for example, or made a dry joint. Or perhaps you've accidentally left a tiny sliver of solder as a short-circuiting 'bridge' between pads.

Other mistakes you might have made are fitting diodes D1 or D2 the wrong way around, or connecting the cliplead wires wrongly. Any of these mistakes will stop the Die from working at all.

Another possibility is that some of the LEDs begin glowing as soon as you connect the battery, but never blink or go out again. This would probably be caused by your fitting a



## Tech Talk: How does it work?

Nothing happens in this circuit until you press the Roll pushbutton switch S1. Then a number of things happen, because when it's pressed S1 connects +9V to both diode D2 and the 4.7 $\mu$ F electrolytic capacitor.

For a start, this allows the 4.7 $\mu$ F electro to charge up to +9V — and very quickly, because there is no resistor in series with S1. So the electro charges up almost immediately, and this makes input pin 5 of IC1b rise to +9V as well. This in turn allows gate IC1b to 'turn on'. As this gate also has a 100k resistor connected between its output (pin 4) and the second input pin 6, with a 330nF capacitor from this input to ground, IC1b begins working as a free-running or **astable** oscillator. It starts producing pulses at about 33Hz, and as you can see these are fed to the clock input of IC2, which is a 4024B binary counter IC.

IC2 therefore begins counting the pulses from IC1b, and as it does its outputs Q0, Q1 and Q2 switch up and down in binary fashion — switching through the combinations 000, 100, 010, 110 and so on. This continues until the combination 011 is reached, where Q1 and Q2 go high together. When they do, this brings both inputs of NAND gate IC1c high, and as a result its output (pin 10) suddenly goes low.

When the output of IC1c goes low, this allows the base of transistor Q1 to draw current through the 22k resistor. The transistor therefore turns on (conducts), and applies +9V to the master reset (MR) input of IC2. This resets the counter, with its outputs (pins 12, 11 and 9) all switching low again.

As soon as this happens, the output of gate IC1c goes high again, which removes the forward bias for Q1. So the transistor turns off again as well, and removes the +9V from the counter's MR input (pin 2). The counter is therefore able to continue counting, but 'starting again' from the output combination 000.

So the counter keeps on counting the pulses, but its count is reset back to 000 by IC1c and Q1 each time it reaches 011. What this feedback reset circuit around IC2 achieves, then, is to convert the counter into a **modulo-6** counter — i.e., one that counts in multiples of six. (The 4024B actually has seven binary counting stages inside and seven outputs, even though we're only using three of them here. It can therefore count up to 128 if you want it to do so.)

Now let's go back to the other event that happens when you press the Roll pushbutton S1. This is that +9V is applied to the anode of diode D2, so the diode can conduct current. This allows the 10 $\mu$ F electrolytic to charge up quickly, just as the 4.7 $\mu$ F electro does.

As you can see when the 10 $\mu$ F electro charges it raises the voltage on the pin 2 input of IC1a, so this gate now has both inputs 'high' (i.e., at +9V). This makes the gate's output on pin 3 switch low, which in turn allows transistor Q6 to draw base current via the 22k series resistor. (Until this happens, transistor Q6 has been turned off because the output of IC1a was high and the transistor couldn't draw any base current.)

When Q6 does turn on, it connects the LEDs to the +9V line. So the LEDs are now able to draw current, at least when we also turn on any of the transistors Q2-Q5 connected at the 'earthy ends' of the LED strings.

Without going into too much detail, the rest of the circuitry connected to the output pins of IC2 (that is, involving diodes D3-D5, gate IC1d and the various 22k resistors) performs the job of **decoding** the output combinations of IC2, and turning on whichever of the LED switching transistors Q2-Q5 are needed to make the right LEDs glow to display that count number.

For example when IC2 reaches a count of one (Q0 high, Q1 and Q2 low), only Q5 gets turned on. This allows LED5 to draw current through Q6 and the 1k series resistor, so LED5 glows and indicates a '1'.

On the other hand if IC2 reaches a count of four (Q0 and Q1 low, Q2 high), transistors Q3 and Q4 both get turned on. This allows LEDs 2 and 4 to conduct current through their 680 $\Omega$  series resistor, and also LEDs 1 and 3 to conduct through their own 680 $\Omega$  resistor. As a result these four LEDs all glow, to indicate a 'four'.

Similarly if IC2 reaches a count of six and is therefore reset to zero by IC1c and Q1, this means that outputs Q0, Q1 and Q2 all go low. This means that none of the three diodes D3-D5 is turned on, and input pin 13 of IC1d is pulled low. This makes the output of IC1d (pin 11) switch high, which turns on all three transistors Q2, Q3 and Q4. This makes LEDs 6, 7, 2, 4, 1 and 3 all glow, to indicate a '6'. Get the idea?

So if you press pushbutton S1 and keep it pressed, all of these things keep on happening. IC1b keeps generating pulses, IC2 keeps counting them (in sequences of six), IC1a keeps transistor Q6 turned on to allow the LEDs to draw current, and transistors Q2-Q5 are switched on and off to make the LEDs indicate the numbers as IC2 counts. So the LEDs blink away, to show the die 'rolling' through all of the numbers.

Finally, let's see what happens when you take your finger off pushbutton S1. Obviously this removes the +9V connection to both the 4.7 $\mu$ F and the 10 $\mu$ F electros, so for a start both electros start discharging through the 1M resistors connected across each one. Because of its smaller value the 4.7 $\mu$ F electro will discharge twice as fast, as you'd expect.

Now as the 4.7 $\mu$ F electro discharges, the voltage across it — and on input pin 5 of IC1b — falls away. Before long the voltage drops to a level where IC1b can no longer work as an oscillator, so it stops. This means there are no more pulses for IC2 to count, so it stops counting. The LEDs therefore display the last count that IC2 reached before it stopped, and this becomes the number that the Die has 'come up with'.

Meanwhile the 10 $\mu$ F capacitor continues to discharge, and about six seconds after the counting stops its voltage drops to a level where gate IC1a is turned off as well. Its output switches up to +9V again, which in turn removes the forward bias for transistor Q6. As a result this transistor now turns off and switches the LEDs off as well. So everything turns off again, and the circuit 'goes back to sleep' until you press S1 again to wake it up.

PN100 (NPN) transistor in position Q6, instead of the correct PN200 (PNP) type.

If the Die seems to work, but doesn't display the right numbers when the LEDs stop, you've probably connected one of the diodes D3-D5 the wrong way around, or possibly one of the transistors Q2-Q5 instead.

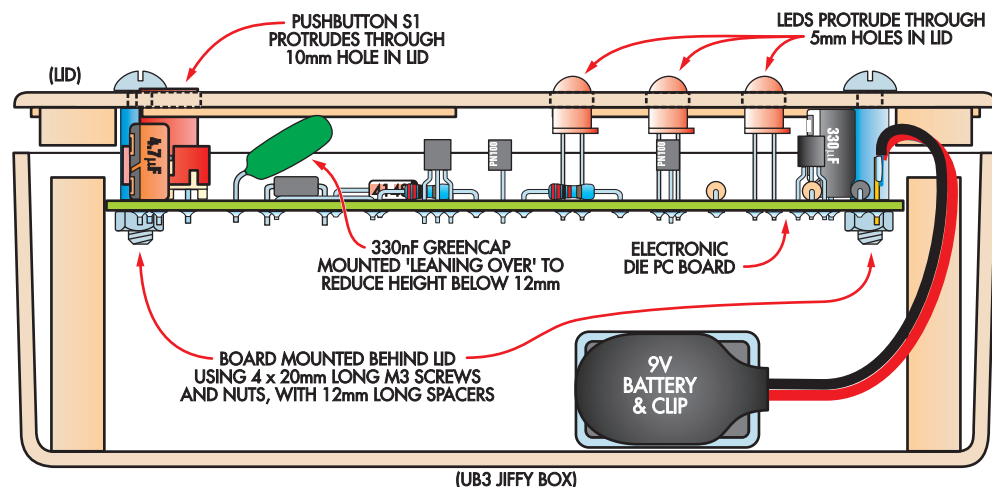
If the LEDs do begin glowing as soon as you press S1, but then immediately go out again as soon as you release the button, this would suggest you've connected the 10 $\mu$ F capacitor around the wrong way. Are you getting the idea of diagnosing the problem from the symptoms?

Once you do track down the cause of your problem and fix it, your Electronic Die should work properly as soon as you reconnect the battery.

### What to do next

If you want to use the Electronic Die whenever your family play board games, you'll probably want to build it into a box to make it neater and protect the electronics from damage. This is quite easy, because we've designed the board so it will fit in a standard UB3 size plastic jiffy box like the Jaycar HB-6023 (grey) or HB-6013 (black).

Here's how the Die's electronics can be built into a standard UB3 size plastic jiffy box, to make it neater and protect the parts from damage. Notice that the 330nF greencap has to be mounted 'leaning over', so it will fit in the 12mm space between the PC board and the box lid. You don't need to fit an On/Off switch, because the circuit turns itself off after each 'roll'...



You can see from the diagram on the next page how the Die is built into this size of box. The PC board assembly is mounted under the box lid, using four 20mm long M3 machine screws and nuts, with four 12mm long untapped metal spacers (like the Jaycar HP-0864) between the lid and board to provide the best spacing. The button of Roll switch S1 protrudes slightly through a 10mm hole in the lid so it can be pressed easily, while the seven LEDs protrude through matching 5mm holes so they can be seen easily.

If you do decide to fit the Die in a box though, notice that you'll probably have to fit the 330nF greencap to the board 'leaning over' at an angle rather than upright, so its effective height will be reduced to fit in the 12mm gap. This is shown in the diagram, with the greencap leaning over IC2.

The battery can be placed in the bottom of the box and held there securely with a strip of gaffer tape. By the way, you won't need to fit an on-off switch when this project is fitted in a box, because it draws almost no current from the

battery when the LEDs are turned off after a 'roll'.

Is it possible to change some aspects of the Die's performance? Yes, it is. For example if you would prefer the LEDs to glow a little longer after a roll before they are turned off, you can extend the 'viewing time' by replacing the 10 $\mu$ F low leakage electro connected from the cathode of diode D2 to ground (the negative line) with one of larger value. If you replace the electro with one of 22 $\mu$ F (like the Jaycar RL-6430) this will make the LEDs glow for twice as long: about 12 seconds.

On the other hand you might like the Die to 'roll' a bit faster than it does at present, to make it even harder for the player to predict what number it will come up with each time. (It's already very hard to do this, anyway.) The way to increase the 'rolling speed' is to increase the frequency of the IC1b oscillator, and the easiest way to do this is by replacing the 100k feedback resistor with one of a lower value — like 82k or 68k.

## Meet the Pioneers of Electronics:

# Thomas Alva Edison

Edison was born in 1847 in the town of Milan, Ohio in the USA. He only received three months of formal schooling, because the authorities judged him as 'retarded' and dismissed him from school. He was not retarded, but partially deaf as a result of suffering scarlet fever in childhood. The rest of his education was provided by his mother, who inspired him to be curious about virtually everything. He set up his first laboratory in the cellar of his parents' home in Port Huron, Michigan.

He began earning money at 12, selling newspapers on trains. By the age of 16 he had taught himself telegraphy, and found casual work as a telegraphist. In his spare time he continued to experiment with electricity, and soon became known as someone capable of fixing and repairing all kinds of electrical equipment.

In 1869 he was asked to repair a 'gold price indicator' at the New York Stock Exchange. He not only repaired it, but developed an improved stock price telegraph printer — his first invention. It was so successful that the Western Electric Telegraph Company gave him a job developing improved equipment.

He set up his own 'invention factory' in Menlo Park, New Jersey in 1876, and here he produced a stream of inventions. These included the carbon resistance telephone transmitter, the Phonograph and the incandescent lamp. Then in 1887 he built a new laboratory 10 times larger, in nearby West Orange. Here he improved some of his earlier inventions and produced many more, including the Kinetograph (one of the first movie cameras) and the Kinetoscope (an early 'peep show' movie viewer). He made and lost huge amounts of money.

More a technology entrepreneur than a scientist, Edison despised theoretical scientists. But by the time he died in 1931, he had 1093 patents to his name.



## Project 17:

# A 'Dalek' Voice Modulator

Ever wondered how they produced those metallic-sounding 'robot' voices in science fiction movies, and in TV series like the famous Doctor Who? By using a voice modulator, that's how. Here's how to build one, so you can try it out for yourself.

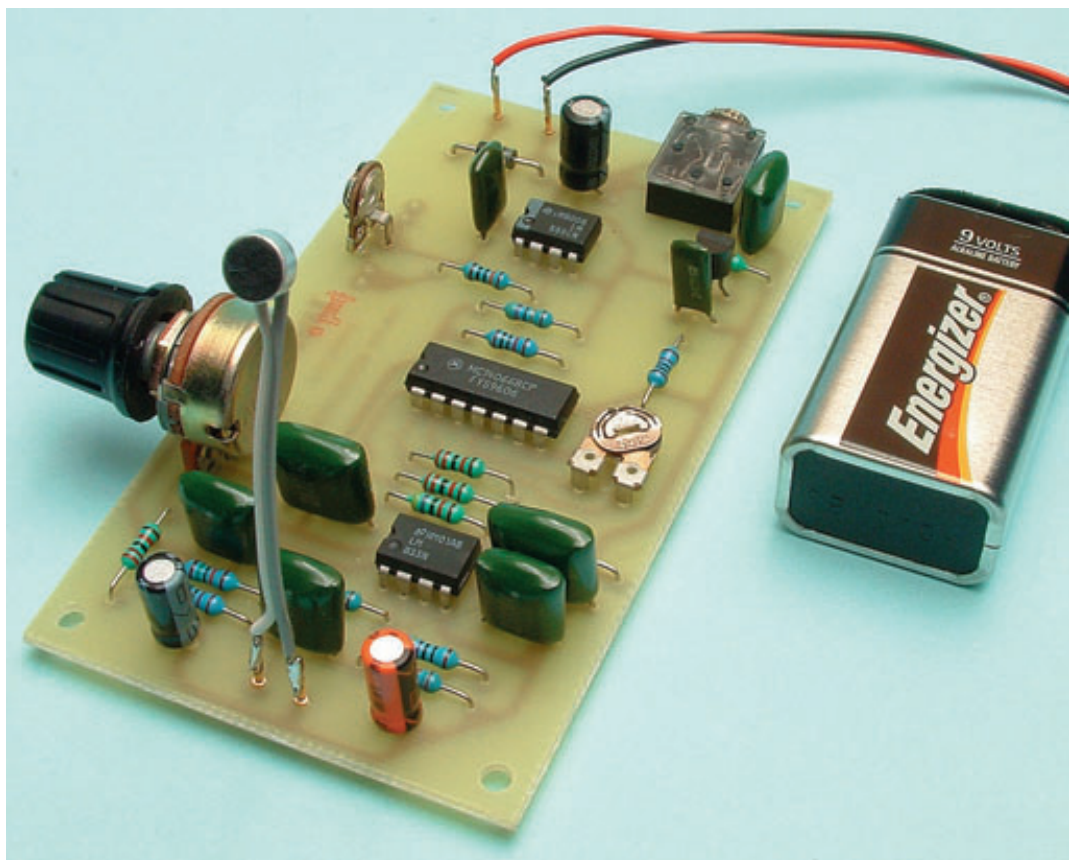
### What does it do?

When you speak into its electret microphone with your normal voice, the Voice Modulator first amplifies the mic signals to make them stronger. Then it feeds them into a special circuit known as a **balanced modulator**, where they are alternately reversed in polarity using a switching signal with a steady (but adjustable) frequency. This has the effect of 'shifting' the frequencies in your voice up or down, depending on the frequency of the switching signal. So your voice is effectively converted into that of a robot — wierd and metallic sounding.

Because the sound of your converted voice does vary quite a bit depending on the frequency of the switching signal, we've given the Voice Modulator a pot so you can adjust the switching frequency over a fairly wide range. This means you can easily experiment with different effects.

You can listen to these strange versions of your voice simply by feeding the Modulator's output signals (the shifted frequencies) into an amplifier like the one we described in Project 9, or any standard hifi amplifier. You can also record them on a tape or video recorder, if you want to use them in a home movie.

In short, it's a project that's not only interesting but also provides a lot of potential for having fun with SFX (sound effects).



### Putting it together

Apart from the battery and electret mic insert, all of the parts used in the Voice Modulator mount on a small PC board coded SHRTC217 and measuring 102 x 57mm.

## The parts you'll need for this project:

- 1 PC board, code SHRTC217, 57 x 102mm
- 1 Mini electret microphone insert
- 1 100k log potentiometer, 24mm or 16mm (VR1)
- 1 Small knob to suit VR1
- 1 9V battery, 216 type
- 1 Battery clip lead to suit
- 4 PCB terminal pins, 1mm dia.
- 1 3.5mm stereo jack, PC board mounting

- 1 Small pack of resin-cored solder

### Semiconductors

- 1 LM833 dual op-amp (IC1)
- 1 4066B quad analog switch (IC2)
- 1 555 timer IC (IC3)
- 1 PN100 NPN transistor (Q1)
- 1 1N4004 diode (D1)

### Capacitors

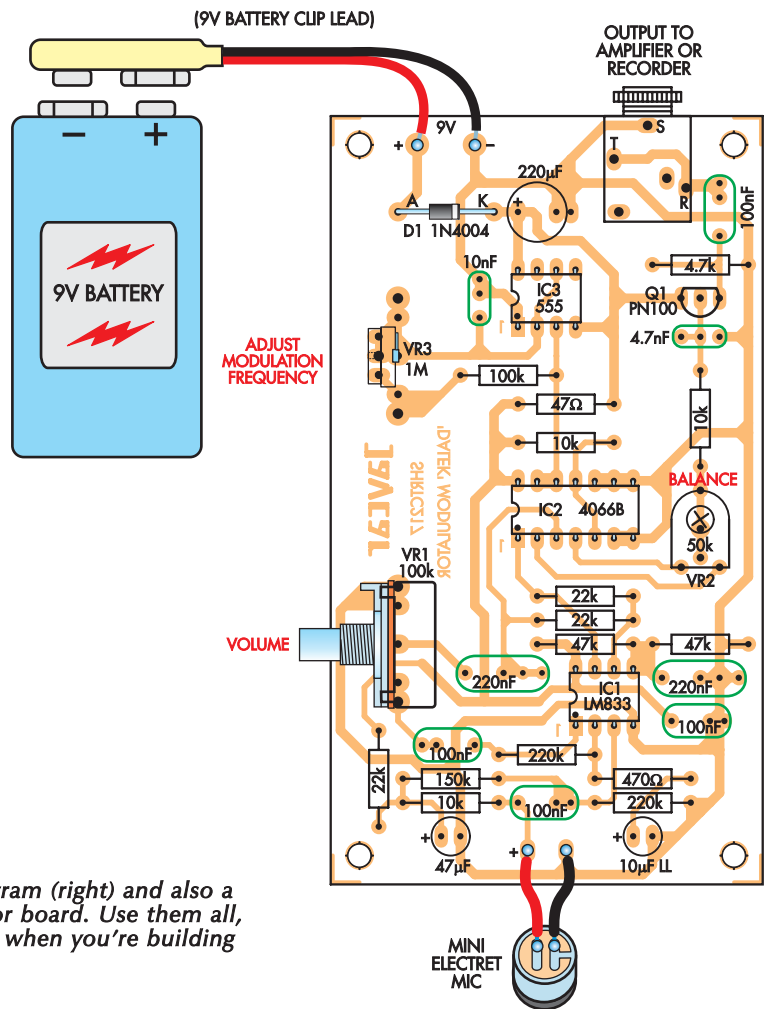
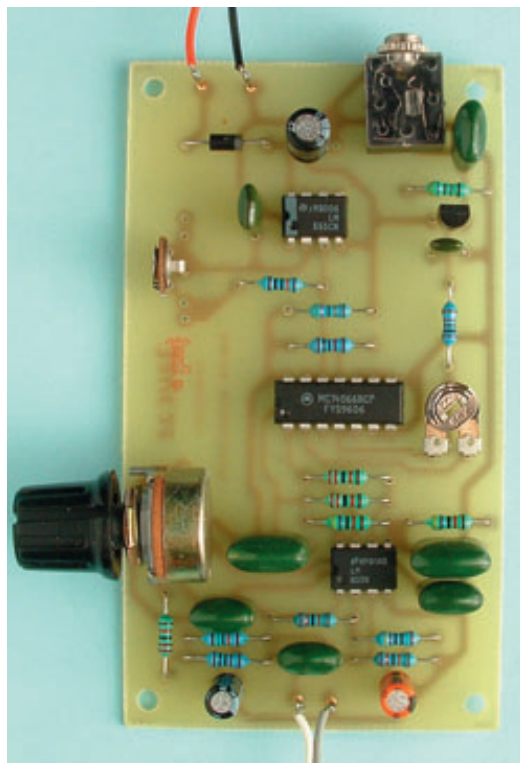
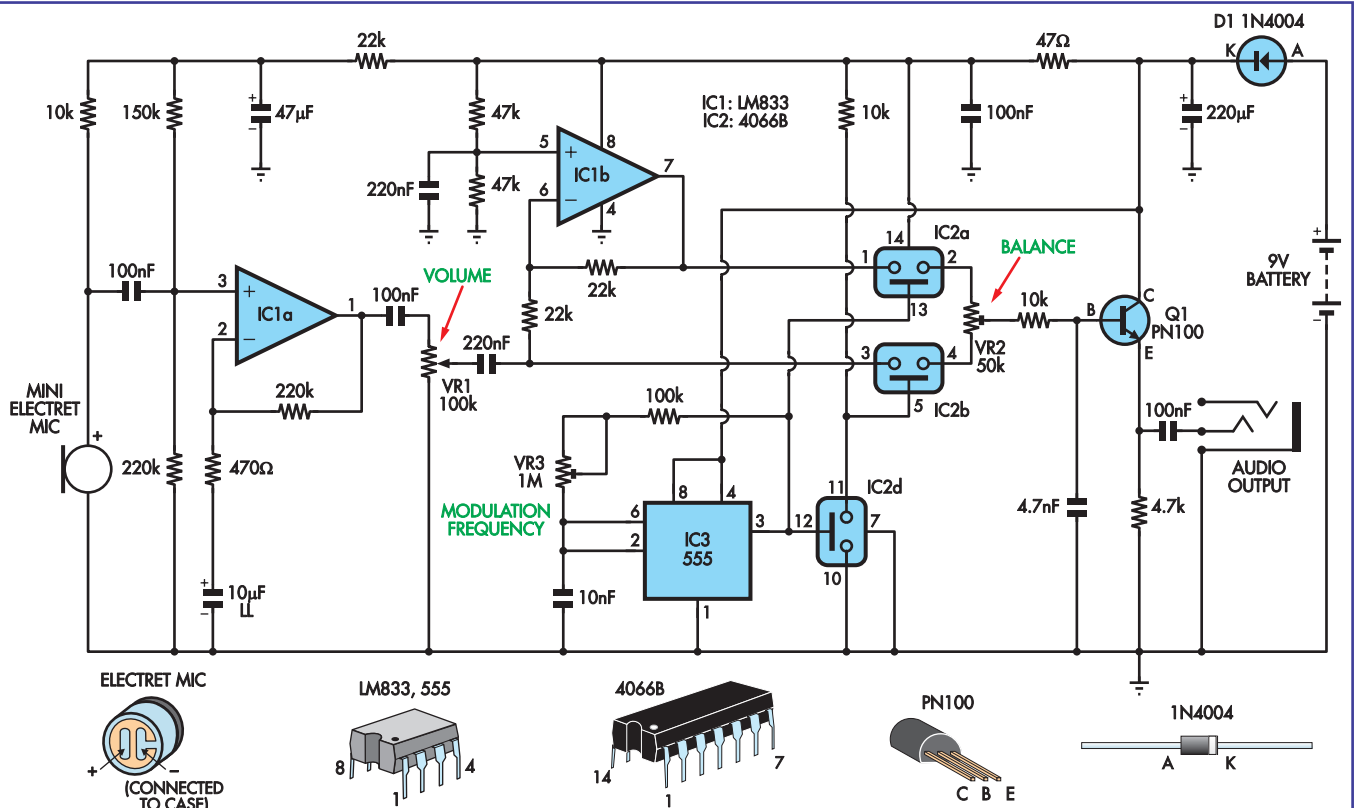
- 1 220 $\mu$ F 16V RB electrolytic
- 1 47 $\mu$ F 16V RB electrolytic
- 1 10 $\mu$ F LL RB electrolytic

- 2 220nF greencap
- 4 100nF greencap
- 1 10nF greencap
- 1 4.7nF greencap

### Resistors (0.25W 1%)

- |   |  |   |              |
|---|--|---|--------------|
| 2 | 220k   | 1 | 150k         |
| 1 | 100k   | 2 | 47k          |
| 3 | 22k  | 3 | 10k          |
| 1 | 4.7k   | 1 | 470 $\Omega$ |
| 1 | 47 $\Omega$  |   |              |
| 1 | 50k horizontal trimpot, 5mm open carbon type (VR2) |   |              |
| 1 | 1M vertical trimpot, 5mm open carbon type (VR3)    |   |              |





Here's the circuit diagram (top), the wiring diagram (right) and also a closeup photo of the top of the Voice Modulator board. Use them all, plus the photo on the opposite page as a guide when you're building up your own modulator kit.

## Tech Talk: How does it work?

The weak audio signals from the Modulator's mini electret mic are amplified by IC1a, which is one half of an LM833 dual op-amp (operational amplifier) IC. This amplifies the signals by 469 times, because of the ratio between the 220k and 470Ω resistors which form a negative feedback voltage divider. The amplification is given by  $(220k + 470\Omega)/470\Omega$ , which works out to 469.

The much stronger audio AC signals from IC1a's output pin 1 are coupled to volume control pot VR1 through the 100nF capacitor, which allows through AC but blocks DC. VR1 then allows you to adjust how much of the amplified signals is fed through to the rest of the circuit, via the 220nF coupling capacitor.

Now the signal switching which provides the project's **balanced modulator** is performed by electronic switches IC2a and IC2b, which are two sections of a 4066B quad analog switch IC. These act very much like a normal switch, except that they have no moving parts. Instead they only provide a connection between their input and output pins (pins 1 and 2, for IC2a) when their control pin (pin 13 for IC2a) is pulled to the 'high' voltage level (like +9V). When the voltage on the control pin is low (0V), the switch is 'off'. So IC2a is turned on and off by changing the DC voltage on pin 13, while IC2b is turned on and off by changing the DC voltage on pin 5.

Why do we need TWO of these switches? Because with a balanced modulator, we need to switch two versions of the input audio signal. And the two versions of the audio have to be opposite in polarity, so one goes positive when the other goes negative and vice-versa.

In this modulator we feed the original audio signal from IC1a and VR1 directly to pin 3 of switch IC2b, as you can see. At the same time we also feed it through IC1b, the second op-amp in the LM833 IC. IC1b has a lot of negative feedback, because of the 22k resistors connected between its output (pin 7) and negative input (pin 6), and in series with the same input. This means that it provides no voltage amplification at all, but simply reverses the audio signal polarity or 'inverts' them. (Which is why this kind of stage is known as a **unity gain inverter**)

As a result of this polarity inversion in IC1b, the audio signals fed to pin 1 of switch IC2a are the same signals fed to pin 3 of switch IC2b, except that they're inverted or 'upside down'. Which is what we need to make the balanced modulator work.

The modulation switching frequency is generated by IC3, which is a low cost 555 timer IC. This is connected as a free running or **astable** oscillator, which oscillates at a frequency controlled by trimpot VR3, the 100k series resistor and the 10nF capacitor connected from pins 2

and 6 to the negative line (0V). With the component values shown, the oscillator frequency can be varied between about 28Hz and 280Hz by varying VR3.

Now just as the balanced modulator switches need two different versions of the input audio signals, they also need to be controlled by two versions of the switching signal as well — one opposite in polarity to the other. So we feed the switching signal from output pin 3 of IC3 directly to IC2a's control pin 13, but at the same time we feed it to the control pin (12) of switch IC2d.

This third switch is connected as an inverter, because pin 10 is connected to the 0V line while pin 11 is connected to the +9V line via a 10k 'pullup' resistor. So when the switch is *off*, pin 11 will be at the +9V level ('high'). But when the switch is turned *on* pin 11 will be connected directly to 0V ('low'). And because this switch is being turned on and off by the switching signal from IC3, its output pin 11 will also be switching up and down — with the opposite polarity. When pin 12 is high pin 11 will be low, and vice-versa.

By connecting pin 11 to control pin 5 of switch IC2b, we therefore end up turning IC2b on whenever switch IC2a is turned off, and turning IC2b off when IC2a is turned on. So the switches are driven in the correct opposite-polarity fashion.

To complete the balanced modulator, we combine the switch output signals from pins 2 and 4 of IC2 via trimpot VR2. This is used for 'balancing' the two outputs, so we can cancel out any of the unwanted original audio signals or switching signals which may appear in the switch outputs. If this isn't done, they can be audible and make the modulator's output sound 'muddy'. Small amounts of the unwanted signals tend to appear in the switch outputs because the inverted audio signal fed to IC2a by IC1b may not be of exactly the same voltage as that fed to IC2b, and also the switching signals fed to the two switches may not have an exact 1-to-1 on/off or 'mark/space' ratio.

VR2 allows us to cancel out the two signals by varying the amount of resistance in series with the two switches, to compensate for these minor circuit imbalances.

As you can see the output signal from VR2 is fed to the base of transistor Q3, via a simple low-pass filter formed by the 10k series resistor and 4.7nF capacitor. These filter out any remaining 'switching spikes', which might be heard as a buzzing sound in the output.

Transistor Q3 is connected as an 'emitter follower', which provides current amplification to make the shifted audio signals stronger and better able to pass through a cable to your amplifier or recorder. The 100nF capacitor couples the AC output signals through to the output socket, but blocks the DC voltage which is present at the emitter of Q3.

Before you start fitting anything to the board though, it's a good idea to open up your kit and lay everything out on the bench to make sure you've received them all. (Check them off against the parts list.) Then give the PC board a good inspection as well, especially on the copper side, to make sure there are no etching faults or holes that have either been undrilled or accidentally filled when the board was solder plated.

There are no wire links to fit on this board, so you can begin assembly by fitting the four PCB terminal pins. Two of these go at the back left of the board for the battery cliplead connections, while the other two pins go at centre front for the electret mic connections. You can see clearly where they go if you refer to the wiring diagram.

Once the pins have been fitted and soldered in place, you can start fitting the fixed resistors. There are 15 of these in this project, and three each of two values: 22k and 10k. There are also two each of two further values: 220k and

47k. We suggest that you pick all of these out and fit them first, to help avoid mistakes. Then fit the five remaining resistors, which are all of different values.

Make sure you follow the wiring diagram carefully, to ensure you fit each resistor in its correct position. Resistors are not polarised, but it's still a good idea to fit them with their colour code bands all reading either west-to-east or south-to-north on the board. This makes it a lot easier to read them if you ever have to troubleshoot the board later.

Next you can fit the greencap capacitors. There are eight of these in this project, two of them with a value of 220nF and another four with a value of 100nF. So to help avoid mistakes, pick these larger greencaps out first and fit them using the wiring diagram as a guide. Then fit the two smaller greencaps.

Notice that the PC board provides extra holes for each of the greencaps, to allow for different lead spacings. Don't let this confuse you though: in each case the extra holes are

simply alternatives for **one** of the greencap's leads.

Always fit one of each greencap's leads into the hole and pad that are 'by themselves', in the group for that capacitor. The other lead should then go into one of the alternative holes, depending on that greencap's particular lead spacing.

The next parts to fit are the electrolytic caps. There are only three of these in this project, all with different values. Don't forget that these parts are electrically polarised, and must go in the board the correct way. In this project they're all fitted with the same orientation: with their positive leads towards the left, and their negative 'stripes' towards the right. The largest 220 $\mu$ F electro goes at the centre of the board and towards the back, while the two smaller electros both go at the front of the board on either side of the terminal pins.

Next fit the two trimpots, VR2 and VR3. The horizontally mounting 50k trimpot becomes VR2, which as you can see from the wiring diagram goes on the right just in front of the centre of the board. On the other hand the vertically mounting 1M trimpot becomes VR3 and mounts on the left just behind the centre of the board.

Now you can fit the 3.5mm output socket, which fits at the back right of the board between the 220 $\mu$ F electro and the 100nF greencap. You may have to straighten the lugs of the socket before they'll all go through the board holes without strain.

Now you can fit diode D1, which as you can see fits at back left and just to the front of the battery terminal pins. Make sure that its cathode (band) end goes towards the right as shown, because if you fit it the other way around the project simply won't work.

