Radio and Electronic Kit X40

X40 Instruction manual

PHILIPS

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Instruction Manual

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Batteries

Note: No batteries are supplied with the kit. Any 9-volt battery of reasonably large capacity will do, but the EverReady PP4, PP7 or PP9 (or their Berek equivalents) are recommended as these have press-studs which will fit the battery leads provided in the kit.

Spares

Spares price list is available free on application to Radionic Products Limited, ESL BRISTOL, St. Lawrence House, Broad Street, Bristol BS1 2HF.

Contents

Introduction

This kit will provide endless hours of fun and interest for anyone who can read and follow the simple instructions, even though they know nothing about electricity or electronics. Everything works from a small battery so that even the youngest enthusiast may safely be left to his own devices. A spanner is the only tool.

Despite its simplicity, the kit will give a quite amazing insight into the growing science of electronics by showing how it is being applied in almost every sphere of life today.

Before starting to build, read the section entitled 'Description and functions of components', and physically identify each component in the kit. Then study the section on 'How to build the Circuits'. Having done that, you may proceed to the experiments.

For those who wish to probe more deeply into the subject the booklet 'Fundamentals of electricity' will add to the interest of the experiments, as well as provide an excellent basis for further study. This booklet is obtainable on request from Radionic Products Limited.

Electricity and electronics

The ancient Greeks knew that if amber was rubbed with another material, such as silk, it would attract small particles. They were thus aware of the phenomenon of 'static electricity'. The Greek name for amber was 'elektron' and from this the modern words electron, electricity and electronics are derived.

Electronics is that part of electricity which is specially concerned with low current electron operated devices, such as valves, television tubes and semiconductor devices as opposed to heavy current flow along conductors (e.g. power supplies). It embraces radio, television, radar, computers and electronic control systems in industry.

For centuries knowledge of electricity made little progress. At the beginning of the seventeenth century William Gilbert, Queen Elizabeth's scientist physician, found that quite a number of substances produced static electricity and, in the eighteenth century, it was realised that this was of two kinds, positive and negative. Later a list of such substances was compiled and so arranged that if any two were rubbed together the one higher in the list would be left with positive electricity and the lower one with negative electricity. Such a list is shown below.

1. Rabbit fur	6. Silk	11. Metals (Copper, Silver, etc.)
2. Glass	7. Cotton	
3. Mica	8. Wood	12. Sulphur
4. Wool	9. Amber	13. Metals (Gold, Platinum)
5. Cat fur	10. Resins	

About this time, in 1780, the development of the steam engine by James Watt marked the real beginning of the Industrial Revolution which transformed the world from isolated communities of craftsmen producing hand-made articles into a world of industrial communities producing machine-made articles by the hundreds, thousands or millions. Scientific and technical activity gained momentum and out of this electric power emerged. Mechanical energy could now be turned into electrical energy, sent along wires to where it was needed, and then turned back by electric motors into mechanical energy or otherwise into heat or light. The first public generating stations were established in London and New York in 1882. These generated direct current. Alternating current, which could be distributed over much greater distances because transformers could step up the transmission voltages and so permit the use of thinner wires, came into use some five years later, having been patented in London in 1881. At about this time too the internal combustion engine started to come into use as a readily available local source of power.

Thus unlimited mechanical power in the hands of man transformed the world in relatively few years into one in which the proverbial wealth of kings now lies within the reach of all. This rich, wonderful world has resulted from an extension of the physical capabilities of man.

And now we are at the beginning of another revolution which could further transform our world in as spectacular a way as did the Industrial Revolution. This is the electronics revolution, now rapidly gathering momentum as a result of the discovery of the transistor in 1943 and of recent developments by which complete electronic circuits can be made in a size no bigger than a pinhead. Electronics already enable us to see and communicate across the world and through space; to probe into the galaxies of outer space with radio telescopes; to see particles over 1,000 times smaller than can be seen with the finest conventional microscope; to control spacecraft around the planets; to compress years of mathematical calculation into seconds. And this is only a beginning.

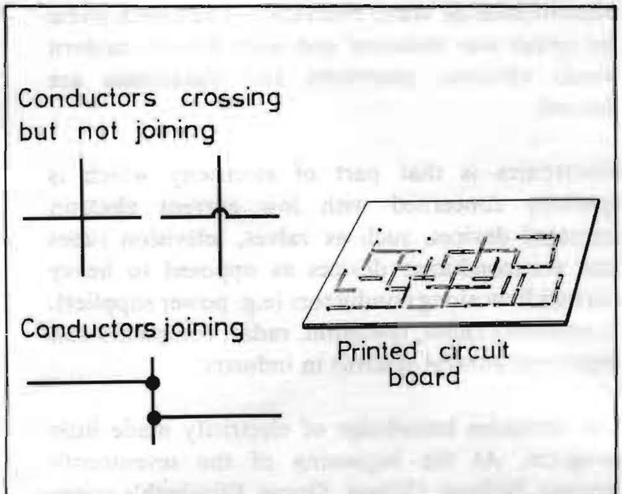
Just as mechanical power extended man's physical capabilities so will the power of man's brain be extended by the development of electronics. What the outcome will be is difficult to imagine but it is clear that from now on electronics will play an increasing part in our lives. It is important therefore that everyone should have a working knowledge of the nature and possibilities of this new technology.

This kit will provide such a knowledge and the experiments will reflect some of the excitement felt by the pioneers when they first saw the results of their researches.

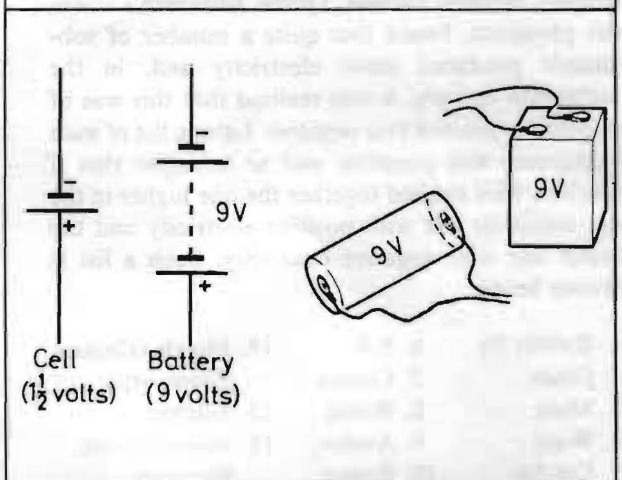
Description and functions of components

The components in this kit are listed below. Against each is a brief description of how the component functions, the symbol used for it in theoretical circuit diagrams and a sketch to help in identification.

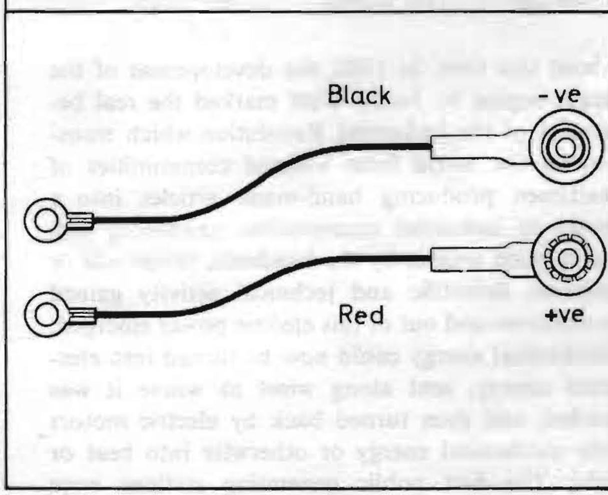
Printed circuit board
The board provides a mounting base for the components and, already etched upon it, the pre-arranged electrical connections for all the experiments described.



Battery (not provided in kit)
A 9-volt dry battery is used to provide direct current (d.c.) for the experiments described. Dry cells provide the energy by electro-chemical action each producing an e.m.f. of 1½ volts. Six such cells are joined together to form a 9-volt battery.



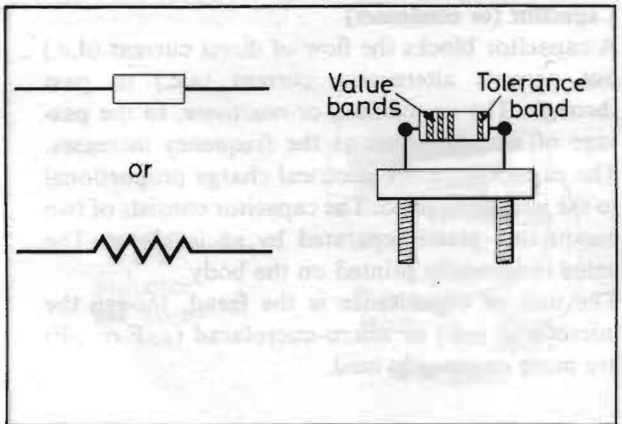
Battery leads
A pair of leads is provided. Each has a tag on one end which is bolted to the printed circuit board and at the other end a press-stud which fits on to the battery. The press-studs ensure correct attachment to the battery.



Resistor

A resistor opposes or 'resists' (and thus reduces) current flow in a circuit. When current is flowing the voltage at one end of the resistor is higher than that at the other end.

Resistors are made by depositing a thin layer of carbon on a ceramic rod. The value of the resistance in ohms is determined by the thickness of the carbon layer. This value and its accuracy, or 'tolerance', are shown on the body of the resistor by colour bands. Appendix B gives the colour code.



Lamp

This is a special kind of resistor consisting of a short length of high resistance wire (the filament) vacuum sealed in a glass bulb. The flow of current heats the filament and makes it glow with an intensity dependent on the amount of current flowing. The resistance of the 6-volt, 40 mA lamp in this kit is some 50 ohms when cold and 150 ohms when the lamp is on.

Caution Only 6-volt, 40 mA or 6-volt, 50 mA lamps should be used in these circuits. The use of other lamps would probably damage the transistors and diodes.

Lamp holder

The lamp holder is a screw-in socket to hold lamp and connect it electrically into the circuit board.

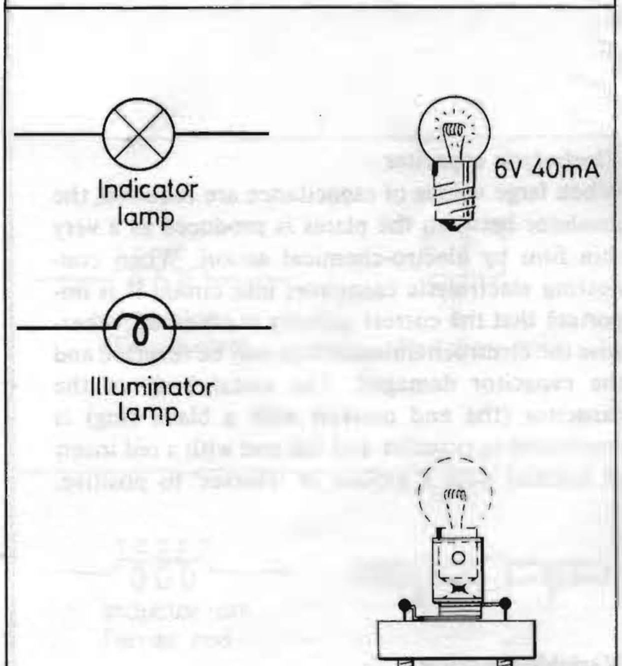
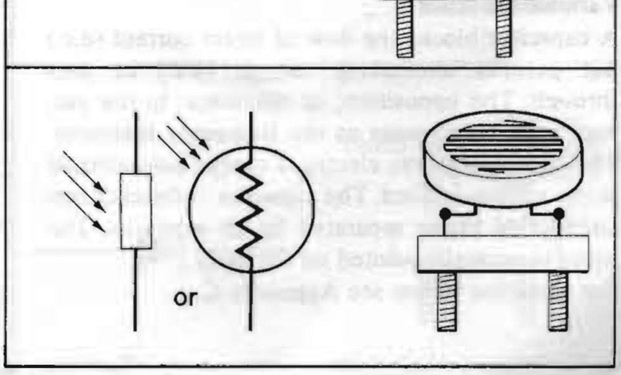


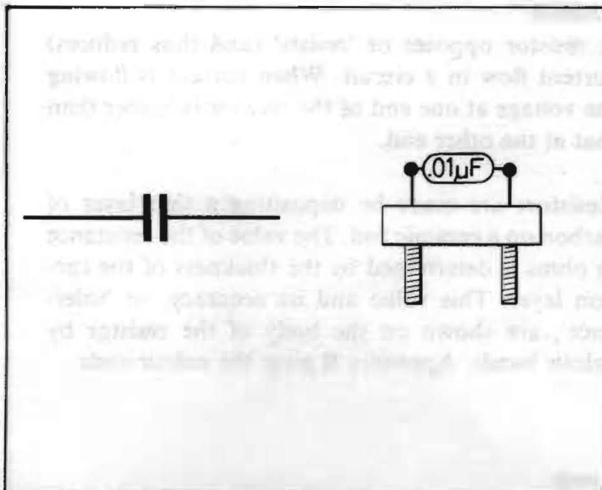
Photo-cell

The photo cell in this kit is a light-dependent resistor (L.D.R.). It utilises the properties of a semiconductor material, cadmium sulphide, and its resistance varies with the amount of illumination falling upon it from about 2,000 ohms in strong light to 5 million ohms in darkness.



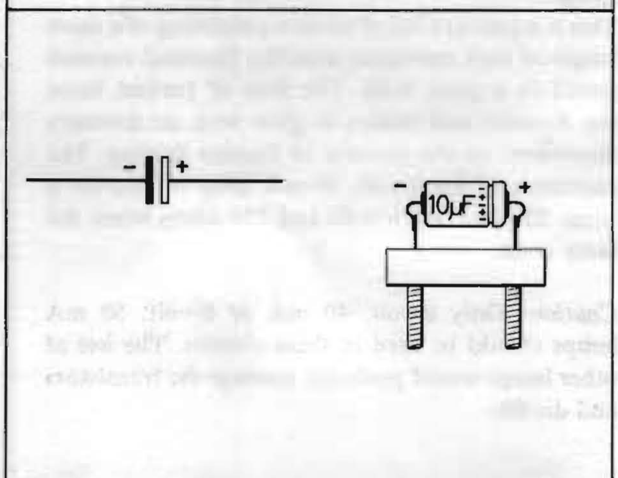
Capacitor (or condenser)

A capacitor blocks the flow of direct current (d.c.) but permits alternating current (a.c.) to pass through. The opposition, or *reactance*, to the passage of a.c. decreases as the frequency increases. The capacitor stores electrical charge proportional to the voltage applied. The capacitor consists of two conducting plates separated by an insulator. The value is normally printed on the body.
The unit of capacitance is the farad, though the microfarad (μF) or micro-microfarad ($\mu\mu$F or pF) are more commonly used.



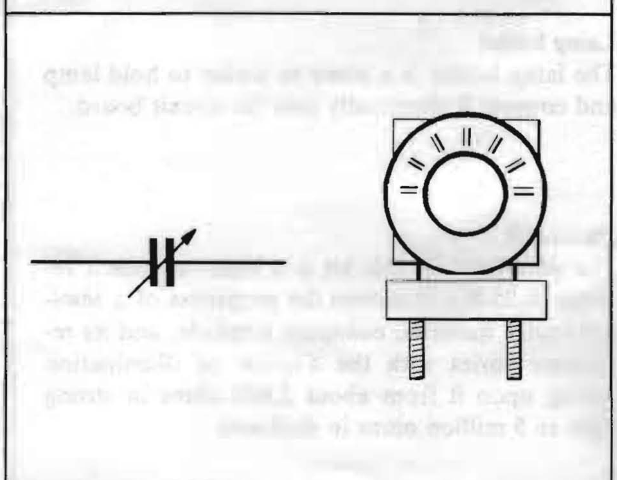
Electrolytic capacitor

When large values of capacitance are required, the insulator between the plates is produced as a very thin film by electro-chemical action. When connecting electrolytic capacitors into circuit it is important that the correct polarity is observed, otherwise the electrochemical action may be reversed and the capacitor damaged. The metal body of the capacitor (the end marked with a black ring) is connected to negative and the end with a red insert or marked with a groove or 'plusses' to positive.



Variable capacitor

A capacitor blocks the flow of direct current (d.c.) but permits alternating current (a.c.) to pass through. The opposition, or *reactance,* to the passage of a.c. decreases as the frequency increases. The capacitor stores electrical charge proportional to the voltage applied. The capacitor consists of two conducting plates separated by an insulator. The value is normally printed on the body.
For capacitor values see Appendix C.



Inductor (coil)
An inductor is a coil of wire which offers little resistance to the passage of direct current but a resistance (called *reactance*) to the passage of alternating current which increases with the frequency. In this sense it behaves in the opposite way to a capacitor. The unit of inductance is the henry.