Next fit transistor Q1. This is a PN100 transistor in a 'TO-92' plastic package, which fits into the board with its flat side towards the back. You'll need to crank its two outer leads outwards and away from the centre lead, so they'll all go through the board holes without strain.

Next again comes the three ICs, which all fit with their notch/dimple ends towards the left as shown in the wiring diagram. The eight pin LM833 dual op-amp device goes near the front as IC1, while the other eight pin LM555 timer goes near the back as IC3. The larger 14-pin 4066B IC goes near the centre of the board as IC2. You'll probably have to bend each row of pins on each IC inwards towards the other row, so they'll all go through the board holes without strain.

Remember to take special care when you're handling and fitting IC2, because it's a CMOS device and therefore susceptible to damage from electrostatic charge. Touch some earthed metalwork to discharge yourself before handling the IC, and use an earthed soldering iron when you're soldering its pins to the IC pads. As usual it's also a good idea to solder supply pins 7 and 14 first, so the IC's internal protection circuitry can begin working as soon as possible.

The next component to fit is the Modulator's volume control pot VR1. This goes on the left of the board near the front, and you'll notice that the board provides holes for mounting pots of either the 16mm or 24mm size. So whichever size of pot comes in your kit, there shouldn't be any problems fitting it.

Just before you do fit the pot though, it's a good idea to cut its control spindle to length ready for the control knob. Cut it at the point about 10mm from the threaded bush using a hacksaw or small jeweller's saw, and smooth off any burrs with a small file. It's a lot easier to do this before you fit the pot to the board.

Next cut a short length (say 50mm) of two-core insulated hookup wire and bare both wires for about 3mm at each end. Then carefully solder one end of the two wires to the connection pads on the back of the electret mic insert — making sure you don't bridge the gap between the pads with solder.

Now solder the other ends of each wire to the terminal pins on the front of the Modulator board, making sure that you connect the wire from the mic pad that's connected to its metal case to the terminal pin on the right. If you make a

mistake here, the mic won't work because its internal circuitry is polarised.

The last assembly step is connecting the two wires of the battery clip lead to the terminal pins on the back of the board. Remember to connect the red wire to the pin on the left, and the black wire to the other pin. If you accidentally swap them, the Modulator won't work.

Your Modulator should now be finished, and you're just about ready to try it out. Just before you do this though, give it a careful once over to make sure you've fitted all of the components in their right positions and with the correct polarity. Also inspect the copper side of the board, just to make sure you've soldered all of the component leads and not left any dry joints or solder bridges between pads.

## Trying it out

If everything looks OK, set trimpots VR2 and VR3 to the centre of their ranges and also turn the spindle of volume pot VR1 to its fully anticlockwise position. Then connect the output of the modulator to an audio amplifier (like the amplifier in Project 9), using a screened audio cable fitted with a 3.5mm jack plug.

Now connect a 9V battery to the Modulator's clip lead, and if you turn up the amplifier's volume control you'll probably start to hear a faint buzzing or whistling sound. If so, use a small screwdriver or alignment tool to adjust trimpot VR2 carefully until this sound becomes as faint as possible. You should find that this happens at only one setting of VR2, because this trimpot adjusts the Modulator's 'balance' — and the buzzing sound becomes faint only when it is balanced.

Next begin speaking quietly into the electret mic, and gently turn up the Modulator's volume control pot VR1. As you do, you should begin to hear a frequency-shifted version of your voice, from the speaker connected to the output of the amplifier.

It should sound pretty weird, but exactly how weird it does sound can be varied by adjusting trimpot VR3 with a small screwdriver. So try different settings and see how your voice sounds at each one. You'll soon find the setting that gives the kind of 'Dalek' sounding voice you like best.

But what if your Voice Modulator doesn't seem to work as we've just described? You guessed it, that will be a sign that you've probably made some kind of mistake in wiring up the board. So disconnect the battery again and look for the cause of the problem.

You might have connected diode D1 the wrong way around for example, or swapped the battery clip lead wire connections to the terminal pins. Or reversed the polarity of the 220 $\mu$ F electro, or even fitted one of the ICs the wrong way around. Any of these things could stop the Modulator from working at all.

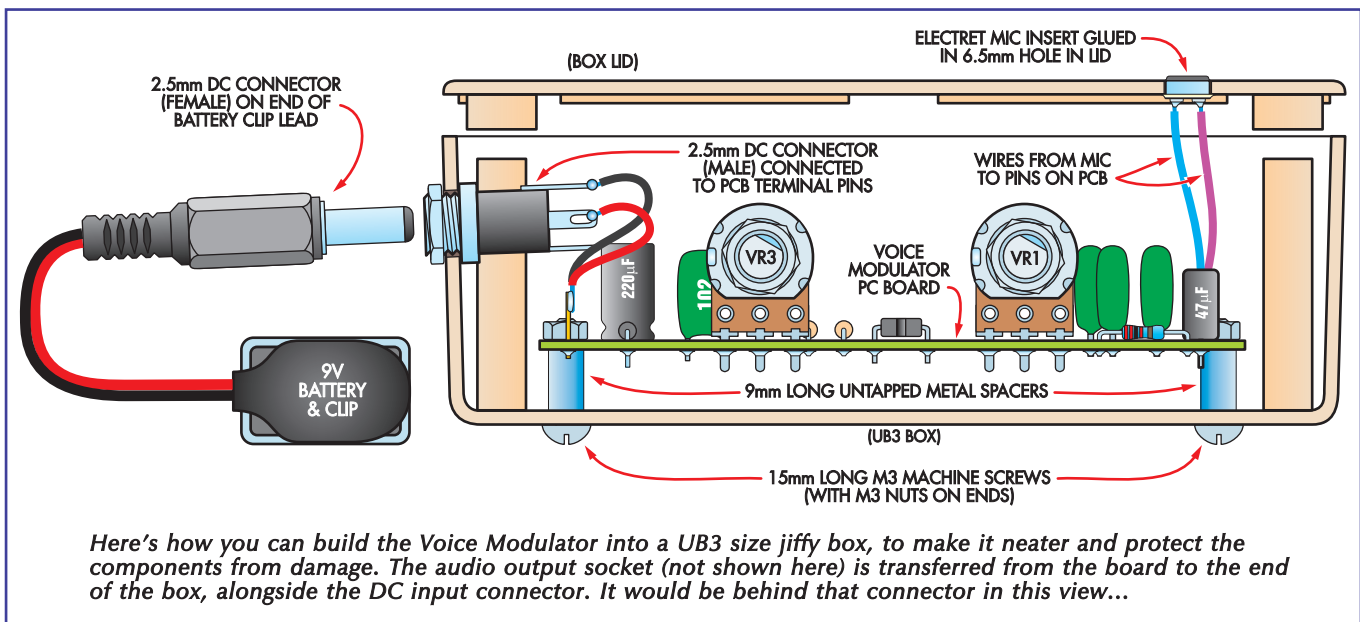
If the Modulator 'kind of works', and does let you minimise the buzzing sound using VR2, but doesn't seem to produce any frequency-shifted audio even when you turn VR1 fully clockwise and speak into the mic, this will probably be because you've connected the electret mic with reverse polarity — or else you've fitted either the 10 $\mu$ F or 47 $\mu$ F electros the wrong way around. A more remote possibility is that you've swapped around some of the resistor values.

Tracking down the problem is a matter of checking each of these things carefully one by one, until you find it. Then when you fix whatever it is, the Modulator should begin working properly as soon as you reconnect the battery.

## What to do next

If you'd like to be able to adjust the modulation frequency more easily without having to use a screwdriver, this is no problem. All you need to do is replace trimpot VR3 with a larger control pot of the same 1M $\Omega$  value. The larger pot can be of either the 16mm or 24mm size, as the board has extra mounting holes and pads to suit either. Suitable pots would be the Jaycar RP-7524 (16mm) or RP-3524 (24mm), either of





which can be fitted with a knob to match the one supplied in the kit for VR1.

You can also change the Modulator's switching frequency range if you wish, to experiment with an even wider range of frequency shifting. You do this by replacing the 10nF greencap (next to IC3) with one of higher or lower value. For example replacing it with a 4.7nF greencap will shift the switching frequency range upwards, while replacing it with a 15nF or 22nF greencap will shift the range downwards.

Perhaps you'd also like to build the Voice Modulator into a box, to make it neater and protect it from damage. This is quite easy, because the board has been designed to fit into a standard UB3 size plastic jiffy box like the Jaycar HB-6023 (grey) or HB-6013 (black). However, because this board assembly does need a fair bit of the internal space, the 9V battery can't be fitted into the box as well. It will have to be outside the box, and connected via a small DC plug and socket like the Jaycar PS-0524 (bulkhead male) and PP-0511 (line female). The PS-0524 would be mounted on the end of the box and connected to the PC board terminal pins, while the PP-0511 is mounted on the end of the battery clip lead.

The PCB assembly can be mounted inside the box using four 15mm long M3 screws (HP-0406), with four M3 nuts (HP-0425) and four 9mm long untapped metal spacers (HP-0862). The spindles of the control pots VR1 and VR3 can emerge from the box through 6.5mm holes drilled in the side (facing you in the diagram above).

Notice that if you do build the Modulator into a UB3 box in this way, the 3.5mm audio output socket will need to be removed from the PC board and mounted instead in a 6.5mm hole drilled in the end of the box (hidden behind the DC connector in the diagram) using the knurled nut provided. The three connections between the socket and the PC board can be made using short lengths of insulated hookup wire, bared about 3mm at each end and soldered to the socket lugs and PCB pads.

When the Modulator is built into a UB3 box like this, the electret mic insert can be either glued into a 6.5mm hole drilled into the box lid, as shown, or else glued into the end of a short length of 6mm ID (internal diameter) brass tubing, to make a separate microphone housing. In this case you'd also fit it with a length of screened microphone cable (say two metres long), and connect the other end of the cable to the input of the Modulator via a small plug and socket — with the plug on the end of the cable and the socket fitted into the end of the box (the right-hand end above).

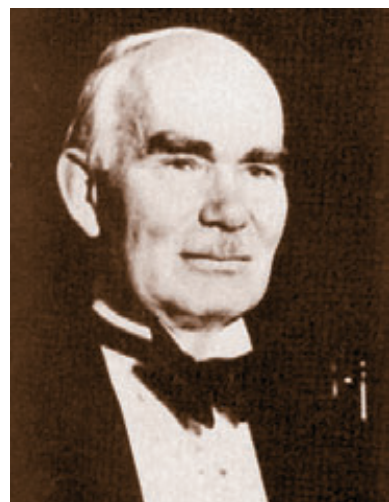
You could use either the PP-0114 3.5mm jack plug and matching PS-0122 socket, or the PP-0240 RCA plug (red) and matching PS-0257 socket. In either case the socket lugs would be connected to the input terminal pins on the Modulator's PC board via a couple of short lengths of insulated hookup wire, like those supplied in the kit to connect the electret mic insert to the board directly. Just make sure you keep the mic connection polarity right.

## Meet the Pioneers of Electronics:

# Lee de Forest

Soon after he had perfected the incandescent lamp in 1883, Thomas Edison noticed that a metal electrode placed inside such a lamp became negatively charged. He didn't follow this up, but in 1904 the British scientist John Ambrose Fleming exploited this 'Edison effect' to develop the first thermionic valve — the **diode**, which he used as a radio detector. Then in 1906, American scientist Dr Lee de Forest developed the 'audion' or **triode** valve, by adding a wire spiral 'grid' between the hot cathode and metal anode. By varying the negative voltage on this grid he could control the number of electrons reaching the anode, and hence achieve amplification. In many ways this was the beginning of electronics, as valves became widely used in radio transmitters and receivers, audio amplifiers and many other devices.

A prolific inventor, De Forest went on to develop one of the first systems for producing 'talkies' — sound movies. He died in Hollywood, California in 1961.



## Project 18:

# A 'Knightrider' Scanner

Here's another novelty project: a simple circuit that makes a row of LEDs glow in sequence back and forth, like the lights on the front of the computerised car in the old TV series *Knightrider* when it was 'scanning'. It's eye catching, it's easy to build, and you can vary the scanning speed if you wish.

### What does it do?

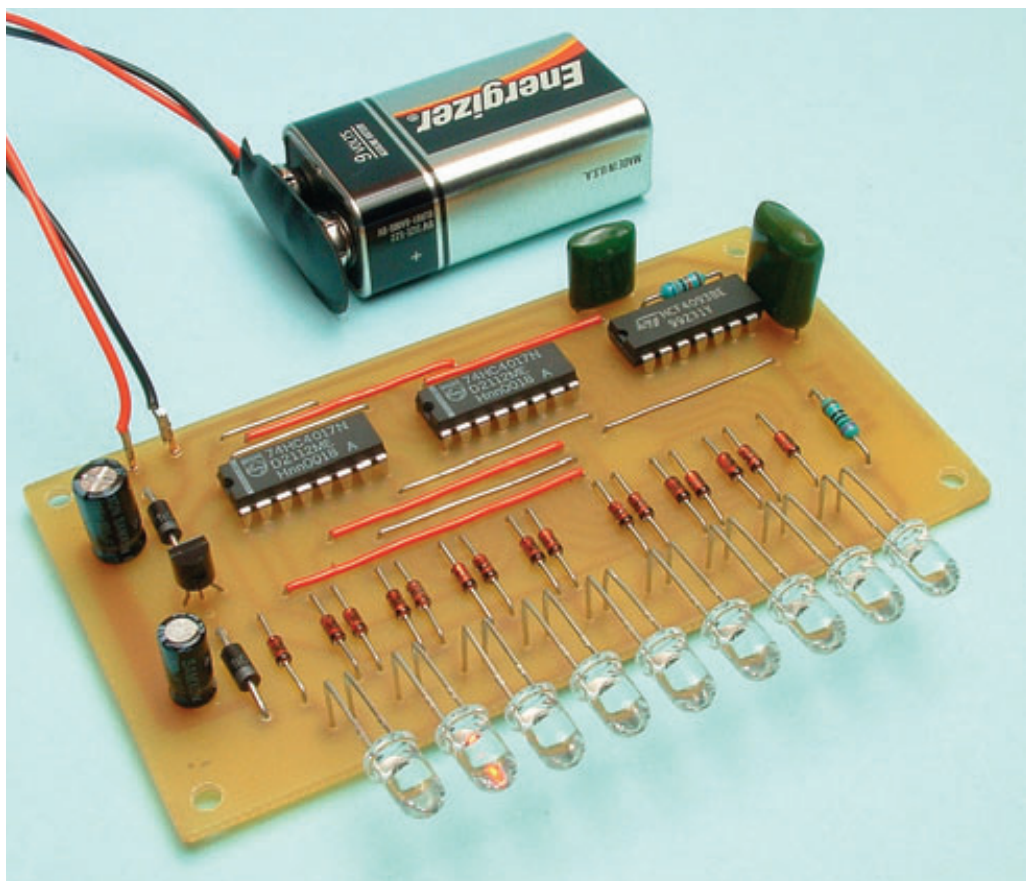
Back in the dim dark ages of TV, there was a series about a computerised car called Knight 2000 or 'Kitt'. This had a row of red lights along the front, which glowed in sequence back and forth when the car was supposedly 'scanning' where it was going. A load of nonsense, of course, but the glowing light scanning from left to right and then back again was certainly eye catching. The same effect was used to represent the 'eyes' of robots in sci-fi movies, as they supposedly watched out for enemies.

The little Knightrider Scanner we describe here produces the same effect, in a row of nine bright red LEDs (light emitting diodes). The LEDs glow in sequence from left to right and then back again, and they keep doing this as long as the project is connected to the 9V battery.

The scanning takes about one second for each back-and-forth cycle, but this can be varied quite easily if you wish. We explain how to do this later, in the What To Do Next section.

### Putting it together

All of the parts used in the Knightrider Scanner are mounted on a small PC board, apart from the 9V battery which provides it with power. The board is coded SHRTC218 and measures 102 x 55mm.



Before you start assembling the project, though, it's a good idea to open up the kit and lay out all the parts so you can make sure you have everything. You can do this by checking them off against the parts list. While you're at it, give the PC board a careful inspection (especially on the copper side) just to make sure that there are no etching 'glitches' or undrilled holes.

If everything seems to be in order, you can begin assembling the project by fitting the two PC board terminal pins. As you can see from the wiring diagram these go at the back of the board on the left, for connecting the battery clip lead wires.

Next fit the wire links. There are quite a few of these in this project — nine of them, to be exact. They can all be made from lengths of insulated hookup wire if you wish, although some of them can easily be made

## The parts you'll need for this project:

- |   |   |    |                                      |
|---|---|----|--------------------------------------|
| 1 | PC board, code SHRTC218, 102 x 55mm                         | 9  | 5mm clear bright LEDs (LED1-9)       |
| 1 | 9V battery, 216 type  | 16 | 1N4148/1N914 silicon diodes (D1-D16) |
| 1 | Battery clip lead to suit                                   | 2  | 1N4004 silicon diode (D17,D18)       |
| 2 | PCB terminal pins, 1mm dia.                                 |    |                                      |
| 2 | Short lengths of tinned and insulated hookup wire for links |    |                                      |
| 1 | Small pack of resin-cored solder                            |    |                                      |

### Semiconductors

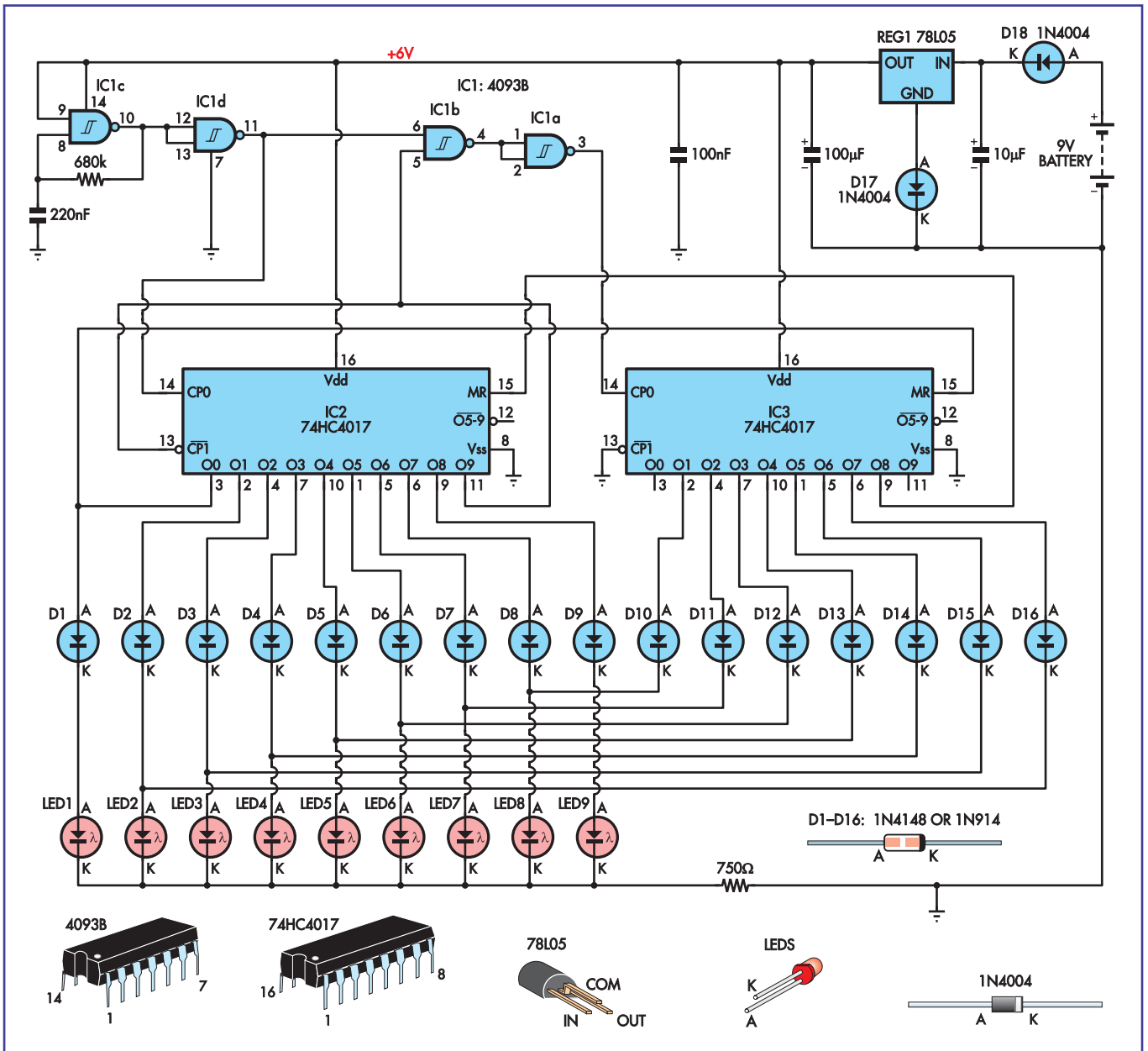
- 1 4093B quad Schmitt NAND (IC1)
- 2 74HC4017 HCMOS counters (IC2,IC3)
- 1 78L05 +5V regulator (REG1)

### Capacitors

- 1 100µF 10V RB electrolytic
- 1 10µF 16V RB electrolytic
- 1 220nF greencap
- 1 100nF greencap

### Resistors (0.25W 1%)

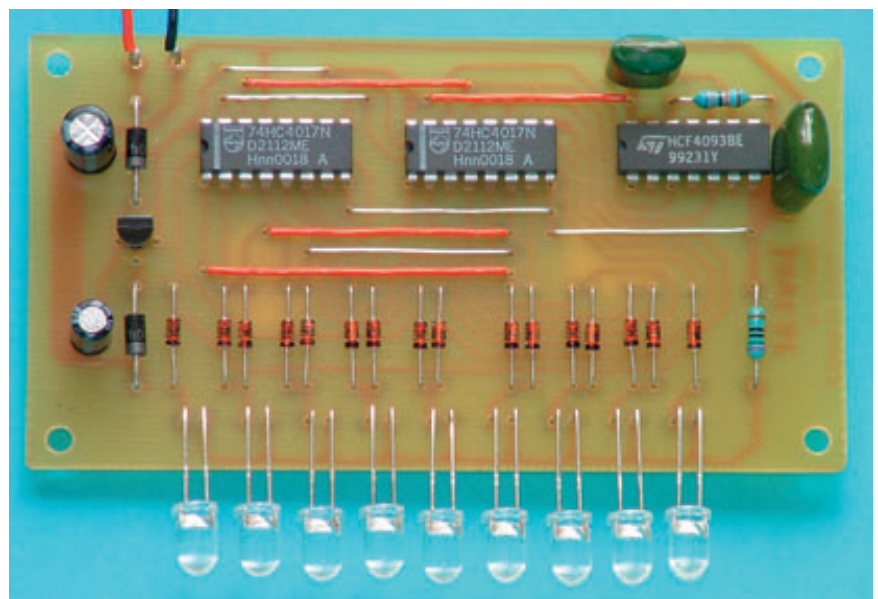
- 1 680k
- 1 750Ω



Here's the circuit diagram (above) for the Knight Rider Scanner, plus a closeup photo of the top of the PC board assembly (right). Use both of them, along with the photo opposite and the wiring diagram overleaf, as a guide when you're building up your own Scanner.

using lengths of tinned copper wire instead as you can see from the photos. The main thing is to use insulated wire for every alternate link where a number of them run in parallel and fairly close to each other. This should be enough to prevent them ever touching one another and causing trouble.

When the links are all fitted and their ends soldered to their pads, you can fit the resistors. There are only two of these in the project, one with a value of 680k which goes at back right, and the other of 750Ω which goes at front right. Be careful not to swap them, because this will stop





## Tech Talk: How does it work?

The circuit of the Knightrider Scanner probably looks a bit complicated, but its operation isn't hard to understand if you break it down into sections.

First, as you've probably guessed, there has to be an oscillator somewhere to produce a stream of 'clock' pulses which set the Scanner's scanning speed. This oscillator is up at the top left corner of the circuit diagram, using gate IC1c. As you can see this is a standard **astable** or free-running oscillator circuit with a 680k feedback resistor and a 220nF capacitor from input pin 8 to ground.

The pulses produced by IC1c are then passed through gate IC1d, connected here just as an inverter and buffer. They are then fed directly to the clock input of IC2 (pin 14), and also to the same input of IC3 via gate IC1b and gate/inverter IC1a. IC2 and IC3 are 74HC4017 counters.

The reason for feeding the pulses to both IC2 and IC3 is that they are connected together to form a **modulo-16 counter** — that is, a counter which counts up to 16 and then drops back to 1 to count over again. (IC2 and IC3 are basically modulo-10 counters, but they can be made to work together as a modulo-16 counter by connecting them as we've done here, using gate IC1b and inverter IC1a.)

So the part of the circuit we've talked about so far produces a stream of clock pulses, and then feeds them

to a modulo-16 counter. As the counter counts the pulses, its 16 outputs (O0-O9 of IC2, O1-O8 of IC3) therefore go high (+9V) one at a time in sequence, and then the process repeats itself.

We use diodes D1-D16 to change this repeated counting up to 16 sequence into an up-and-back sequence of glows by the LEDs. This is done simply by connecting the diodes so the LEDs glow in the 'up' direction from the outputs of IC2, but then in the 'down' direction from the outputs of IC3. As you can see diodes D1-D9 provide the 'up' drive currents for LED1-LED9, while D10-D16 provide the 'down' drive currents for LED8-LED2. (Notice that LED1 and LED9 only glow once in each up-down cycle, while the others glow twice.)

Because only one LED conducts current and glows at any instant, we can use a single resistor to limit the current in them all. This is the 750Ω resistor connected between their common cathodes and ground (the negative line).

Since the LEDs are being driven directly from the outputs of IC2 and IC3, via diodes D1-D16, we need to run the two counter ICs from a reasonably high voltage so the LEDs glow brightly. However the maximum supply voltage that can be used for the 74HC4017 devices is 6V, so they can't be run directly from the 9V battery. Instead we use REG1, a 78L05 5V voltage regulator, with diode D17 connected in series with its GND lead. This boosts the regulator's output to very nearly +6V, so IC2 and IC3 are happy while the LEDs glow quite brightly.

the Scanner's LEDs from glowing at all.

Next after the resistors, fit the greencap capacitors. Again there are only two of these, and they both go on the right near the back of the board. The larger 220nF greencap goes on the far right, while the smaller 100nF greencap goes

about 20mm to the left and at the very back.

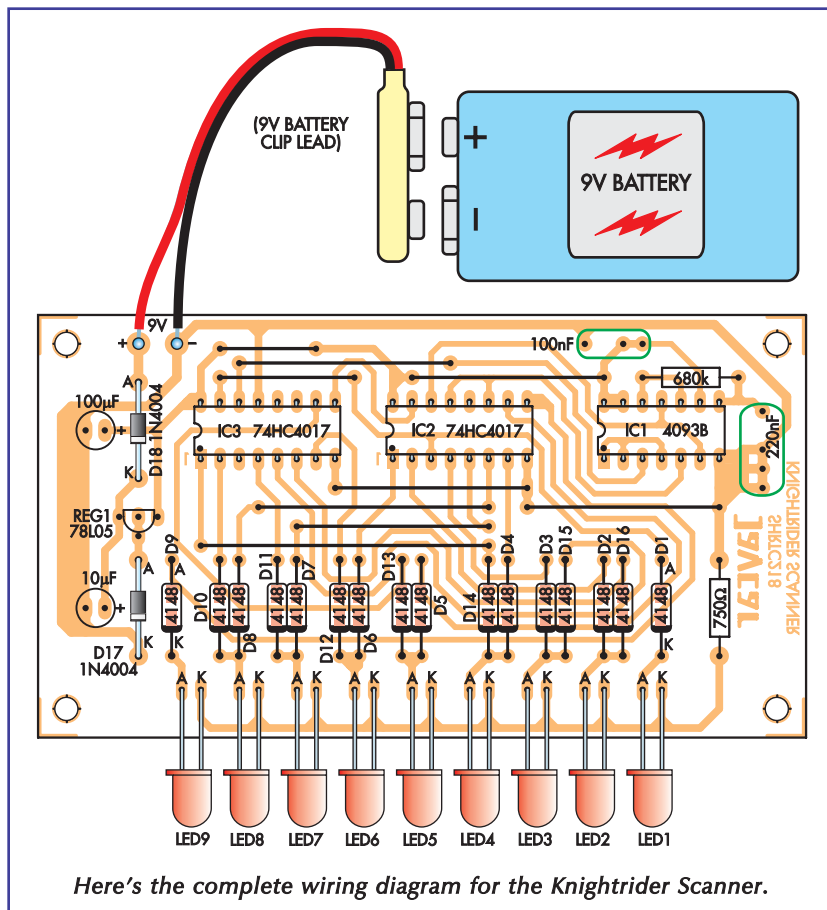
Now fit the electrolytic caps, and there's again only two of these. They're polarised, of course, and they both fit at the left-hand end of the board with their negative 'stripe' sides towards the left and their positive leads on the right. The larger 100µF electro goes towards the back, while the smaller 10µF electro goes down near the front.

Next fit the two 1N4004 power diodes, which are in plastic packages and become D17 and D18. As you can see from the wiring diagram these fit just to the right of the two electros, with their cathode 'band' ends both towards the front. Make sure you don't fit either of these the wrong way around, because this can make the Scanner either not work at all, or damage the ICs.

Next you can fit the sixteen 1N4148 signal diodes, which are in a smaller glass package. These diodes become D1-D16, which are all in a row near the front of the board — between D17 and the 750Ω resistor. Notice that they should all be fitted with their cathode band end towards the front, just like diodes D17 and D18.

Next fit the 78L05 regulator REG1, which comes in a small TO-92 plastic package just like a transistor. This fits on the left-hand end of the board in the centre, between D17 and D18. Make sure you fit it with its flat side towards the rear, as shown in the wiring diagram. You'll probably have to crank its two outer leads away from the centre lead, so they'll all go through the board holes without strain.

Now you can fit the three ICs, which all go in a row near the back of the board. They're all orientated with their notch/dimple ends towards the left, to make things easier. The 4093B device goes on the right and becomes IC1, while the two 74HC4017 devices go in the centre and on the left and become IC2 and IC3.



Here's the complete wiring diagram for the Knightrider Scanner.

You will probably need to bend the rows of pins on each IC carefully inwards towards each other, so they'll all pass through the board holes without strain. But remember that all three ICs are CMOS devices, and susceptible to damage from electrostatic charge. So discharge yourself by touching some earthed metalwork before handling the ICs, and of course solder their pins to the board pads using an earthed soldering iron. Also try to solder their supply pins first (pins 7 and 14 of the 4093B, pins 8 and 16 of the 74HC4017's), so their internal protection circuitry can begin working as soon as possible.

The last components to fit are the nine high-brightness LEDs which, as you can see, go in a row along the front of the board. They are all orientated with their flat side and shorter cathode (K) leads towards the right.

So that the LEDs all emit their light towards the front of the board, their leads are all bent down by 90° about 14mm away from the LED's body. It's easier to do this neatly if you bend the leads before you fit the LEDs to the board; then all you have to do is solder each one's leads to the pads underneath while holding the LED and the horizontal sections of the leads about 8mm above the top of the board. When you finish, all nine LEDs should be neatly in line.

All that should be left now to finish building the Scanner, is to solder the ends of the battery clip lead wires to the terminal pins at the back of the board. Make sure you solder the red wire to the pin on the left, and the black wire to the other pin.

Just before you congratulate yourself on finishing the project, though, give it a careful inspection to make sure you've fitted all of the components in the correct positions and with the right orientation. You might want to check the copper side of the board too, to make sure you haven't forgotten to solder any of the component leads — or left a dry joint, or even a bridge of solder shorting between two pads or tracks.

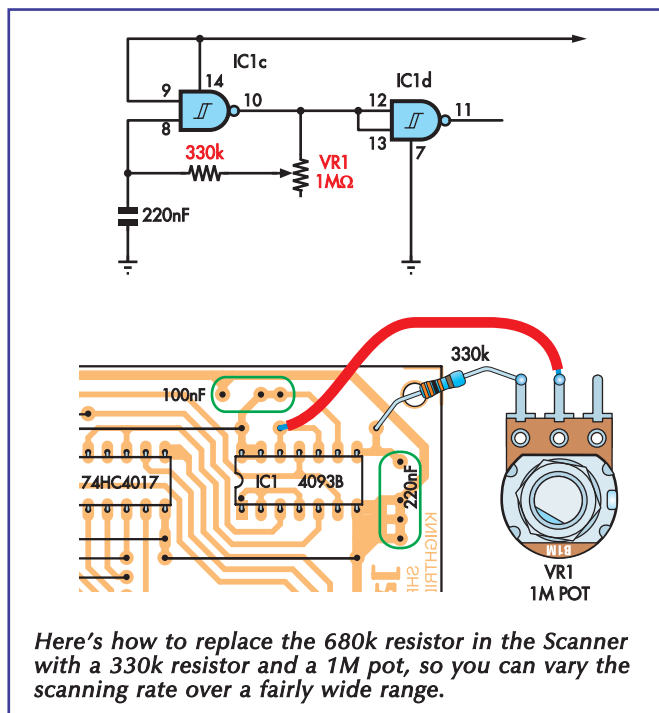
## Trying it out

If everything seems OK, connect up a 9V battery to the clip lead. You should immediately be rewarded by seeing LED1 glow, and then LED2, LED3 and so on. When the 'glow' reaches LED9 it should reverse and swing back again towards LED1. Once it returns to LED1 it should reverse again and move back towards LED9, repeating this back-and-forth scanning over and over as long as the battery is connected.

That's all there is to it — so if this is what happens with your scanner, it's working just as it should.

OK, but what do you do if *your* scanner doesn't, and just sits there as dead as a dodo with no LEDs glowing at all? You can probably guess what this means: yes, that's right, you must have made some kind of mistake in wiring it up.

Perhaps you've accidentally connected the battery clip



lead wires the wrong way around, or fitted diode D18 backwards. Or forgotten to solder one of the leads of D18, or of REG1. Or perhaps you've made a dry joint on one of these leads, so they're really not making a good connection.

If LED1 just glows steadily, without any attempt to 'pass' the glow along to any of the other LEDs, you may have made a dry joint on one of the pins of IC1, or the leads of the 680k resistor or 220nF capacitor. On the other hand if most of the LEDs seem to be 'passing the glow' correctly except one or two, the odds are that you've connected those LEDs in backwards — or some of the 1N4148 diodes in back to front...

Depending on your Scanner's symptoms, then, the idea is to disconnect the battery and track down the fault by checking each of these possible mistakes in turn. Then when you do find the problem and fix it, your Scanner should spring into life as soon as you connect the battery again.

## What to do next

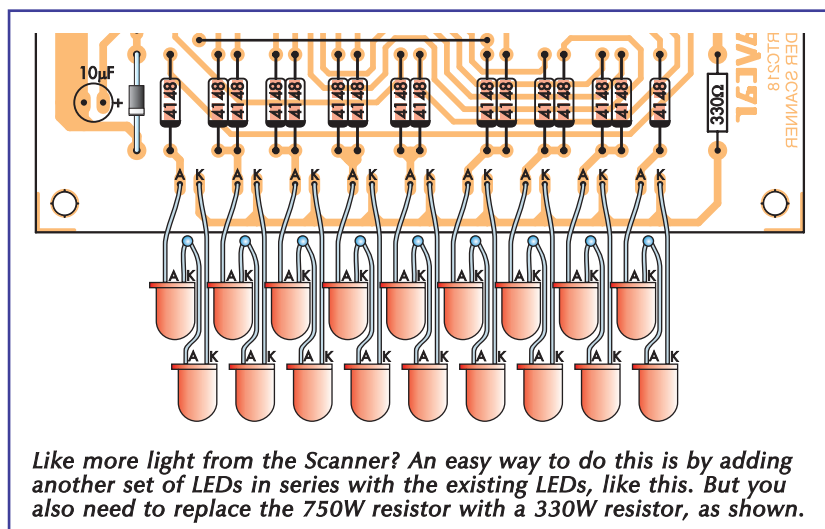
If you'd like the Knightrider Scanner's LEDs to pass the glow back and forth faster or more slowly than the speed they do, this is easy to change. All that's needed is to replace the 680k resistor with one of a different value.

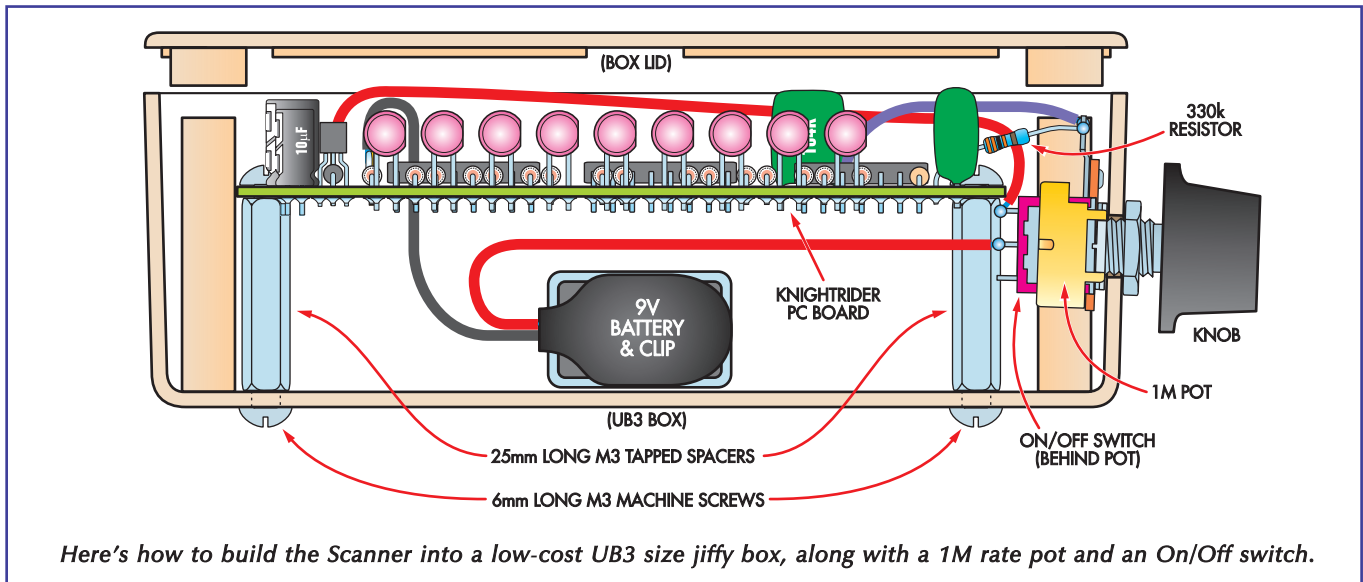
For example, to make the scanning faster, you can replace the resistor with one with a value of say 470k, 390k or even 330k. On the other hand replacing it with a higher value resistor like 820k or 1M will slow down the scanning.

If you'd like to be able to adjust the scanning rate easily at any time, you can remove the 680k resistor from the board and run some wires out to a 1M pot and a 330k resistor connected in series, as shown in the small diagram. Then you can vary the scanning rate over a wide range simply by adjusting the pot.

The 1M pot you use for this can be of either the 16mm or 24mm size, like the Jaycar RP-7524 or the RP-3624. The series 330k resistor can be a standard 0.25W metal film type like the Jaycar RR-0632.

If you'd like the Scanner to produce more light output, this can be done fairly easily by





connecting another set of LEDs in series with the original LEDs — in other words, replace each LED with two connected in series. The additional LEDs should be of either the same type as we provide in the kit (Jaycar type ZD-1796) or else the even brighter ZD-1777.

If you do connect a second set of LEDs in series, make sure that the new LEDs are connected with the same polarity. This means that the junction of the two LEDs in each position should be cathode (K) to anode (A), as shown in the diagram. Note too that when you add the additional LEDs, the 750Ω series resistor needs to be replaced with a 330Ω resistor (Jaycar RR-0560) to achieve the same LED current level.

You might also want to build your Knightrider Scanner into a plastic box, especially if you add an off-board pot to vary the scanning rate. Building it into a box will make it much neater, and at the same time protect the components from damage.

It's quite easy to build the scanner into a standard UB3 size jiffy box, so the logical box to use would be one like the

Jaycar HB-6023 (grey) or HB-6013 (black). Choose the colour you want.

The way to build the Scanner into a UB3 box is shown in the diagram above. As you can see the PC board assembly is supported inside the bottom of the box on four 25mm long spacers tapped with M3 threads. This allows the spacers to be fixed inside the box using four 6mm long M3 machine screws, with another four of the same screws used to attach the board to the tops of the spacers.

There's room for the 9V battery under the board, and also room for a 16mm 1M pot to be mounted in the right-hand end of the box so you can adjust the scanning rate without having to open it up. In fact there's room as well to fit a small toggle switch (like the Jaycar ST-0335) at the same end of the box next to the pot, so you can switch the scanner on and off just as easily.

Needless to say the long side of the box (not shown in the diagram) needs to have a row of nine 5.5mm diameter holes for the LEDs to protrude through and be visible.

## Meet the Pioneers of Electronics:

# Edwin Howard Armstrong

Born in New York in 1890, Edwin Armstrong obtained a degree in electrical engineering at Columbia University and put his knowledge to work in World War 1, when he was a captain in the Signal Corps stationed in France. He developed the regenerative radio receiver in 1912, and then conceived and built the first **superheterodyne** radio receiver in December 1918, receiving a patent for this in 1920. His 'superhet' principle, involving the beating or heterodyning of signals down to a lower frequency so they could be better amplified, has been the basis of all high performance radio receivers since then.

In 1920 Armstrong also conceived and built the first **super-regenerative** radio receiver, which became used in early VHF and UHF radio receivers. But his next really outstanding contribution to radio and electronics came in 1935, when he announced the development of FM (frequency modulation) radio broadcasting – offering higher fidelity and a much lower noise level than AM (amplitude modulated) broadcasting.

Armstrong spent more than US\$1 million developing high quality equipment suitable for FM, and in 1939 his first FM broadcasting station went on the air in the VHF spectrum. The public were so delighted with FM that by November of the same year, 19 more FM stations were operating in the USA. FM broadcasting grew rapidly in many countries, although it only began in Australia in 1974.

Depressed following a court case in 1954, Armstrong committed suicide by jumping from the window of his New York apartment.





## Project 19:

# Resistance/Capacitance Bridge

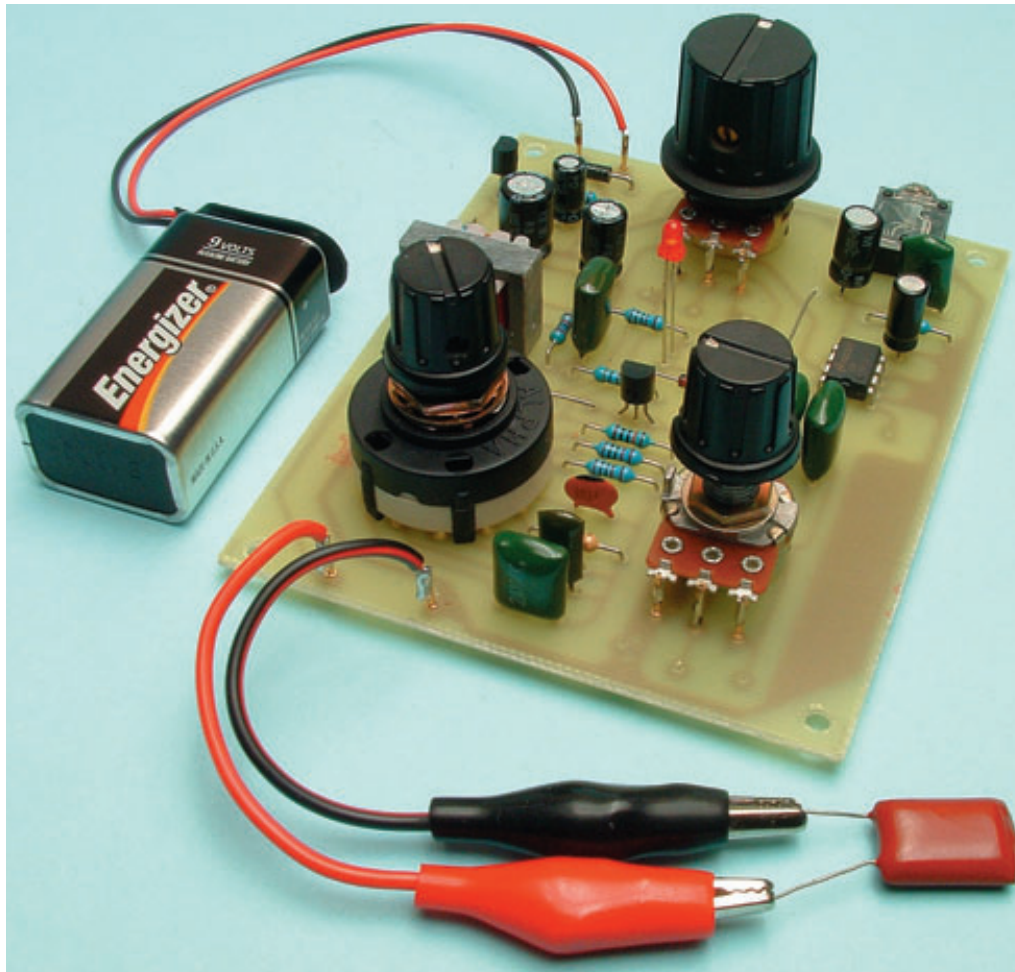
One of the handiest test instruments in electronics is an R/C Bridge, which lets you measure the value of resistors and capacitors over a fairly wide range. Here's a simple bridge that you can build for yourself, to measure components in your own workshop.

### What does it do?

A Resistance/Capacitance or 'R/C' Bridge is an instrument which allows you to measure the value of resistors and capacitors, by comparing them against 'reference' resistors and capacitors of known value. This sort of instrument is called a **bridge** because it makes the measurement by balancing the value of the unknown component against that of the reference, and works out the ratio between the two — a bit like an old-time 'weighbridge', used to weigh trucks and other vehicles. Electrical measurement bridges have been used for about 150 years.

The build-it-yourself bridge we're presenting here can be used to measure resistance values from below 10Ω (ohms) up to over 1MΩ (1,000,000Ω), and capacitor values from below 10pF (picofarads, or a million-millionth of a farad) up to over 1μF (microfarad, or a millionth of a farad).

It does this by comparing the values of the 'unknown' components against one of eight reference components (four resistors and four capacitors), at a frequency of about 1kHz (1000Hz). The measurement is carried out by turning a 'balance' pot (potentiometer) to adjust the bridge's balancing ratio, and then listening to the bridge's output with a pair of headphones. The sound heard in the 'phones dips down to a minimum or **null** when you have adjusted the



## The parts you'll need for this project:

- 1 PC board, code SHRTC219, 81 x 102mm
- 1 Mini audio transformer 1k/8 ohms (T1)
- 1 Single pole 8 position rotary switch (S1)
- 1 3.5mm stereo phone jack, PC board mounting
- 1 9V battery, 216 type
- 1 Battery clip lead to suit
- 10 PCB terminal pins, 1mm dia.
- 3 Small control knobs
- 2 Crocodile test clips
- 2 Short lengths of hookup wire
- 1 Small pack of resin-cored solder

### Semiconductors

- 1 LM386N amplifier (IC1)
- 1 PN100 NPN transistor (Q1)
- 1 PN200 PNP transistor (Q2)
- 1 3mm red LED (LED1)
- 1 1N4004 silicon diode (D1)
- 1 1N4148/1N914 silicon diode (D2)

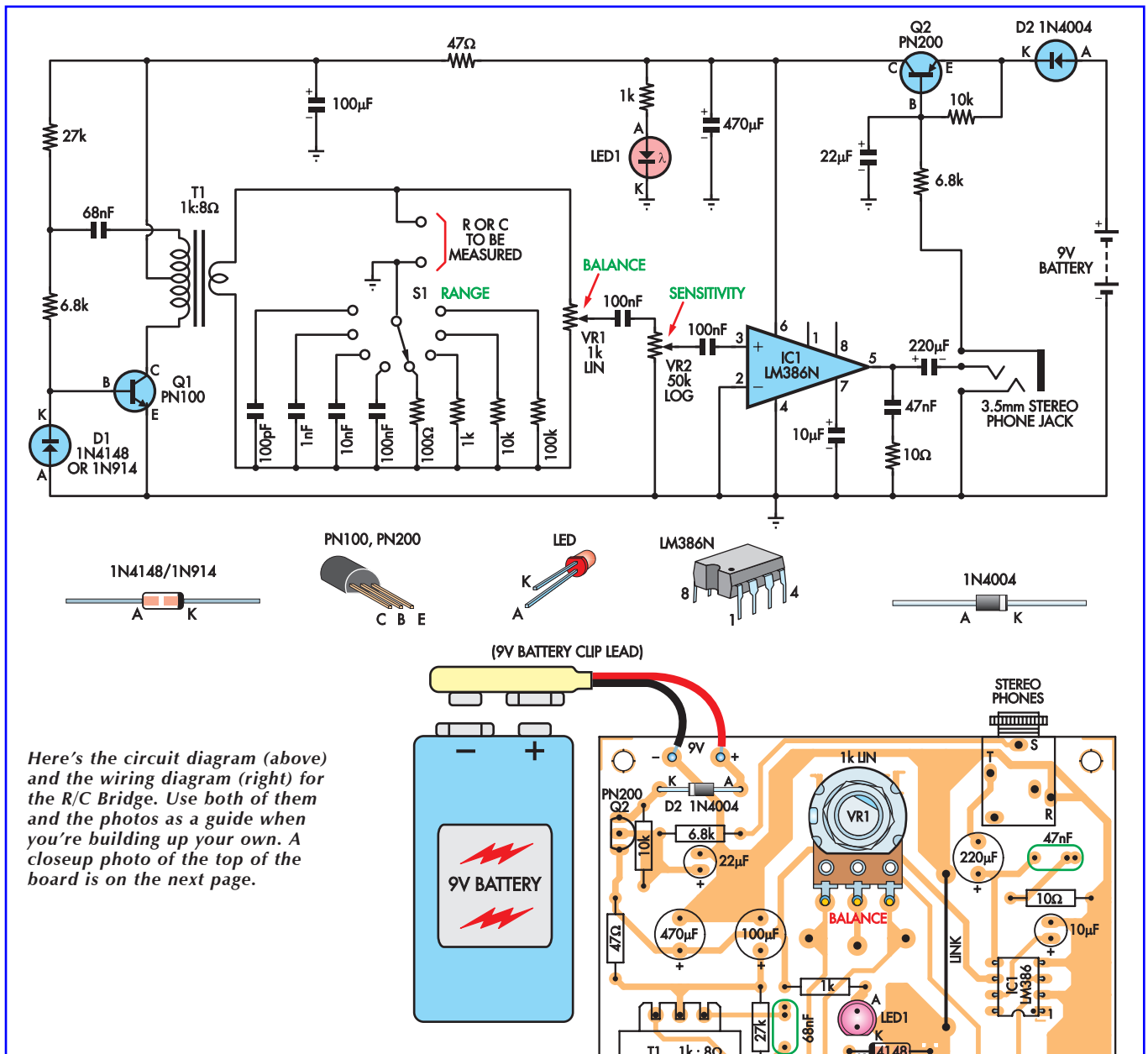
### Capacitors

- 1 470μF 16V RB electrolytic
- 1 220μF 16V RB electrolytic
- 1 100μF 16V RB electrolytic
- 1 22μF 16V RB electrolytic
- 1 10μF 16V RB electrolytic

- 3 100nF greencap
- 1 68nF greencap
- 1 47nF greencap
- 1 10nF greencap
- 1 1nF disc ceramic
- 1 100pF disc ceramic

### Resistors (0.25W 1%)

- |   |   |   |      |
|---|---|---|------|
| 1 | 100k                                      | 1 | 27k  |
| 2 | 10k                                       | 2 | 6.8k |
| 2 | 1k  | 1 | 100Ω |
| 1 | 47Ω                                       | 1 | 10Ω  |
| 1 | 1k linear potentiometer, 24 or 16mm (VR1) |   |      |
| 1 | 50k log potentiometer, 24 or 16mm (VR2)   |   |      |



balance pot for the exact ratio needed to balance the bridge, and when this happens you can easily tell the value of your component from the setting of the balance pot.

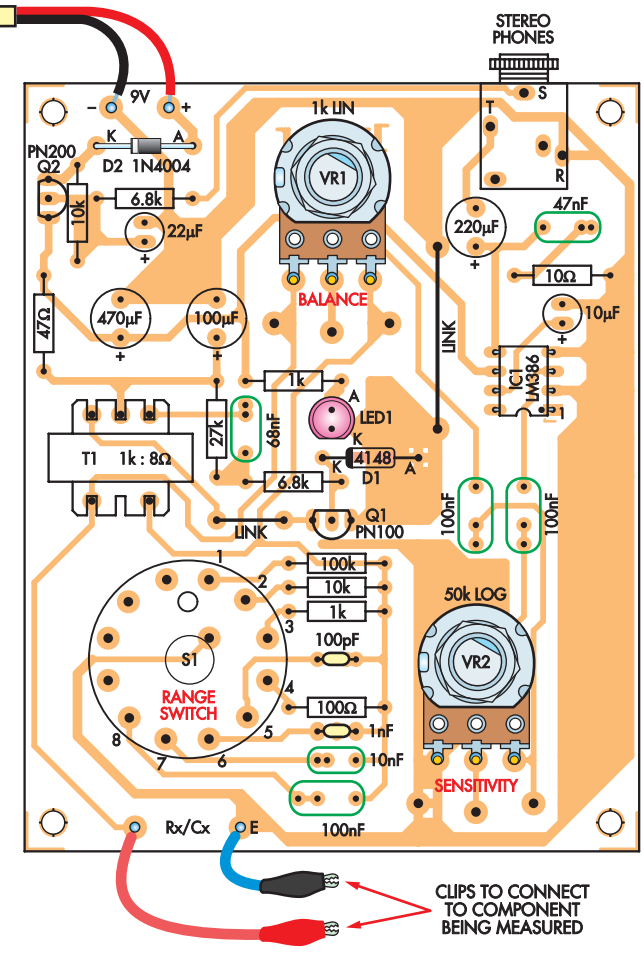
We'll tell you more about 'driving' the bridge later, in the Trying It Out section.

## Putting it together

All of the parts used in the Bridge mount on a small PC board — apart from the battery which powers it, the headphones you use to listen for the null and the unknown component you're measuring. The board measures 102 x 81mm and is coded SHRTC219.

Before you start to assemble the kit, open it up and lay the parts out so you can make sure you have everything by checking against the parts list. At the same time give the copper side of the board a quick inspection, to satisfy yourself that there are no etching 'glitches' or undrilled holes. It's better to find these and fix them now, rather than later on.

Start the actual assembly by fitting the 10 terminal pins to the PC board. Two of these go near the back of the board on the left, to take the battery lead connections. Another two go



down at the front of the board on the left, to take the test leads — or wires to the test lead sockets. The remaining six pins go in two groups of three, because they're used to make

the connections for the Balance pot VR1 and the Sensitivity pot VR2. So one group goes at centre rear, while the other group goes at front right. But in either case there are two options when it comes to fitting the pins in the board holes, because this depends on whether your kit comes with pots of the '16mm' or '24mm' size.

Because the availability of these pots can vary, we've made the board so you can use either the 16mm or 24mm size in either position. So it's a matter of checking which size of pot you've received in the kit for VR1 and VR2, and then fitting the terminal pins in the matching holes. In the photos and wiring diagram we show them fitted in the closer-spaced holes, to suit 16mm pots. However if your kit provides 24mm pots instead, simply fit the pins in the wider-spaced holes just in front of these.

Don't try to fit the pots themselves at this stage, though. They're best left until later.

Next fit the two wire links used in the Bridge. There's a long one running 'South-North' on the right of the board near the back, and a much shorter one running 'East-West' just to the left of the centre of the board. They shown quite clearly in the wiring diagram. Both links can be made from tinned copper wire, as there's no real risk of them contacting anything else.

Now you can fit the small 3.5mm stereo jack socket, which fits at the back of the board on the right. This has five lugs underneath it in an asymmetrical pattern, and these may need to be straightened slightly before they'll all go through the matching board holes without strain. Push the socket

gently down against the board before you solder the lugs to the pads underneath.

Next you can fit the fixed resistors. There are 11 of these in this project, with three groups of two resistors having the same values: 1k, 6.8k and 10k respectively. To help avoid mistakes it's a good idea to pick these 'twins' out and fit them into the board first, using the wiring diagram as a guide to where they go. Then you can fit the remaining single value resistors.

Resistors are not electrically polarised, so you don't have to worry about polarity. But you might still want to fit them all with their colour codes reading either South-North or East-West respectively, so they'll be easier to read later on.

After the resistors come the smaller non-polarised capacitors. There are two disc ceramics (100pF and 1nF), which go in the centre of the board near the front. There are also six greencaps, three with the same value of 100nF and the other three with different values (68nF, 47nF and 10nF). Use the wiring diagram as a guide when you're fitting each of these, and perhaps fit the three 100nF greencaps first to avoid mistakes. The board provides additional holes in each position to suit greencaps with different lead spacings.

Next fit the electrolytic capacitors or 'electros'. There are five of these in all, each with a different value. They're all polarised, so make sure you fit each one the right way around as shown in the wiring diagram. In this project they're all orientated so their positive leads are towards the front of the board, and their negative stripes facing the rear.

Now you should be able to fit T1, the small audio transformer. You'll find that this has five wire leads, two of which emerge from one side of the transformer's core and three from the other side. Use the leads to work out which way around the transformer is fitted to the board, but you'll probably have to straighten them all carefully before they'll pass down through the board holes for soldering. The transformer is attached to the board by these leads, so you'll have to hold it in place by hand before you solder them to the board pads.

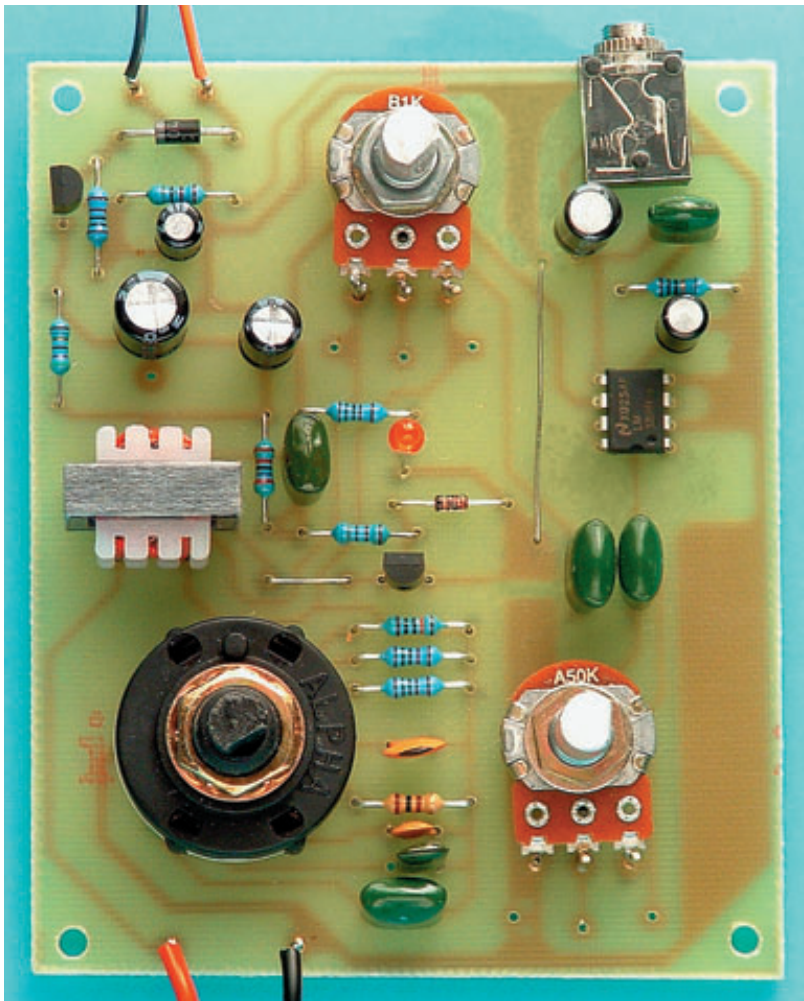
You should now be ready to fit rotary switch S1, but before you do it's a good idea to cut its control spindle to about 10mm long — i.e., just long enough to take a small knob. Cut the spindle using a small hacksaw or jeweller's saw, and smooth off any burrs with a small file.

The switch is fitted to the board with its moulded locating spigot in the '12 o'clock' position (i.e., towards the rear), as shown in the photo at left. You may again have to straighten some of the leads on the back of the switch though, before they'll all go through the board holes without strain.

These switches are capable of providing any number of positions between 2 and 12. They're 'programmed' for the number of positions you want by orientating a washer with a 'stop pin'. In this case we want the switch to have eight positions, so you'll need to set it to do this.

Don't panic, because it's easy. Just unscrew the large nut from the threaded mounting bush at the front of the switch, and remove both the nut and the lockwasher under it. You'll find the stop pin washer directly underneath, so use a small screwdriver to prise this up as well. Underneath you'll see a circle of tiny slots in the plastic body of the switch, with numbers moulded between them. Find the slot between the numbers '8' and '9', because you'll soon have to refit the stop washer with its small pin passing down into this slot. This will set the switch for eight positions.

Just before you refit the stop washer though, turn the switch spindle by hand (or gently with a pair of pliers) as far as it will go in the anticlock-



Here's a closeup photo of the top of the Bridge's PC board, showing where the components go and their orientation. Note that although 16mm pots are shown here for VR1 and VR2, the PC board will also take 24mm pots.



## Tech Talk: How does it work?

Measurement bridges like this one work by comparing one component's value with another. Their ratio is found by varying the ratio of another pair of resistors or other components, until the bridge 'balances' when the two ratios match. This is usually indicated by a minimum or null in the output of the bridge.

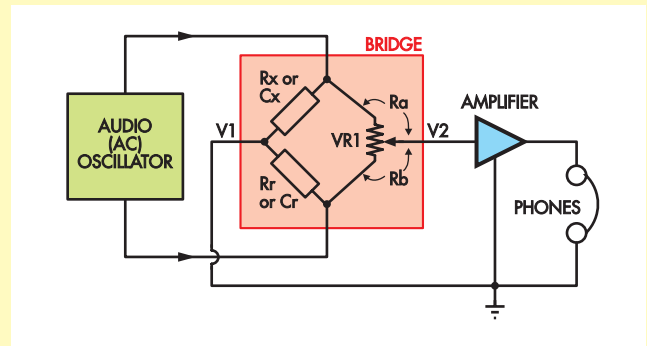
The basic idea is shown in the small diagram. As you can see the actual bridge has four 'arms', two formed by the unknown resistor  $R_x$  (or capacitor  $C_x$ ) and the reference resistor  $R_r$  (or capacitor  $C_r$ ) on one side, and the other two arms formed by the two halves of balance pot VR1 —  $R_a$  and  $R_b$  — on the other side.

AC voltage from a small oscillator (usually 1kHz) is fed into the bridge between the top and the bottom, where the left and right side arms connect together. This means that an audio current flows through each side of the bridge and a certain AC voltage  $V_1$  will appear at the point between  $R_x$  and  $R_r$ , according to the ratio of their values. It also means that a similar voltage  $V_2$  will appear at the rotor of VR1, again according to the ratio of  $R_a$  and  $R_b$  — in other words, where we set the pot.

You've probably guessed already what happens next. By adjusting pot VR1 (the Balance pot), we can make the ratio of  $R_a$  to  $R_b$  match the ratio of  $R_x$  to  $R_r$ . When this happens voltage  $V_2$  will match  $V_1$ , so the voltage fed into our monitoring amplifier will drop to zero. That's why we hear a minimum or 'null' in the headphones, when the bridge is balanced.

In our R/C Bridge circuit, the actual bridge itself is formed by the resistor or capacitor connected to the test terminals, whichever reference resistor or capacitor is selected by range switch S1, and the two sides of Balance pot VR1. The junction of the unknown R or C and the reference R or C is connected to ground (the negative line), so bridge output voltage  $V_1$  is tied to this level. But output voltage  $V_2$  at the rotor of VR1 is taken to Sensitivity pot VR2 through the 100nF capacitor, and then from VR2 to the monitoring amplifier IC1. So IC1 amplifies the difference between the bridge output voltages  $V_1$  and  $V_2$ , or at least the proportion of their difference selected by VR2.

The audio AC signal to drive the bridge is generated by transistor Q1. This is connected in a simple audio oscillator circuit using the centre-tapped 1kW winding of transformer T1 to reverse the polarity of AC signals fed back to the base of Q1 via the 68nF capacitor and the 6.8k resistor. The feedback is therefore positive, making



the transistor oscillate at about 1kHz. Diode D1 is there to protect the transistor from damage, by stopping the base from being driven more negative than 0.6V below ground.

As the oscillator operates, the 1kHz signal is induced in the 8W secondary winding of T1, and as you can see this is connected to the top and the bottom of the bridge arms.