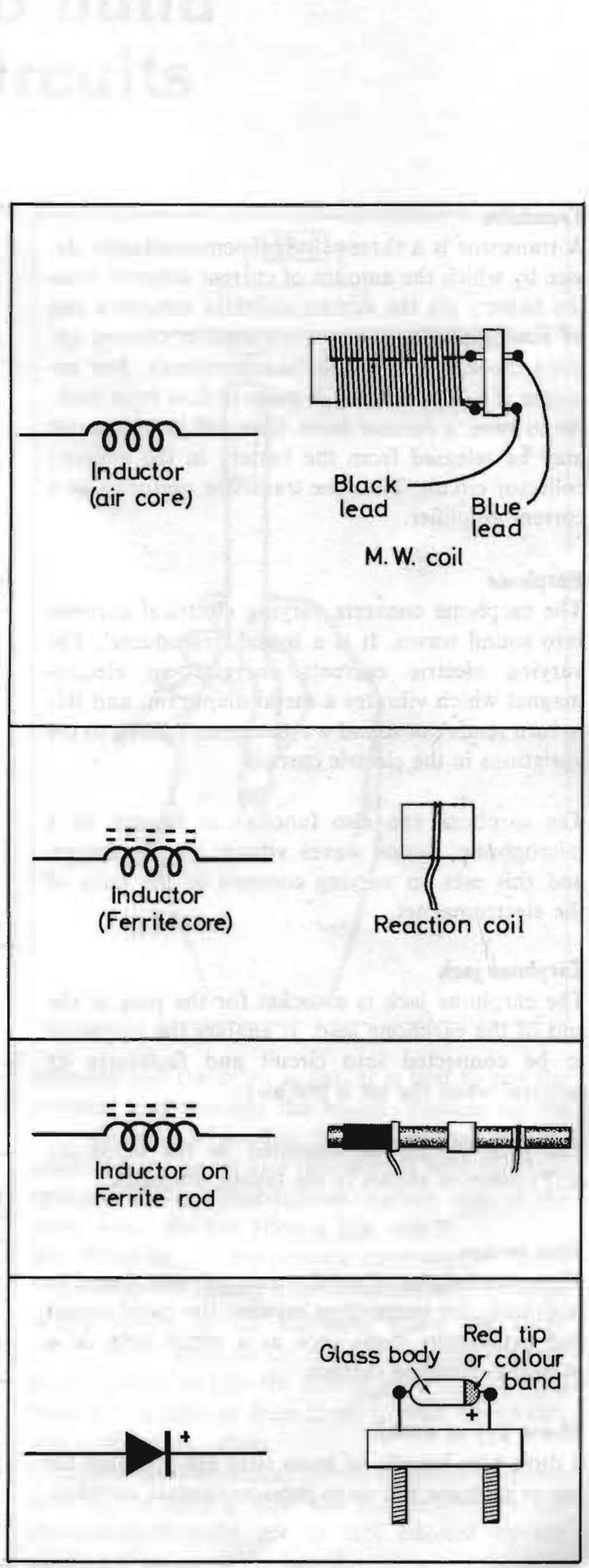
If an inductor and a capacitor are joined in parallel with each other and an electrical charge is placed on one of the plates of the capacitor, the charge will oscillate between one side of the capacitor and the other, through the coil, at a frequency dependent on the size of the capacitor and the inductance of the coil.

An inductor and capacitor are thus used to 'tune' a receiver to the frequency of the transmitter.

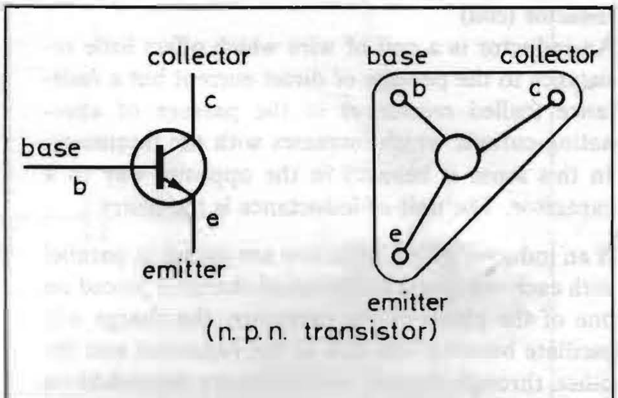
Reaction coil
A small inductor is used to feedback energy from one part of the circuit to another. If the feed-back is 'positive', the total energy in the circuit is increased. If the coil is reversed, the feed-back becomes 'negative' and the total energy in the circuit is decreased.

Ferrite rod
This is a rod made of ceramic ferromagnetic materials which concentrates the electromagnetic field through the inductor on the rod. This has two effects. It increases the inductance of the coil so that fewer turns are needed. It also increases the amount of radio signal that is picked up in the inductor and thus in many cases eliminates the need for a wire aerial.

Diode
A diode is a two-terminal semiconductor device which allows current to flow easily in one direction and virtually prevents it flowing in the other. (Note: Conventional, or 'Hole', current can only flow in the direction of the arrowhead.)

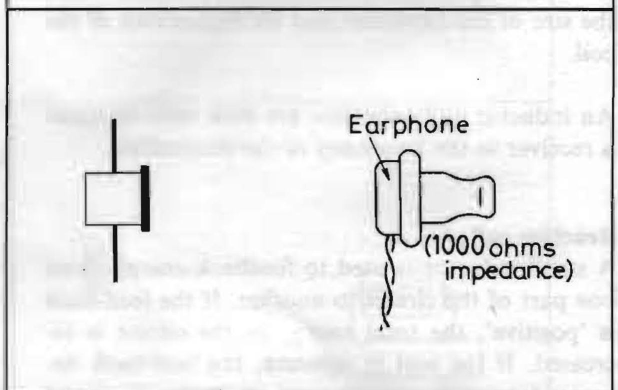


Transistor
A transistor is a three-terminal semiconductor device by which the amount of current released from the battery via the emitter/collector terminals can be controlled by a very much smaller current applied through the emitter/base terminals. For example, if a small current is made to flow from emitter to base, a current more than 100 times greater may be released from the battery in the emitter/collector circuit. Thus the transistor performs as a current amplifier.



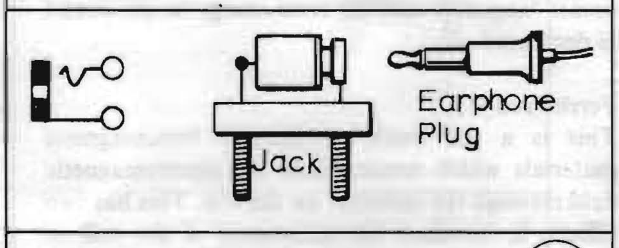
Earphone
The earphone converts varying electrical currents into sound waves. It is a sound 'transducer'. The varying electric currents energise an electromagnet which vibrates a metal diaphram, and this in turn sends out sound waves corresponding to the variations in the electric current.

The earphone can also function in reverse, as a microphone. Sound waves vibrate the diaphragm and this sets up varying currents in the coils of the electromagnet.

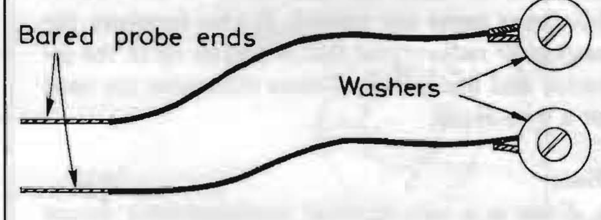


Earphone jack
The earphone jack is a socket for the plug at the end of the earphone lead. It enables the earphone to be connected into circuit and facilitates its removal when the set is put away.

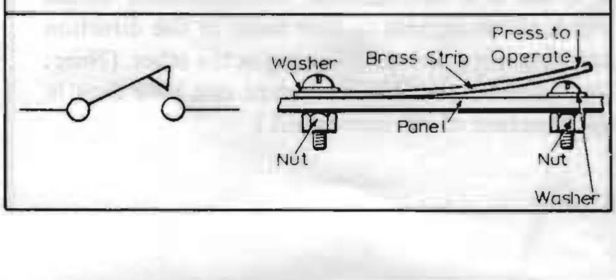
The jack should be mounted in the earphone (E/P) position shown in the layout diagrams.



Wire probes
These are lengths of solid, insulated wire, bared at both ends, for connection between the panel circuit and extraneous items such as a metal strip or a moisture detecting surface.



Morse key or switch
2 three-hole lengths of brass strip are provided for use as a Morse key or as press-to-operate switches.



How to build the circuits

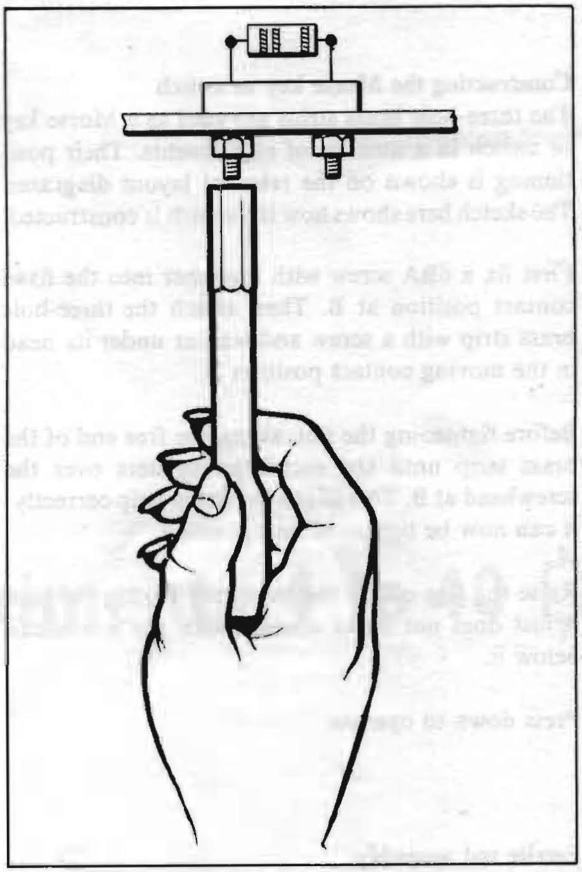
With the new and unique printed circuit board which forms a basis for this kit, the building of the circuits is extremely simple. At the same time, the building methods are in close conformity with the most modern printed circuit board techniques. Thus, while you may build quickly, you are learning how modern electronic designers lay out and construct the circuits used in modern technology.

Our printed circuit board is unique in two ways. First, no soldering is needed. The components are merely placed in position and secured there with nuts at the back of the board. Secondly, the pattern of the board is not confined to one circuit only, as is usually the case, but is carefully designed to enable all the circuits to be built upon it.

The building procedure is simply as follows:
(1). Study the layout diagram for the experiment you are doing. This shows a picture of the board, the outline of the components used in the experiment, the nature and values of these components, and the way round in which they should be fitted where this is important—for example, for electrolytic capacitors.
(2). Select from the kit all the components needed for the experiment. These are all marked on the layout diagram.
(3). Place the printed circuit board in front of you with the tinned copper conductors on the *upper* side, exactly as in the layout diagram.

(4). Take the components, one at a time, and position each in the panel using the holes shown in the layout diagram. Do this carefully because an error will prevent the circuit from working. Fit the transistors first as this will help to position the other components. Fit the coils, the tuning condenser and the earphones last.

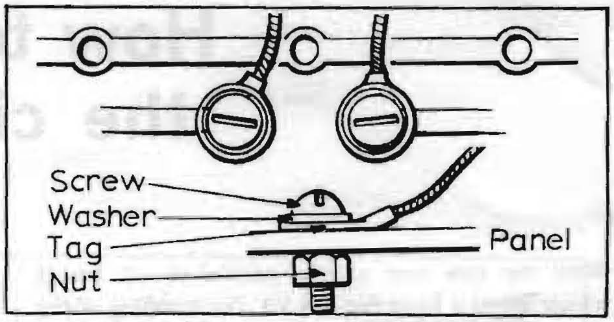
(5). As each component is placed in position raise the board so that the threads protrude fully through the underside of the board and screw a nut onto each of the threads. One end of the nut is



rounded and the other is flat. It is best to put the rounded end towards the board. Tighten up the nuts finger-tight so that the component is fully seated on the panel and then finally with the box-spanner. Do not over-tighten; tighten only to the point where the nut offers a firm resistance.
(6). When all the components have been mounted connect up the battery and the circuit will function.
When mounting the resistors, place the silver colour bands towards the right or towards the rear of the board, so that the colour code may be read from left to right or from front to rear. This helps you in checking values.
Compare the theoretical circuit diagram with the final layout noting how the connections in the theoretical diagram are in fact effected by the conductor strips on the board.

Attachment of leads

When the coil or battery leads are being bolted to the board, place a washer between the screwhead and the tag at the end of the wire lead. Also ensure that the tag does not touch a neighbouring conductor strip or tag. Swing the tags around to the positions shown in the layout diagrams to avoid this.



Constructing the Morse key or switch

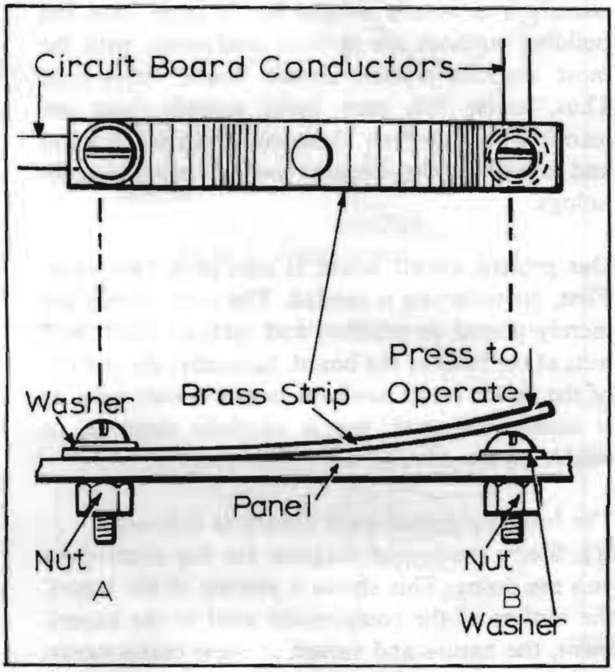
The three-hole brass strips are used as a Morse key or switch in a number of experiments. Their positioning is shown on the relevant layout diagrams. The sketch here shows how the switch is constructed.

First fix a 6BA screw with a washer into the fixed contact position at B. Then attach the three-hole brass strip with a screw and washer under its head in the moving contact position A.

Before tightening the nut, swing the free end of the brass strip until the end hole registers over the screwhead at B. This aligns the brass strip correctly; it can now be tightened into position.

Raise the free end of the strip very slightly, so that it just does not make contact with the screwhead below it.

Press down to operate.



Ferrite rod assembly

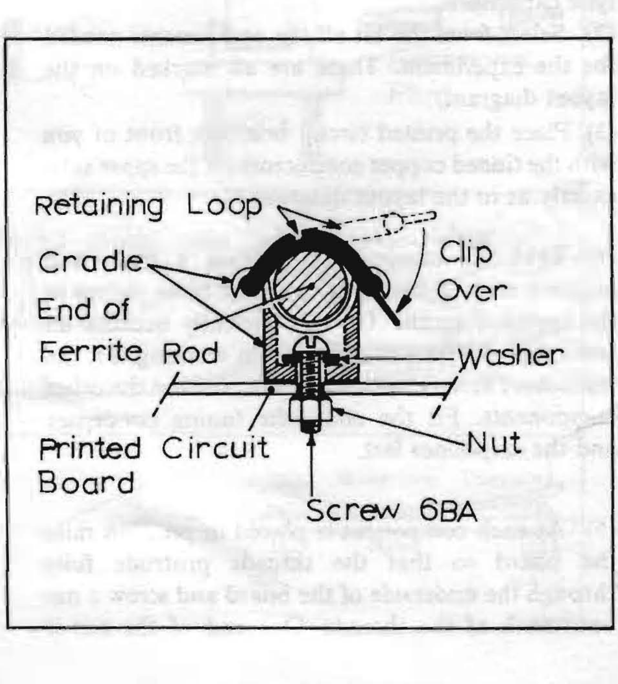
The ferrite rod assembly consists of the ferrite rod, the cradle, the retaining loop and a 6BA screw, washer and nut.

To mount the rod on the panel:

(*a*) Attach the cradle to the panel using a 6BA screw with a washer under its head. Secure with a nut under the panel.

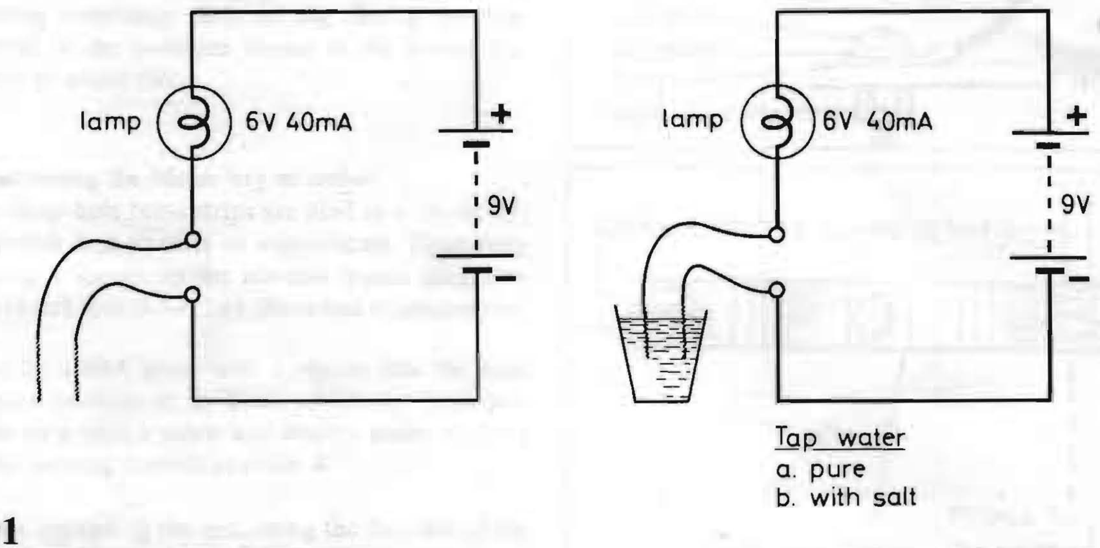
(*b*) Place the rod centrally in the hollow of the cradle and clip it into place with the loop. If the loop is warmed first this process may be done fairly easily with the fingers. Otherwise the tip of a screwdriver or the handle of a teaspoon may be used to lever it into position.

Alternatively the loop may be placed in position first, the end of the ferrite rod then being pushed underneath it with a rotating movement.