Monitoring amplifier IC1 is an LM386N audio amplifier IC, which provides an amplification or voltage gain of 20 times. This is plenty to drive a pair of stereo headphones from the bridge's output signal from VR1 and VR2, allowing you to hear clearly when you've adjusted VR1 to make the bridge balance for a null.

But what's the purpose of transistor Q2, which is also connected down to the phone jack socket? Ah, that's to provide the Bridge's automatic power switching.

When you haven't plugged any 'phones into the socket, Q2 has no forward bias current flowing through its base. The base is merely connected back to the emitter, via the 10k resistor. So Q2 is turned off, and this also prevents Q1, IC1 and the rest of the bridge circuit from drawing any current from the 9V battery.

When you do plug in the 'phones, they complete the circuit between Q2's 6.8k base resistor and ground (the negative line), and Q2 is able to draw a small base current. This is enough to switch it on, and allow the rest of the bridge circuit to draw current from the 9V battery. Including LED1, which draws current through the 1k resistor and glows to indicate that the bridge is working.

So the R/C Bridge is automatically turned on when you plug in the 'phones, and automatically turned off again when you unplug them. Nifty, don't you think?

wise direction. (This is to make sure that the switch rotor is now inside the range of positions 1-8, so we don't accidentally 'lock it out'.) Then refit the stopwasher with its pin in the correct 8-9 slot, and push it down against the plastic body. After this add the lockwasher and screw on the nut again, and your switch programming is done.

The next components to be fitted to the board are diode D1 and D2. D2 is a 1N4004 diode in a plastic package which goes at the back of the board on the left; D1 is a 1N4148 (or 1N914) diode in a small glass package which goes near the centre of the board. They are both fitted with their cathode 'band' ends towards the left, as you can see from the wiring diagram.

Next fit transistors Q1 and Q2. These are both in small TO-92 plastic packages, but be careful not to confuse them: the one marked PN100 becomes Q1, while the one marked PN200 becomes Q2. If you swap them around the Bridge won't work.

Take care to orientate the transistors as they're shown in the wiring diagram: Q1 goes with its flat side towards the rear, while Q2 goes with its flat side to the left. You'll need to crank the outer leads of each transistor away from the cen-

tre lead by a little over a millimetre, so they'll all pass through the board holes without strain.

Now you can fit IC1, the LM386N audio amplifier IC. This comes in a plastic 8-pin package, and in this project it's orientated with the notch/dimple end facing toward the front of the board. You may have to bend each row of pins inwards slightly towards each other, so they'll all pass through the board holes without strain.

Next you can fit the two pots. These sit on the top of the board, with their spindles vertically upwards to match the switch spindle. Before you do fit them though, cut their spindles off with a small hacksaw or jeweller's saw, at a point about 10mm away from the ends of their threaded mounting bushes. Also smooth off any burrs from the cut ends of the spindles with a small file.

Now take a pair of fine narrow-nose pliers, and carefully bend the narrow ends of each pot's three connection lugs, down at 90°. This will allow them to fit parallel with, and just behind the three terminal pins on the board, in each pot's mounting position. Then all you have to do is hold each pot carefully in place against the top of the board, while you solder each of its three lugs to their matching

terminal pins. Don't forget that the 1k linear ('B') pot goes at the centre rear of the board as the Balance pot VR1, and the 50k log ('A') pot goes at front right as the Sensitivity pot VR2. Swapping the two would still let the Bridge work in a fashion, but not properly.

The last component to fit to the board is the power indicator LED1. This is a red LED in a 3mm diameter body, which is mounted in the centre of the board with the leads straight and vertical, and the body about 19mm above the board. Make sure you fit it with its cathode 'flat' side towards the front of the board, as seen in the top photo.

Your R/C Bridge board assembly should now be complete, apart from soldering the battery clip wires to the terminal pins of the back of the board. Remember that the red wire connects to the pin on the right, and the black wire to the pin on the left.

You might also like to connect a couple of short lengths of insulated hookup wire to the terminal pins on the front of the board, to become temporary test leads. If you fit small alligator clips to the ends of the wires, this will make it easier to connect them to the components to be measured.

Just before you pat yourself on the back for a job well done, give the Bridge PC board a careful 'final checkout' to make sure you've fitted all components in their correct positions — and the right way around, for polarised parts. Inspect the underside of the board as well, to make sure you've soldered all of the component leads and that there are no dry joints.

### Trying it out

If everything seems OK, set Balance pot VR1 to its fully clockwise end and turn Sensitivity pot VR2 to its fully anticlockwise end. Also turn switch S1 to its most clockwise position. Then connect a 9V battery to the clip lead.

Nothing should appear to happen at first, but when you plug your stereo headphones into the 3.5mm jack socket on the rear of the board, The LED should begin glowing — showing that the circuit is now operating.

Next slowly turn up the sensitivity, by turning pot VR2 clockwise. As you do, you should begin to hear an audio



*To set switch S1 for eight positions, turn its rotor fully anticlockwise and then make sure that the stop pin is in the slot between the moulded '8' and '9' figures.*

tone or 'whistle' in the 'phones. This is the 1kHz signal that the Bridge uses to compare resistors or capacitors, and you'll be hearing it because the Bridge currently isn't balanced yet. Turn up the sensitivity until the sound is fairly loud, but not uncomfortable.

Now connect a 100nF capacitor to the test leads. The tone in the 'phones should drop a little, and if you turn Balance pot VR1 slowly anticlockwise it should keep fading. In fact it should get weaker and weaker until you reach the centre of the pot's rotation (1.0), when it will probably be inaudible. Then if you keep turning anticlockwise, it will become louder again.

That point where the sound virtually disappears is the **null**, where the bridge is balanced. To find the exact null point you may need to turn up Sensitivity pot VR2, so you can hear the precise point where the minimum occurs.

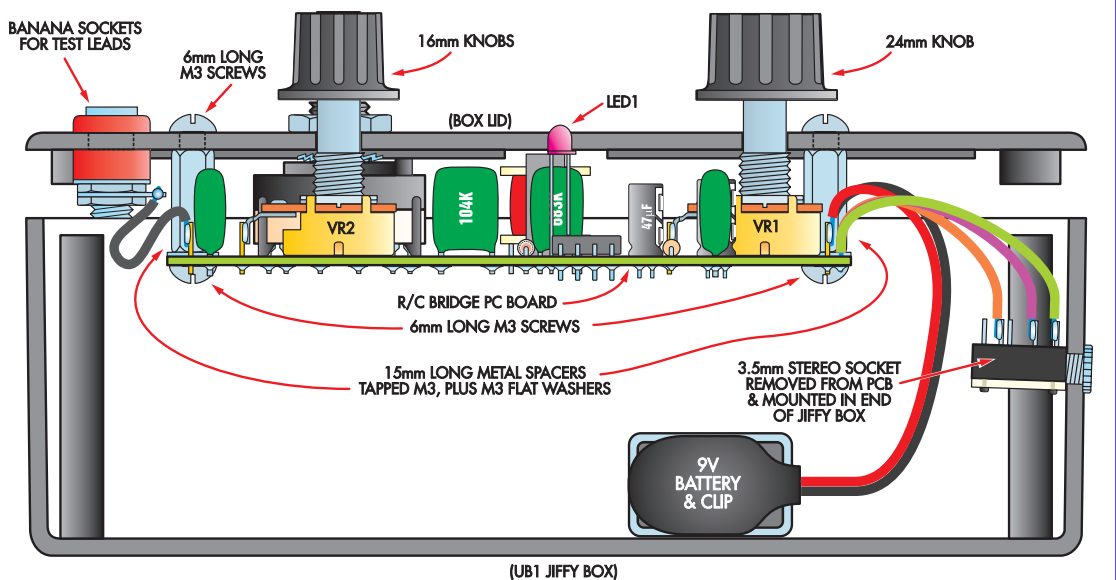
If everything has happened so far as we've described, your R/C Bridge is working as it should. But if it hasn't, the odds are that this will be because you've made a mistake in wiring up the project. So disconnect the battery again, and start looking for the cause of the problem.

You might have connected the battery lead wires with reversed polarity, for example, or fitted diode D2 the wrong way around. Or swapped over Q1 and Q2, perhaps. Any of these mistakes will stop the Bridge from working at all.

If the LED glows when you plug in the headphones, but you can't hear any audio tone even with the Sensitivity pot VR2 turned fully clockwise, that will suggest that your Bridge's tone oscillator isn't working. This might be due to your having fitted either transistor Q1 or diode D1 the wrong way around, or having forgotten to solder one of the component leads.

If you hear a tone but simply can't find a null anywhere in the range of Balance pot VR1, your Bridge isn't balancing. This would point to a dry joint (or a joint you've forgotten to solder at all) in the connections to switch S1, or those for transformer T1.

Another possibility is that you find a kind of null, but it's right at the extreme anticlockwise end of Balance pot VR1's rotation. This is likely to be due to a different problem:



*Here's how the R/C Bridge can be built into a UB1 size jiffy box, to protect it from damage and make it easier to use.*

| RANGE SWITCH S1 POSITION | MEASURING RANGE OF BALANCE POT VR1                     | COMP. TYPE |
|--------------------------|--|------------|
| 1                        | BELOW 10k $\Omega$ ← 100k $\Omega$ → ABOVE 1M $\Omega$ | R          |
| 2                        | BELOW 1k $\Omega$ ← 10k $\Omega$ → ABOVE 100k $\Omega$ |            |
| 3                        | BELOW 100 $\Omega$ ← 1k $\Omega$ → ABOVE 10k $\Omega$  |            |
| 4                        | BELOW 10 $\Omega$ ← 100 $\Omega$ → ABOVE 1k $\Omega$   |            |
| 5                        | ABOVE 1nF ← 100pF → BELOW 10pF                         | C          |
| 6                        | ABOVE 10nF ← 1nF → BELOW 100pF                         |            |
| 7                        | ABOVE 100nF ← 10nF → BELOW 1nF                         |            |
| 8                        | ABOVE 1 $\mu$ F ← 100nF → BELOW 10nF                   |            |

instead of connecting a 100nF capacitor to the test leads, you've probably connected one of a different value by mistake. In that case you'll probably be able to find the real null for that capacitor by turning switch S1 to a lower range, and turning VR1 until the bridge does become properly balanced. (Basically when you find a minimum at one end of the range on VR1, this indicates that the *real* null is on another setting range of S1.)

Hopefully it won't take you long to track down the cause of your problem, and once you do find it and fix it, your Bridge should then work as we've described.

## What to do next

This is one project which really should be built into a box, so it can be used properly. That's because the Balance pot VR1 in particular needs to be fitted with a pointer knob, with a calibrated scale so you can read out its ratio when the Bridge is balanced (to work out the value of the component you're measuring).

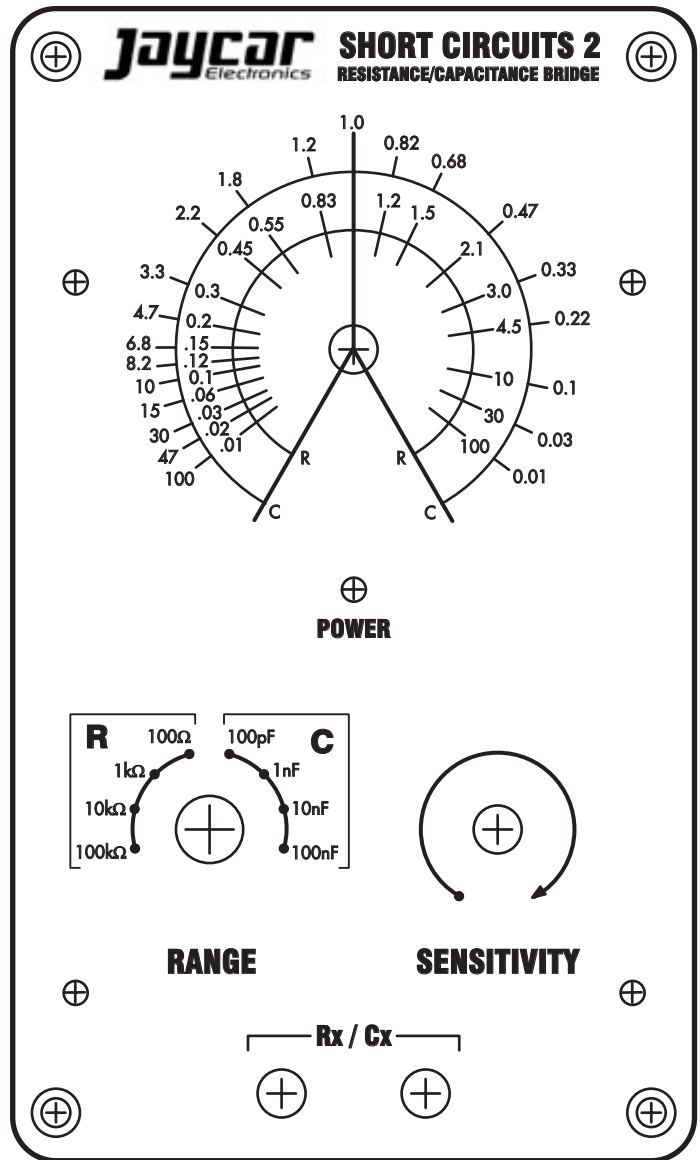
We've designed the board to fit in a standard UB1 size jiffy box (158 x 95 x 53mm), such as the Jaycar HB-6011. As you can see from the diagram on the page opposite, the board mounts up behind the lid of the box, spaced behind it by four 15mm long M3 tapped metal spacers – plus an additional M3 flat washer under each spacer to increase the total spacing to 16mm. (This is necessary to clear the transformer T1.) Four 6mm long M3 machine screws attach the spacers to the lid, while another four of the same screws attach the PC board assembly to the spacers.

The threaded bush of range switch S1 extends through a 10.5mm diameter hole in the lid, allowing the nut to be fitted on the top. This provides additional support for the PC board assembly. On the other hand the spindles of pots VR1 and VR2 simply pass through 6.5mm clearance holes in the lid, so they can be fitted with their knobs.

The PCB assembly needs to be mounted on the lid with the spindle of Balance pot VR1 at least 45mm from the top end, as shown. This is to allow plenty of room around the pot's knob, for its dial scale. As a result the headphone jack socket can't be left on the board, because it would end up too far inside the box to be accessible. So the socket needs to be unsoldered from the board (or not fitted to it when you're assembling the Bridge), and mounted instead on the end of the box as shown. It's connected back to the board via three short lengths of insulated hookup wire.

There is plenty of room in the bottom of the box for the 9V battery when the lid and PC board assembly are fitted. This allows the battery to be located in the bottom, held in place by a strip of gaffer tape. There's no need to fit an on/off switch, of course, because the R/C Bridge circuit is turned on and off automatically when you plug in or unplug the headphones.

To make it easy to connect test leads to the Bridge input terminal pins, another two short lengths of insulated hookup



wire are used to connect the pins to a pair of 4mm internal diameter 'banana' sockets, mounted at the front end of the box lid. The sockets accept any standard test leads, or you can make up a couple of suitable leads with a banana plug at one end and an alligator clip at the other, to connect to the leads of any component you want to measure.

To help you in building the R/C Bridge into a box, and also to help you use it when it's finished, we've prepared some actual-size artwork for the box lid front panel (above). You can use a photocopy of this as a template for marking out the holes that need to be drilled in the lid, and then attach another photocopy to the finished front panel to provide the legends and the measuring dial scale for the Balance pot. The panel can then be covered with clear adhesive film (like 'Contact'), to protect it from damage and keep it clean.

We're also providing a table which shows the range of values you are able to measure with the Bridge on each of the eight positions of Range switch S1 (above left). Notice that the ranges overlap quite a bit, so many components can be measured on either of two ranges.

Although each position of S1 is marked with a particular value, this is really the reading that corresponds to a null in the very centre of Balance pot VR1's range. As the table shows, each range extends to beyond 10 times this value in one direction, and beyond 1/10th the value in the other direction.



## Project 20:

# A Simple 3-Digit Counter

Digital counters are in all kinds of equipment, counting away and showing things like the frequency your FM radio is tuned to, how long your VCR has been recording, the number of seconds left before your microwave turns itself off or the time on your digital watch. Here's how to build a small 3-digit counter which not only demonstrates how they work, but can also be used for real-world counting jobs.

### What does it do?

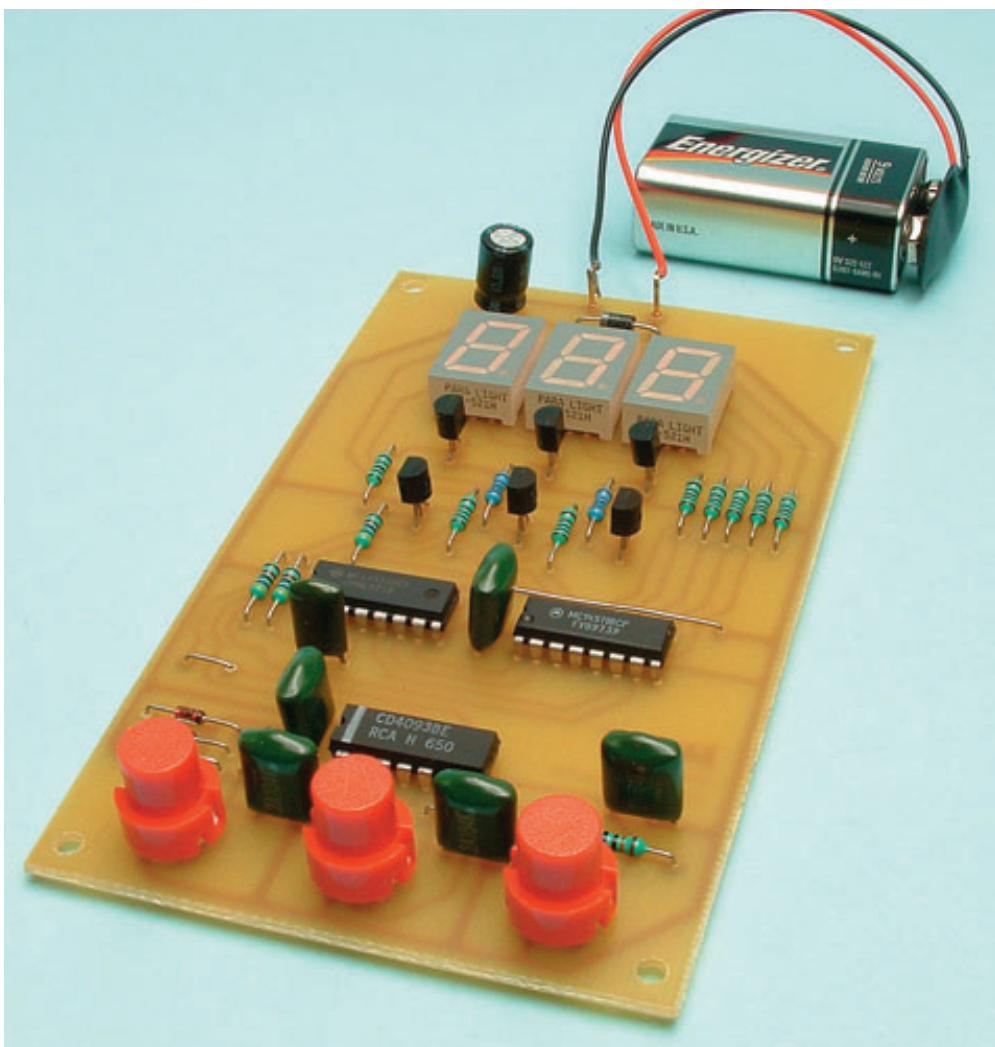
Like all digital counters, this one basically counts electrical pulses — brief up-and-down changes in voltage. In this case it can count pulses which are either generated by you pressing a small button on its PC board, or else fed into the counter from some other circuit 'outside'. It can count up to 999 pulses before it has to be reset, and it displays the number of pulses it has counted on three '7-segment' LED (light emitting diode) readouts.

It's quite easy to build and get going, because most of the hard work is done inside a counter IC (integrated circuit). At the same time there's enough extra circuitry to demonstrate some important concepts, so the project makes an excellent 'hands on' introduction to digital electronics. That's quite apart from it giving you a handy 3-digit counter which can be used for all kinds of jobs — like lap counting in slot car races, or counting the number of people visiting a shop, or fete or concert.

### Putting it together

Apart from the 9V battery which provides its power, all of the parts used in the counter fit on a small PC (printed circuit) board. The board measures 127 x 76mm and is coded SHRTC220.

Before you begin assembling the counter, open up the kit and lay the parts out on your work table so you can check that you have everything. It's also a good idea to check the copper side of the PC board, to make sure it



## The parts you'll need for this project:

- 1 PC board, code SHRTC220, 76 x 127mm
- 3 Pushbutton switches, PC board mounting (S1-S3)
- 1 9V battery, 216 type
- 1 Battery clip lead to suit
- 2 PCB terminal pins, 1mm dia.
- 1 50mm length of 0.8mm tinned copper wire (for links)

- 1 Small pack of resin-cored solder

### Semiconductors

- 1 4093B quad Schmitt NAND gate (IC1)
- 1 4553B 3-decade counter (IC2)
- 1 4511B 7-segment decoder (IC3)
- 3 PN200 PNP transistors (Q1-Q3)
- 3 PN100 NPN transistors (Q4-Q6)

- 2 1N4148/1N914 diodes (D1,D2)
- 1 1N4004 silicon diode (D3)

### Capacitors

- 1 330 $\mu$ F 16V RB electrolytic
- 5 100nF greencap
- 1 22nF greencap

### Resistors (0.25W 1%)

- |        |        |
|--------|--------|
| 3 100k | 3 47k  |
| 3 10k  | 1 2.2k |
| 7 1k   |        |

has no minor etching defects or undrilled holes. In the unlikely event that there are any problems, they're easier to fix at this stage rather than later on.

There are two wire links needed on this board, as you can see from the wiring diagram and top photo. So bend these up from short lengths of tinned copper wire, fit them to the board and solder their ends to the pads under their holes.

The board also needs two PCB terminal pins, which mount at the back centre of the board for the battery connections. So fit these next, pushing their 'short ends' through the board holes from the top before you solder them underneath.

Now you can fit the fixed resistors. There are 17 of these used in the counter, including seven with a value of 1kΩ, three groups of three with values of 10kΩ, 47kΩ and 100kΩ, and a solitary 2.2kΩ resistor. To help avoid mistakes we suggest that you pick out and fit the 1k resistors first, then the 10k, 47k and 100k resistors, and finally the 2.2k.

Use the wiring diagram and top photo as a guide, so you fit each resistor into its correct position on the board. Although resistors aren't electrically polarised, it's also a good idea to fit them with their colour codes reading either west-to-east or south-to-north, to make them easier to read in the future.

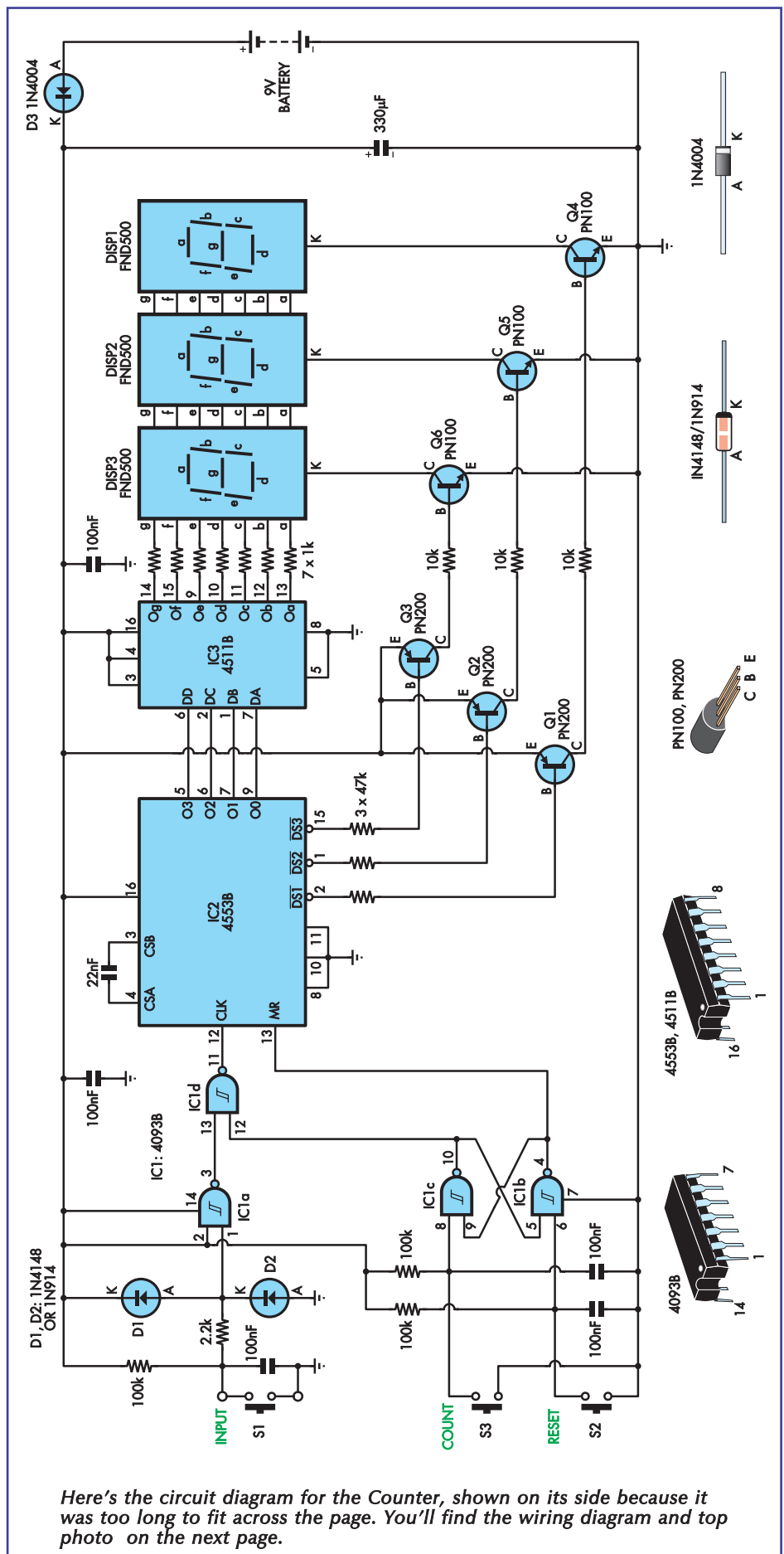
Next we suggest that you fit the remaining low-profile parts, which are the diodes. D1 and D2 are fitted near the front left of the board as you can see. D3 is a 1N4004 power diode in a plastic package, and this goes at the back of the board just to the front of the battery terminal pins.

Notice that diodes D1 and D3 are fitted with their cathode bands towards the left, while D2 is fitted the opposite way around, with its cathode band to the right. So follow the wiring diagram and top photo carefully to avoid mistakes.

Now fit the unpolarised greencap capacitors. There are six of these in all, with five of them having a value of 100nF and the remaining smaller one a value of 22nF. You might want to fit the 22nF greencap first, to help prevent mistakes. Then fit the 100nF greencaps, with four of them going near the front of the board and the fifth going in the middle of the board just in front of the long wire link.

You'll notice that the board provides extra holes for each greencap, to suit components with different lead spacings.

Next fit the counter's one and



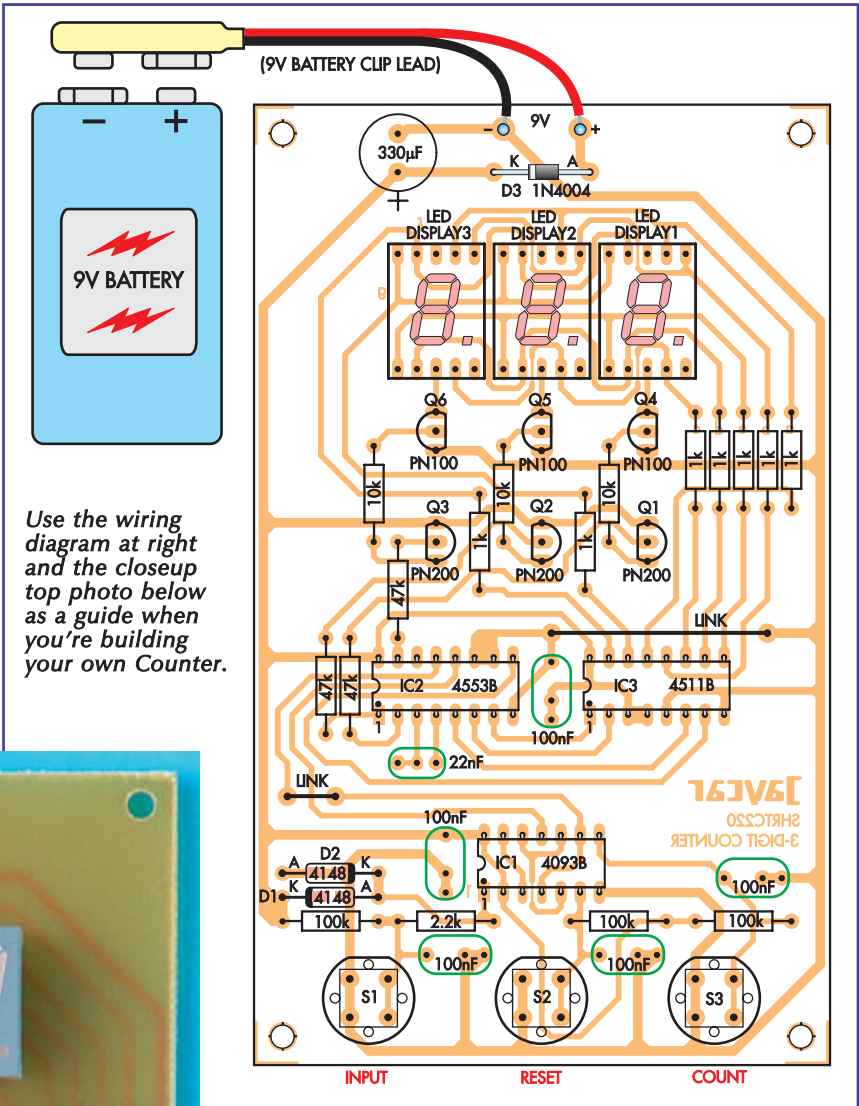
Here's the circuit diagram for the Counter, shown on its side because it was too long to fit across the page. You'll find the wiring diagram and top photo on the next page.

only electrolytic capacitor. This is a 330µF electro which goes at the back left of the board. Notice that like all electros it's polarised, and in this case it should be fitted with its negative stripe facing towards the back of the board.

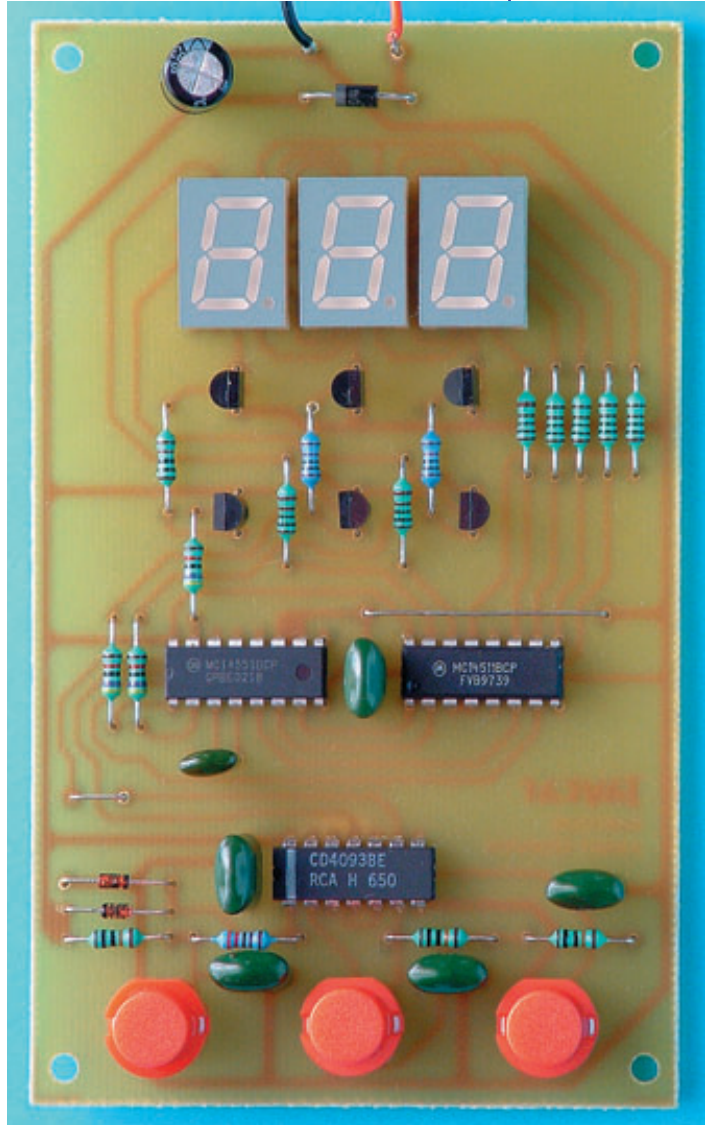
Next fit the three 7-segment LED displays. As you can see these come in small rectangular packages, with a row of five pins underneath at both top and bottom. You may need to straighten these pins before they'll all go through the matching board holes without strain.