Experiments 1 to 40

Experiment 1



1·1

The electrical circuit (conductors, semi-conductors and insulators)

For electrical current to flow there must be a source of electrical energy such as a battery and an electrical circuit or path along which current can flow. The circuit normally connects the source of energy to the 'load' or that part of the circuit where the current is made to do useful work. If the circuit is complete it is a 'closed' circuit and current flows. If the circuit is broken, say by a switch, it is an 'open' circuit and no current can flow. The amount of current which flows depends on the resistance offered by the circuit. Some materials, called 'conductors', offer an easy path. Others, called insulators, offer a high resistance. In between are the semiconductors which can conduct in certain conditions.

This experiment demonstrates the action of a simple electrical circuit and the difference between conductors, semiconductors and insulators. Connect up the circuit shown in the layout diagram and bring the ends of the two copper wires out to the front of the board.

Touch the bared ends together and the lamp will light brightly. This shows that a current of some 50 milliamps is flowing through the circuit which includes the battery, the copper conductors, the probe leads and the lamp which in this case constitutes the 'load'.

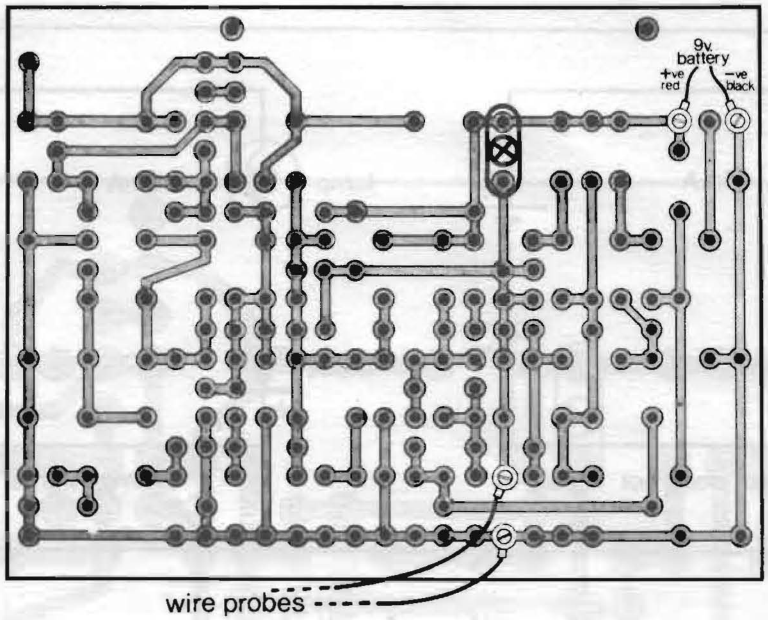
Separate the wires and the lamp will go out. The touching and separating of the wires represents the action of 'switching' by which electrical energy, in batteries or power lines, can be controlled.

The two wire probes may now be used to list very roughly the conductivity of a variety of substances. Delicate meters would be needed to do this accurately but the lamp will show roughly whether the substance is a good conductor or a bad one.

Place the two leads on a piece of dry wood. The lamp will not light, indicating that dry wood is an insulator. Touch them on a piece of tin, aluminium, copper, or steel and the lamp will light. This shows that metals are good conductors.

Place the two bared leads in a glass of tap water, about ½ an inch apart. The lamp will not light (although a current of a few milliamps will in fact be flowing through it). This shows that tap water is a poor conductor at low voltages. If distilled water were used practically no current would flow.

Now, put in a pinch of ordinary household salt and the lamp will glow brightly. The addition of the salt has changed the water into a good conductor.



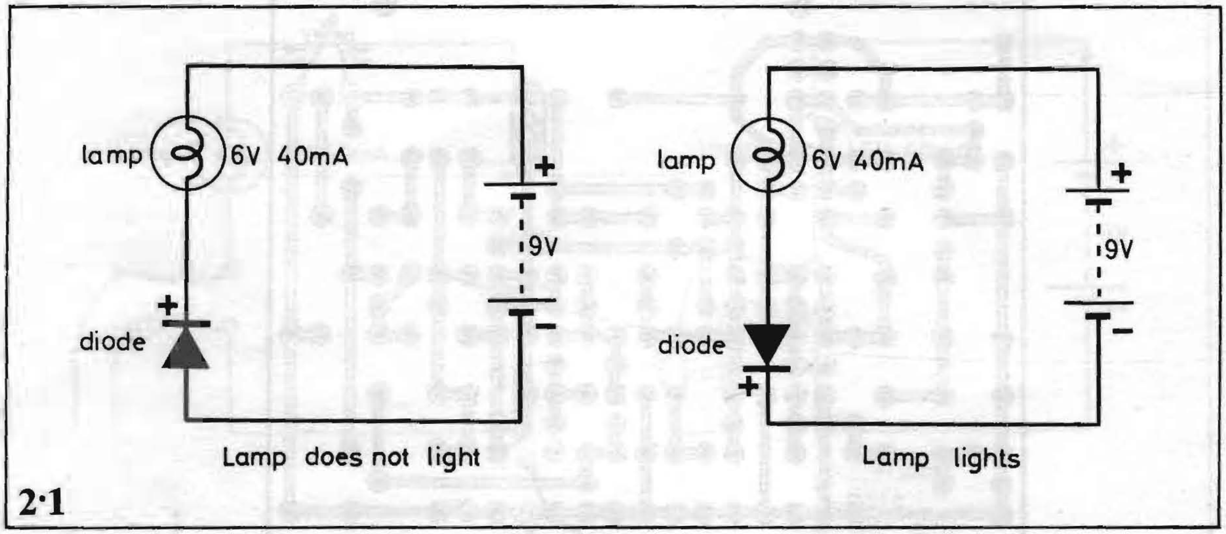
Explanation
Electric current is the passage of electrical charges from one point to another. These charges are usually the charges possessed by electrons. All electrons have the same charge. Atoms of different substances have different structures and possess varying numbers of electrons ranging from 1 (in the case of hydrogen) to 102 (nobelium). Most electrons are closely tied to their atoms but some, termed 'free' electrons, can be detached from their atoms. When this happens the free electron goes off with its fixed negative charge and leaves its atom deficient—that is, with an equivalent positive charge. This atom may then attract to itself any other free electron in its vicinity to restore its electrical equilibrium.

If an electrical potential of, say, a 9-volt battery is applied across a conductor, 'free' electrons will be drawn away from the atoms nearest the positive pole of the battery. These atoms will then be left with a positive charge which will attract electrons from their neighbours. There will be a transfer of electrons from one atom to the next all along the conductor and this will constitute what we know as electric current flow.

In some substances the displacement of electrons is easy and these substances are called 'conductors'. In others displacement is difficult and very little current will flow if a potential is applied. These substances are called 'insulators'. Most metals are conductors while substances such as mica, porcelain, glass, silk, paper and cotton may be classed as insulators. In between these extremes are other substances called 'semiconductors' and of these germanium and silicon are examples. By adding impurities to germanium and silicon they can be made to act as conductors in certain conditions and this is done in the manufacture of semiconductor diodes and transistors. Other semiconductors, including cadmium sulphide, are used for other purposes such as the photo-cell contained in this kit.

In this experiment we have a battery, a lamp and copper conductors. The battery, by chemical action, has a surplus of electrons at the negative pole and a deficiency of electrons at the positive pole. Electrons will flow from the negative to the positive pole if they are joined by a conductor. If the conductor has a high resistance at some point along its length the electrons will have to do work to get through and this will produce heat. The lamp provides such a resistance and its brightness will give some indication of how many electrons are being forced through it by the pressure from the battery. Water may be classed as a semiconductor, its actual conductivity depending on the amount of impurity, such as salt, it contains.

Experiment 2

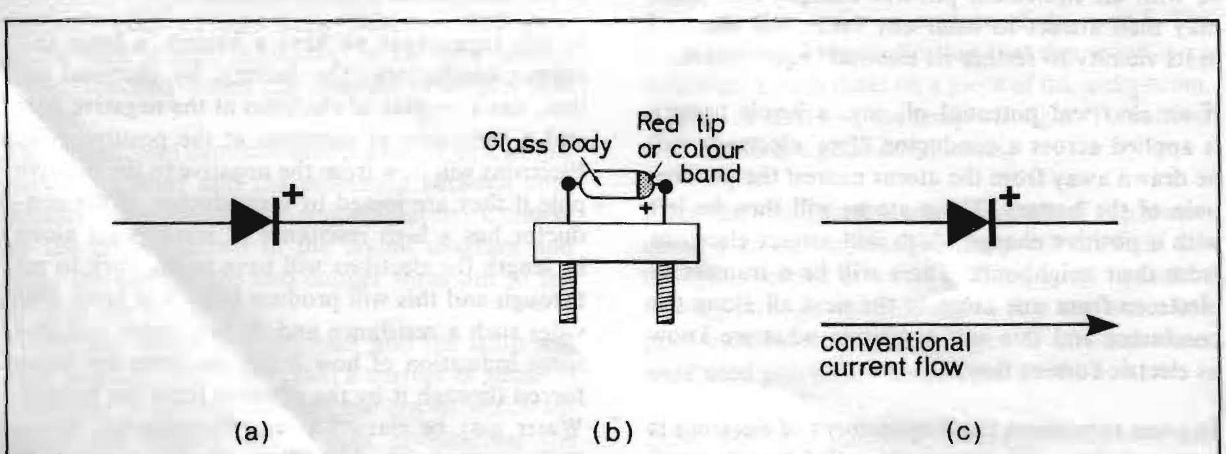


2·1

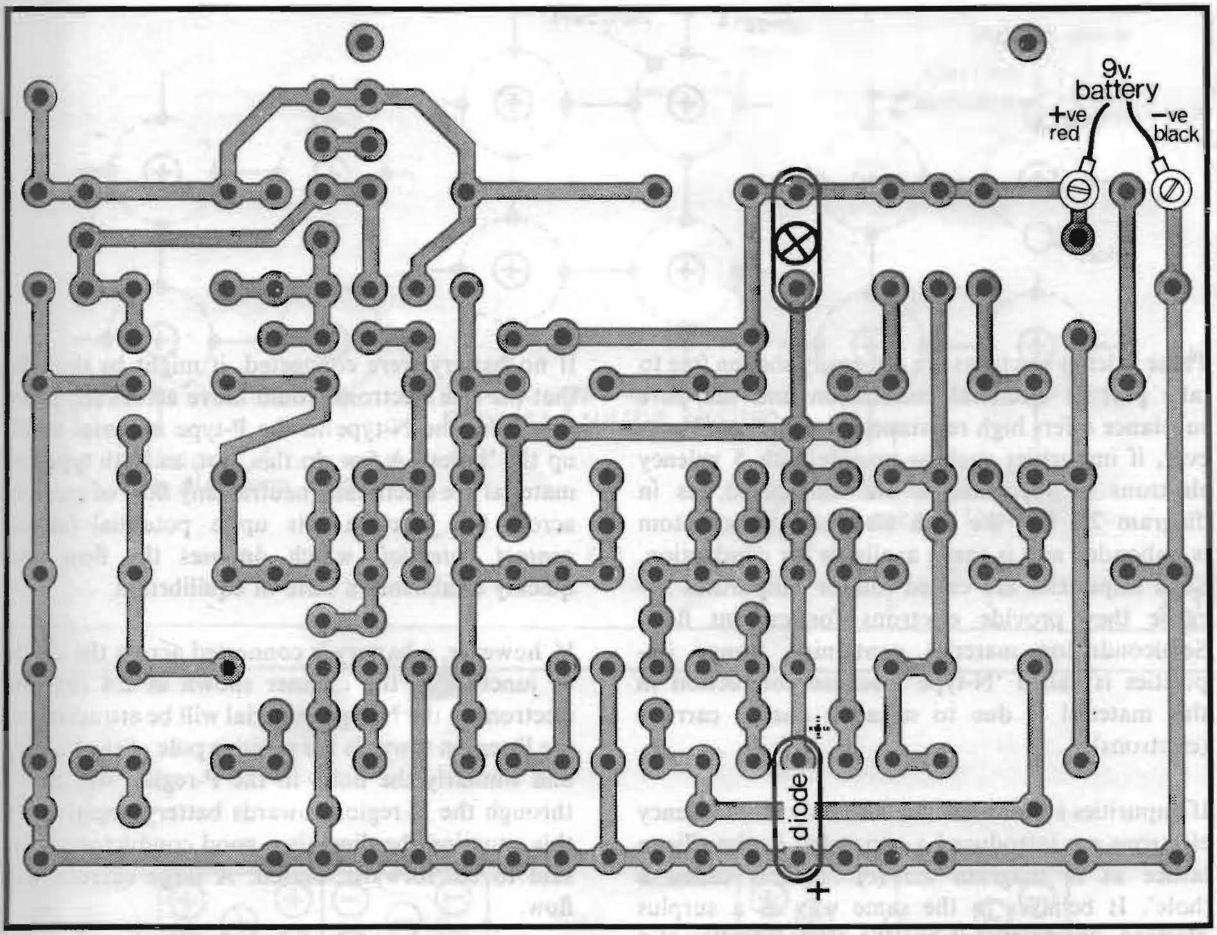
The action of a diode

The purpose of this experiment is to demonstrate that a diode acts as an efficient conductor in one direction and as an insulator in the reverse direction. It is a one-way device.

Diagram 2.2 shows (*a*) the standard circuit symbol for a diode, (*b*) its connections to its mounting and recognition of its polarity and (*c*) the direction of current flow through the diode.



2·2



Set up the circuit shown in the layout diagram making sure that the polarity is as shown. The lamp will light. Turn the diode round 180° so that the positive end of the diode is reversed (shown by the dotted '+' sign). The lamp will not light.

Explanation

Germanium and silicon atoms have four 'free' or valency electrons and when the substance is in a pure state the atoms bind themselves together into a tight crystal or 'diamond' lattice as shown in diagram 2.3 (*a*).

Experiment 2 (contd.)

These valency electrons are not easily shaken free to take part in electrical conduction and the pure substance offers high resistance to such flow. However, if impurities such as arsenic with 5 valency electrons in their atoms are introduced, as in diagram 2.3 (*b*), the fifth electron in each atom is unbonded and is easily available for conduction. Such impurities are called 'donor' impurities because they provide electrons for current flow. Semiconductor material containing donor impurities is called 'N-type' because conduction in this material is due to negative charge carriers (electrons).

If impurities such as indium with only three valency electrons are introduced a gap is left in the silicon lattice as in diagram 2.3 (*c*). This is called a 'hole'. It behaves in the same way as a surplus electron, except that it has the characteristics of a positive charge as opposed to the negative charge of an electron. Impurities of trivalent character are called 'acceptor' impurities and the semiconductor material which contains them is called 'P-type', because conduction in this material is due to positive charges (that is, holes).

If a potential is applied across semiconductor material containing impurities, electrons will drift towards the positive terminal and the 'holes' towards the negative.

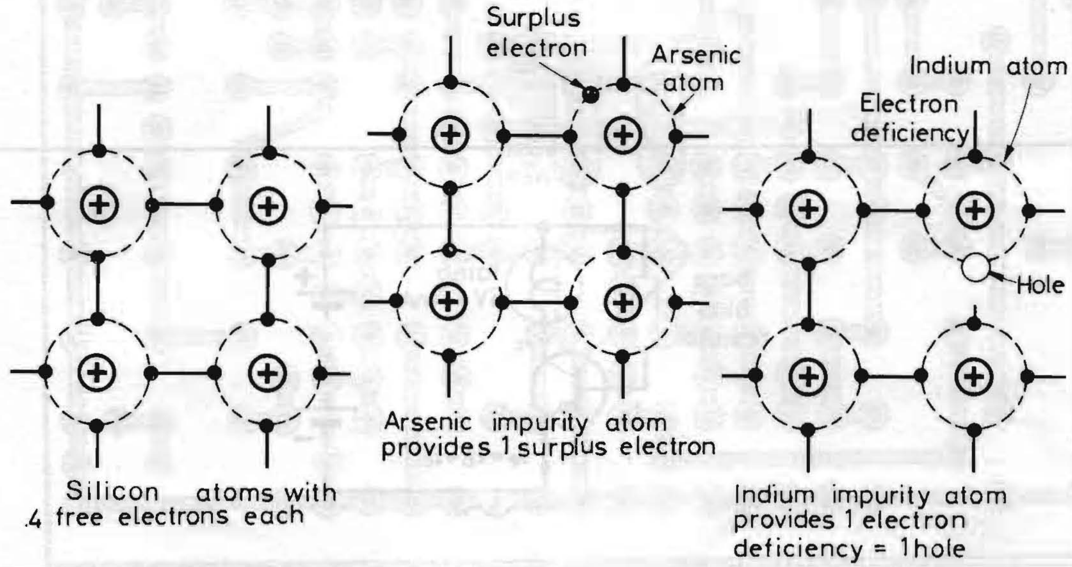
The semiconductor diode consists of a junction of P-type and N-type materials (a P-N junction). This is illustrated in diagram 2.4 (*a*).

If no battery were connected, it might be thought that the free electrons would move across the junction from the N-type to the P-type material to fill up the 'holes'. A few do this, but, as both types of material are electrically neutral, any flow of carriers across the junction sets up a potential (called *contact potential*) which opposes the flow and quickly establishes a state of equilibrium.

If, however, a battery is connected across the diode or junction in the manner shown at 2.4 (*a*), the electrons in the N-type material will be attracted via the P-region towards the positive pole of the battery and similarly the holes in the P-region will move through the N-region towards battery negative. In this situation the diode is a good conductor and is said to be 'forward' biased. A large current will flow.