The three displays are identical, so you can fit them in any of the three positions. But they are polarised, so notice that each one must be fitted with its small round 'decimal point' LED at lower right as shown in the wiring diagram. We don't actually use the decimal point LEDs in the counter, but they're visible on the front of each display and they're handy for getting the display's orientation right.

Now fit the six transistors. These are all in plastic TO-92 packages, which look identical except for their markings. The three marked 'PN200' are PNP transistors which go in the board positions Q1, Q2 and Q3, while the other three marked



Use the wiring diagram at right and the closeup top photo below as a guide when you're building your own Counter.



'PN100' are NPN transistors which go in positions Q4, Q5 and Q6.

As usual you'll need to crank the outer leads of each transistor outwards and away from the centre lead by about 1mm, so they'll all go through the board holes without strain. Follow the wiring diagram carefully when you're fitting each transistor to the board, too. Notice that Q1-Q3 fit with their flat sides towards the left, while Q4-Q6 fit the other way around. Don't swap them around, or your counter won't work properly.

Next fit the three ICs. IC1 is a 4093B device in a 14-pin DIL (dual-in-line) package, while IC2 and IC3 are 4553B and 4511B devices respectively, in 16-pin DIL packages.

These are all CMOS devices and therefore susceptible to damage from electrostatic charge. So touch some earthed metalwork to discharge yourself before handling them, and also use an earthed soldering iron when you're soldering their pins to the board pads.

You may need to bend the two rows of pins on each device gently in towards each other, so they'll all go through the board holes without strain. Notice that all three ICs fit into the board with their notch/dimple ends facing towards the left of the board.

The last components to fit to the board are pushbutton switches S1, S2 and S3 — or at least S2 and S3, if you're not planning to fit S1 to the board because you'll only be using the counter to count pulses fed in from 'outside'. When you fit the switches, make sure you fit them with their 'flat' sides facing towards the rear of the board. This



## Tech Talk: How does it work?

All of the Counter's actual pulse counting is done inside IC2, which is a 4553B device. This contains about 12 flip-flops, connected so they form a three-decade counter — in other words, three modulo-10 counter stages which are connected one after the other so they count units, 10's and 100's respectively. Together they count from 000 to 999, before they all return to zero and start again.

The pulses to be counted by IC2 must be fed into its 'clock' input pin (pin 12). More about this shortly. However the counter's output — the three digits which represent its current count — are fed out of the device in an interesting way. They're not made available continuously via separate output pins, but in serial order (1-2-3-1-2-3...) on a single 'shared' set of output pins. This is known as **time multiplexing**.

The shared output pins are the pins marked O0-O3, which are pins 9, 7, 6 and 5 respectively. As you can see there are just four output pins, and that's because the decimal digit values are fed out in binary coded decimal or 'BCD' form rather than in plain decimal. This uses different combinations of four binary digit (bit) values to represent each of the ten decimal digits, as the small table shows. A decimal '0' is represented by binary combination 0000, decimal '1' by binary '0001' and so on.

So IC2 makes each of its counter digits available in these BCD codes one after the other, on the same output pins O0-O3. But how do we work out which digit is which? This is easier than you'd think, because the counter IC also provides digit select output signals on output pins DS1, DS2 and DS3. Each time digit 1's code is on the four main output pins, DS1 is switched low. Similarly DS2 is switched low to indicate when digit 2's code is available, and DS3 switches low to indicate when digit 3's code is available.

As you can see, we use these three digit-select outputs to turn on the correct LED display for each digit, using transistors Q1-Q3 and then transistors Q4-Q6. When each DS output of IC2 switches low, this allows either Q1, Q2 or Q3 to draw base current via one of the 47k resistors. That transistor therefore 'turns on', and this in turn provides base current for one of the display driver transistors Q4, Q5 or Q6. So one of these transistors is switched on as well, allowing that particular LED display to draw current and display the right digit.

But what's the purpose of IC3? Ah, that's a 4511B decoder, which we need to convert the BCD output codes from IC2 into the right kind of signals to drive the 7-segment LED displays. That's because the LED displays indicate the various decimal digits using combinations of their seven LED 'segments' — the three horizontal LED strips and four vertical LED strips in each display, arranged in a kind of figure-8 pattern.

You can see the segment patterns needed for the displays to show the various digits in the last column of the table. So what IC3 does is convert each BCD digit code from IC2 into the right combination of signals on its seven output pins Oa — Og, to turn on the right combination of segments in either DISP1, DSP2 or DISP3 (whichever is switched on to show the digit concerned).

By the way you may be wondering what is the job done by the 22nF capacitor connected between pins 3 and 4 of IC2. This capacitor controls the speed of an oscillator inside IC2, which sets how quickly IC2 cycles around the three digit outputs in its output multiplexing. The value of 22nF makes this cycling fast enough so you shouldn't notice any flickering in the LED displays.

So that's a quick idea of the way the basic counter and its displays work. Now let's look at how we make them count the pulses we want counted.

As mentioned earlier, pulses to be counted by IC2 must be fed into its pin 12 input. The IC is also designed to count brief negative-going pulses — in other words, it increases its count each time the voltage on pin 12 drops down to the 'low' (0V) level. But this only happens if there is also a low voltage level on its MR (master reset) input pin 13, at the same time. On the other hand if pin 13 is

taken high (+9V), the IC not only stops counting but also resets its internal counters to zero (000) and pulls all three of its DS outputs high as well, to blank out the LED displays.

To control the counter, we use gates IC1c and IC1b which are connected as a simple set/reset flipflop. This means that only one output of these gates can be high at any time, and when one gate is high the other must be low. When IC1b's output pin 4 is high IC1c's output pin 10 is low, and vice-versa.

We control which of these two 'states' the flipflop is in at any time using the two pushbutton switches S2 and S3. As you can see these are each connected from one 'free' input of IC1c and IC1b to ground (0V). The same inputs are each taken up to +9V via a 100k resistor and down to ground via a 100nF capacitor, so when neither switch is pressed both capacitors are able to charge up to +9V and the inputs rest at this high level. But when either button is pressed it discharges that capacitor and pulls that input down to ground. This makes the flipflop switch states, to the state where that gate's output is high.

So when we press S2, the flipflop switches to the state where IC1b output pin 4 is high, pulling the counter reset pin high as well and resetting the counter. On the other hand when we press S3, the flipflop switches to the other state where IC1c output pin 10 is high, and pin 4 goes low — allowing the counter to start counting again.

We also use the pin 10 output of the flipflop to control gate IC1d, as you can see. The job of this gate is to control whether our input pulses can reach the counter's input pin 12. When the flipflop's output pin 10 is low this pulls IC1d's input pin 12 low as well, so the gate's output pin 11 is held high and no pulses can get into the counter. But when the flipflop's output pin 10 is high, IC1d's input pin 12 is pulled high as well and this turns the gate on, allowing pulses to pull its output low and pass into the counter input.

Our input pulses themselves (the ones we count) are produced either by pressing switch S1, or by closing an external pair of contacts connected to the input terminals. However as you can see this produces a negative-going pulse, because the input terminals are normally pulled high by a 100k resistor, with another 100nF capacitor to ground. So when either S1 or the external contacts are closed, this discharges the 100nF capacitor and pulls input pin 1 of IC1a low, via the 2.2k resistor.

Gate IC1a is used to invert these negative-going pulses to make them positive-going, because they need to be positive going to pass through IC1d and into the counter.

You're probably wondering why each of the three pushbutton switches S1, S2 and S3 have a 100k resistor to the +9V line, with a 100nF capacitor across each switch itself. These are simple 'debounce' circuits, which are needed because mechanical switch contacts never close cleanly. They always 'bounce' very briefly at the instant of touching, so when you think you're pressing the switch just once, the contacts almost always close a number of times in rapid succession.

The capacitors across each switch make sure that the voltage goes low as soon as the first contact closure discharges the capacitor, and stays low while the button is pressed because the capacitor can't recharge rapidly through the 100k resistor. The capacitor only recharges again when you release the button.

But what's the purpose of the 2.2k resistor in series with the pulse input, and diodes D1 and D2? These don't really do anything when you use S1 to produce the pulses for counting. They are to protect gate IC1a from damage due to static electricity, when you connect other switches or contacts to the counter input. Diode D1 ensures that the pin 1 input of IC1a can't be pulled positive to more than 0.6V higher than the +9V line, while diode D2 makes sure that the same input pin can't be pulled more negative than 0.6V below ground (0V). The 2.2k resistor is to limit any current that may flow in the diodes when they are conducting, to discharge any electrostatic charge that comes in via the input terminals.

is to make sure that their two pairs of internally connected pins are fitted so they don't short circuit between the board pads even when the button isn't pressed.

Now if you're planning on using the counter just to demonstrate digital counting with pulses generated by pushbutton S1, this switch can be mounted at the same time. But if you're going to be using the counter only to count pulses from other 'outside' switches, we suggest that you fit another pair of PCB terminal pins instead of S1. The pins are fitted in the front two holes of the four provided for S1, with the other two holes left unused.

By the way, if you **do** want to use S1 to demonstrate counting but you also want to use the Counter for counting pulses from outside switches or contacts, this is also quite easy. Just fit S1 to the board at this stage, and later connect a pair of input wires to its contact pads under the board.

Your Counter assembly should now be complete. All that remains is to connect the battery clip lead wires to the PCB terminal pins at the back of the board, making sure that you solder the positive (red) wire to the pin on the right and the negative (black) wire to the pin on the left.

Just before you take a deep breath and prepare to give your Counter its first tryout, though, play safe by giving it a careful final inspection. Make sure you've fitted all of the components in their correct positions, and the right way around in the case of polarised parts like the diodes, electro, transistors and ICs. Check the copper side of the board as well, just in case you've forgotten to solder one of the component leads or left a troublesome dry joint.

## Trying it out

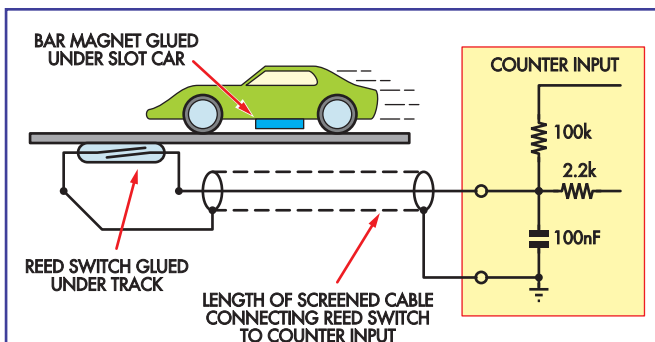
If everything seems to be in order, you should be just about ready to try the Counter out.

There may be one thing left to do, but only if you haven't fitted pushbutton S1 to the board. This is to connect the pushbutton to the terminal pins on the front of the board temporarily, so it can be used to feed test pulses into the counter. Do this using two short lengths of insulated hookup wire, connecting one pin on each side of the switch to one of the terminal pins.

Now connect a 9V battery to the clip lead, and watch the displays. They'll probably all start displaying a zero, so you'll get a display of '000'.

Next press pushbutton S1, regardless of whether it's on the board or simply connected to the front terminal pins. The display on the right should immediately change to a '1', giving a full display of '001' and showing that the counter received and counted one pulse.

Pressing the S1 pushbutton again should change the



*Here's how easy it is to use the Counter to count how many laps a slot car has travelled. Many other counting jobs can be done almost as easily.*

| DECIMAL COUNT | COUNTER BCD CODE |    |    |    | 7-SEGMENT OUTPUT FROM 4511 |    |    |    |    |    |    | DISPLAY |
|---------------|------------------|----|----|----|----------------------------|----|----|----|----|----|----|---------|
|               | 03               | 02 | 01 | 00 | 0a                         | 0b | 0c | 0d | 0e | 0f | 0g |         |
| 0             | 0                | 0  | 0  | 0  | 1                          | 1  | 1  | 1  | 1  | 1  | 0  | 0       |
| 1             | 0                | 0  | 0  | 1  | 0                          | 1  | 1  | 0  | 0  | 0  | 0  | 1       |
| 2             | 0                | 0  | 1  | 0  | 1                          | 1  | 0  | 1  | 1  | 0  | 1  | 2       |
| 3             | 0                | 0  | 1  | 1  | 1                          | 1  | 1  | 1  | 0  | 0  | 1  | 3       |
| 4             | 0                | 1  | 0  | 0  | 0                          | 1  | 1  | 0  | 0  | 1  | 1  | 4       |
| 5             | 0                | 1  | 0  | 1  | 1                          | 0  | 1  | 1  | 0  | 1  | 1  | 5       |
| 6             | 0                | 1  | 1  | 0  | 0                          | 0  | 1  | 1  | 1  | 1  | 1  | 6       |
| 7             | 0                | 1  | 1  | 1  | 1                          | 1  | 1  | 0  | 0  | 0  | 0  | 7       |
| 8             | 1                | 0  | 0  | 0  | 1                          | 1  | 1  | 1  | 1  | 1  | 1  | 8       |
| 9             | 1                | 0  | 0  | 1  | 1                          | 1  | 1  | 0  | 0  | 1  | 1  | 9       |

*When the three decimal counters inside the 4553 count, they do so in binary-coded decimal or 'BCD'. The 4511 IC then converts these BCD codes into the right combinations to display the corresponding decimal numbers on the 7-segment LED displays, as this table shows.*

display to '002', and then '003' and so on. Until you press S1 for the tenth time, when it should change to '010'. Then if you keep on pressing the count should continue increasing to reach '099', and then change to '100' on the one hundredth pulse.

If you have the patience to keep pressing right up to 999 times, you should also see the counter reset back to '000' with the very next press of S1.

Keep pressing S1 a few more times, to get a convenient display on the LEDs. Then try pressing Reset button S2, which should turn off the LEDs altogether — so they won't be displaying anything at all. If this happens as it should, press Count button S3. This should turn the LEDs back on, but displaying '000' once again.

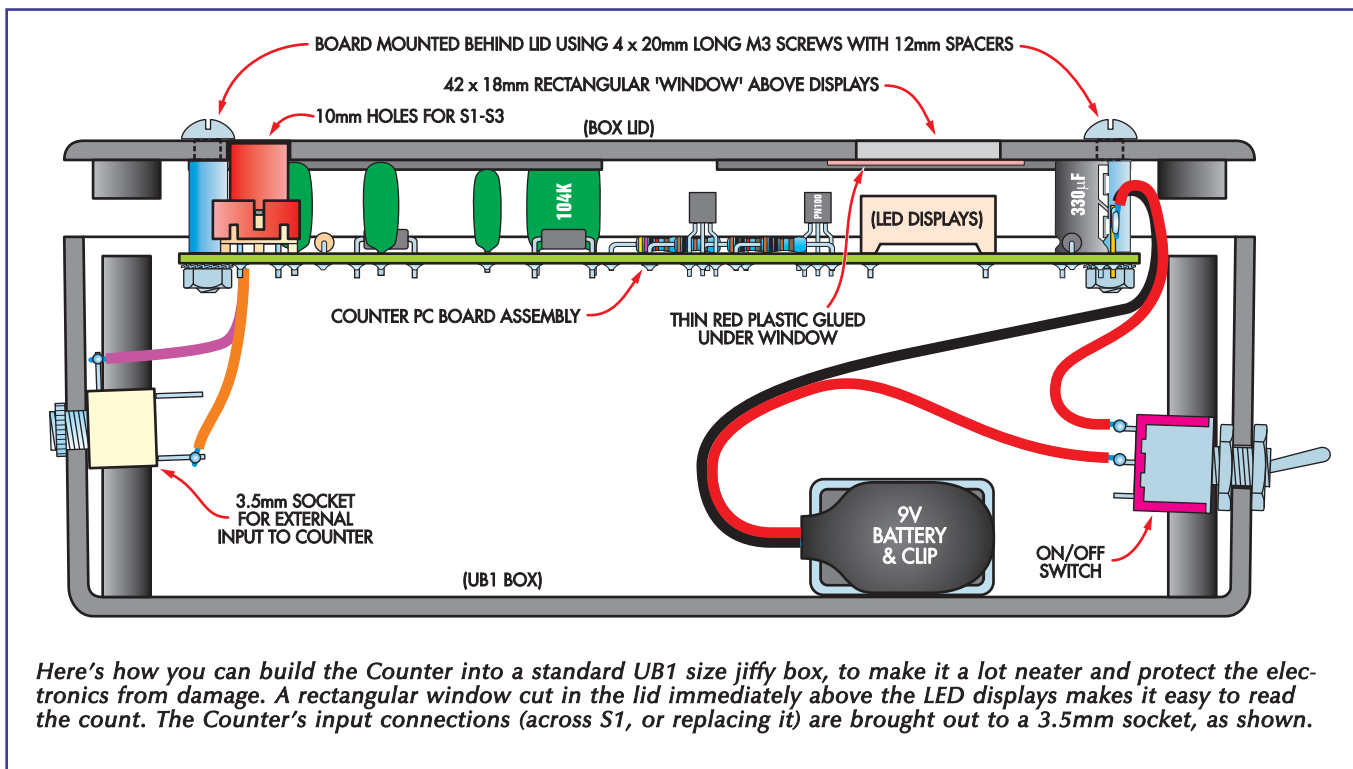
If your counter has behaved as we've just described, it's working as it should and you can congratulate yourself on another project successfully completed. You'll also have a nifty little 3-digit counter, to use for a variety of counting jobs.

But what if you've struck trouble — with **your** Counter either not working at all, or not behaving in the way we've described? Well, you can probably guess what we're going to tell you about a Counter that doesn't go at all. That's right, this will be almost certainly because you've made some kind of mistake in wiring up the Counter. You may have forgotten to solder one of the component leads, or soldered one so poorly that you've left a dry joint which isn't really a joint at all. Or you might have fitted diode D3 the wrong way around, or swapped the battery clip lead connections.

Other possibilities are that you've accidentally swapped the PN100 and PN200 transistors, which will stop the 7-segment LEDs displays from working.

If the Counter does seem to be working after a fashion, but not properly, this too is likely to be because of a wiring mistake. You might have swapped around some of the resistors, or perhaps connected either D1 or D2 the wrong way around. So again it's a matter of disconnecting the battery and checking all of these things, until you find the mistake and fix it. Then your Counter should spring into life and work properly.

There is one way in which your Counter might work a little differently from the way we've described, without it having any wiring mistakes or other problems at all. This is if it doesn't come up with a display of '000' as soon as you connect the battery. It might instead 'power up' with no



Here's how you can build the Counter into a standard UB1 size jiffy box, to make it a lot neater and protect the electronics from damage. A rectangular window cut in the lid immediately above the LED displays makes it easy to read the count. The Counter's input connections (across S1, or replacing it) are brought out to a 3.5mm socket, as shown.

display at all. If this is what happens with your Counter, don't panic — just try pressing Count button S3. If the correct '000' display now appears, there's nothing wrong with your Counter; its ICs simply prefer to go into the Counter's reset mode when the battery is first connected, rather than into its counting mode. You'll just have to press S3 before counting can start, each time the battery is connected.

### What to do next

You can use the Counter to count the laps of a slot car as it races around a track, or to count people walking through a doorway, or other simple counting jobs like this. What is needed for counting any sequence of events is a way of making those events operate a pair of switch or relay contacts, so the contacts will produce pulses when they're connected to the Counter's input pins (replacing S1).

For example to use the Counter as a lap counter for slot cars, you can cement a small magnet under each slot car and also cement a small reed switch (such as the Jaycar SM-1002) under the track at a suitable point. Then each time a car passes over the reed switch, its contacts will be closed briefly and then opened again. If the reed switch contacts are connected back to the Counter input pins via a screened cable, as shown in the small diagram opposite, this will produce an input pulse for the Counter each time a car passes over the switch.

Similarly you can use the Counter to count people walking through a doorway by fitting a pressure-sensitive mat in the doorway under the carpet or lino. The mat's switch contacts will be closed briefly each time someone's foot rests on the mat. So again if the contacts are connected to the Counter's input pins, a pulse will be produced each time to operate the Counter.

If it's too hard to get hold of a pressure-sensitive mat, or to fit one under the floor covering, you can alternatively use a light-beam sensing unit of the kind used to produce a 'ding dong' sound each time a person walks through the doorway and interrupts the light beam briefly. Just connect the sensor unit's relay contacts to the input pins of the Counter, instead of the 'ding-dong' sound maker.

Yet again you could use a PIR (passive infra-red) sensor unit, like the Jaycar LA-5030. These work by sensing the

changes in infra-red light level when someone moves past, and then operating a pair of contacts. Just connect these contacts up to the Counter's input pins via a length of screened cable, and Bob's your uncle.

You could also use one of these optical sensors to adapt the Counter for counting the number of sheep or cattle to pass through a dip, or going up a ramp into a road train or railway wagon.

If you do use the Counter for 'real world' counting jobs like this, you'll probably also want to build it into a box so the electronics is protected from damage. This is fairly easy to do, as the board has been designed to fit inside a standard UB1 size (158 x 95 x 53mm) jiffy box — like the Jaycar HB-6011.

The Counter board is mounted behind the lid of the UB1 box, using four 20mm long M3 machine screws and four 12mm untapped metal spacers, with M3 nuts and lock-washers on each screw as shown in the diagram above. You may need to mount the 330µF electrolytic and the various 100nF greencaps on the board 'tilted over' though, to bring their effective height down to below 12mm.

As well as the four 3mm diameter holes drilled in the lid to take the board mounting screws, you'll also have to drill and ream two or three 10mm diameter holes to allow access to the pushbuttons. You'll also need to make a neat rectangular hole measuring 42 x 18mm in the lid directly over the LED displays, so they can be seen easily. To make the Counter really neat you can glue a 50 x 30mm rectangle of thin red cellophane or plastic up behind this 'display window', to stop dust from getting in.

When the Counter is mounted in a box, you'll need to add a small switch to allow the power to be turned on and off easily. The switch to use is the Jaycar ST-0335 mini toggle or similar, and as shown it can be mounted in a 6mm hole drilled in the end of the box. As usual two of its contact lugs are connected in series with the positive (red) battery lead.

You'll also want to bring the counter's input connections out to a 3.5mm mono jack socket (like the Jaycar PS-0122), mounted on the front end of the box as shown. This will allow you to connect all manner of external switches and contacts to the Counter, easily and neatly. If you've fitted S1 to the board, the wires to the socket simply connect to the front two pads under S1.



## Project 21:

# A Personal FM Radio

Here's how to build a personal FM radio that's small enough to fit in your shirt pocket. It will tune in to any of your local FM stations, and gives good volume in a pair of low cost stereo earphones. At the same time it's very easy to build and get going.

### What does it do?

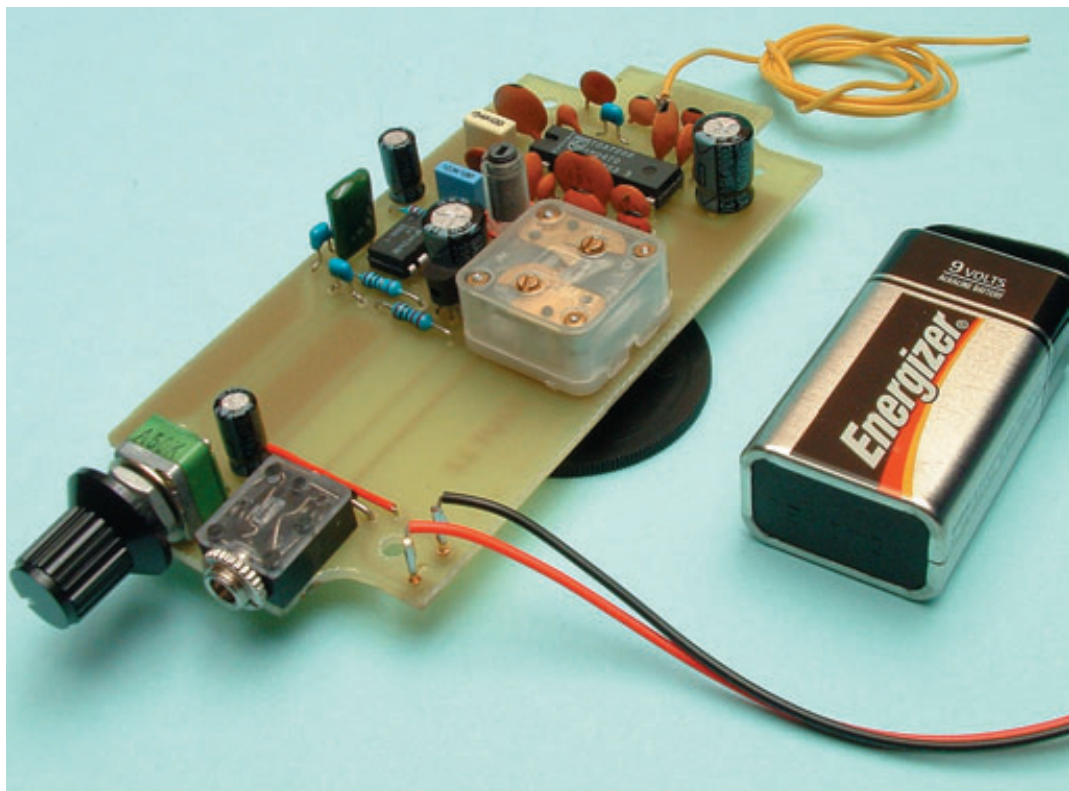
Do you like to listen to the FM radio stations while you're jogging, or sitting in the bus or train? That's exactly what this Personal FM Radio is designed to do. It's sensitive enough to bring in just about all of the FM stations in your area, using just a short length of wire as an antenna (aerial), and it gives you plenty of volume in almost any pair of low cost stereo earphones.

Sure, you can buy a ready-made personal FM radio in bargain stores, for not much more than you'll pay for this kit. But there's much more satisfaction and enjoyment when you're listening to a radio you've built yourself!

### Putting it together

All of the parts used in the radio mount on a very small PC (printed circuit) board measuring 108 x 51mm, and coded SHRTC221.

Before you begin assembling the radio, open up the kit and lay the parts out carefully on your work table so you can check that you have everything. While you're doing so, it's also a good idea to inspect the copper side of the PC board, to make sure it has no minor



etching defects or undrilled holes. There probably won't be any such problems, but it's better to find them now because they're much easier to fix at this stage rather than later on.

## The parts you'll need for this project:

- 1 PC board, code SHRTC221, 51 x 108mm
- 1 6-160pF tuning capacitor (VC1)
- 1 Mini coil former and base, 5.1mm OD with F29 slug
- 1 100mm length of 0.5mm enamelled copper wire
- 1 750mm of 13 x .012mm insulated hookup wire
- 1 50k log potentiometer, 9mm square PCB type (VR1)
- 1 Small instrument knob to suit VR1
- 1 3.5mm stereo jack, PC board mounting
- 1 9V battery, 216 type
- 1 Battery clip lead to suit

- 3 PCB terminal pins, 1mm dia.
- 1 Small pack of resin-cored solder

### Semiconductors

- 1 TDA7000 FM receiver (IC1)
- 1 LM386 audio amplifier (IC2)
- 1 PN200 PNP transistor(Q1)
- 1 1N4004 silicon diode (D1)

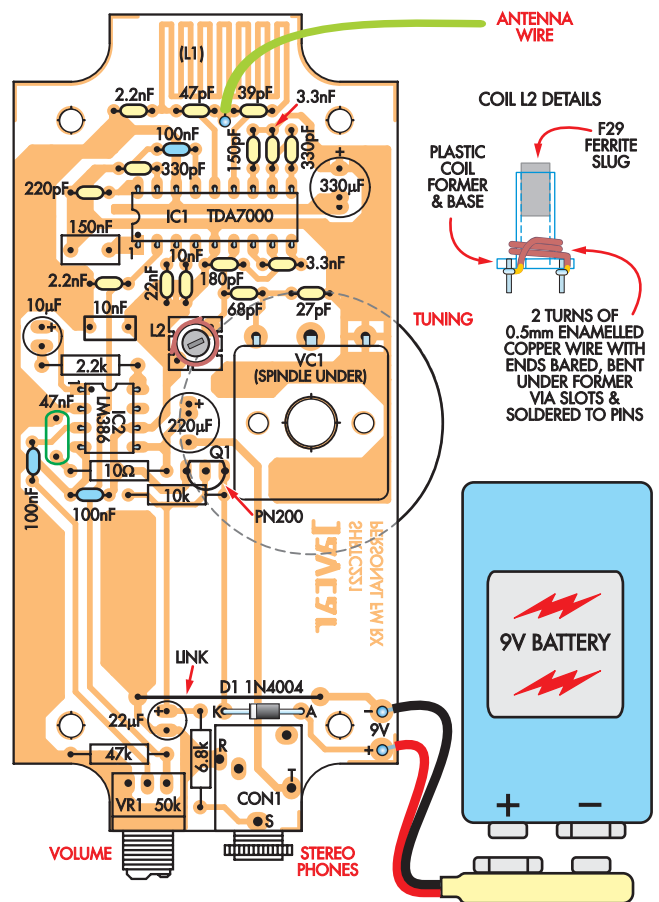
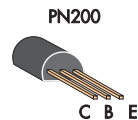
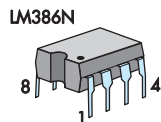
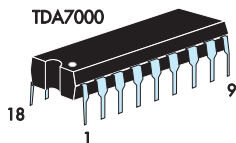
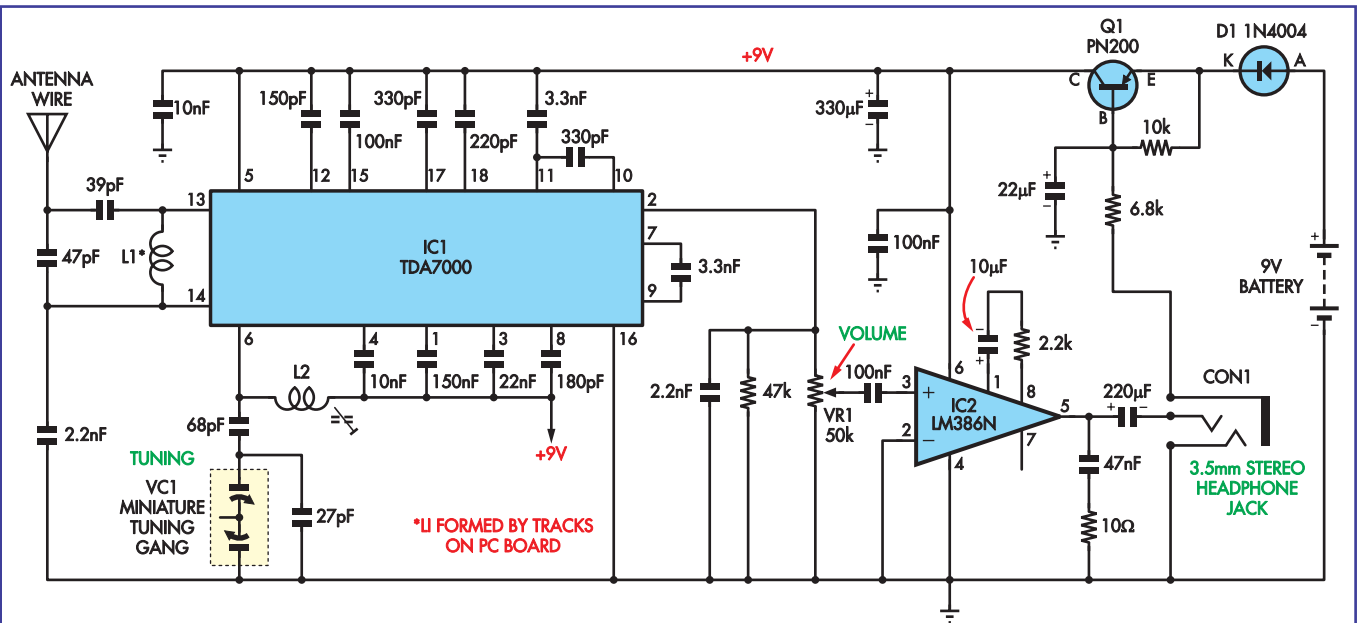
### Capacitors

- 1 330 $\mu$ F 16V RB electrolytic
- 1 220 $\mu$ F 16V RB electrolytic
- 1 22 $\mu$ F 16V RB electrolytic
- 1 10 $\mu$ F 16V RB electrolytic
- 1 150nF MKT polyester
- 3 100nF multilayer monolithic
- 1 47nF greencap

- 1 22nF disc ceramic
- 1 10nF disc ceramic
- 1 10nF greencap or MKT
- 2 3.3nF disc ceramic
- 2 2.2nF disc ceramic
- 2 330pF disc ceramic
- 1 220pF disc ceramic
- 1 180pF disc ceramic
- 1 150pF disc ceramic
- 1 68pF disc ceramic
- 1 47pF disc ceramic
- 1 39pF disc ceramic
- 1 27pF disc ceramic

### Resistors (0.25W 1%)

- |               |        |
|---------------|--------|
| 1 47k         | 1 10k  |
| 1 6.8k        | 1 2.2k |
| 1 10 $\Omega$ |        |



Here's the circuit diagram (top), the wiring diagram (above) and the closeup top photo of the FM Radio's PC board assembly (left). Use them all as a guide when you're building up your own Radio.