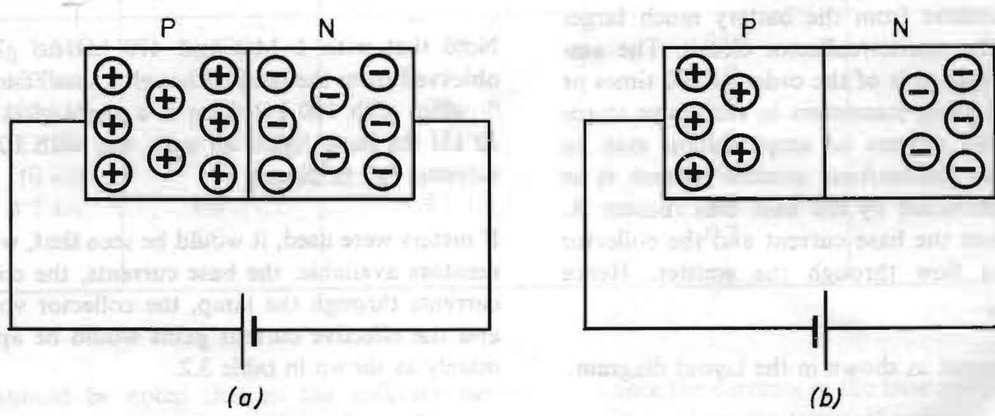
If the battery is reversed, as shown in 2.4 (*b*), the positive charge carriers in the P-material will be drawn away from the barrier towards the negative terminal of the battery and the negative carriers in the N-material towards the positive terminal. No current will flow in the circuit and the diode in this case will behave as an insulator.

If an alternating current is applied to a diode, current will flow when it is going in the sense of the battery shown in 2.4 (*a*), but not when the a.c. is moving in the sense of 2.4 (*b*). Only a direct or one-way current will flow through the diode. The diode thus converts or 'rectifies' alternating current into direct current.



Surplus electron
Arsenic atom
Indium atom
Electron deficiency
Hole
Arsenic impurity atom provides 1 surplus electron
Silicon atoms with 4 free electrons each
Indium impurity atom provides 1 electron deficiency = 1hole
(a)
(b)
(c)

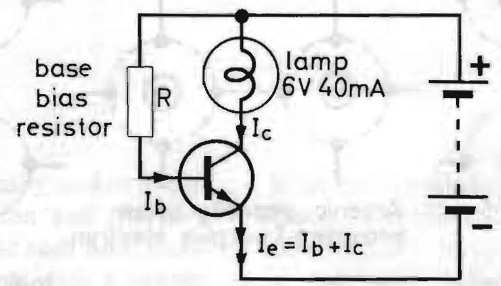
2·3



P
N
P
N
(a)
(b)

2·4

Experiment 3



3·1

How a transistor works

This experiment demonstrates the basic function of a transistor which is that of a current amplifier. A small control current applied in the emitter/base circuit can release from the battery much larger currents in the emitter/collector circuit. The amplification achieved is of the order of 100 times or more and by using transistors in successive stages extremely high degrees of amplification may be achieved. The emitter/base control current is in this case determined by the base bias resistor R. Note that both the base current and the collector current must flow through the emitter. Hence $I_e = I_b + I_c$.

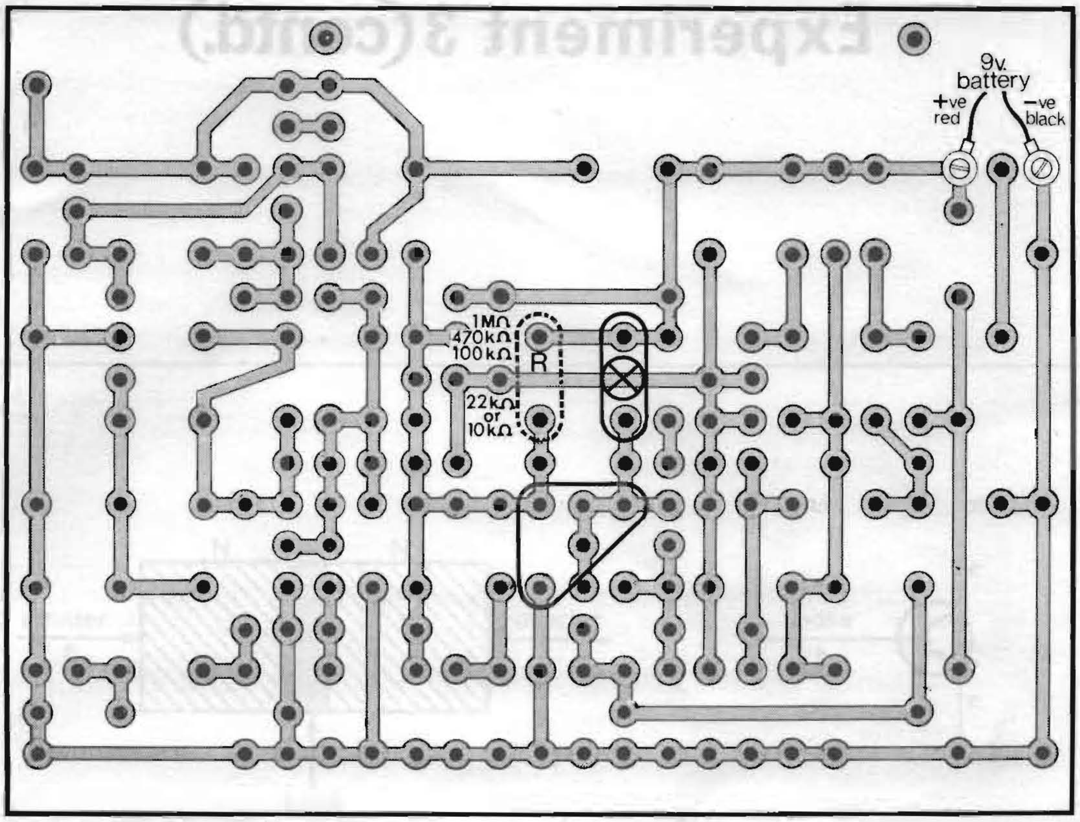
Set up the circuit as shown in the layout diagram.

Apply, across the position indicated (do not insert into the panel) the various resistors available down to 10 kΩ; that is, 1 MΩ, 470 kΩ, 100 kΩ, 22 kΩ, and 10 kΩ, in that order. These resistors allow current to flow from the positive terminal of the battery through the resistor R, emitter/base diode and back to the negative terminal of the battery. The amount of current is determined by the value of the resistor R and the battery voltage.

Note that with 1 MΩ and 470 kΩ no glow is observed from the lamp although a small current is flowing; with 100 kΩ there is a slight glow; with 22 kΩ the lamp lights up well; and with 10 kΩ it achieves full brilliance.

If meters were used, it would be seen that, with the resistors available, the base currents, the collector currents through the lamp, the collector voltages, and the effective current gains would be approximately as shown in table 3.2.

These figures show an initial current gain of nearly 400, but a fall-off as the collector current is increased. The reason for the fall-off is that, in this circuit, the collector current cannot exceed some 58 mA, which is the current that flows when the lamp is connected directly across the battery itself.



resistor	base current (mA)	collector current (mA)	collector voltage	approximate current gain
1 MΩ	·006	2·6	9·05	430
470 kΩ	·017	6·4	9·0	380
100 kΩ	·09	28·0	6·6	310
22 kΩ	·34	55	1·2	162
10 kΩ	·62	56	0·6	90
4·7 kΩ	1·6	57	0·4	36
1 kΩ	6·0	58	0·2	10

3·2

It should be noted that as the *collector current through the lamp increases*, the voltage drop across the lamp increases proportionately (Ohm's law), and hence the *voltage at the collector falls.*

It is important to note also that an increase in base current produces an increase in collector current and hence the currents in the base and collector circuits are *in phase*. In terms of voltages however an increase in base current produces an increase in base voltage, an increase in collector current and a *decrease* in *collector voltage*. The *voltage* at the collector is 180° out of phase with the voltage at the base.

Experiment 3 (contd.)

Explanation

We have described the junction diode and the diagram 3.3 shows the construction and circuit symbol of an NPN transistor.

It will be seen that the transistor consists virtually of two junction diodes placed back-to-back. In the case of an NPN transistor, a wafer of P-type material is sandwiched between two sections of N-type (in a PNP transistor, N-type material is sandwiched between P-type).

The three sections are called emitter, base and collector as shown in the diagram 3.3.

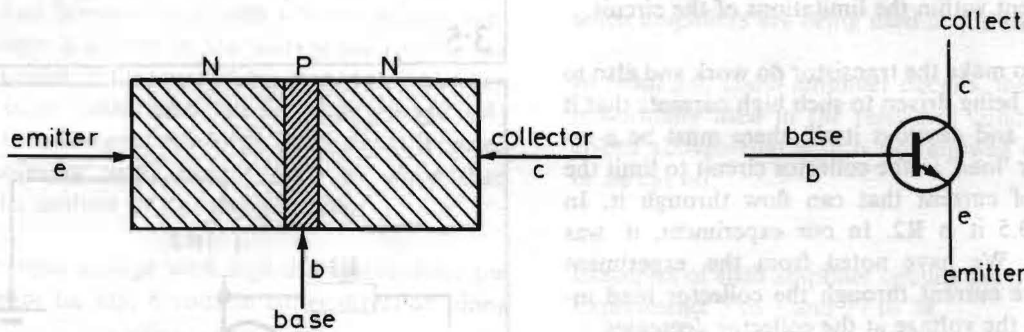
If two batteries are connected between the three electrodes, as shown in diagram 3.4, with the negatives of both batteries to the emitter, it will be noted that the emitter to base diode is forward-biased, so that current will flow. At the same time, the collector to base junction is reverse-biased (B2 being of higher voltage than B1) and would not normally be expected to conduct.

The current through the emitter/base circuit is determined entirely by the voltage of B1 and the resistance in the base/emitter circuit. If the base/emitter circuit were broken, no current would flow in it and virtually none would flow in the collector circuit. This is because the collector/base junction is reverse-biased.

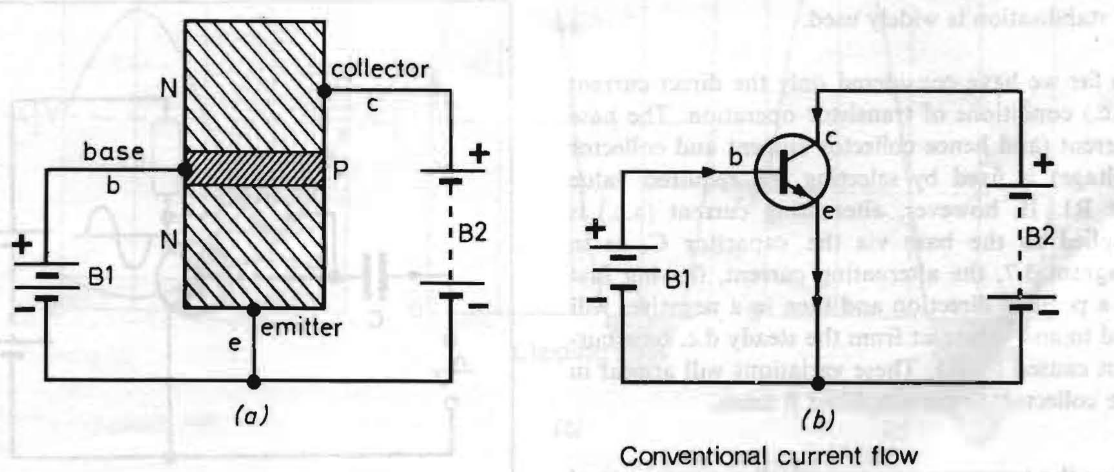
When both batteries are connected, however, electron current flows from the emitter N-region into the P-type base material. The base is made very thin and because of this a high proportion of the electrons will diffuse across to the collector junction under the influence of the positive potential of the collector. They will there be drawn towards the positive terminal of the collector battery. This flow constitutes the collector current.

In practice the vast majority of electrons from the emitter region are absorbed by the collector. Only a small proportion are absorbed at the positive terminal of B1 in the form of base current.

The ratio of collector current to base current in the configuration shown in the diagram (grounded emitter) is known as β (β is the current amplification factor) and is some 100 or more for the transistors we use in this kit.



3·3



Conventional current flow
(opposite direction to electron flow)

3·4

In practical circuits only one battery is normally used and the base current is derived from a base bias resistor, R1 in the diagram right.

The base current flows from the positive of the battery through the base and emitter via R1 to the battery negative. R1 is the controlling factor which determines the amount of base current which can flow.

Virtually no current will flow through a silicon transistor until the base voltage is about 0·6 volts (the 'knee' voltage—this is about 0·15 volts for a germanium transistor). Once this point of conduction is reached the collector current is β times the base current within the limitations of the circuit.

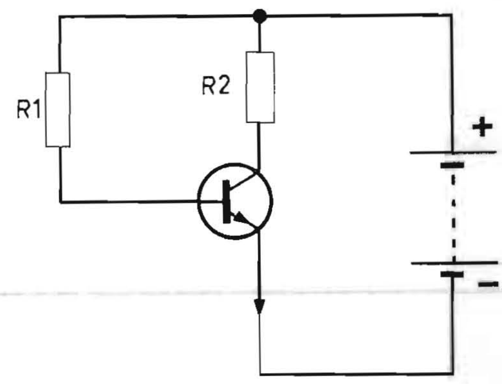
In order to make the transistor do work and also to prevent it being driven to such high currents that it overheats and destroys itself, there must be a resistance or 'load' in the collector circuit to limit the amount of current that can flow through it. In diagram 3.5 it is R2. In our experiment, it was the lamp. We have noted from the experiment that as the current through the collector load increases so the voltage at the collector decreases.

The bias resistor may be taken from the collector of the transistor instead of direct from the battery positive as in diagram 3.6

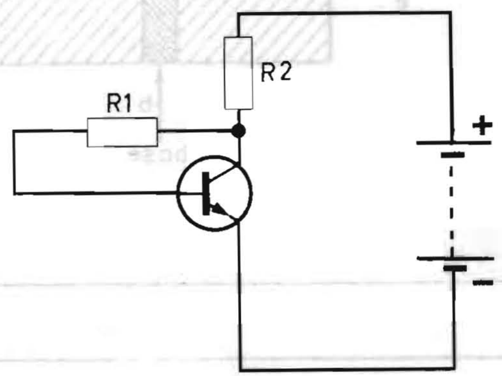
This arrangement has a stabilising effect. As the current through R2 tends to rise the voltage of the collector falls. As R1 is taken from the collector the voltage at the base and hence the base current tends to fall, so reducing the collector current. This form of stabilisation is widely used.

So far we have considered only the direct current (d.c.) conditions of transistor operation. The base current (and hence collector current and collector voltage) is fixed by selecting the required value for R1. If, however, alternating current (a.c.) is applied to the base via the capacitor C, as in diagram 3.7, the alternating current, flowing first in a positive direction and then in a negative, will add to and substract from the steady d.c. base current caused by R1. These variations will appear in the collector circuit amplified β times.

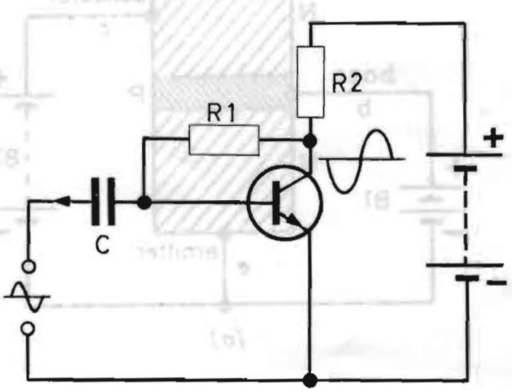
Thus the transistor can amplify direct current and alternating current. The alternating currents can be at audio or radio frequencies.



3·5



3·6



3·7

When the transistor is used as an amplifier it is important that the small signal at its input should be reproduced faithfully at the amplified output. In diagram 3.8(*a*), these conditions are illustrated diagrammatically.

(With transistors it is usual to deal with currents. But voltage differences are set up when these currents pass through resistances, such as the collector load resistor, and the emitter/base diode, and it is easier to deal with this aspect of transistor operation if we deal in volts.)

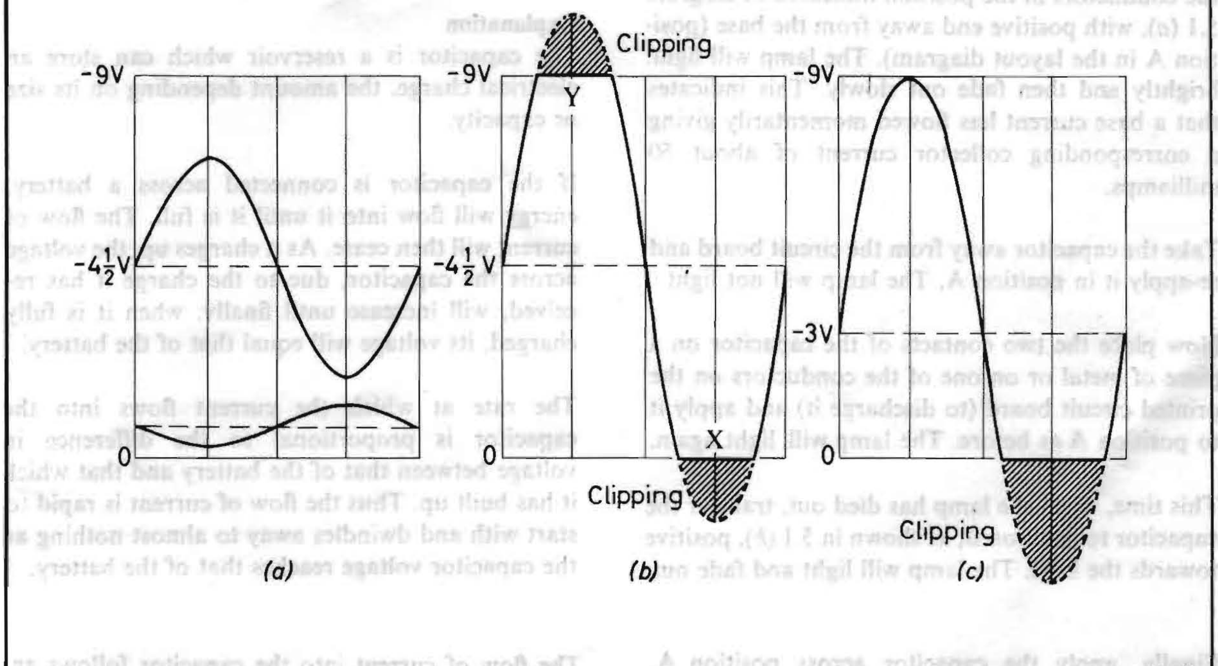
In 3.8 (*a*), a small change in input voltage produces a correspondingly large change in output voltage. It is clear however that, with a 9-volt battery supply, there is a limit to the voltage swing that can be obtained. If the transistor is biased so that when there is no input signal, the collector voltage is 4½ volts then however much the input signal is varied the collector volts cannot alter by more than 4½ volts positive or 4½ volts negative.

If the input voltage were high enough to drive the transistor to, say, 6 volts in either direction along the dotted curve shown in 3.8 (*b*), the transistor would try to follow but could not. The top and bottom of the theoretical curve would be flattened out at the voltage limits set by the battery. This is shown in full line in 3.8 (*b*). The transistor would be saturated or 'bottomed' at 'X' and 'cut-off' at 'Y'. This would result in serious distortion; in amplifiers the transistor is operated within limits which prevent this occurring.

If the transistor were biased so that with no input signal the collector voltage was *not* half the battery voltage, the clipping of the waveform would be unequal (see diagram 3.8 (*c*)) and the distortion would be worse. A correct-bias point is important when amplifiers are being used at full output.

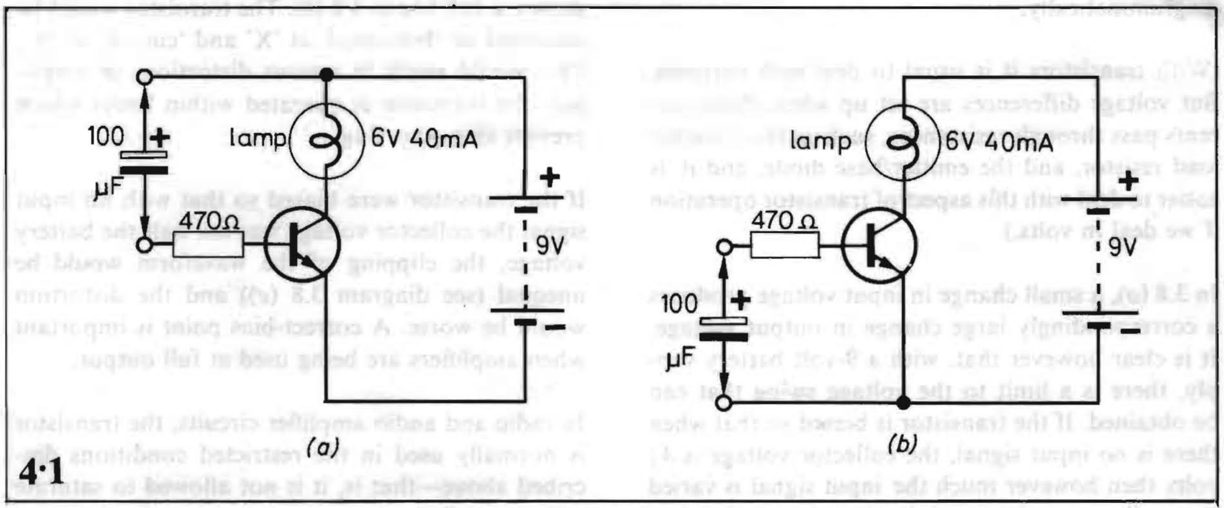
In radio and audio amplifier circuits, the transistor is normally used in the restricted conditions described above—that is, it is not allowed to saturate or be cut off.

Examples of such amplifier circuits are described in Experiments 5 to 7 and 27 to 34.



3·8

Experiment 4



4·1

Capacitor action using a transistor

Having described how a transistor works, we can now use it to demonstrate the properties of a capacitor. Set up the circuit shown in the layout diagram, but do not fit the 100μF electrolytic capacitor into the board. Place it in contact with the conductors in the position indicated in diagram 5.1 (*a*), with positive end away from the base (position A in the layout diagram). The lamp will light. brightly and then fade out slowly. This indicates that a base current has flowed momentarily giving a corresponding collector current of about 50 milliamps.

Take the capacitor away from the circuit board and re-apply it in position A. The lamp will not light.

Now place the two contacts of the capacitor on a piece of metal or on one of the conductors on the printed circuit board (to discharge it) and apply it to position A as before. The lamp will light again.

This time, when the lamp has died out, transfer the capacitor to position B, as shown in 5.1 (*b*), positive towards the base. The lamp will light and fade out.

Finally, apply the capacitor across position A. When the lamp has faded out, remove the capacitor and place it on the table taking care not to touch the metal contacts with your fingers (which would allow some charge to leak away). After three or four minutes apply the capacitor across position B. The lamp should still light up.

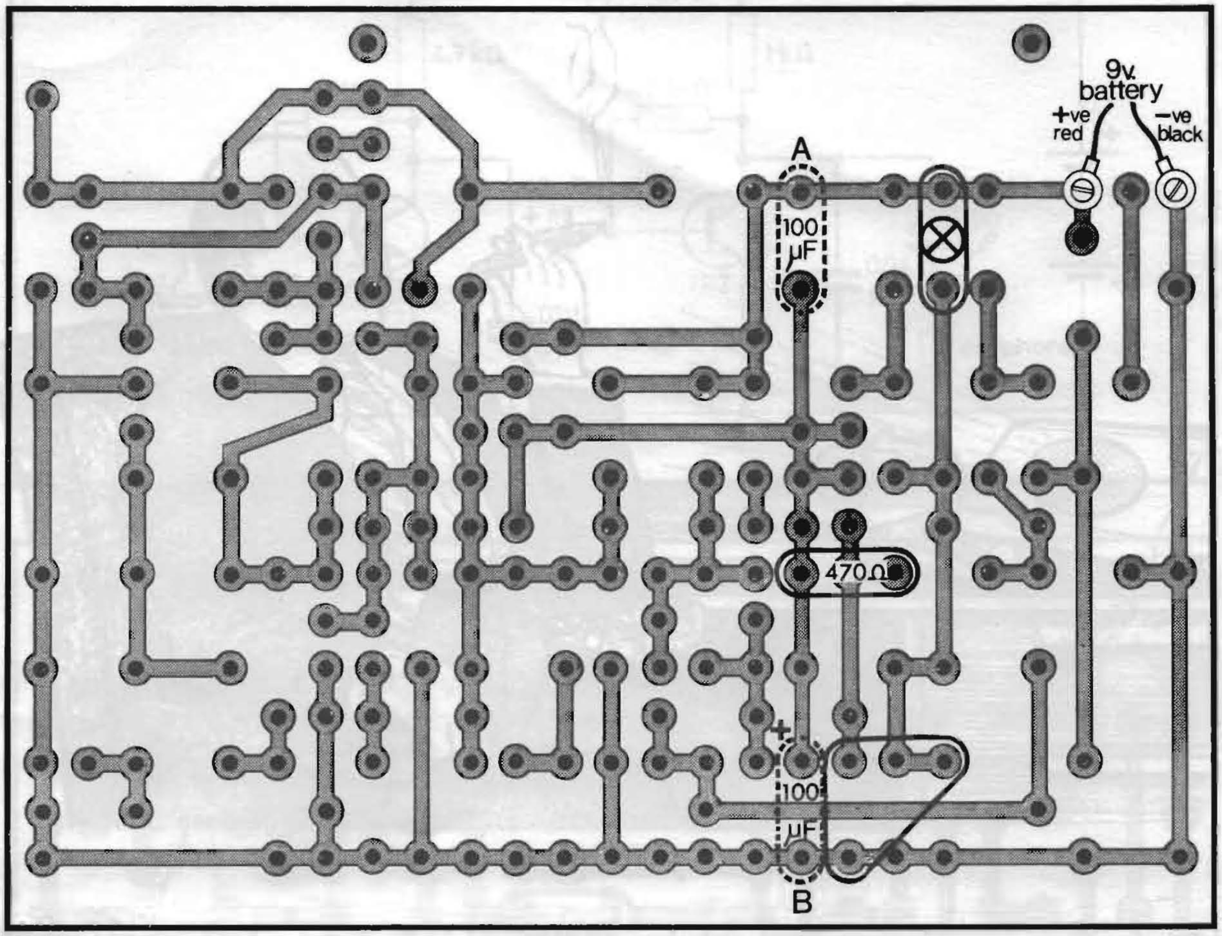
Explanation

The capacitor is a reservoir which can store an electrical charge, the amount depending on its size or capacity.

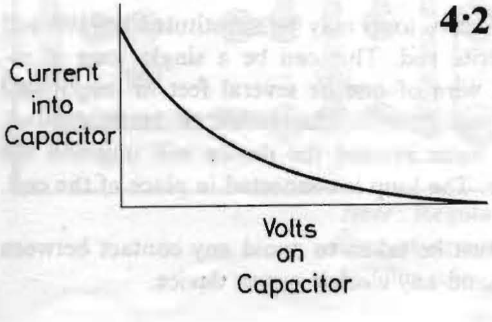
If the capacitor is connected across a battery, energy will flow into it until it is full. The flow of current will then cease. As it charges up, the voltage across the capacitor, due to the charge it has received, will increase until finally, when it is fully charged, its voltage will equal that of the battery.

The rate at which the current flows into the capacitor is proportional to the difference in voltage between that of the battery and that which it has built up. Thus the flow of current is rapid to start with and dwindles away to almost nothing as the capacitor voltage reaches that of the battery.

The flow of current into the capacitor follows an exponential curve similar to diagram 5.2.



When the uncharged capacitor is connected between the positive rail and the base of the transistor, current will flow into it rapidly via the emitter/base diode to charge it up. This flow of base current will induce enough collector current to light the lamp. As the base current dies away the lamp will fade out. In position A the capacitor acts as a base bias resistor of resistance low to start with but rapidly rising to a value at which it cannot hold the transistor in a state of conduction.

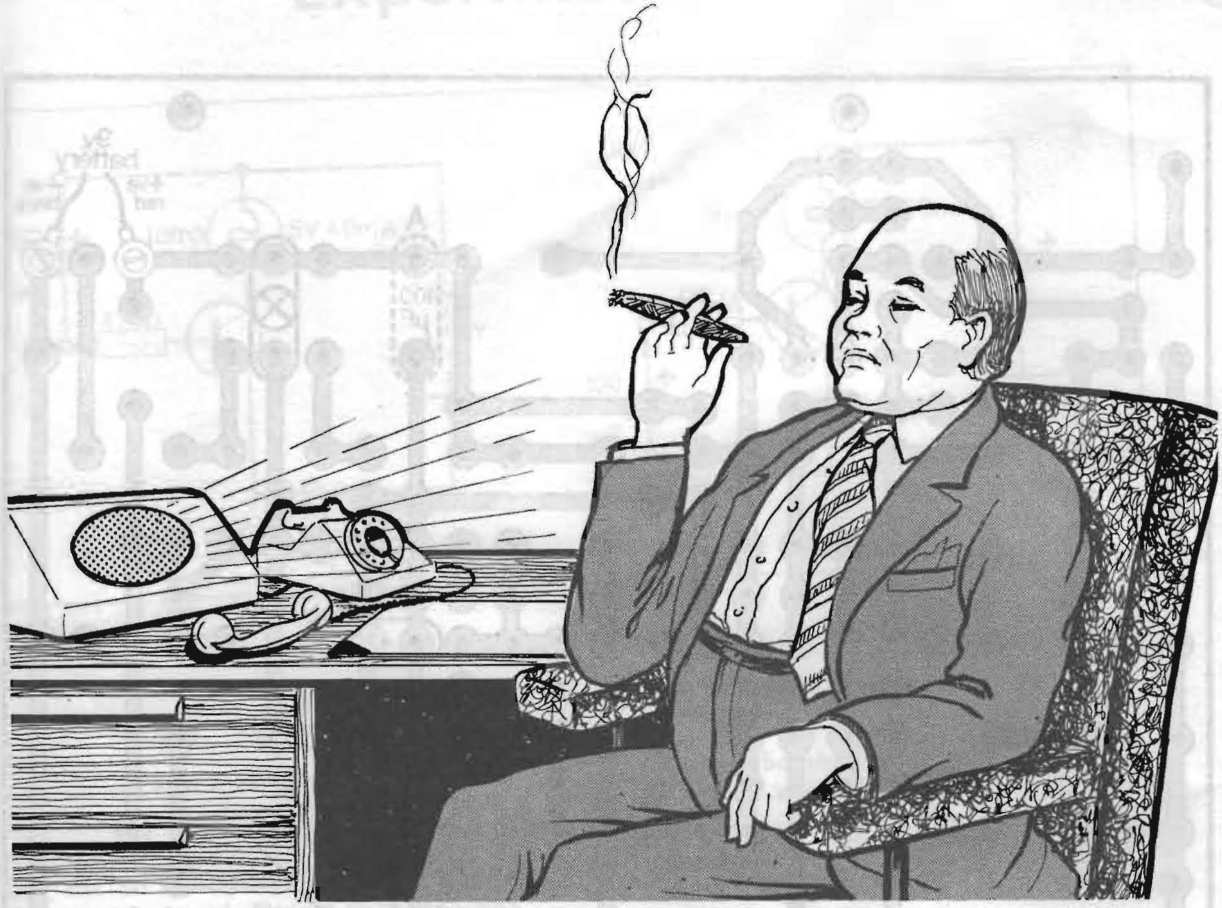


4·2

When a charged capacitor is placed across position B it functions as a base bias battery but its charge is soon used up and the lamp fades out.

A charged capacitor will hold its charge indefinitely in the absence of leakage.

Experiment 5



Telephone pick-up and amplifier

This is a most interesting experiment and gives scope for a great deal of experimentation and fun.

The circuit uses both transistors as audio amplifiers. The signals are picked up and fed to the base of TR1 by an induction coil L, which in this case can be the tuning coil mounted on the ferrite rod.

When you have completed the circuit as shown in the practical layout diagram get a member of your family to telephone a friend. While they are speaking, place the ferrite rod close up to the telephone console. You will be able to overhear the speech quite clearly.

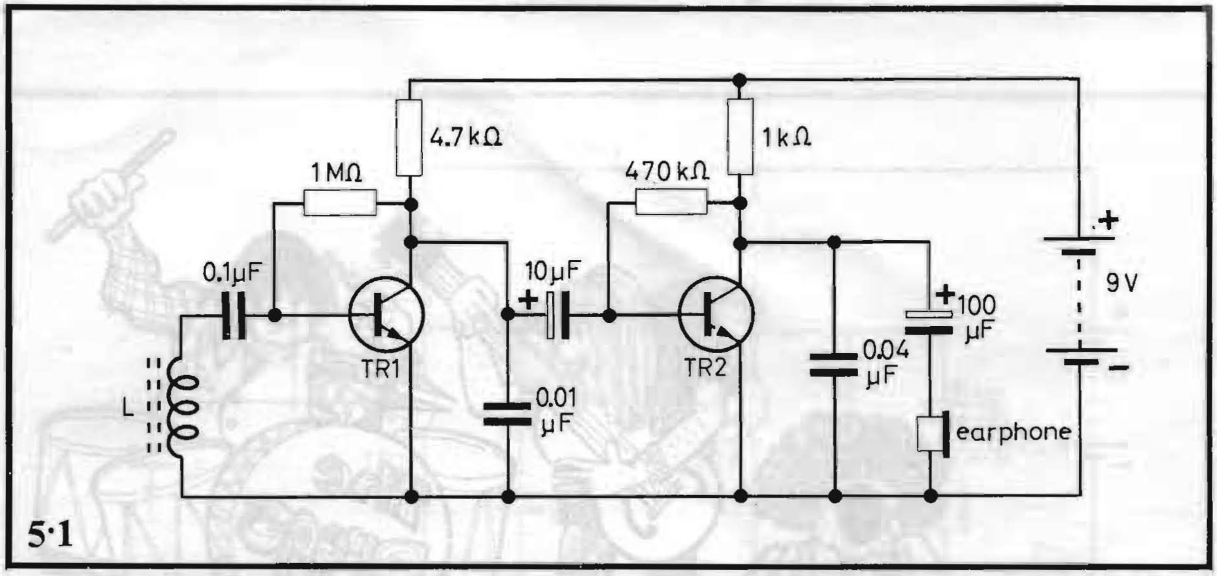
Experiment to find the best position; alongside, over the top of the console, or close to the earpiece. Try the end of the ferrite rod. It is also possible to pick up signals at junction boxes along the telephone wiring in the house.

If desired the ferrite rod and coil may be removed from the panel, the coil then being connected to the panel by flex extension leads.