## Tech Talk: How does it work?

The heart of the FM Radio circuit is IC1, which is a TDA7000 IC containing most of the electronics needed to receive FM signals and convert them into audio again.

The TDA7000 is fairly complicated inside, so we're not going to try explaining how it works in detail. But in broad terms, it uses the **superheterodyne** or 'superhet' principle, to shift the incoming FM signals down to a much lower frequency, so they can be more easily amplified and cleaned up or **limited**. Then these amplified and limited FM signals are fed into an FM detector or **demodulator**, to recover the original music or vocal audio signals.

If you look at the circuit diagram, the FM signals come in from the antenna wire and are then fed into pin 13 of IC1, after being broadly tuned by coil L1 and the 39pF and 47pF capacitors. Inside the IC they're then fed into a mixer, where they mix or **heterodyne** with a local oscillator ('LO') signal. This signal is generated inside the chip by an oscillator transistor which uses coil L2, tuning capacitor VC1 and the 68pF and 27pF capacitors for its tuning circuit — i.e., to set and adjust its frequency. When you adjust VC1, you're therefore varying the local oscillator frequency.

When the LO signal mixes with the incoming FM radio signals in the mixer, this produces a much lower **intermediate frequency** or 'IF' signal, with a frequency corresponding to the *difference* between the LO and FM signals. It's this IF signal which is then passed through the IC's amplifier and limiter stages, to amplify and clean it up ready for demodulation.

Inside the TDA7000, the IF amplifier and limiter are designed to handle an IF signal centred on quite a low

frequency: 70kHz. That's why VC1 tunes the local oscillator over the range from 88.07MHz to 108.07MHz, so it can be tuned 70kHz higher than the station you want to receive (giving a difference of 70kHz between the two, and hence an IF signal of 70kHz).

By the way, many of the capacitors which are connected to pins 1, 3, 4, 7, 8, 9, 10, 11, 12, 15, 17 and 18 of IC1 are used as part of the tuning of the IF amplifier and limiter.

At the end of the IF amplifier and limiter, the signals are fed through an FM demodulator to extract the modulation. Then the resulting audio output emerges from pin 2 of the IC.

As you can see, from there the audio signals are taken to volume control VR1. This selects the proportion of them that is fed to IC2, which is an LM386 audio amplifier. The boosted audio signals then emerge from output pin 5 of IC2, and are fed through the 220µF coupling capacitor to the earphone socket.

If you're wondering what is the purpose of transistor Q1, this is the radio's automatic power on/off switch. It allows current to flow from the 9V battery into the two ICs only when you plug your stereo 'phones into the output socket CON1.

When the phones are not plugged in, Q1's base is connected only back to its emitter, via the 10k resistor. It therefore can't draw any base current, and stays turned off. But when you do plug in the phones, this completes the DC circuit from the base down to the negative line, via the 6.8k resistor and one of the earphones. As a result Q1 is able to draw a small base current, and this turns it on — to allow current to flow into IC1 and IC2. So the radio is turned on, and can begin working.

There is one wire link to fit on the board, so this should be fitted before anything else. It goes down near the bottom of the board, as you can see from the wiring diagram and top photo. Use a 31mm length of the enamelled copper wire supplied in the kit to make the link, carefully straightening it and scraping off the enamel from about 4mm at each end. The ends are then bent down at 90°, passed through the matching holes in the board and soldered to the pads underneath. (The rest of the enamelled copper wire will be used to wind coil L2, a little later.)

After the wire link is prepared and fitted, fit the three PC board terminal pins used in this project. One of these fits near the top of the board in the centre, to connect the radio's antenna wire. The other two pins fit down near the bottom of the board on the right, to connect the battery clip lead wires.

Next identify the radio's five fixed resistors. These all have different values, so be careful to fit each one in the right position. Resistors aren't polarised of course, but it's still a good idea to fit them so their colour code bands read from either 'west to east' or 'south to north' on the board — in case you ever need to check their values in the future.

After the fixed resistors, pick out diode D1 and fit it next. It goes down near the bottom of the board, just below the wire link. Since diodes are polarised, make sure you fit it with its cathode band end towards the left as shown in the wiring diagram.

Now it's a good idea to fit the volume control pot (potentiometer) VR1. This is a very small '9mm' size 50kΩ pot, which mounts directly on the board down at the bottom and on the left. It has three closely spaced pins underneath, which are soldered to the pads under the board while you hold the pot firmly against the top. The pot spindle is already cut to the right length for the small instrument knob supplied.

You can also fit the 3.5mm stereo socket CON1 next. As you can see it mounts just along from VR1, the other side of

the 6.8k resistor. You may have to straighten some of the socket's pins carefully before they'll all go through the board holes without strain, before soldering.

The next components to fit are the small disc ceramic capacitors. There are quite a few of these in the radio — 15, in fact. So work carefully, making sure you fit each one in its correct position. Notice that there are two each of three different values: 330pF, 2.2nF and 3.3nF. If you pick these out and fit them first this will help avoid mistakes.

Disc ceramic capacitors are not polarised, so you don't need to worry about their orientation. Just fit them so their value markings can still be seen, wherever possible. But you may need to crank some of their leads carefully inwards or outwards, so they'll pass through the board holes without strain.

Next pick out the three 100nF multilayer monolithic capacitors, which are smaller than the disc ceramics and usually blue in colour. One of these goes at the top of the board near the antenna connection pin, while the other two go down near the centre of the board on the left. Again you may need to crank their leads inwards or outwards, before they'll pass through the board holes easily.

Now fit the remaining three unpolarised capacitors. Two of these will probably be greencaps: the 10nF and the 47nF. The remaining 150nF capacitor will probably be an MKT capacitor, in a small rectangular cream-coloured package.

Next fit the four electrolytic capacitors. These are polarised of course, so be careful to fit each one with the right orientation. In this case they all mount with their negative 'stripe' side facing towards the bottom of the board, and their positive leads towards the top as shown in the wiring diagram.

Now you should be ready to wind coil L2, the only coil which needs to be wound for the radio. (Antenna coil L1 is formed from a 'zig-zag' of copper tracks on the board, near the top.) As you can see from the wiring diagram, L2 is made



by winding only two turns of the 0.5mm diameter enamelled copper wire on the plastic coil former supplied in the kit.

Here's how to wind the coil: first, make sure that the two connection pins on the base of the coil former are straight and parallel, so they'll pass down through the PC board holes without strain when the coil is finished and ready to mount. Then cut off a 60mm length of the enamelled copper wire and carefully straighten it. After this scrape off the enamel from 5mm at each end of the wire, leaving bare copper ready for soldering.

Now take your long-nose pliers and carefully bend one bared end of the wire into a tiny loop which will slip down over one of the coil former's pins. Push this loop down on the pin as far as it will go (i.e., against the former's base), and carefully solder it to the pin. Use only a small amount of solder — just enough to make a good joint, without leaving a huge blob of solder.

Next, holding the coil former in one hand, carefully bend the free length of wire close to the solder joint so that it swings up towards the coil former itself, while resting in one of the grooves in the base. Then bend it again down against the top of the base, so it's resting against the very bottom of the former. This will allow you to wind it around the former in two tightly spaced turns — or strictly speaking, almost 2.5 turns — until the end of the wire reaches the top of one of the base grooves near the former's second connection pin. Then bend the wire down so it rests in that groove, which should leave the bared end underneath and ready to be looped around the second pin. It's then soldered to the base of the pin like the start of the wire.

Once this is done your coil should be finished and ready to mount into the board. As you can see from the wiring diagram it goes in the centre of the board, just above the 220µF electro. Push the pins through the matching board holes as far as they'll go, and then hold the coil former against the top of the board while you solder both pins to the pads underneath.

Next you can fit transistor Q1 and the two ICs. Q1 is a PN200 transistor in a plastic TO-92 package, which fits on the board just below the 220µF electro. As you can see from the wiring diagram it mounts with its flat side towards the electro and the top of the board. You will probably need to crank its two outer leads outwards and away from the centre lead by about 1mm, so they'll all go through the board holes without strain.

IC1 is a TDA7000 device in the larger 18-pin DIL (dual inline) package, which mounts up near the top of the board with its notch/dimple end facing toward the left. As with most DIL devices you may need to bend its two rows of pins slightly inwards and towards each other, before they'll all go through the board holes without strain.

IC2 is an LM386N device in the smaller 8-pin DIL package. This mounts on the left-hand side of the board in the centre, with its notch/dimple end towards the top of the

board. Again you'll probably have to bend the rows of pins slightly inwards so they'll all pass through the board holes easily.

Neither IC1 nor IC2 is a MOS device, so don't be worried about handling them. There's no need to discharge yourself by touching earthed metalwork, because bipolar ICs like these are not especially vulnerable to damage from electrostatic charge.

The last component to fit on the board is VC1, the tuning capacitor. This is a very compact two-section variable capacitor using plastic film dielectric, in a semi-clear plastic case measuring 20 x 20 x 11mm. It comes complete with mounting screws and a matching disk 'knob', which screws to the end of the spindle.

In this project we mount the capacitor directly on the top of the board, but facing downwards so the spindle protrudes underneath. To prepare it for mounting, carefully straighten its three connection leads and then bend them by 90° towards the 'front' of the capacitor, about 0.5mm from the body. Then you should be able to pass them down through the holes in the board without strain, until the capacitor body is resting on the top of the board. At the same time the capacitor's tuning spindle should pass freely through the 8.5mm hole in the board.

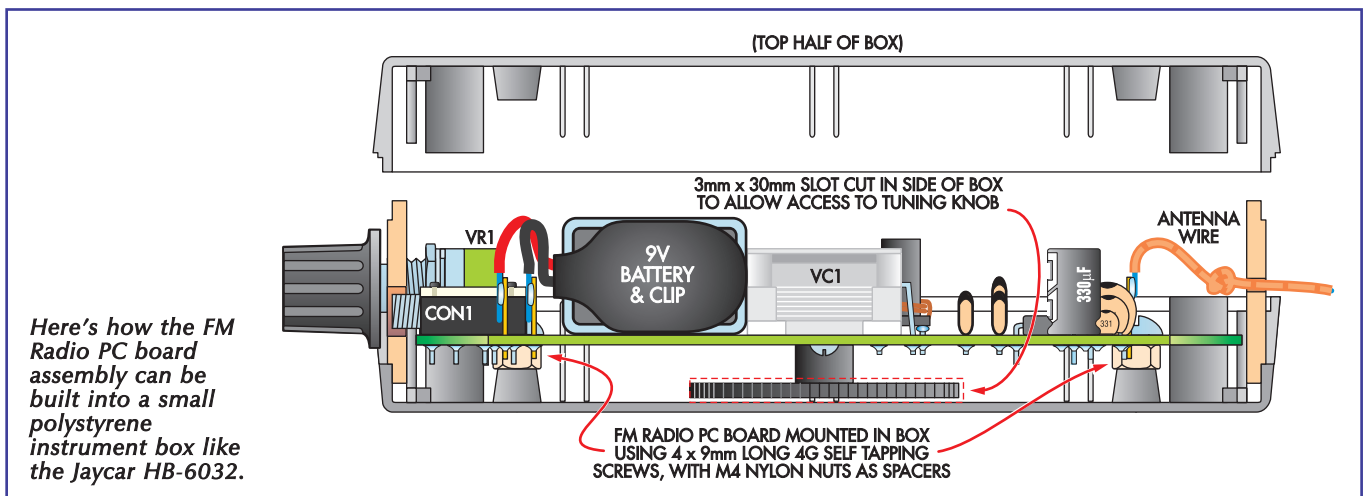
Now take two of the 3.5mm long M2 screws which come with the capacitor, and use these to fasten the capacitor in place. They screw up into the tapped holes provided in the 'front' of the capacitor, on either side of the spindle. The PC board has holes to take these screws, so it should be an easy operation.

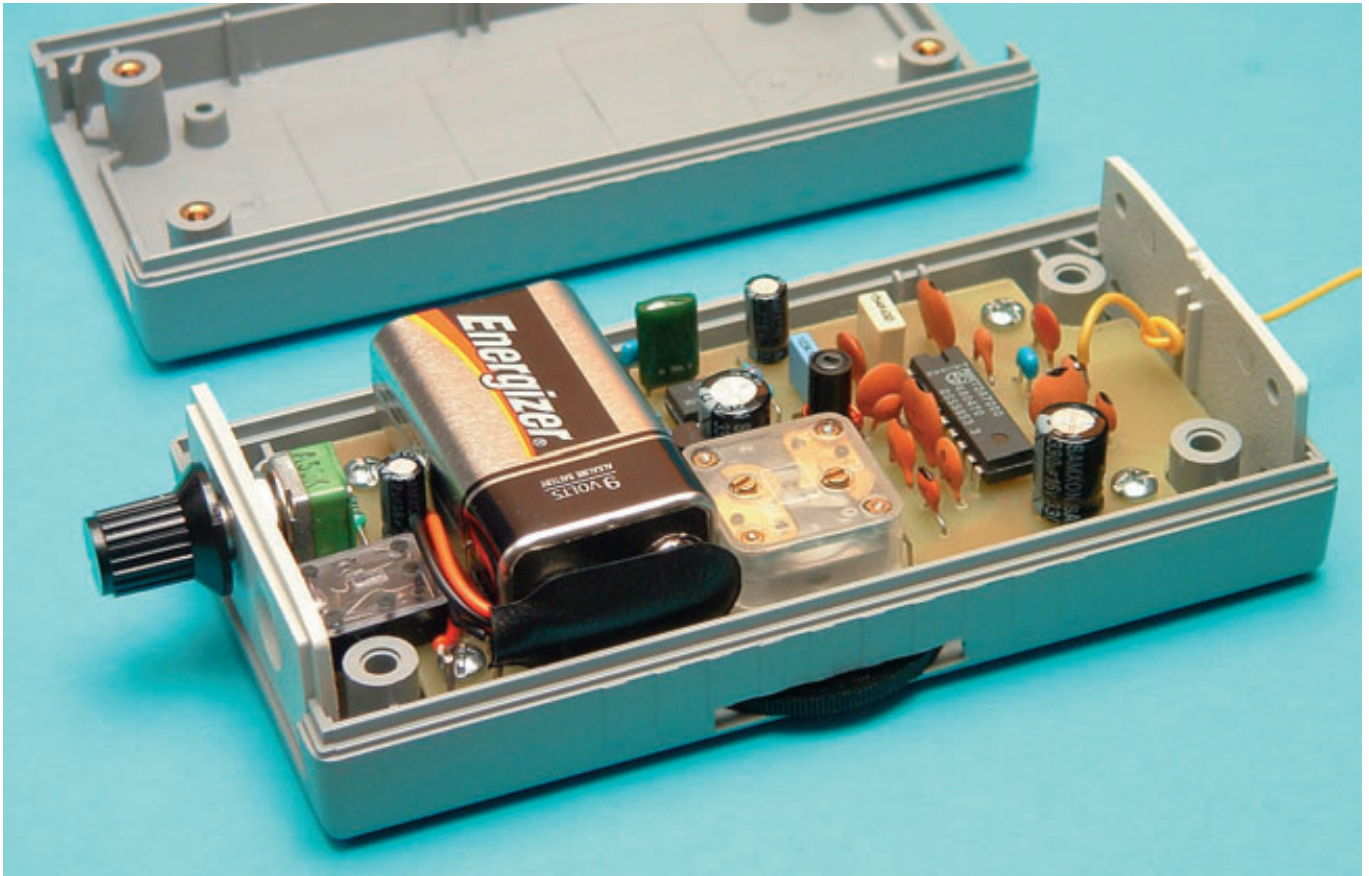
When the capacitor is mounted on the board in this way, you can then solder each of its three leads to the pads under the board. Then cut off any excess lead length, just above the solder joints. You should then be able to fit the capacitor's tuning knob to the end of its spindle, using the remaining 3.5mm long M2 screw. But when you do this, notice that the end of the spindle has two small machined flats, while the blind hole in the centre of the knob has indentations to match these flats. This stops the knob from rotating on the spindle, without having to tighten the screw excessively.

Your FM Radio should now be just about finished, and ready to be tried out. All that remains is to solder the ends of the battery clip lead wires to the two terminal pins at the bottom of the board, and solder one end of the antenna wire to the terminal pin at the top of the board.

Make sure you connect the positive (red) battery lead wire to the lower of the two terminal pins, and the negative (black) wire to the upper pin. The antenna wire is simply a 750mm length of light duty insulated hookup wire.

Now give your board assembly a quick check to make sure that you've fitted all of the components in their correct positions and with the right orientation. Also inspect the





*If you do want to build the Personal FM Radio into the HB-6032 box, here's another photo to help you. Everything fits in, but there isn't much room to spare. Cutting the slot for the tuning knob is a bit fiddly too, but isn't hard if you drill a row of 2.5mm holes carefully first. Then open up the slot and neaten it using small jeweller's files.*

copper side of the board carefully, just in case you've forgotten to solder one of the component leads or left a dry joint to cause trouble.

One last thing to check is that there is a ferrite tuning slug inside the L2 coil former. This looks a bit like a headless grub screw, with a thread along the side and a slot moulded into the end so the slug's position inside the former can be adjusted using a plastic or ceramic alignment tool. It should have been supplied already inside the kit's coil former, but if it came separately just screw it gently into the former using an alignment tool or your fingers. It should be screwed into the former so its top end is just level with the top of the former, as a starting position.

### Trying it out

Now for the big test. First turn volume control VR1's knob fully anticlockwise, and also turn the tuning knob on VC1 to about the middle of its range. Then connect a 9V battery to the clip lead, and finally plug a pair of stereo earphones into the radio's phone socket.

Next turn up the volume control slowly, to about halfway. You probably won't hear an FM station as yet, because the radio hasn't been tuned to one. But you should at least hear a gentle hissing, to show that the radio is working.

Now try turning the tuning knob very slowly, in one direction or the other. Before long you should find a station, and be able to tune to it for loud and clear reception without difficulty. Further tuning should allow you to find other stations, too.

If this all happens as described, your Personal FM Radio is basically working as it should. But if your radio just sits there sulking in silence, that will be almost certainly because you've made some kind of mistake in building it. So unplug the earphones, disconnect the battery and start checking it all again to look for the problem.

You might have connected the battery clip lead wires the wrong way around for example, or fitted diode D1 in reverse. Or perhaps you've forgotten to solder one end of the wire link on the board, or you've left a dry joint somewhere. Another possibility is that you may have accidentally fitted transistor Q1 the wrong way around, as this too will prevent the radio from working at all.

So it's a matter of inspecting your board very carefully step by step, until you find the cause of the problem. Once you do find it and fix it, your radio should spring into life.

### What to do next

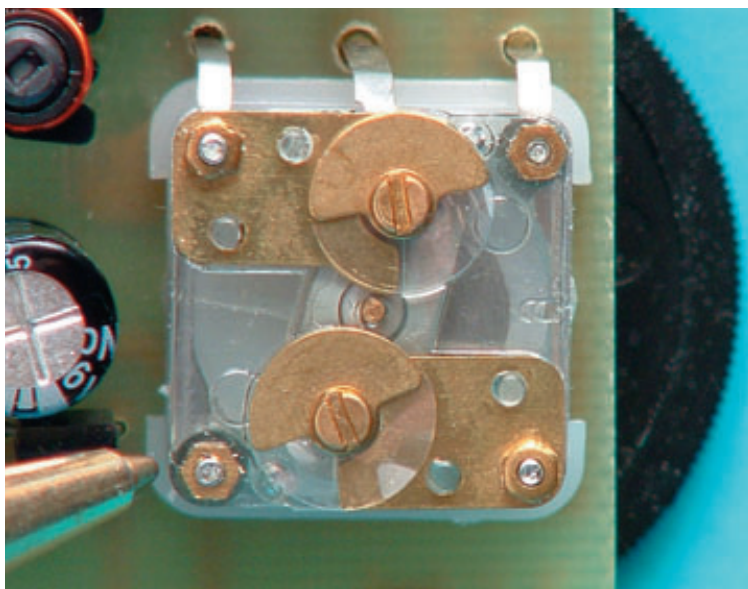
If you've assembled the radio just as we've described, it should give good reception of local FM stations that are almost anywhere in the standard FM band — which extends from 88MHz (megahertz) to 108MHz. However if one of your local stations is right near one end of this band, it's possible that you may need to make a small adjustment before that station can be tuned in.

This is fairly easy to do, but the exact adjustment needed will depend on whether the station you can't-quite-tune-in is at the high end of the band (i.e., up near 108MHz) or the low end of the band (down near 88MHz). So if you know which station the radio isn't receiving, you may need to look in the FM radio guides to find the station's operating frequency. Then you'll know whether it's near the high end or the low end of the band.

Once you know this, you can make the adjustment to move the radio's tuning range up or down, so it brings the station in.

If the missing station is up at the high end of the band, the tuning range needs moving up a little. This can usually be done by adjusting one or both of the tiny 'trimmer' capacitors on the back of VC1, using a small alignment tool or jeweller's screwdriver. As you adjust the trimmers you can see





*Inside the back of tuning capacitor VC1 there are two small 'trimmer' capacitors, with semicircular rotating plates which move over fixed plates. We've removed the back cover here to make them easier to see. You can adjust either trimmer using a small screwdriver to vary the radio's tuning range, as we explain in the text below.*

the trimmer's semicircular plate inside moving over or away from a fixed metal plate, and in this situation you need to adjust the trimmers so that less of their moving plates is over the fixed plates (see photo above).

If you can't bring in the missing station even when both trimmers are adjusted so that their moving plates are fully away from the fixed plates, you may also have to unscrew the tuning slug in coil L2 by half a turn. But this shouldn't be necessary.

On the other hand if your missing station is down at the **low** end of the FM band, the tuning range needs moving down a little. In this case it's the tuning slug in L2 which is where the adjustment is made, not the trimmers in VC1. The slug needs to be screwed into the former a little further, so do this by say half a turn and then see if the station can be tuned in. If it still can't be found, screw the slug in another half-turn and try again. Keep doing this until the missing station can be tuned in easily near the low end of VC1's tuning range.

So that's how the radio's tuning range can be adjusted, to make sure you can receive all your local stations. The trimmers in VC1 are mainly used to adjust the high end of the tuning range, while the slug in L2 is mainly used to adjust the low end. But there is some interaction between the two, so always make the adjustments carefully in small increments. If you don't, you may find that a station at one end of the band 'disappears' when you shift the range too far away to bring in a station at the opposite end.

Once your radio is working as it should and tuning in all the local stations, you'll probably want to build it into a box so it's neater and easier to use. This isn't too hard to do, as the radio's electronics has been designed to fit (just!) in a very small and low cost polystyrene utility box: the Jaycar HB-6032, which measures only 120 x 60 x 30mm overall. This box comes in two mating halves, with small end plates which fit into slots at each end. The two main halves are then held together with four 20mm long countersink-head M3 screws.

The FM Radio's PC board has been designed so that it will fit inside this box. That's the reason for those rounded notches at each corner of the board, because these are to provide clearance for the pillars inside the box. A 7mm hole is drilled in one of the box's end plates to allow the volume control spindle to emerge for its knob, and also a 9mm hole to allow the earphone plug to mate with the radio's 3.5mm socket. Another 1mm hole is drilled in the centre of the other end plate, to bring out the antenna wire.

But the most fiddly part of building the FM Radio into this box is cutting a small rectangular slot in the side of the bottom case half, to allow the tuning capacitor's flat disk 'knob' to emerge from the box for tuning. The slot needs to be 30mm long and 3mm wide, and should be located in the centre of the box side but right at the bottom — so its lower edge is level with the inside surface of the bottom of the box. The easiest way to make the slot is to drill a row of 2.5mm holes first, and then open them up to form the slot using small jeweller's files.

The FM Radio's PC board is mounted inside the bottom half of the box using four 9mm long 4G self-tapping screws, which mate with the box's four small moulded pillars. However you also need to add an M4 nylon nut on each screw as a spacer, so the board sits high enough over the bottom of the box to allow the tuning knob to rotate (see diagram).

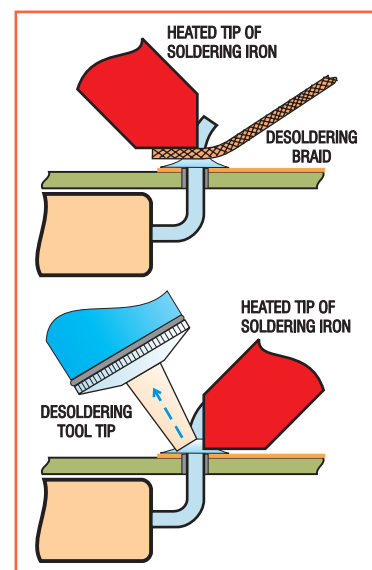
Hopefully you can see how it all goes together from the diagram and the internal photo. It's a fairly tight squeeze, especially for the battery, but everything does fit in — just.

## Desoldering techniques

Parts often need to be removed from an existing PC board, either to replace them if they've become faulty, or to re-use them in another project. Whatever the reason, in order to remove them without damaging them — or the board and the other components on it — you need to remove the solder joining their leads to the PC board pads. This is known as **desoldering**, and it can be done in either of two ways.

One way is by using **desoldering braid** (also called 'solder wick'), which is a narrow ribbon of copper wire mesh impregnated with resin flux, and sold in small rolls. It's quite easy to use: you simply place the end of the braid on the top of the joint you want to desolder, and then place the tip of your hot soldering iron on top of the braid. The iron heats up both the braid and the solder, and as soon as the solder melts it is sucked up into the braid by capillary action. If the joint has a lot of solder to be removed, you might need to snip off the solder-filled end of the braid and repeat the operation to remove the solder that remains.

The other approach is to use a **desoldering tool** or pump (also called a 'solder sucker'). This is a small hand tool a bit like a syringe, with a spring inside so when you press a release button, the spring makes an internal piston fly up and create strong suction in the hollow tip. So if the tip is placed on the top of a solder joint which is being heated up by your soldering iron tip, the pump will suck up the molten solder.





## Project 22:

# 3-Stage FM Transmitter

Would you like to build an FM radio microphone with more output and range than the two transistor design in project 12? This is the one for you, then. It has an extra transistor for more 'grunt' and does need a little more effort to build and get going — but the payoff is improved performance. You can also use it as a wireless audio link, to feed the output from your personal CD or tape player into a hifi system — even one in another room.

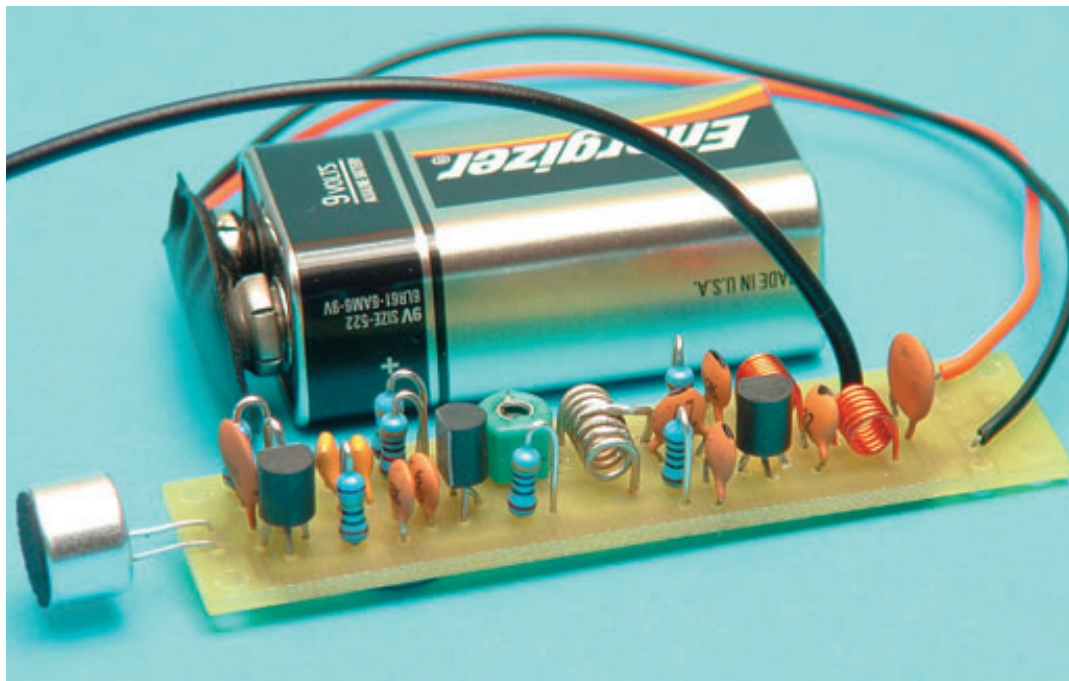
### What does it do?

This project is really a miniature FM radio transmitter, just like the FM radio microphone in project 12. This means that it takes the audio signals from either a microphone or a CD player, etc., and uses them to produce an FM radio signal which you can receive on a standard FM radio receiver.

It doesn't produce a radio signal that's nearly as strong as one of the FM radio stations — after all, it's only operating from a 9V battery. But if the tuned circuits are properly adjusted, the output signal will be strong enough to be received clearly over distances of up to one kilometre in the open, or shorter distances through walls and trees.

So using the electret microphone supplied in the kit, you'll be able to use the transmitter as a 'wireless mike' for singers and stage performers, for example. This allows their voices to be picked up and fed through a public address sound system, without them having to risk tripping over a mike cable.

Similarly you can use the transmitter as a 'baby minder', allowing mum to listen in the kitchen, laundry or even in the backyard for when baby wakes up and starts crying in the nursery or bedroom.



Another use for the transmitter is as a tiny FM radio station, where family members can sing, recite poetry or act in radio plays which can be received elsewhere in the house or even in a neighbour's house.