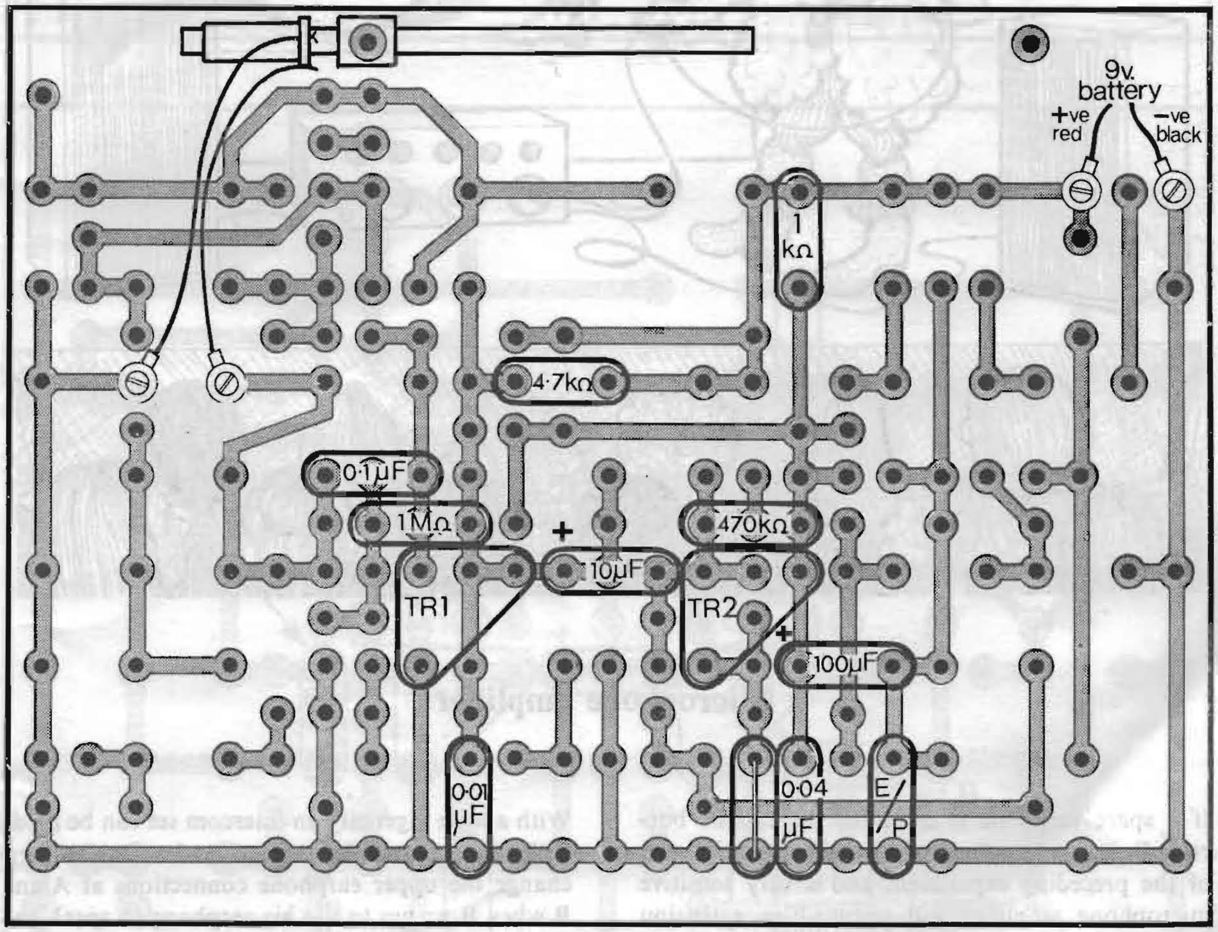
This circuit will pick up signals from any electromagnetic device such as a loudspeaker or transformer in an audio amplifier, an electric power meter, or the type of earphone used in this kit.

An inductive loop may be substituted for the coil and ferrite rod. This can be a single loop of insulated wire of one or several feet in length laid around or close to the device to be monitored. A few turns around the device will improve the pick-up. The loop is connected in place of the coil.

Care must be taken to avoid any contact between the set and any electric power device.

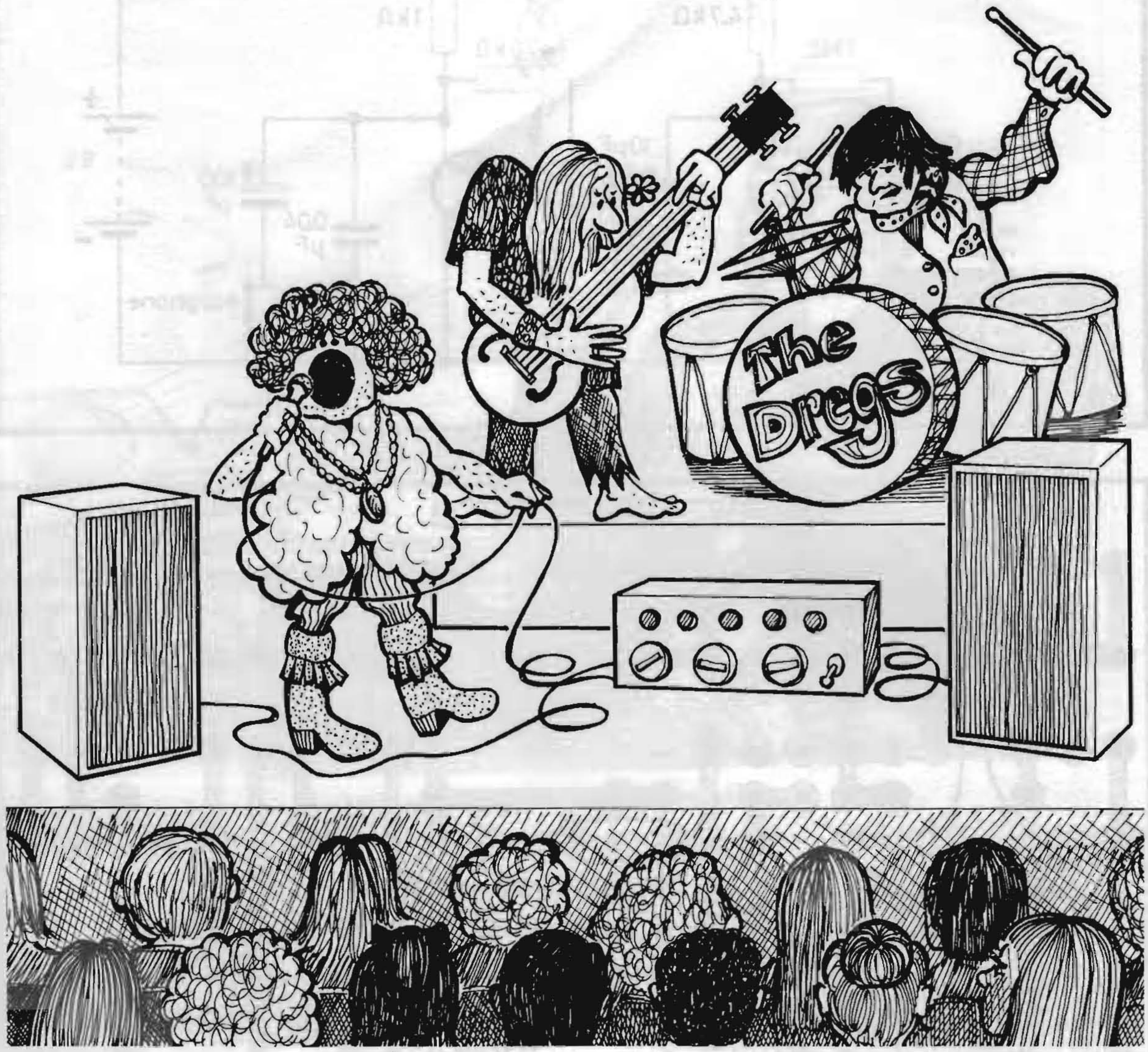


5·1



Note: Regulations prohibit the attachment of this type of equipment to G.P.O. telephones in Britain. Similar rules apply in certain other countries.

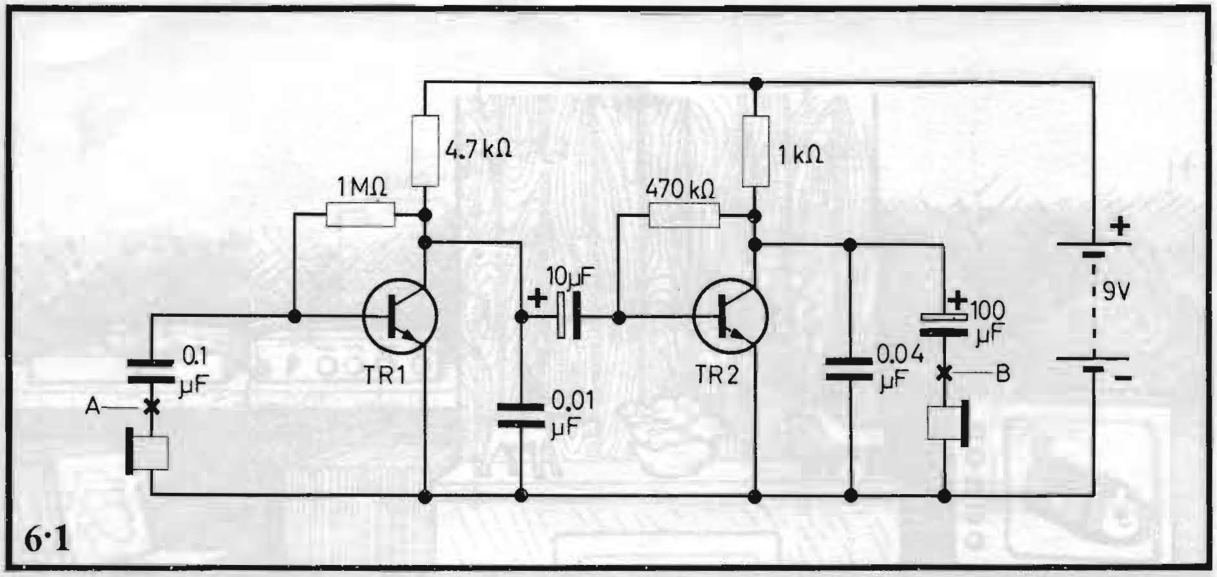
Experiment 6



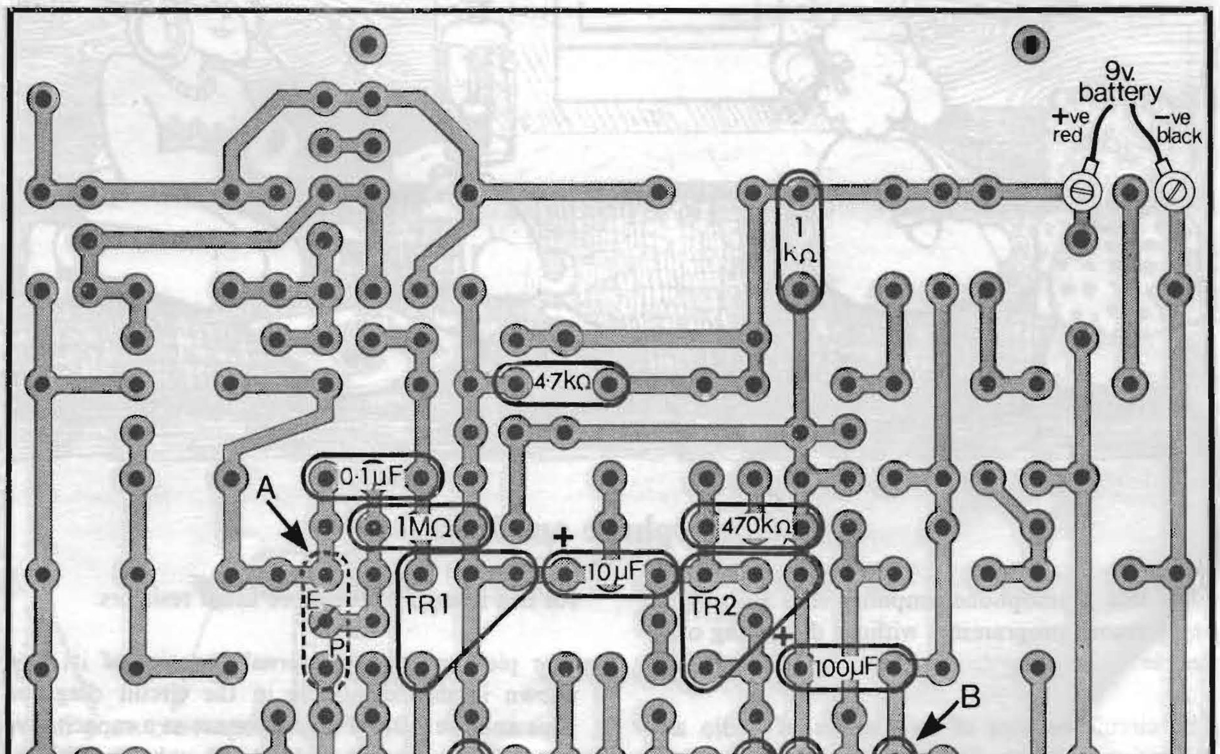
Microphone amplifier

If a spare earphone is available (or can be borrowed), it can be substituted for the induction coil of the preceding experiment and a very sensitive microphone amplifier will result. Flex extension leads may be used for the microphone if it is required in a remote situation—for example, as a baby alarm.

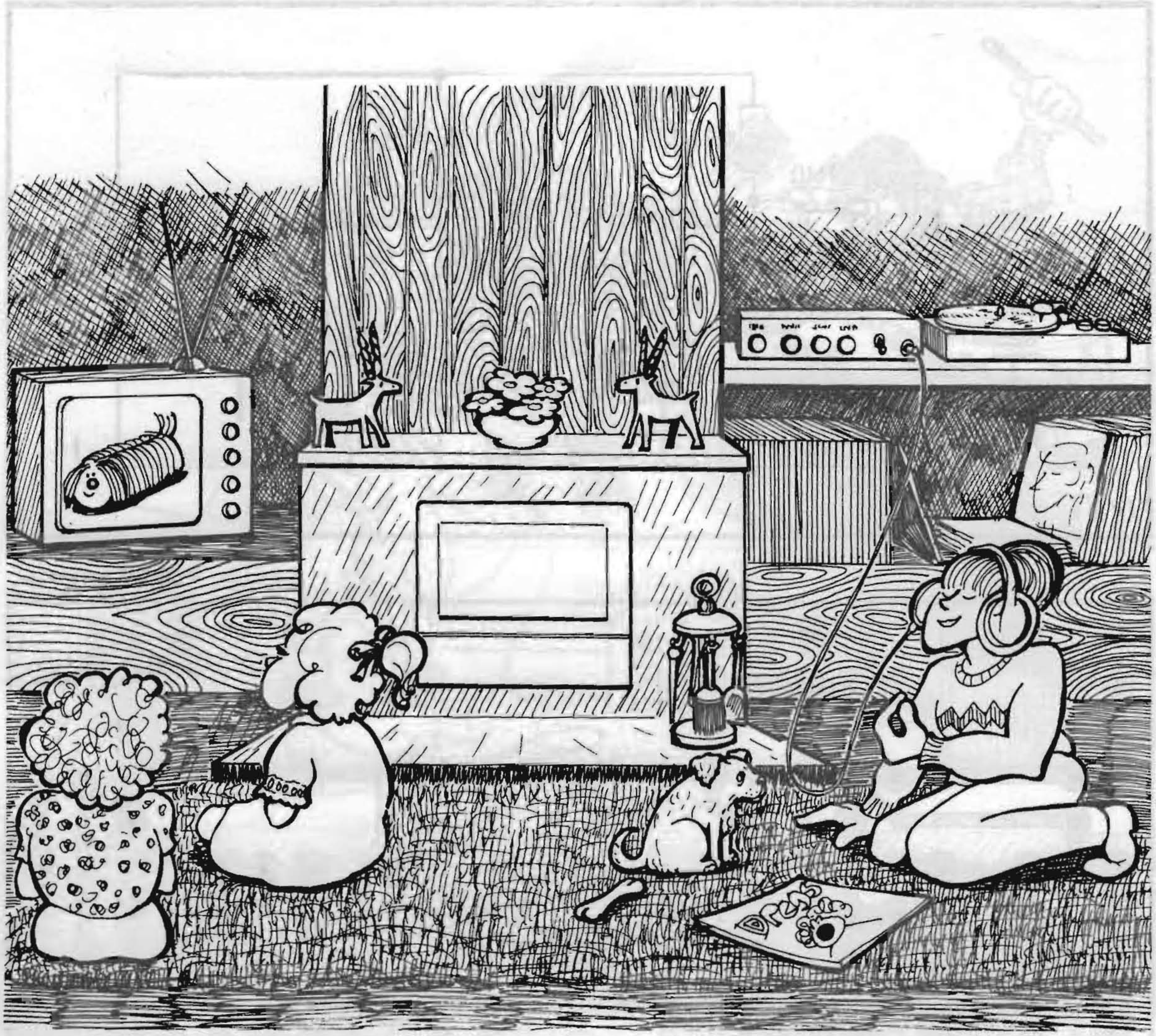
With a little ingenuity an intercom set can be made with this circuit. All that needs to be done is interchange the upper earphone connections at A and B when B wishes to use his earphone to speak and A to listen. The lower ends of both earphones are permanently connected to the negative line.


4.7 kΩ
1 kΩ
1MΩ
470 kΩ
10µF
+
9V
-
100
µF
0.1
µF
0.04
µF
0.01
µF
TR1
TR2
A
B

6·1


9v.
battery
+ve
red
-ve
black
1
kΩ
4·7kΩ
0·1µF
1MΩ
470kΩ
10µF
TR1
TR2
100µF
A
B
E
P
0·01
µF
0·04
µF
E/
P

Experiment 7



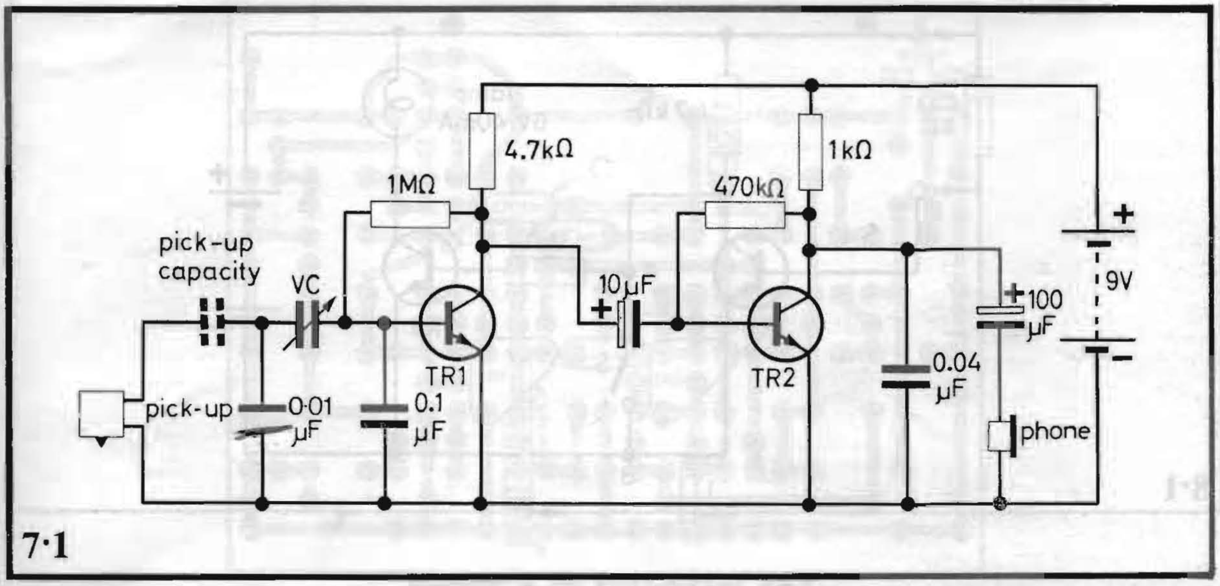
Gramophone amplifier

With this gramophone amplifier it is possible to enjoy record programmes without disturbing other people.

The circuit consists of two stages of audio amplification, with the input from the pick-up of a gramophone deck.

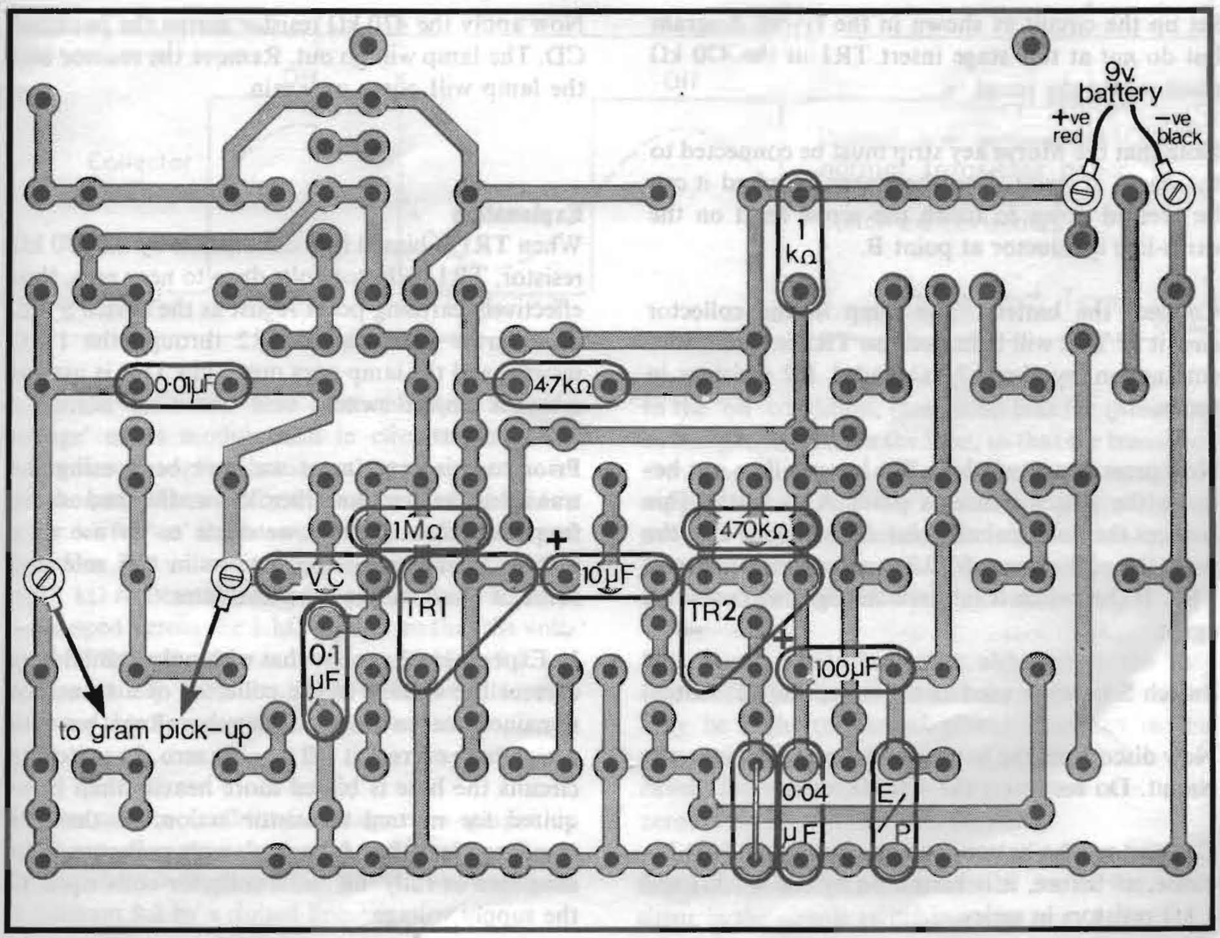
The volume available from the pick-up is far in excess of requirements and in this case two potential dividers are used to reduce it. Capacitors are used for this instead of the more usual resistors.

The pick-up has an internal capacity of its own shown in dotted outline in the circuit diagram. This and the 0·01 μF capacitor act as a capacitative potential divider to reduce the volume initially. Then the tuning capacitor VC and the 0·1 μF capacitor act as a second potential divider to reduce it further to comfortable listening levels. By varying VC the volume can be adjusted as required. VC acts as a volume control.



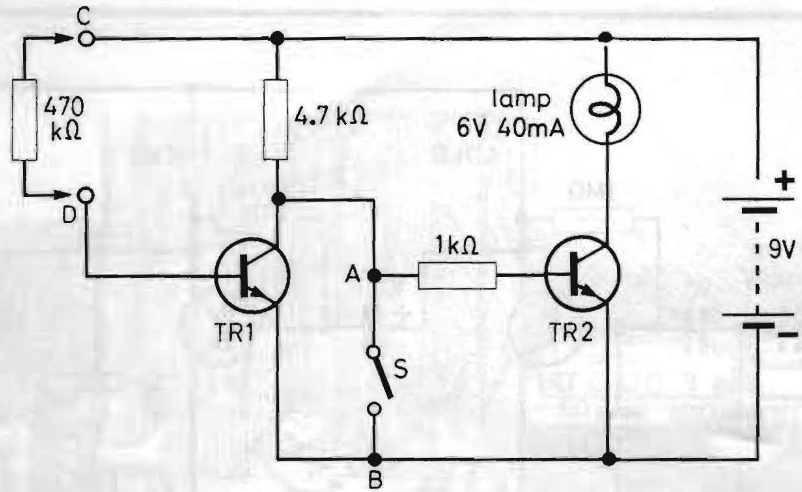
pick-up
capacity
VC
1MΩ
4.7kΩ
10µF
TR1
470kΩ
1kΩ
TR2
100
µF
9V
0.04
µF
phone
pick-up
0·01
µF
0.1
µF

7·1



9v.
battery
+ve
red
−ve
black
1
kΩ
0·01µF
4·7kΩ
1MΩ
470kΩ
VC
10µF
TR1
TR2
0·1
µF
100µF
to gram pick-up
0·04
µF
E
P

Experiment 8



8·1

The transistor as a switch

Set up the circuit as shown in the layout diagram but do *not* at this stage insert TR1 or the 470 kΩ resistor into the panel.

Note that the Morse key strip must be connected to the panel at point A so that when required it can be pressed down to touch the screw head on the earth-line conductor at point B.

Connect the battery. The lamp in the collector circuit of TR2 will light because TR2 is biased into conduction by the 4·7 kΩ and 1 kΩ resistors in series.

Now press down switch S. The lamp will go out because the switch connects point A to earth. This reduces the potential of point A and hence also the potential of the base of TR2 to zero, thus cutting off TR2. If the switch is released the light will come on again.

Switch S is being used as a simple, 'on/off' switch.

Now disconnect the battery and insert TR1 into the circuit. Do *not* insert the 470 kΩ resistor.

Connect up the battery and the lamp will light because, as before, it is biased on by the 4·7 kΩ and 1 kΩ resistors in series.

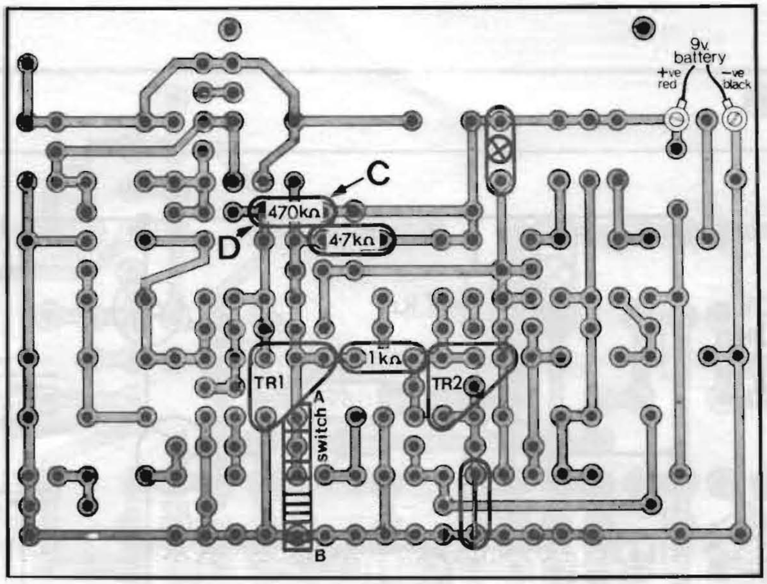
Now apply the 470 kΩ resistor across the positions CD. The lamp will go out. Remove the resistor and the lamp will come on again.

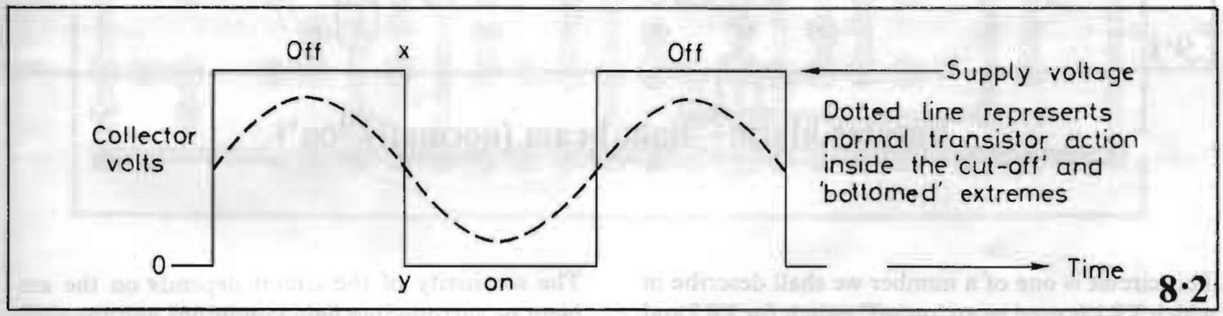
Explanation

When TR1 is biased into conduction by the 470 kΩ resistor, TR1 collector volts drop to near zero, thus effectively earthing point A just as the switch S did. This earths the base of TR2 through the 1 kΩ resistor and the lamp goes out. Thus TR1 is used as a simple 'on/off' switch.

Prior to this experiment we have been using the transistor as an amplifier of audio and radio frequency signals. Now we come to its use as a switch. It has many applications in this role and some of these will be described later.

In Experiment 3 we saw that with only a small base current the voltage at the collector of a transistor remained near to that of the supply voltage, but with a high base current it fell to near zero. In switching circuits the base is biased more heavily than is required for normal transistor action, so that the transistor is either fully 'on' with collector volts near zero or fully 'off' with collector volts equal to the supply voltage.





8·2

It should be noted here that the term 'supply voltage' needs modification in circuits which involve direct coupling between the transistors, as in the theoretical circuit for this experiment. If TR1 is off and TR2 'on' the base of TR2 is at 0·8 volts and therefore 8·2 volts is dropped across the 4·7 kΩ and 1 kΩ resistors. Of this $8{\cdot}2 \times 1/5{\cdot}7$ or 1·45 volts is dropped across the 1 kΩ resistor so that the voltage of TR1 collector cannot exceed $1{\cdot}45 + 0{\cdot}8$, or, approximately 2·2 volts. TR1 collector alternates between this figure and near zero volts.

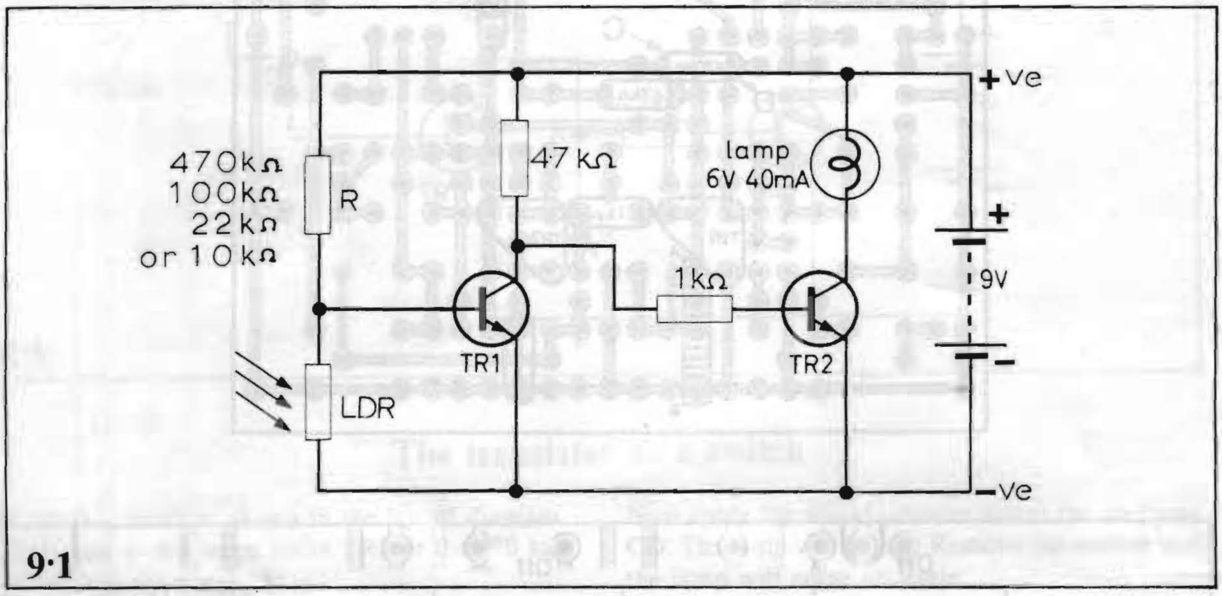
The waveform (collector voltage/time graph) is really an exaggerated version of the waveform sketch 3.8 (*a*) in Experiment 3 which is shown again in diagram 9.2 by a dotted line.

In the 'off' condition, there is no bias (or there may be a negative bias) on the base, so that the transistor draws no current and the collector volts remain at supply voltage. In the 'on' condition, a heavy positive base bias switches the transistor fully 'on' along the line *xy* so that the transistor remains bottomed until the bias is removed.

It is worth noting here that, although in the bottomed condition the current through a transistor may be high, the actual power absorbed in the transistor (heat dissipation) is relatively low because the volts across the transistor are near zero. (Power = volts times current.)

Experiments 9 to 16 illustrate the use of the transistor in the simple switching role.

Experiment 9



9·1

Burglar alarm—light beam (normally 'on')

This circuit is one of a number we shall describe in which TR1 is used as an 'on/off' switch for TR2 and in which TR1 itself is switched on or off by means of a light dependent resistor (LDR).