If you feed the signal from a tape or CD player into the transmitter (we show you later how to do this), you can also use it as a wireless audio link. This allows you to play your

## The parts you'll need for this project:

- 1 PC board, code SHRTC222, 17 x 70mm
- 1 Electret microphone insert, with pins
- 1 9V battery, 216 type
- 1 Battery clip lead to suit
- 1 Short length of 0.5mm tinned copper wire (for winding L1)
- 2 Short lengths of 0.5mm enamelled copper wire (for winding coils L2, L3)
- 1 750mm length of insulated hookup wire (for antenna)
- 1 Small pack of resin-cored solder

### Semiconductors

- 2 BC547 NPN transistor (Q1, Q2)
- 1 BC548 NPN transistor (Q3)

### Capacitors

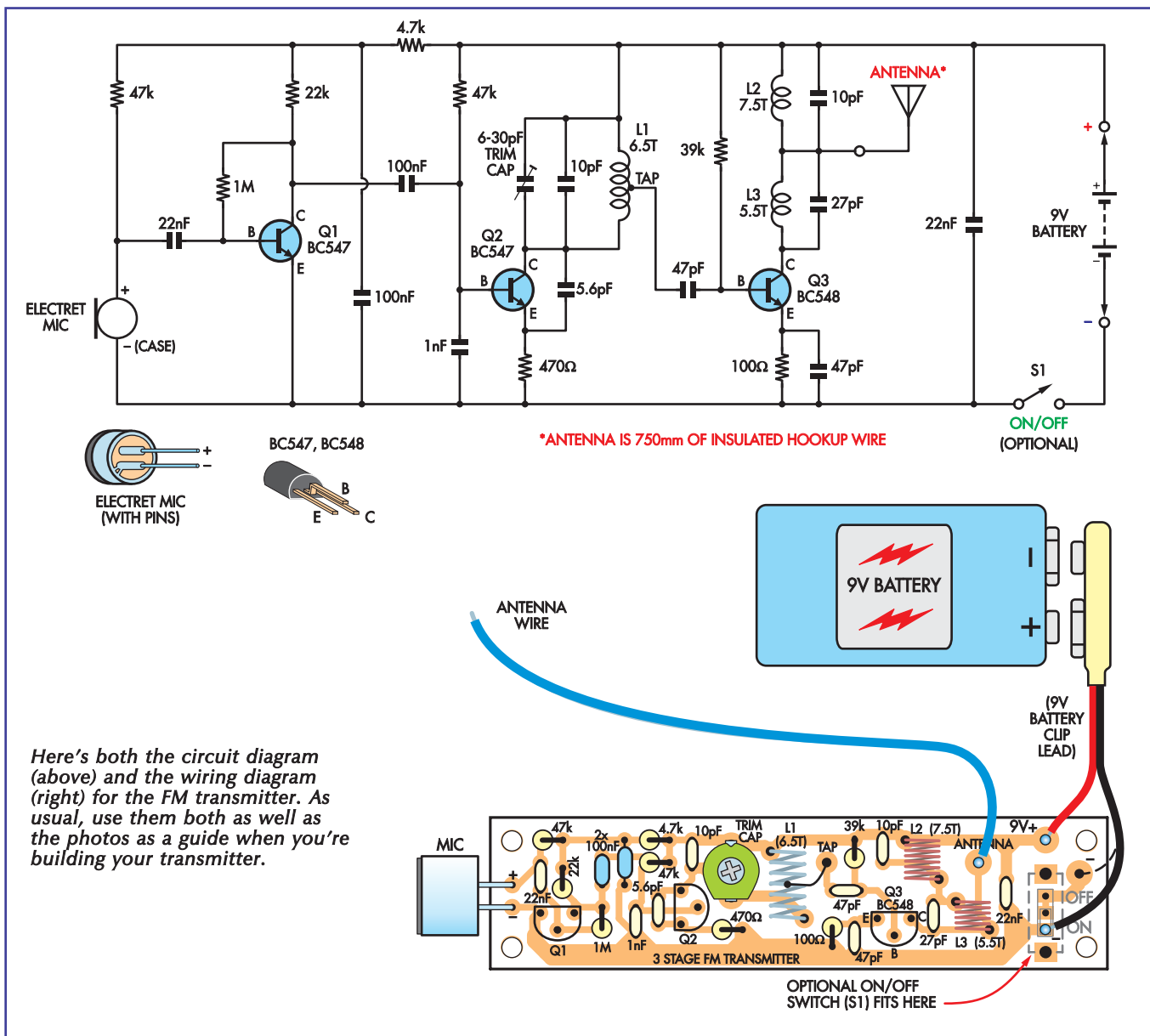
- 2 100nF multilayer monolithic
- 2 22nF disc ceramic
- 1 1nF disc ceramic
- 2 47pF NPO disc ceramic
- 1 27pF NPO disc ceramic
- 2 10pF NPO disc ceramic
- 1 5.6pF NPO disc ceramic
- 1 6-30pF trimcap (green)

### Resistors (0.25W, 1%)

- |        |        |
|--------|--------|
| 1 1M   | 2 47k  |
| 1 39k  | 1 22k  |
| 1 4.7k | 1 470Ω |
| 1 100Ω |        |

### For RF tuning detector

- 1 100pF disc ceramic capacitor
- 1 100nF disc ceramic capacitor
- 2 1N4148/1N914 silicon diodes



tapes and CDs through dad's hifi system, without having to worry about special sockets and connecting cables.

Of course if you were a spy or private detective you'd also be able to use the transmitter as a 'bug' to eavesdrop on people. But you wouldn't want to use it for that sort of thing, would you?

### Putting it together

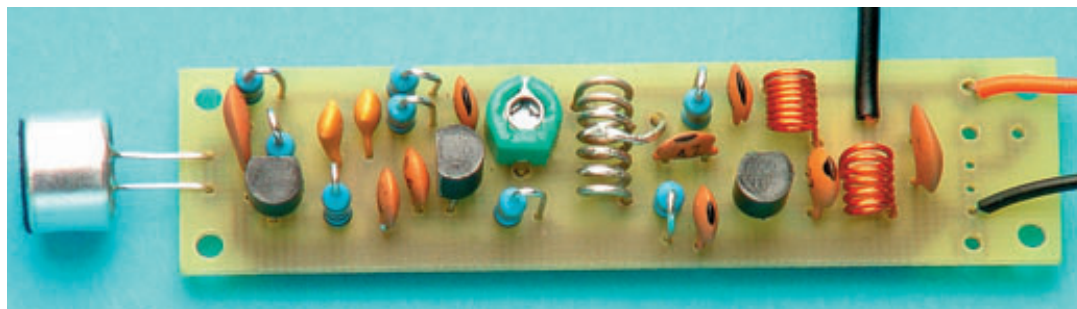
Like all of our other projects this one is assembled on a single PC board. The only difference is that here the board is quite small (only 17 x 70mm), which means that the components are more tightly packed. The resistors are mounted on end, so you do have to be a little more careful in bending the component leads and soldering them into the board.

Start by making sure that your kit has all of the components shown in the parts list. Check that you can identify

them all and 'read' the resistor and capacitor values, etc.

The first component to fit is the trimcap. This should be mounted with its 'flat' end towards where the 470 ohm resistor will go, as shown in the wiring diagram.

Now you can fit the fixed capacitors. These are all quite small ceramic components, which mount down against the board with their leads pushed through as far as they'll go without straining the capacitor. Note that some of the capacitors may need to have their leads carefully cranked either slightly closer together or slightly further apart, so that they pass easily through the board holes. As usual do this



## Tech Talk: How does it work?

The transmitter is said to consist of three 'stages' because each of the three transistors Q1, Q2 and Q3 and the components around them have a separate and clearly defined role. For example Q1 and the parts around it form a common-emitter audio amplifier stage, which takes the weak audio signals produced by the electret microphone and boosts them so they're strong enough to *modulate* the frequency of our RF oscillator stage — which is formed in turn by Q2 and the parts around it.

Transistor Q2 oscillates and produces RF energy because the 5.6pF capacitor between its collector and emitter couples some of its collector energy back to its input without a polarity reversal, so there's *positive feedback*. And it oscillates at our chosen frequency in the FM band because its collector 'load' is a tuned circuit formed by coil L1, the trimcap and the 10pF capacitor. We adjust the trimcap so that the tuned circuit *resonates*

and has a maximum impedance at this frequency.

By feeding the amplified audio signal from Q1 to the base of Q2 via the 100nF capacitor, we allow the audio to vary the bias voltage at Q2's base. This varies both Q2's gain and also its internal capacitances, which in turn varies its oscillating frequency. This is how we achieve frequency modulation or 'FM'.

Q3 and the parts around it form an RF amplifier stage, which takes the modest RF output from oscillator Q2 and boosts its strength to feed out to the antenna. We pick off some of the RF voltage from the tap on coil L1, and feed it via the 47pF capacitor to the base of Q3. The amplified RF pulses which appear at the collector of Q3 then 'kick' into oscillation the output tuned circuit (or 'tank') formed by coil L3 and the 27pF capacitor across it, and also coil L2 and the 10pF capacitor across it. The use of two LC tuned circuits in the collector circuit of Q3 allows us to provide a lower impedance output to the antenna, and also helps reduce any harmonics or other unwanted output signals.

with your long nose pliers.

None of the capacitors is polarised, so they can all mount either way around. But as usual, make sure you fit the correct value part in each position. To help avoid mistakes it's a good idea to identify the two 100nF multilayer monolithic capacitors (they have a shinier coating and a marking of either '104' or '100n') and fit these first.

Next come the resistors, and in this project these are all mounted vertically to save space. So before you fit each one, you have to bend one of its leads carefully around with long-nose pliers, so that its end becomes parallel with the unbent lead and only about 2.5mm away from it. Make sure you don't strain the resistor itself when you're bending the lead.

With the lead bent around in this way, both leads can be pushed through the holes in the board and soldered. Make sure that you mount each resistor value in the correct position and orientated with its longer 'bent down' lead as shown in the wiring diagram.

Once the resistors have been fitted, you can add the two BC547 transistors Q1 and Q2. These have to be orientated with their 'flat' side as shown in the wiring diagram. Note that in most cases BC547 transistors come with their centre (base) lead already 'cranked' so that the three leads form a triangle with the base lead at the apex, and this project's PC board has the holes for Q1 and Q2 laid out the same way. So if your BC547 transistors don't come this way, you'll need to bend it yourself carefully using long nose pliers.

Even if their base leads are already cranked, you'll still need to crank the other two leads outwards as well, so that all three leads will pass through the board holes easily and allow the transistor to be mounted with the bottom of its body only about 3mm above the board, before soldering the leads to the pads.

When you've fitted both Q1 and Q2 and soldered their leads, you can fit the BC548 transistor Q3. This again comes with its centre lead cranked, but in this case it must be carefully straightened and cranked back the other way — i.e., towards the 'flat' side of the transistor. As before you also have to crank the other two leads outwards slightly, so that all three will pass through the PC board holes easily.

Next you can fit the electret microphone insert. This fits up at the end of the board nearest transistor Q1 and the main thing you have to watch is fitting it the correct way around, because it too is polarised.

The electret mic used here comes with two pins already fitted, ready to connect directly to the PC board. The pin that connects to the '-' board pad is the one that's clearly connected at the back of the insert to its metal case; the other connects to the '+' pad. Bend both pins downward at 90° about 3mm from their outer ends, so the ends will pass through the board holes and allow you to solder them to the pads.

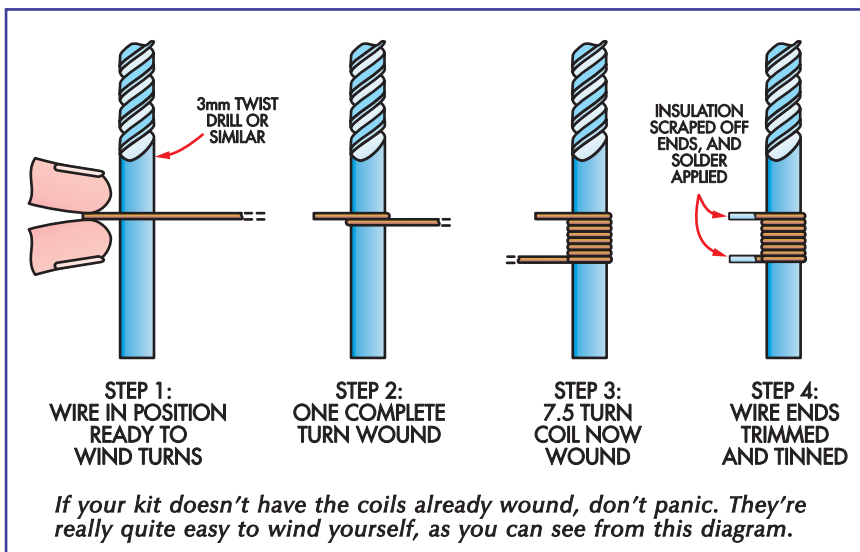
The final components to fit are the three coils L1, L2 and L3. We've left these until last because although we hope to be able to include pre-wound coils in all kits, this may not always be possible — so in some cases you may have to wind them yourself.

If your kit *does* include pre-wound coils, all you'll have to do is pass their end wires through the corresponding holes in the board and solder them to the pads beneath. Just make sure that you fit the silvery-looking 6.5-turn coil in the L1 position, the 5.5-turn coil in the L3 position and the 7.5-turn coil in the L2 position.

### If you need to wind the coils

Luckily even if your kit doesn't include pre-wound coils, it's very easy to wind them because they have only a small number of turns. The easiest way to wind them is by using the smooth shank of a 3mm or 1/8" twist drill as a 'mandrel'; then after they're wound you simply slide them off the drill shank.

Coil L1 is wound using the short length of 0.5mm or 0.71mm tinned copper wire





you'll find in the kit. This is the wire that looks silver in colour, rather than coppery. All you need do is hold one end of the wire about 10mm from the drill shank, with the rest of the wire at 90° to the drill axis. Then carefully wind this part of the wire around the drill shank (clockwise) to form six and a half turns, close together and with the far end leaving parallel with the start — but on the other side of the drill and coil. The diagram on the page opposite shows how it's done.

Before you slide the wound coil off the drill shank, gently take the two wire ends and pull them apart to 'expand' the coil so that the total length extends to 7.5mm and the turns are all spaced apart evenly by about 1mm. Then trim both wire ends to be about 6mm from the coil, and it's ready to slide off the drill and fit to the PC board. Push the wire ends through the board holes until the bottom of the coil is only about 1mm above the board, and then solder them to the pads. Then trim off any excess wire with your side cutters.

Coils L2 and L3 are wound in exactly the same way as L1, but this time using the 0.5mm enamelled copper wire (copper in colour). L3 has 5.5 turns, but in this case the turns are left close together after winding — not pulled apart to space them. On the other hand after you've wound the coil and trimmed the two wire ends to about 6mm long, both ends have to have the thin enamel coating scraped off to leave bare copper, ready for soldering.

L2 is wound in exactly the same way as L3, but it has two extra turns (i.e., 7.5 turns in all). Again the turns are left close together and the ends have to have the enamel scraped off to allow easy soldering.

Both L3 and L2 are fitted to the board in the same way as L1, with the bottom of the coil turns only 1mm or so from the board before the leads are soldered to the pads underneath.

Once all three coils are fitted, you can use a short length of tinned copper wire (or a resistor lead offcut) to make the 'tap' connection to the centre of coil L1. This is soldered at one end to the very top of the centre turn on L1, with the other end bent down and passed through the hole in the board nearby, marked 'TAP'. Keep this tap wire fairly short, but don't let it touch any other part of L1. Needless to say it's also soldered to the pad under the board below the TAP hole.

Your FM transmitter board should now be complete. All that remains is to solder the ends of the battery clip lead wires to the '+9V' and '-' pads at the end of the board furthest from the microphone, and also one end of the insulated antenna wire to the 'ANTENNA' pad. Remember that the red battery clip wire solders to the 9V+ pad, and the black wire to the '-' pad. Take special care with these connections, because this project doesn't have protection against damage from connecting the battery with reversed polarity.

Needless to say you also have to strip off about 5mm of insulation from one end of the antenna wire, so you can solder the wire to its pad on the board.

## Tuning it up

The transmitter should begin working as soon as you connect the battery to the clip lead. But before you can use it, you need to adjust the tuning of its RF oscillator so that it's not transmitting on the same frequency as any of the FM

stations in your area. Otherwise you won't be able to receive its signals clearly. To get the best performance out of the transmitter its output tuned circuit or 'tank' must also be tuned to resonate at the same frequency as the oscillator, so that the output stage amplifies the signal as efficiently as possible.

First things first, though. To adjust the oscillator's tuning to a 'clear' frequency you'll need to use an ordinary FM radio. Turn the radio on, and carefully tune it over the normal 88-108MHz FM band until you find an area which seems to be clear of any stations. This may well be around 98-100MHz, but it will depend on your particular area and the number of local FM stations.

Now place the radio near the transmitter (or vice-versa), and very slowly and carefully adjust the transmitter's trimcap with a plastic alignment tool or very small screwdriver until you hear its signal on the radio. You'll probably hear a 'feedback howl', as the transmitter's microphone picks up the sound from the radio and transmits it back to the radio. If so, turn down the radio's volume control and re-adjust the transmitter trimcap until you have to turn the radio volume down as far as possible to prevent the howling. This will also

be the setting that gives the quietest background noise from the radio, and the brightest glow from its signal strength light (or the highest reading on its tuning meter, if it has one).

Once this is done, your transmitter's oscillator is working on a good frequency for you to receive it clearly. So you're now ready for the final step, of adjusting the transmitter's output tuning to match this frequency and hence give the strongest output signal, and the best range and performance.

If your FM radio has a signal strength light or meter, you can again use it to make this adjustment (perhaps moving it a bit further away from the transmitter). But if it doesn't, you'll need to make up the little RF detector circuit shown in the small

diagram. This hooks up to your digital multimeter (set on the lowest DC voltage range, like 2V), so that it can be used to measure the strength of the transmitter's RF output signal. As you can see from the diagram the detector also connects to the transmitter's 'ANTENNA' and '+9V' pads.

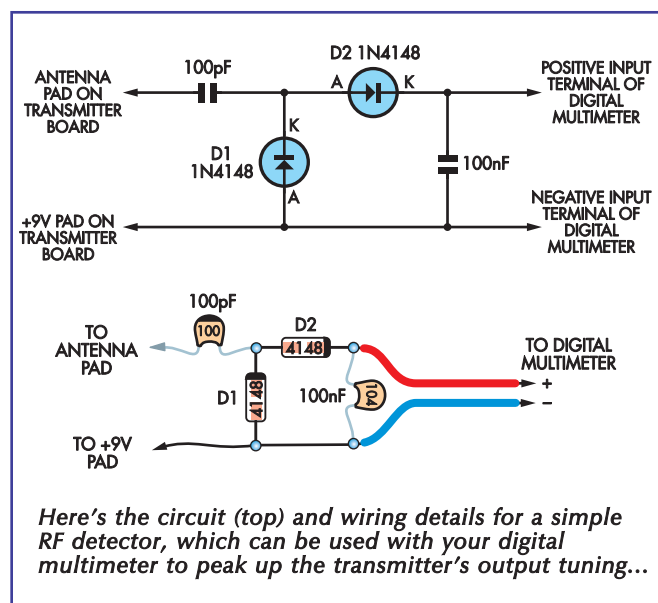
The adjustment itself is quite easy. All you need is a plastic alignment tool, or a piece of plastic knitting needle with its end filed into a thin flat 'screwdriver' blade. And you use this to lever apart gently the turns of the transmitter's output tuning coil L3 slowly, until the output signal reading reaches a maximum or 'peaks', as indicated by either the radio's signal strength light or meter, or the digital multimeter's reading.

If you can't reach a peak even with the turns of L3 spaced well apart, you might have to space the turns of L2 apart a little as well.

That's it; once the output is peaked, your transmitter is finished and ready for use.

## Using it

There's nothing technical about using the transmitter. You simply place it in a position where the microphone will pick up the sounds you want to transmit to the FM radio, stretch out the antenna wire so that it will be able to transmit properly, and connect the clip lead to the battery. Any normal FM radio within range should now be able to receive





# Frequency & Wavelength

Radio and TV broadcasting, radar, shortwave and satellite communications and mobile phones — they all use electromagnetic (EM) radiation, where energy **propagates** (or spreads out) through space or materials in the form of oscillating electric and magnetic fields. So too does optical communication, both in space and along glass fibres, and even the infra-red remote control you use to change the channels on your TV. When you're out in the sun, the light that allows you to see and the direct warmth you feel are both EM radiation — as also is the ultra-violet (UV) radiation that gives you a tan (and skin cancers).

When you heat up a frozen meal in your microwave oven, you're also making use of EM radiation. And when the dentist or radiologist takes an X-ray of some part of your body, they too are using EM radiation.

Although these types of EM radiation might seem quite different, they're really only different in terms of their **frequency** and the length of their propagating waves.

As you may know, when early radio pioneers began working with radio waves, they generally described them in terms of their wavelength. Transmissions were said to be on 'long waves', 'medium waves' or 'short waves' and their actual wavelength was given in metres. Nowadays we tend to describe EM radiation in terms of its **frequency** — in hertz (Hz), kilohertz (kHz), megahertz (MHz) and so on.

How can you convert between the two? As with any moving waves, the frequency and wavelength are simply related by the **velocity**, or the speed at which they move:

$$\text{velocity} = \text{frequency} \times \text{wavelength}$$

Where we have EM radiation propagating through free space or a vacuum, its velocity is well known. It's the so-called *speed of light*, usually labelled *c*:

$$c = 299,793,000 \text{ +/- } 300 \text{ metres/second (m/s)}$$

As you can see, this is very close to 300 million metres per second — closer than 0.1%, in fact. So for most purposes, we can be quite accurate enough calling it 300 million (or  $3 \times 10^8$ ) m/s.

This means that for EM radiation in free space or a vacuum, the frequency and wavelength are related by this simple expression:

$$300,000,000 = f \times \lambda$$

Where *f* is the frequency in hertz, and  $\lambda$  (lambda) is the wavelength in metres.

For many practical situations, this expression can be simplified even further:

$$300 = f \times \lambda$$

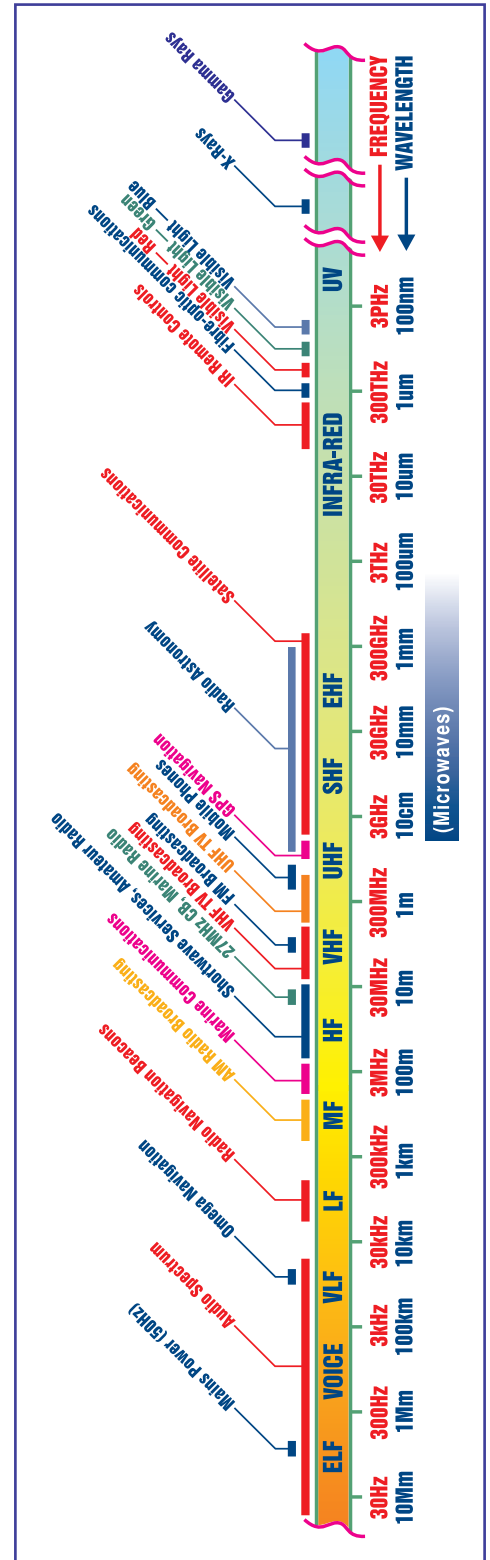
Here both sides have been divided by one million, so the frequency *f* is now directly in megahertz (MHz), and *c* has become simply 300.

As the propagation velocity of EM radiation in air is very close to that in a vacuum, this same expression also gives quite accurate results for radiation in air. So in most cases, to find either the frequency or the wavelength, knowing the other one, you simply divide the one you know into 300. Just remember that the wavelength will be in metres and the frequency in MHz.

It's very easy to remember this: just remember that a wavelength of one metre corresponds to 300MHz, and that doubling the frequency halves the wavelength and vice-versa. Similarly dividing the frequency by 10 gives 10 times the wavelength, and so on.

So the wavelength at 1MHz becomes 300 metres, for example, while at 30GHz the wavelength has shrunk to 10mm (1m divided by 30,000/300).

Don't forget, though, that this rule of thumb relating frequency and wavelength really only applies to EM radiation in free space, a vacuum or air. When EM waves are propagating in an insulating material like the polyethylene



Right: a map of most of the EM spectrum, from audio up to cosmic rays.

| Metric multipliers commonly applied to Frequency |         |   |
|--|---------|---|
| Multiplier/unit                                  | Abbrev. | What it means                               |
| millihertz                                       | mHz     | Thousandths of a hertz ( $10^{-3}$ Hz)      |
| hertz  | Hz      | Basic unit of frequency (=one cycle/second) |
| kilohertz  | kHz     | Thousands of hertz ( $10^3$ Hz)             |
| megahertz  | MHz     | Millions of hertz ( $10^6$ Hz)              |
| gigahertz  | GHz     | Thousands of megahertz ( $10^9$ Hz)         |
| terahertz  | THz     | Millions of megahertz ( $10^{12}$ Hz)       |

inside a co-axial cable, their velocity slows down, by a factor roughly equal to the square root of the medium's dielectric constant. So the wavelength of the radiation in these materials will also be shorter, by the same factor. ★



# Technical Terms Explained

**AC:** Abbreviation for 'alternating current'. The voltage we get from a power point or from an unrectified transformer is AC. The voltage waveform is a sine wave and it alternates between a positive voltage and a negative voltage continuously.

**AC 240V:** The nominal voltage available from a domestic power outlet in Australia and New Zealand (also called 'mains' voltage). Other countries have different voltages — 110V, 115V, 220V and 230V AC are common overseas. Mains voltages are lethal!

**AC-coupled:** Method of connecting two sections of a circuit together so that DC is blocked but AC signals can pass. The usual method of doing this is via a suitable series 'coupling' capacitor.

**Amp:** Abbreviation for Ampere, the unit of current.

**Ampere:** Basic unit of current flow. Can be further defined with metric prefixes (eg milli-, kilo-). A typical transistor radio might draw a few tens of milliamps from its batteries; a typical lightning strike might have a current flow of hundreds of thousands of amperes. The normal 'shorthand' for ampere or amp is 'A' but in equations and on circuits, current is usually denoted by the letter 'I'.

**Amplifier:** Any active device or circuit (eg, using transistors or op-amps) where there is an increase in level between the input and the output. The amount of increase is the amplifier's gain.

**Anode:** The positive terminal of any component. (Applies particularly to diodes and LEDs as far as this book is concerned).

**AND gate:** A logic gate which will have a high level output only if all of its inputs are high.

**Antenna:** A wire, coil or metal structure connected to a circuit to pick up or radiate radio and TV signals (also known as an aerial).

**Astable:** Refers to a multivibrator circuit (or an IC connected as one) which has two states, high or low, and constantly swaps back and forth between them of its own accord.

**Attenuation:** A decrease in signal level, measured as a change in voltage, current or power level, achieved through the use of an attenuator.

**Attenuator:** Any device which decreases the level of a signal; typically a potentiometer.

**Audio Frequency (AF):** Normally regarded as the frequency range between 20Hz and 20kHz. However, high quality audio circuits are usually made to operate over a significantly wider range than this — from less than 20Hz up to 50kHz or more.

**Back EMF:** The voltage which is induced in an inductor or coil when the magnetic field in it changes rapidly or is interrupted.

**Base:** The input or control connection to a transistor. A small current into the base of a transistor causes a much larger current to flow through the collector.

**Battery:** A number of chemical cells connected together in series to provide a higher DC voltage, or in parallel to provide more current. A typical single 'dry cell' produces 1.5V (see 'cell').

**Bias:** A small DC current or voltage applied to a diode, the base of a transistor or the gate of a FET to turn it on. In the case of an op-amp, the bias sets the reference voltage above and below which the output will swing.

**Bipolar:** Literally means 'two poles'. Most common use is in referring to transistors — bipolar transistors are the most common type used in electronics.

**Bistable:** An electronic circuit (or device) which has two stable output states (eg high and low), and requires some form of external control input to make it swap from one to the other. See flipflop.

**Block Diagram:** A simplified diagram of a circuit which demonstrates its operation without showing individual components. Each operational section of the circuit is shown as a functional block.

**Bridge Rectifier:** A set of four silicon diodes (either individual or encapsulated in one package) which provides full wave rectification of AC to DC.

**Buffer:** A circuit or component which acts to prevent one section of a circuit from interfering with the operation of another section.

**Capacitive Load:** Any load on a circuit involving capacitors or the effect of capacitance (for example, a long run of screened or coax cable has capacitance). Such a load is said to exhibit *capacitive reactance*.

**Capacitor:** A component which stores electric charge. It consists of two conducting plates separated by an insulator. The amount of capacitance is measured in Farads, but this is much too large a unit for everyday use. Instead we use microfarads ( $\mu\text{F}$  — one millionth of a Farad) and smaller units. Capacitors let AC signals pass through them but block DC voltages. Capacitors come in many types including electrolytic, polyester, polypropylene, ceramic, paper and mica (the last two are not common these days).

**Cathode:** The negative terminal of any polarised electrical or electronic component, like a diode. (Converse is 'anode').

**Cell:** A container of chemicals which react together to produce electrical energy. A number of cells connected together form a battery.

**Circuit:** An arrangement of electronic components so arranged to perform some function or task. The simplest circuits may have only two components (eg a battery and a torch bulb); the most complex have many millions of components.

**Circuit Diagram:** The graphical representation or drawing, usually on paper, of all the elements of an electronic circuit using commonly understood symbols for components (eg resistors, diodes, ICs and so on) with lines joining the components together showing their inter-connections. Also known as a 'schematic' or 'schematic digram'. See also Block Diagram and Component Overlay.

**Charge:** The quantity of electrons stored in a capacitor or battery. When a capacitor is connected to a battery, it will charge to the same voltage as the battery but the time it takes to do so depends on the resistance in the circuit. The opposite to 'charged' is discharged or 'flat'.

**Chip:** Abbreviation for 'silicon chip', a common name for an integrated circuit or IC.

**Choke:** Another name for an inductor or coil. In most cases (though certainly not all) chokes are wound on a core of ferrite or iron to increase their inductance for the size of the coil.

**Clipping:** Where the top and/or bottom of the signal waveform is flattened, either deliberately or accidentally, due to circuit overload.

**Clock:** A section of a circuit which generates pulses at a

preset rate for use by other sections of the circuit. All computers have a clock, which can typically run at anywhere between 1MHz and 3000MHz. Can also be used to mean the action which occurs when a clock pulse is received by a circuit or component.

**Coil:** Another name for an inductor — wire wound around a former to hold a certain shape, size and number of turns.

**Collector:** One of the three terminals of a transistor. On an NPN transistor, the collector connects to the positive side of the circuit; on a PNP transistor, the negative side.

**Comparator:** An op-amp circuit which compares two voltages. For example, if one voltage is higher than the other, the comparator's output might be high. But if the two inputs are the same, or reversed in levels, then the comparator's output might be low.

**Component Overlay:** See PC board overlay.

**Conductor:** Any material which will allow electric current to flow along or through it easily. Most metals — for example, copper, gold, silver, mercury and aluminium are good conductors. (Converse: 'insulator').

**Continuity:** The ability of a circuit to pass current with either no resistance or very low resistance.

**Coupling:** The method of connecting components together in a circuit to allow signals to pass between them. 'Cross coupling' is used in multivibrators where the base of each transistor is connected to the collector of the other, via capacitors.

**Crystal:** A tiny pellet of quartz which is etched so that it oscillates at a very precise frequency when stimulated by an electric current. Crystals are often part of clock circuits or pulse generators when high accuracy is required. Every digital and 'quartz' watch contains a crystal, usually oscillating at precisely 32,768Hz.

**Current Flow:** A flow of electrons from one part of a circuit to another. Electrons are caused to flow when there is a difference of potential or voltage, between the two points. In this book wherever we talk about current we mean 'conventional current flow' where current flows from the positive supply through the circuit and back to the negative supply.

**dB:** Abbreviation for 'decibel', a logarithmic unit of ratio between voltage, current or power levels and also a unit of sound level compared with a known reference level.

**DC:** Abbreviation for 'direct current' — the current available from a battery or from a rectifier. Unlike AC, direct current always flows in the same direction.

**DC-Coupled:** Also known as 'direct coupled' — sections of a circuit connected together so that both AC and DC can pass between them.

**DC Offset:** In a direct-coupled amplifier, the output should generally be purely AC with an average level of zero. However in most amplifiers there is always a small DC voltage across the output (either positive or negative with respect to earth), due to component tolerances, faults or poor design. This unwanted DC voltage is called the DC Offset. It is often just a few millivolts and can be ignored, but if it is several hundred millivolts or more it may cause distortion and other problems.

**Decoupler:** Usually refers to a capacitor used in a circuit to either smooth a supply line or to help remove any noise on that supply line. Basically, it holds a DC level constant but allows any AC to flow to earth.

**Demodulation:** The process of extracting an audio, video or data signal which has been conveyed from one place to another by modulating an RF or other carrier signal. (See 'modulation')

**Demodulator:** An electronic component or circuit which

performs the process of demodulation.

**Detector:** An AM demodulator. In a radio receiver the detector extracts the audio signal modulation from the RF signal. In many cases, a germanium diode is used because of the low voltage drop across it (0.2V).

**Dielectric:** The insulating material in the space between the two plates of a capacitor, which assists in establishing an electric field.

**Diode:** A semiconductor which allows DC to pass easily in one direction but not in the other. Diodes are typically made from two types of semiconductor, germanium (now usually only used for detectors in radio circuits), and silicon (most modern diodes are made from silicon).

**Discharged:** The state where a component (eg, a capacitor or battery) has no (or little) charge stored in it. In many cases, the component is said to be discharged long before the voltage level has actually dropped to zero, but is too low to be of any use.

**Distortion:** A process, usually unwanted, by which the shape of a signal is altered. Distortion results in the generation of signal harmonics which can make the sound less pleasant.

**DPDT:** Abbreviation for 'double pole, double throw'. A switch (or relay) which comprises two individual switch elements, operated at the same time by the same actuator. Each switch element has one terminal (the 'common') which connects to either of the other two terminals, depending on the switch position or coil energisation. Also known as a 'changeover' switch or relay. If a circuit calls for an 'SPDT' switch or relay, it is usually OK to use a DPDT type, either ignoring one set of contacts or connecting the two sets in parallel.

**DPST:** Abbreviation for 'double pole, single throw'. A switch or relay with two individual switch elements or contact sets, moved at the same time by the same actuator. In this case each switch element has only two terminals, which are either connected together (switch 'on') or not (switch 'off'), depending on the switch position or coil energisation.

**Duty Cycle:** In a bistable circuit, the proportion of the total time that the output is 'high', rather than 'low'. If the duty cycle is 50%, the high and low times are equal. An earlier way of describing this was in terms of the 'mark/space' or high/low ratio.

**Dynamic Microphone:** A microphone based on a coil of wire suspended in a magnetic field. Sound waves entering the microphone move the coil, generating tiny alternating currents which can be amplified.

**Earth:** A reference point for measurements in a circuit, having (or assumed to have) a potential of zero volts. Also known as *ground*. The voltage in a circuit can go either positive (+ or +ve) or negative (– or –ve) with respect to earth. In homes and other buildings, one side of the AC power mains circuit is physically connected to a water pipe buried underground and this becomes a 'real' earth connection. If a circuit is operating entirely from batteries (like the projects in this book), there is obviously no electrical connection with earth, but the negative battery connection is often assumed to be at earth potential or zero volts (0V). This is then regarded as the reference voltage level for the rest of that circuit.

**Earthed:** The action of physically or electronically connecting a point in a circuit to the circuit earth (eg, in order to discharge a capacitor). Also known as 'grounded'.

**EMF:** Abbreviation for 'electromotive force', an older term for voltage.

**Equalisation:** A method of reducing distortion in audio recordings by applying certain characteristics to various bands of frequencies.

**Electret Microphone:** A microphone based on a capacitor

with a permanently charged dielectric. Sound waves entering the microphone vibrate the 'plates' of the capacitor, thus altering its capacitance and varying the voltage across it. An electret microphone also includes a FET preamp stage, which requires a small DC voltage to operate.

**Electrolytic:** Usually an abbreviation for 'electrolytic capacitor'. It actually refers to the conducting liquid or paste inside the capacitor. The vast majority of electrolytic capacitors are polarised, which means they can only be installed in a circuit one way. (Often shortened to 'electro'.)

**Electronic Eye:** A component or circuit which operates when a beam of light is interrupted — by an object or intruder, for example.

**Emitter:** One of the three terminals of a transistor. In an NPN transistor, the emitter connects to the more negative side of the circuit.

**Feedback:** The action of returning some of the output signal from a circuit back to its input. Feedback can be negative or positive, depending on its polarity. Positive feedback can cause a circuit's output to increase and if pushed too far, it will break into oscillation. The howl you hear when a microphone is placed too close to speakers in a public address system is an example of positive audio feedback and oscillation. Negative feedback reduces the output of a circuit and is generally applied to improve the performance in some way.

**Ferrite:** A group of ferromagnetic materials which are compounds of iron oxides and elements such as cobalt, nickel, manganese and zinc. Ferrites can be used in the powerful magnets in speakers and also as the cores of inductors and high frequency transformers.

**Ferrite Bead:** A tiny cylinder-shaped ferrite component which helps reduce interference from RF. It is usually slipped over a wire or component lead at the input to a circuit.

**FET:** Abbreviation for 'field effect transistor', a special type of transistor which has a very high input impedance.

**Figure-8 Cable:** A very popular form of 2-conductor cable so called because its cross-section (ie, viewed end-on) looks like an '8'. It is available in various voltage and current ratings.

**Filter:** Any circuit (or component) which can allow some signal frequencies to pass through but not others. Filters can be 'high pass' (HP) — allowing signals above a certain frequency to pass; 'low pass' (LP) — allowing signals below a certain frequency to pass; or 'band pass' (BP) which are in effect a combination of high and low pass — signals above one frequency, but below another can pass. The pass frequencies of filters are determined by the values of the components (particularly capacitors and inductors) in them.

**Flipflop:** A logic device which has two stable states and usually, two outputs. One output always has the opposite voltage level to the other (ie, either high or low), but they can swap over in terms of which one is high or low. In the most common types, a clock or trigger pulse will cause the two outputs to flip from one state to the other; then the next pulse will cause them to flop back again — and so on. Hence the name, flipflop!

**Former:** A tube or cylinder on which a coil of wire can be wound. The former may or may not stay inside the coil (also known as a mandrel).

**Frequency:** The rate at which a recurring event occurs. Frequency is measured in Hertz, and is also referred to as the number of cycles per second which occur.

**Frequency Response:** The way in which the gain or amplification of an amplifier or other circuit varies across the range of frequencies it handles. Ideally the gain should be constant (ie, it should have a 'flat' response), but this is seldom achieved in practice.

**Full-wave Rectifier:** A rectifier using two or four diodes to convert both halves of the AC waveform to fluctuating DC; gives a better result than a half-wave rectifier, which usually uses a single diode.

**Gain:** The factor by which a signal is increased by a circuit. If an input signal to an amplifier circuit is 100mV and the output signal from that amplifier is 1V, the circuit has a gain of 10. If the gain is shown as a minus figure (eg, -10) then the circuit still has a gain of 10 but the signal at the output is inverted in polarity with respect to the input.

**Gate:** A logic device which, like a gate in a fence, can be either open or closed. Whether it is open or closed depends on what type of gate it is and what the logic levels are at its inputs. Common gate types include AND, OR, NAND, NOR and NOT (which is strictly not a gate, but an inverter).

**Germanium:** A semiconductor element from which the first transistors were made; now mostly limited to germanium detector diodes. The advantage of a germanium semiconductor junction is that it has a much lower forward voltage drop across it than does a silicon junction (0.2V compared to 0.6V).

**Grommet:** A plastic or rubber sleeve which protects a cable from chafing where it passes through a hole in a metal panel or plastic box. Cord-grip grommets also anchor the cable firmly to prevent it from being pulled out of the panel or box.

**Ground:** Another name for 'earth', or zero volts.

**Half-wave Rectifier:** A rectifying circuit which only allow one half of an AC signal waveform (eg, the positive half cycles) to pass through and be converted into pulsating DC. The other half of the waveform is lost. Usually results in poorer quality DC than from a full-wave rectifier, but less components are required.

**Hardware:** Components such as potentiometers, switches, indicator LEDs, dials or other parts which are often mounted separately from the PC board.

**Harmonic:** A multiple of a particular frequency. For example, a complex audio frequency of 1000Hz could have a 'second harmonic' occurring at 2000Hz, a third harmonic at 3000Hz and so on. A pure sine wave contains no harmonics, only the 'fundamental' frequency.

**Heatsink:** A metal object which conducts heat away from things that get hot such as power transistors. Usually the transistor is screwed or clamped to the heatsink for good heat transfer, but may be electrically insulated from it.

**Hertz:** The term for 'cycles per second' — the number of times each second that an AC signal goes from zero to a positive peak, back to zero, to a negative peak and back to zero again. Abbreviated to 'Hz'. Can be further modified with metric multipliers (eg, kilohertz or kHz; megahertz or MHz, etc).

**High:** When referring to digital logic circuits, the state or logic level which is the higher voltage of the two.

**High Frequency Rolloff:** Attenuation or reduction of high frequencies passing through or amplified by a circuit. Many amplifiers are capable of working with frequencies far in excess of the required frequencies, but this can lead to instability and interference problems. For this reason, a high frequency rolloff may be applied.

**Hysteresis:** The difference between the positive and negative input voltages in a comparator or switching circuit. Hysteresis ensures that switching takes place cleanly and without any tendency for the circuit to oscillate when switching between the high and low levels.

**Hz:** Abbreviation for 'Hertz'.

**IEC:** Abbreviation for 'International Electrotechnical Commission', a body which sets standards so that electronic



devices around the world are compatible with each other.

**IC:** Abbreviation for 'Integrated Circuit'.

**Impedance:** A term which describes the more complex way that a circuit or component resists the flow of AC, because of its inductance and/or capacitance. For example, an inductor or coil may have a high impedance to AC but a low resistance to DC, because of its inductive reactance.

**Inductance:** The property of a coil of wire which produces a magnetic field when a current passes through it and thereby stores electrical energy. Inductance is measured in Henries (H), or metric sub multiples like millihenries (mH) or microhenries ( $\mu$ H).

**Induction:** A process which occurs when the current flowing through an inductor is suddenly interrupted or changed. The resulting change in the associated magnetic field produces (or 'induces') a voltage in the inductor (and any nearby inductor). This voltage is proportional to the rate of change of current and also to the number of turns in the inductor(s).

**Inductive Load:** Any load on a circuit which includes inductance or the effect of inductance (eg, a transformer is an inductive load).

**Inductor/Inductance:** A component based on a coil of wire, possessing inductance.

**Insulator:** A material which theoretically will not allow current to pass through it. Most plastics, rubbers, glass, fibreglass, mica and even dry air are examples of insulators. No insulator is perfect; all will allow a very small current to pass, especially when very high voltage is applied. But in most cases the current is so small it can be ignored.

**Integrated Circuit:** A number, often a vast number, of circuit elements all constructed on a tiny wafer of semiconductor material, usually silicon. Integrated circuits have replaced huge numbers of discrete components in modern electronics. Generally abbreviated to 'IC'.

**Inverter:** Any circuit or device which reverses the polarity of an AC signal or the logic levels between its input and output. Positive-going signal excursions become negative-going and vice versa; logic highs become logic lows and vice versa. Another type of inverter is a type of power converter which converts DC into AC to run power tools, appliances, etc away from the mains supply.

**Junction:** A point where circuit components or wire join. Also, within a semiconductor, a region where P-type and N-type materials meet.

**'k' and 'K':** Both abbreviations of the metric multiplier 'kilo'. However k = 1000 times while K = 1024 times ( $2^{10}$ ). 'K' is often used in reference to memory or data bits in computers while 'k' is more common in analog electronics. Another use for 'K' is the abbreviation for 'cathode' — it comes from the German word for cathode.

**kHz:** Abbreviation for kilohertz.

**Kilohertz:** One thousand Hertz (abbreviation kHz). See also Hertz.

**LC or L/C:** Abbreviation for inductance (L) and capacitance (C). Usually refers to a circuit consisting of both L and C, such as a tuned circuit.

**LDR:** Abbreviation for 'light dependent resistor', a component which changes its resistance in response to changes in the amount of light striking it.

**LED:** Abbreviation for 'light emitting diode', a semiconductor diode which emits light (either visible or invisible) when conducting a current.

**Linear:** Describes any circuit which has an output directly proportional to its input. Also applies to a potentiometer which changes its resistance in direct proportion to the rotation of its rotor or control spindle.

**Link:** A short length of wire used to connect two points on a PC board where there is no room for a copper track underneath. Cut-off resistor or capacitor leads can often be used for short wire links.

**Load:** The resistance or impedance connected to the output of a circuit, and into which it drives current or power. For example a speaker is a load for an amplifier.

**Logarithmic:** A type of potentiometer which theoretically varies its resistance in logarithmic proportion to the shaft rotation. In practice, the resistance increases rapidly at first then more slowly. Often shortened to 'log'.

**Logic Circuit:** Any circuit which operates following the rules of digital logic, using only high and low states. Also referred to as a digital circuit. (Converse: Linear)

**Low:** In digital circuits, the state or logic level which is represented by a lower voltage than the alternate 'high' state. There is usually a significant voltage difference between the low and high levels, but the low level may not be at 0V. It may be either a smaller positive voltage, or even a negative voltage level.

**Low Frequency Rolloff:** Attenuation or reduction of low frequencies passing through or amplified by a circuit. Can be used to stop hum or other low frequency noise being amplified by a circuit.

**Low Leakage Electrolytic:** Most electrolytic capacitors have a small but significant leakage current between their plates due to the way they are made. Some types are specially constructed to offer much lower leakage (but still not zero) for circuits where this is important; eg, in timing circuits. These are low leakage or 'LL' electrolytics.

**mA:** Abbreviation for milliamp, or 1/1000 amp.

**Magnetic Flux:** Refers to the imaginary lines of force of a magnetic field.

**Mains:** A supply of electrical power, such as 240V AC.

**Mandrel:** See Former.

**Megahertz:** One million Hertz. Abbreviation 'MHz'.

**Metric Multipliers:** Commonly used in electronics to signify smaller or greater multiples of the basic metric units. Examples are p = pico (one million-millionth);  $\mu$  = micro (one millionth); m = milli (one thousandth); c = centi (one hundredth) k = kilo (one thousand times); M = Mega (one million times); and G = Giga (one thousand million times).

**Microamp ( $\mu$ A):** 1 millionth of an ampere.

**Microfarad ( $\mu$ F):** 1 millionth of a farad.

**Microvolt ( $\mu$ V):** 1 millionth of a volt.

**Milliamp (mA):** 1 thousandth of an Amp.

**Millisecond (ms):** 1 thousandth of a second.

**Millivolt (mV):** 1 thousandth of a volt.

**MKT Polyester:** An encapsulated metallised polyester type of capacitor which is used extensively in electronic circuits.

**Modulation:** The process of applying the information, data or intelligence carried in one signal to another signal, so that it is carried from one point to another. For example where audio frequency signals are applied to a radio frequency signal or 'carrier' so they can be transmitted over long distances. The two most common types of modulation are *amplitude* modulation (AM) where the level or amplitude of the carrier signal is made to vary in sympathy with the modulating information, while the carrier's frequency remains constant; and *frequency* modulation (FM) where the carrier's frequency is varied in sympathy with the modulating information but its amplitude remains constant.

**Monitor:** Any circuit or device which continually examines

another circuit or component. Usually has the ability to react if certain circumstances occur (either give a warning or change something).

**Mono:** Abbreviation for monaural, meaning one channel.

**MOSFET:** Abbreviation for Metal-Oxide-Silicon Field Effect Transistor — a special type of transistor offering extremely high gate impedance.

**Multiplexing:** Techniques which allow more than one signal to be sent down a single circuit path. 'Time multiplexing' involves switching or selecting the signals alternately or in sequence, while 'frequency multiplexing' involves modulating each signal on a different carrier frequency so they can be separated later using filter circuits.

**Multivibrator:** A circuit which continuously oscillates, producing a sequence of high and low output levels. Sometimes a flipflop is called a 'bistable multivibrator'.

**Mute:** To produce silence, by preventing a signal (usually an audio signal) from passing.

**mV:** Abbreviation for millivolt (1/1000 volt).

**NAND Gate:** A logic gate which will have a low level output only if all of its inputs are high.

**NC:** Abbreviation for 'normally closed' — a contact in a relay or switch which is normally connected to the 'common' (COM) contact when the relay is not energised or the switch is turned off.

**Negative:** Refers to any point in a circuit which has a voltage of less than zero volts (0V). Also means the lower voltage output terminal of a battery or power supply.

**nF:** Abbreviation of 'nanofarad', or one thousand-millionth of a Farad ( $10^{-9}$ F). A unit of capacitance, it is midway between pF and  $\mu$ F.

**NO:** Abbreviation of 'normally open' — a contact in a relay or switch which is not normally connected to the common (COM) contact when the relay is not energised or the switch is turned off. The NO contact only connects to COM when the relay is energised, or the switch turned on.

**Noise:** Unwanted signals, often 'random' in nature and generated within a circuit's components due to thermal (heat) energy or interference from other circuits, which interferes with the wanted signals. Also refers to unwanted radio signals which might hide or 'mask' distant or weak radio signal one is trying to receive. Some radio noise is man-made (eg, from sparking in motors) while some occurs naturally (eg, static from thunderstorms).

**NOR Gate:** A logic gate which will have a low level output if any of its inputs are high.

**NOT Gate:** A logic gate or element which has only one input and output, and simply reverses the logic level — if the input is high, the output is low and vice versa. Also known as an inverter.

**Nominal Value:** Where a value is specified loosely. For example, a nominal 12V supply voltage might be somewhere between 11 and 14V.

**Non-Inverting Amplifier:** An amplifier circuit where the polarity of the output signal is the same as the input signal (positive-going signal excursions stay positive going, etc).

**NPO Capacitor:** An abbreviation for 'negative-positive-zero'. Usually refers to ceramic capacitors constructed to exhibit a very low temperature coefficient of capacitance (ie, their capacitance varies very little with temperature).

**Ohm:** The unit of electrical resistance (abbreviation  $\Omega$ )

**Ohm's Law:** The most basic rule in electronics. The current (I) which flows in a circuit is directly proportional to applied voltage (V), and inversely proportional to the circuit's

resistance (R) — or  $I = V/R$ . Therefore, if you know any two out of these three values, you can work out the third. For example, consider a 1.5V battery connected to a 100 $\Omega$  resistor: ie,  $V = 1.5\text{V}$  and  $R = 100\Omega$ . So the current I will be given by  $V/R = 1.5/100 = .015$  amps or 15mA. Note that the formula can be turned around to find either voltage or resistance, knowing the other two: eg,  $V = I \times R$  and  $R = V/I$ . (The letter E is sometimes used for voltage instead of V, so you may also see Ohm's law expressed as  $I = E/R$ , or  $E = I \times R$  or  $R = E/I$ .)

**Op Amp:** Abbreviation for 'operational amplifier'.

**Operational Amplifier:** A very high gain amplifier (usually an IC or part of an IC) which can have positive or negative feedback applied to it to define the circuit gain and other performance factors.

**OR Gate:** A logic gate which will have a high level output if any of its inputs are high, or a low output if none of its inputs is high.

**Oscillate:** To change polarity or logic level continuously.

**Oscillator:** A circuit which is designed to oscillate and deliver a continuous AC signal. Also known as an 'astable'.

**Oscilloscope:** A device which enables you to observe and measure signal waveforms on a small screen, similar to a TV screen; very handy for circuit development and service work.

**Overload:** A situation which occurs when any component or circuit is driven beyond its normal capabilities. Sometimes overload can damage a component or circuit. Occasionally circuits are deliberately overloaded under control to produce special characteristics.

**Parallel:** A method of connecting components so that each lead of one component connects to the corresponding lead of the other. When capacitors are connected in parallel, their capacitances add; when resistors are connected in parallel, the total resistance is always less than the smallest resistor.

**PC Board:** Abbreviation for 'printed circuit board'.

**PC Board Overlay:** A drawing showing how components are laid out on a printed circuit board, viewed from above the board and as if it was X-rayed to show the copper pattern underneath.

**PC Stake/Terminal Pin:** A small metal post or pin designed for mounting on a PC board, to which leads and wires can be soldered much more easily than soldering through the hole in the PC board.

**Peak-to-Peak:** The absolute maximum value of a waveform in the positive and negative directions (with respect to earth). For example if a signal goes 12V positive (peak) and then 12V negative (peak) it is said to be 24V peak-to-peak.

**pF:** Abbreviation of 'picofarad', or one million-millionth of a Farad. A very tiny amount of capacitance, but capacitors with a value of 1pF and up are commonly available.

**Phase:** A particular stage in a waveform, such as a peak, trough or zero-crossing point. If two waveforms of the same frequency are locked together so they are exactly in step, they are said to be 'in phase'.

**Pitch:** The frequency of an audible sound or musical note.

**Pk-Pk (or P-P):** Abbreviation for peak-to-peak.

**Polyester:** A plastic material commonly used for manufacturing capacitors, and especially as their dielectric.

**Positive:** Refers to any point in a circuit which has a voltage higher than zero volts; also means the more-positive terminal of a battery or power supply.

**Pot:** Abbreviation for 'potentiometer'.

**Potentiometer:** Typically a three-terminal variable resistance component. The resistance element is usually connected between two of the terminals while the third terminal is a wiper contact which can make contact anywhere along the resistance element. A potentiometer is typically used to control the signal level or the voltage being fed to a circuit.

**Polarity (1):** When referring to voltage, whether it is positive or negative with respect to earth or 0V.

**Polarity (2):** When referring to components, the way they are connected in circuit. The positive terminal of an electrolytic capacitor, for example, must be positive with respect to its negative terminal (usually marked with a negative sign). If the polarity is reversed, the capacitor and/or circuit may be damaged.

**Primary:** The input winding of a transformer. In the case of a power transformer, the winding which is connected to the 240V mains.

**Printed Circuit Board:** A thin piece of (usually) fibreglass onto which is laminated an even thinner layer of pure copper. A pattern is etched into the copper which then forms the circuit connections for the various components. Components with leads are mounted with the leads passing through holes in the PC board from the fibreglass side and soldered to the copper underneath. Unleaded or 'surface mount' components are mounted on the copper side and soldered directly to the copper.

**Probe:** A metal prod, usually insulated, used to make electrical connection in, or to, a circuit.

**Pullup Resistor:** Some components, particularly some ICs, have pins which must not remain unconnected — or instability or damage will result. Some need to be connected to a 'high' logic level, but not directly to the positive supply. A resistor is used to connect, or 'pull up' these pins. (Converse: A 'pull down' resistor connects to the 0V or negative supply).

**Pulse Generator:** A circuit designed to continuously oscillate or produce clock pulses which will trigger another circuit or a section of the circuit.

**Radio Frequency:** Frequencies above about 200kHz are said to be radio frequencies. Often abbreviated to 'RF'.

**Rectifier:** A device (usually a silicon diode) which rectifies, or converts AC to a fluctuating DC. A large smoothing capacitor is normally required after the rectifier. A single diode will provide half-wave rectification, while two or four diodes are required for full-wave rectification. See also Bridge.

**Regulator:** A circuit or semiconductor component which maintains a constant voltage or current. In this book, the term usually refers to a voltage regulator, a small three-terminal device.

**Relay:** A type of switch which is operated by a lever or plunger, moved by the electromagnetic force generated by a current passing through a coil. Often used to isolate one section of a circuit from another — ie, a low voltage circuit being used to switch a high voltage circuit.

**Resistance:** The property of any material which opposes electrical current when voltage is applied to it. Any resistance produces heat when current is passed through it, and the amount of heat can be calculated by multiplying the resistance in ohms ( $\Omega$ ) by the current in amps (A) squared, to obtain power expressed in watts.

**Resistive Load:** Any load for a circuit or component composed entirely of resistance.

**Resistor:** A component with a defined value of resistance. Resistors are available in values from zero ohms (0 $\Omega$ ) through to many, many millions of ohms (megohms, or M $\Omega$ ) and in power ratings from 1/8 watt (or less) through to thousands of watts.

**Resonance:** The set of conditions in a circuit which results in the optimum response; usually applies to a narrow band of frequencies at which tuned 'resonant' circuits give their best performance.

**Reverse Polarity:** For our purposes, the incorrect connection of a battery or power supply. Instead of + to + and 0V to 0V, reverse connection is + to 0V and 0V to +. Unless the circuit is designed to cater for this possibility, damage will often occur. Most of the circuits in this book feature reverse polarity protection diodes.

**Reverse Polarity Protection:** A diode will only allow current to flow one way. By placing a suitably-connected diode in series with the supply or battery connection to a circuit, it won't matter if the supply is connected with reverse polarity — the diode will not conduct and the circuit simply will not work. The down side is that there is a small voltage loss (about 0.6V) across a normal silicon diode, so a circuit being supplied with 9V will actually only receive about 8.4V.

**RF:** Abbreviation for 'radio frequency'.

**Ripple:** Unwanted AC present on a DC supply, generally due to insufficient filtering after the rectifier.

**RMS:** Abbreviation for Root-Mean-Square.

**Rolloff:** The reduction or attenuation of signal frequencies above or below a nominal figure.

**Root-Mean-Square:** A method of measuring the 'work' value of an alternating voltage or current. 12V RMS will heat a certain value of resistor exactly the same as 12V DC. The mains voltage in Australia is nominally 240V RMS.

**Saturation:** A transistor is controlled by the current flowing into its base. If no current is flowing, the transistor is off and no current flows between collector and emitter. As the base current is increased the collector/emitter current also increases. At some point no matter how much base current is increased, there is no further increase in collector/emitter current. At this point the transistor is said to be saturated, or fully turned on.

**Schematic Diagram:** See circuit diagram.

**Schmitt Trigger:** A semiconductor gate or circuit (usually an IC but not necessarily) which has very sharply defined on and off points.

**Screened Cable:** A type of cable which is intended to minimise hum and noise pickup. There is an inner conductor (sometimes solid, sometimes multi-wire) surrounded by a layer of insulation, surrounded by a braided wire sleeve, surrounded by an outer insulation. In virtually all cases, the braided sleeve connects to the earth or 0V side of the circuit. Also called shielded cable, coaxial cable or 'coax'.

**Secondary Winding:** The output winding of a transformer, usually (but not always) with a lower voltage than the input or primary winding.

**Semiconductor:** Refers to those elements which are intermediate between conductors (most metals) and insulators (most non-metals). Commonly includes the elements germanium, silicon and selenium but there are many others. Semiconductors are used to manufacture the millions of semiconductor devices we now use — diodes, transistors, integrated circuits, etc.

**Series:** Where the end of a component is connected to one end of another, so the same current flows through both. When resistors are connected in series, their resistances add.

**Short Circuit:** A mistaken or accidental connection of two wires or components which allows current to flow where it shouldn't. Short circuits can cause irreparable damage to components or circuits.

**Shielded Cable:** See screened cable.

**Silicon Chip:** See Integrated Circuit.



**Solenoid:** A coil or inductor wound in a cylindrical form. Solenoids are often used to form the electromagnet which pulls or pushes a switch actuator in a relay or electromagnetic water valve, etc.

**SPDT:** Abbreviation for 'single pole, double throw' — a switch or set of relay contacts with one set of three terminals, with one terminal (the 'common') being connected to either one of the other two terminals depending on the switch position or relay coil energisation. Also known as a 'changeover' switch or relay contact set.

**SPST:** Abbreviation for 'single pole, single throw' — a switch or set of relay contacts with only two terminals, which are either connected together or not, depending on the switch position or the relay coil energisation.

**Stereo:** Two channels of information (usually audio).

**Subsonic:** A frequency below the range of human hearing. Usually means below 15Hz.

**Supersonic:** A frequency above the range of human hearing. Usually means above about 20,000Hz (20kHz).

**Supply Rail:** The voltage (usually DC) made available to a circuit for it to work, eg, from a battery or power supply. Generally there are two supply rails, one providing the positive voltage and the other 0V or earth. However there can often be a third rail, a negative voltage which is lower than 0V. Also called 'supply lines'.

**Tinned:** Copper wire which has been given a thin plating of tin. This prevents it tarnishing, thus making soldering easier and more reliable. Many component leads are either tinned or given a thin plating of gold. Can also mean 'soldered'.

**Transformer:** A type of inductor with two or more windings, usually one on top of the other (but insulated from each other). An AC voltage applied across into one winding induces a voltage into the other windings, in proportion to the ratio between the number of turns of wire on each one. The most common type of transformer is a power transformer which has a large number of turns on the primary winding (the winding which connects to mains power) and one or more secondary windings with a relatively small number of turns.

**Transient:** A short term signal surge, usually unintended and unwanted, which usually enters a circuit via a supply rail. Also called a 'spike'.

**Transistor:** One of the most common semiconductor components we use. It has three terminals which are base, collector and emitter. These terms are defined elsewhere in this glossary. Transistors are used as switches or amplifiers and are used in large numbers in op amps and other ICs, and in exceedingly large number in microprocessors.

Normally come in two types, NPN and PNP.

**Trimmer (or Trimcap):** An abbreviation for 'trimmer capacitor', a small variable capacitor used to make circuit adjustments (especially in RF circuits). Usually adjusted with a small non-metallic screwdriver or 'alignment tool'.

**Trimpot:** A small potentiometer used to make small and infrequent adjustments to circuit resistance. Usually adjusted with a small screwdriver or alignment tool.

**Tuned Circuit:** A circuit, usually consisting of capacitor(s) and inductor(s), which is resonant at a particular frequency. Varying either the capacitor or inductor will vary the resonant frequency.

**µA:** Abbreviation for microamp (1/1,000,000 amp).

**µV:** Abbreviation for microvolt (1/1,000,000 volt).

**UHF:** Abbreviation for 'ultra high frequency'. Used to describe radio signals with frequencies above 300MHz, but below 3GHz.

**VHF:** Abbreviation for 'very high frequency'. Used to describe radio signals with frequencies above 30MHz but below 300MHz.

**Volt:** The basic unit of electrical pressure or potential difference. When there is a difference in potential between two points in a circuit, electrons flow from one to the other in an effort to equalize the potential difference. This flow of electrons we know as an electric current.

**Voltage Controlled Amplifier (VCA):** An op-amp circuit in which the gain is controlled by varying a DC voltage rather than rotating a potentiometer knob.

**Voltage Divider:** Two or more resistors connected in series across a power supply. The junction of the resistors provides a voltage division in proportion to the ratio of their resistances. For example, if two 10kΩ resistors in series are connected across a 10V supply, the voltage at their junction would be 5V. If both resistors were increased to 100kΩ, the voltage would still be 5V because the ratio has not changed.

**Wiring Diagram:** A pictorial diagram of the way a circuit is assembled. It will normally include connections to any PC board used, but may not necessarily include the PC board pattern or component overlay.

**Zener Diode:** A special type of diode which is used as a voltage reference. Reverse biased, it breaks down and the voltage across it remains quite stable.

**Zobel Network:** A small R/C (resistor/capacitor) circuit connected to the output of an amplifier to help prevent supersonic oscillation or instability. ★

## Meet the Pioneers of Electronics:

# Shockley, Bardeen & Brattain

William Shockley, John Bardeen and Walter Brattain were three physicists working at Bell Laboratories in the 1940s, each doing research into a different aspect of the way electric currents were conducted in solid state crystals. In 1945 they formed a team to see if they could develop a solid state device made from silicon or germanium, which would allow currents to be controlled in a similar way to thermionic valves or 'tubes'.

They were able to demonstrate their first crude **transistor** on December 23, 1947. The device had two gold 'point contact' electrodes touching the surface of a sliver of pure silicon, very near each other. A small current passing through one contact could control a larger current passing through the other contact, so the device had current and power gain. The next day they made it oscillate, and Bell Labs had their solid state amplifying and switching device. The semiconductor revolution had begun.

Since then, their transistor has replaced most of the valves used in electronic devices, and also formed the foundation of integrated circuits or ICs.





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# The Short Circuits Learning System

Since its inception, the Short Circuits learning system has become the preferred platform from which students can comfortably tackle the various levels of modern electronics. The system consists of three Short Circuits books and their own series of construction projects. They are incredibly thorough without being intimidating and are written with an emphasis on FUN! The books are lavishly illustrated and collectively boast over 70 exciting projects.



## Short Circuits Volume 1 Second Edition (Cat. BJ-8502)

Our first book in the series is designed for the absolute beginner and is based on a brilliant yet simple system, called a baseboard that enables anyone, especially young people to build all of the projects in the book without the need for supervision. Paper templates showing the circuit diagram are included and make construction an easy and simple process. In fact, the system is so good that the projects are almost guaranteed to work - first go!



## Short Circuits Volume 2 (Cat. BJ-8504)

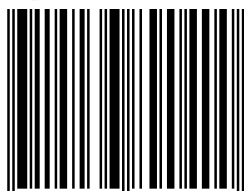
Once you have mastered the basic skills taught in Short Circuits 1, you are ready to have some real fun with the more advanced projects in Short Circuits 2. With Short Circuits 2 you can make such things as a mini strobe light, police siren, mini organ, radio transmitters, an FM radio - even a 'Knight Rider' scanner. The book also teaches you basic soldering techniques and further enhances your electronics knowledge by encouraging you to experiment with the circuits provided and observing the results. (Project kits can be purchased separately).



## Short Circuits Volume 3 (Cat. BJ-8505)

Short Circuits 3 completes the education process and gives the reader a thorough understanding of electronics concepts and simple diagnostic techniques. After you have completed this book, there is no reason why you would not be able to tackle any of the construction projects published in electronics magazines. Short Circuits 3 will help you develop the skills and knowledge to become a fully fledged constructor. (Project kits can be purchased separately).

The complete series of books, and the components required to complete all the projects are available from a Jaycar store near you. Call in and take a look. You'll like what you see.



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Electronics

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