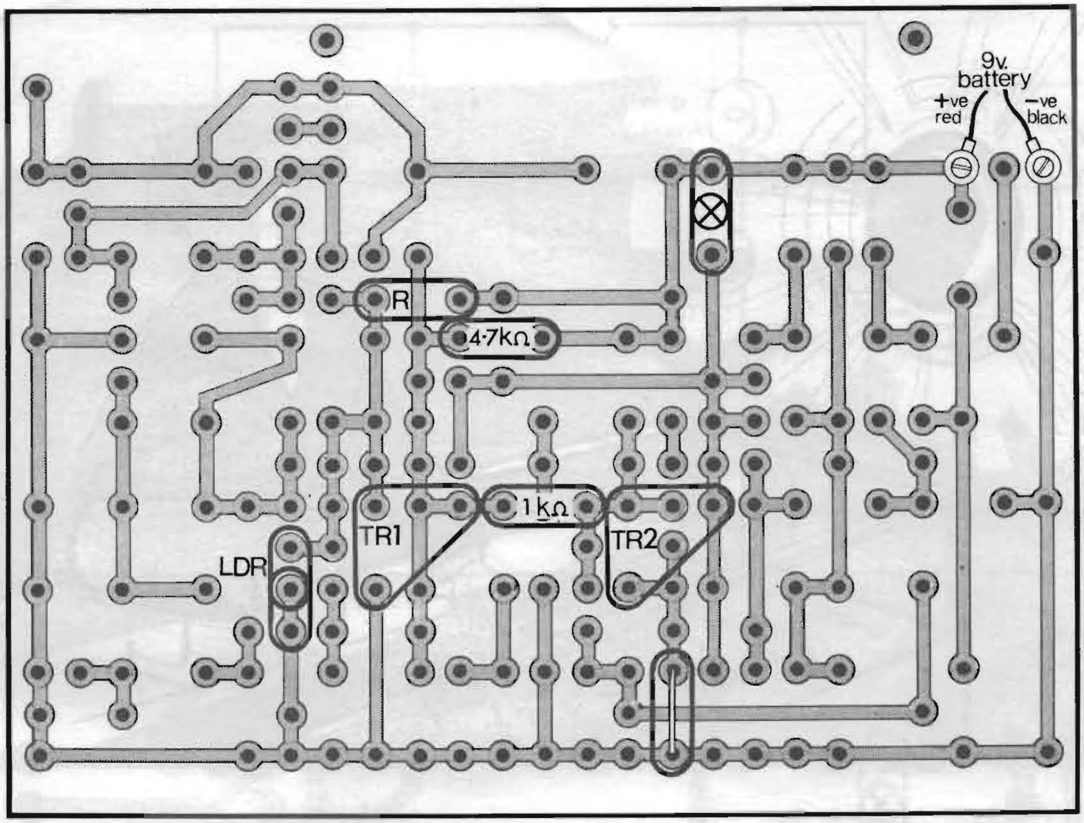
In this circuit TR2 lights a lamp when it conducts, but it could equally operate a relay to open or close mains power circuits.

Light-controlled circuits of this kind are widely used for street lighting control, automatic parking lights, production line counting, automatic brilliance control in television receivers, and fire warning and burglar alarms.

In the circuit shown above the lamp remains 'on' as long as light is falling on the cell. When the light is cut off, the lamp goes out.

The sensitivity of the circuit depends on the ambient or surrounding light conditions and the value of the resistor R. If the circuit is being tested in an ordinary room in daylight, one value of R may be best, while a different value might be more suitable if it is being used as a burglar alarm with a well-focused hidden beam of light.

Ideally R should be a variable resistor which could be adjusted to suit conditions so that TR1 is just *not* conducting (that is, the lamp is just fully on) when the LDR is unscreened. In practice, one of the resistors 470 kΩ, 100 kΩ, 22 kΩ or 10 kΩ, will give good sensitivity. If too low a resistance is fitted, the lamp will stay out because TR1 will be conducting all the time. Select the lowest value which allows the lamp to stay alight when the LDR is not shaded. When selecting the best value care should be taken not to shield the LDR in the process as otherwise the wrong answer might result.



Explanation

The light cell in this kit makes use of a semi-conductor material, cadmium sulphide, which has the characteristic that its electrical resistance varies with the intensity of the light falling upon it. The stronger the light, the lower its resistance. The amount by which the resistance varies can be adjusted in manufacture to suit a variety of different purposes. Such devices are sometimes called 'LDR's' or 'Light Dependent Resistors'.

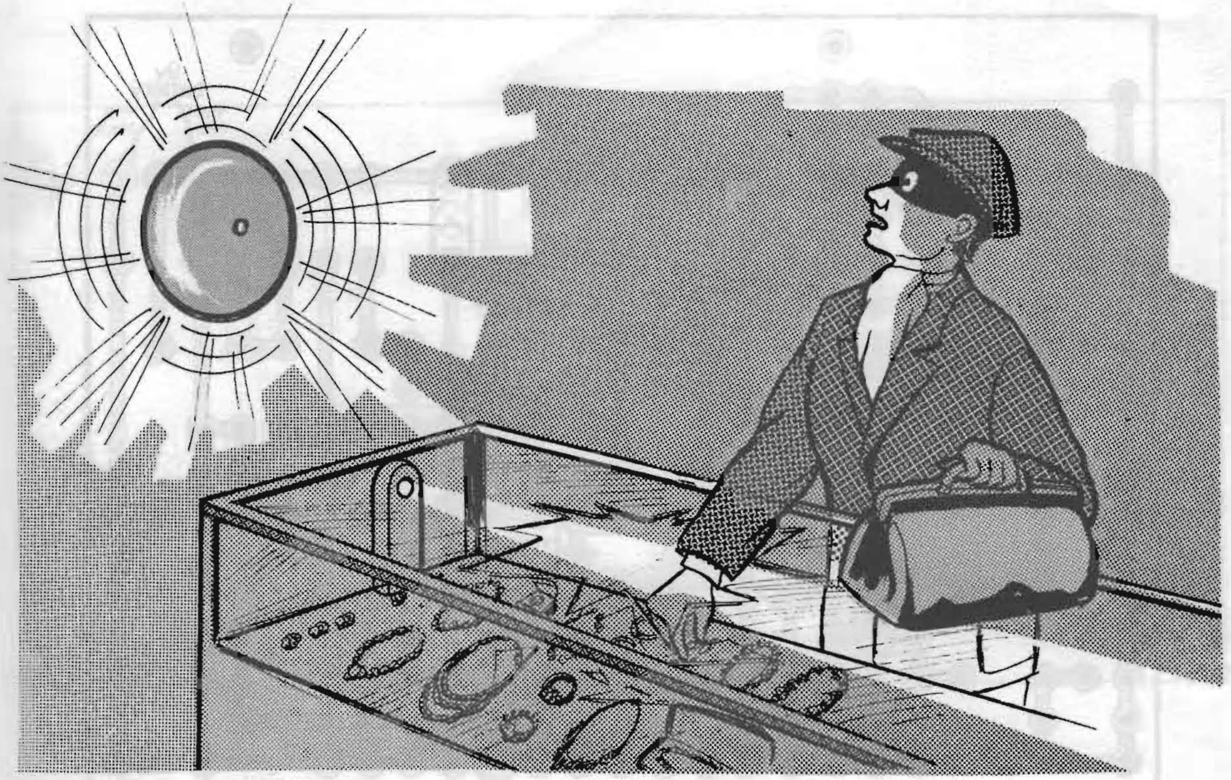
The particular device in this kit has a resistance which varies from about 2,000 ohms in strong light to several millions of ohms in darkness.

The base bias of TR1 is determined by the potential divider consisting of the resistor R in the upper half and the light dependent resistor (LDR) in the lower half.

In strong room lighting the resistance of the LDR is so low compared with 22 kΩ that the base of TR1 is not sufficiently positive for TR1 to conduct. TR1 is cut off; no current is therefore being drawn by it through its 4·7 kΩ collector load resistor and its collector voltage would normally rise to supply volts. In these conditions the 4·7 kΩ resistor and the 1 kΩ in series can supply base current to TR2 and this holds TR2 on and the lamp is alight.

If the light falling on the LDR is reduced, the resistance will increase and when it reaches a point at which the potential divider makes the base of TR1 more than about 0·6 volts, TR1 will conduct. Its collector will then fall to near-zero volts and this, via the 1 kΩ resistor, will cut off TR2 and the lamp will go out.

Experiment 10



Burglar alarm—light beam (normally 'off')

This circuit works in a sense opposite to that of the preceding experiment. The lamp is normally 'off' and it comes on when the light falling on the LDR is decreased.

It can be used for purposes similar to those outlined in Experiment 9 and also as an automatic parking light. The lamp is normally 'off' in daylight conditions when the LDR is illuminated. TR1 consumes very little current. At dusk, however, when the daylight fails, TR1 goes out of conduction and the lamp switches on automatically.

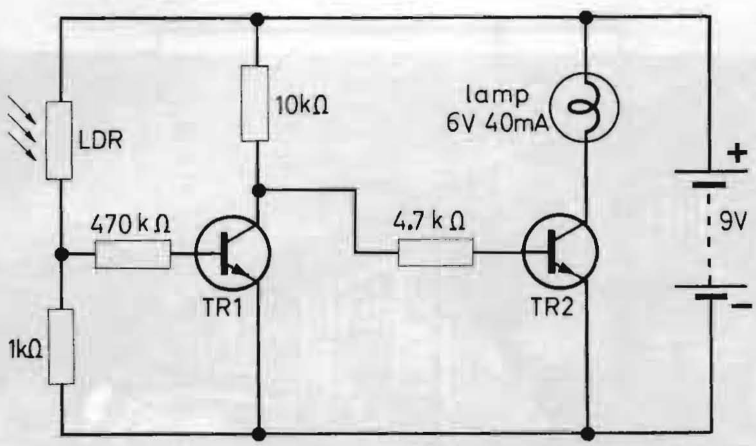
The circuit can also be used as an automatic night light, so that whenever the room lights are extinguished the lamp comes on automatically. Try this in a darkened room. Lights on, lamp out; lights out, lamp on.

The circuit works as follows. The base bias of TR1 is determined by the potential divider consisting of the LDR in the upper half and the 1 kΩ resistor in the lower half, and the 470 kΩ resistor which connects their common point to the base of TR1.

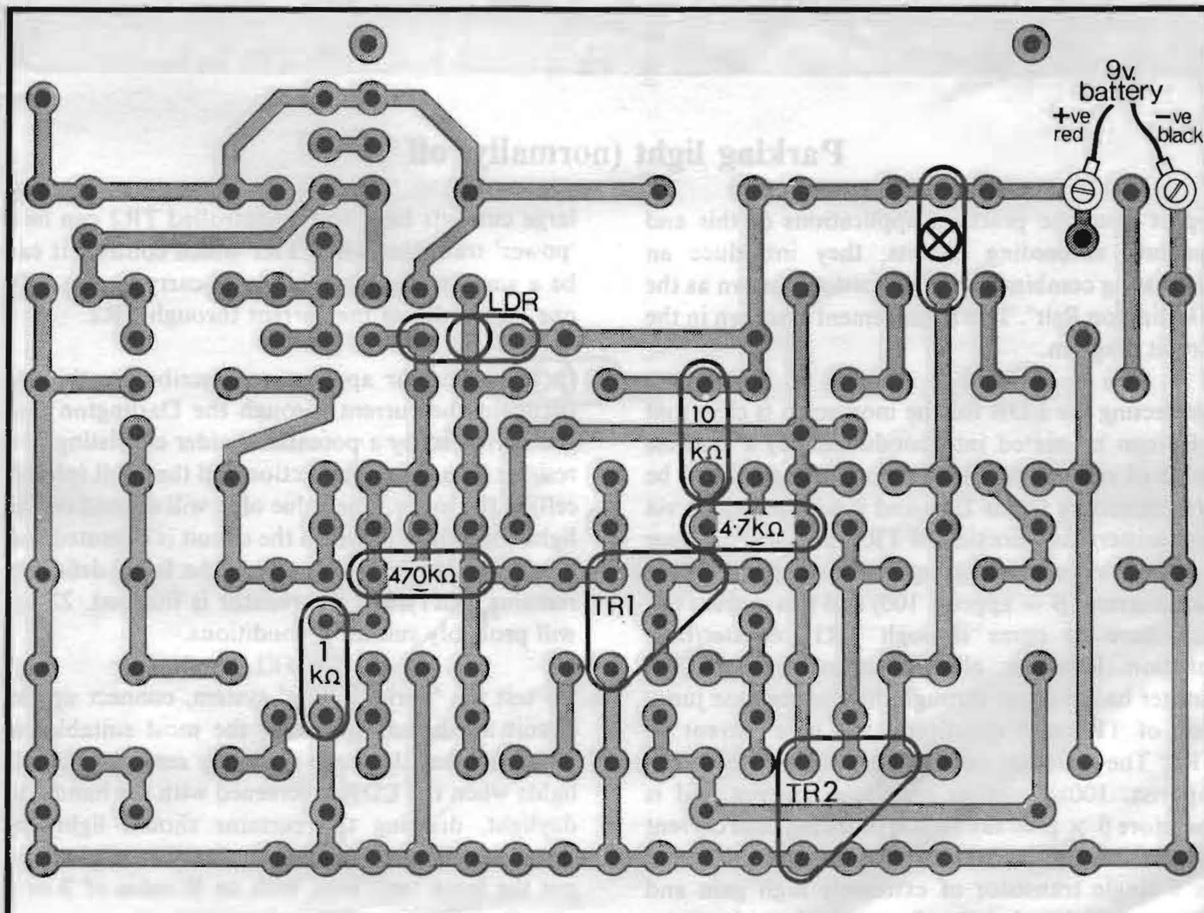
TR1 is normally conducting and consequently the base of TR2 is at near-earth potential. TR2 is off and the lamp 'out'.

If the LDR is shielded from the light its resistance is increased; TR1 goes out of conduction and the lamp lights up.

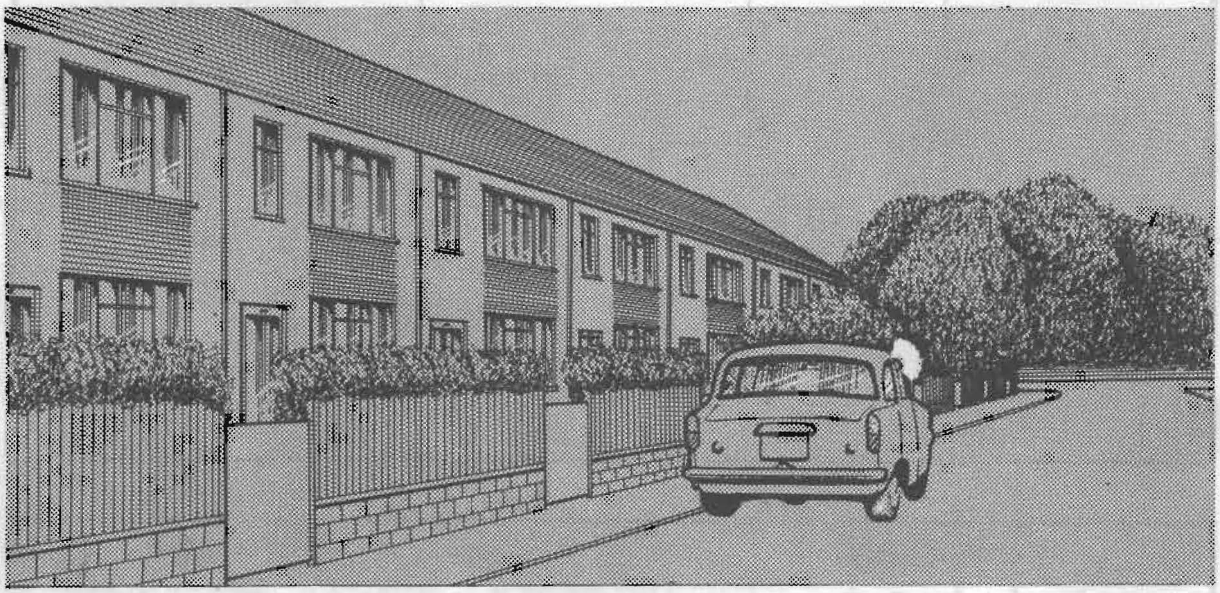
The sensitivity of the circuit may be reduced by interchanging the 1 kΩ and 4·7 kΩ resistors.


LDR
10kΩ
lamp
6V 40mA
+
9V
−
470 kΩ
4.7 kΩ
TR1
TR2
1kΩ

10·1


9v.
battery
+ve
red
−ve
black
LDR
10
kΩ
4·7kΩ
470kΩ
TR1
1
kΩ
TR2

Experiment 11



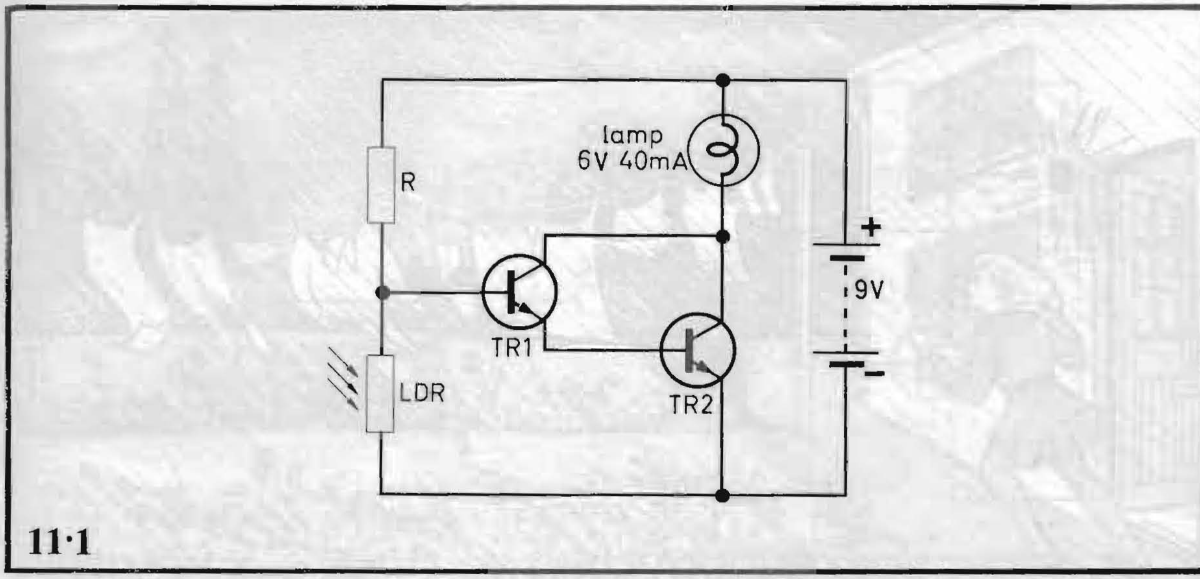
Parking light (normally 'off')

Apart from the practical applications of this and the three succeeding circuits, they introduce an interesting combination of transistors known as the 'Darlington Pair'. This arrangement is shown in the circuit diagram.

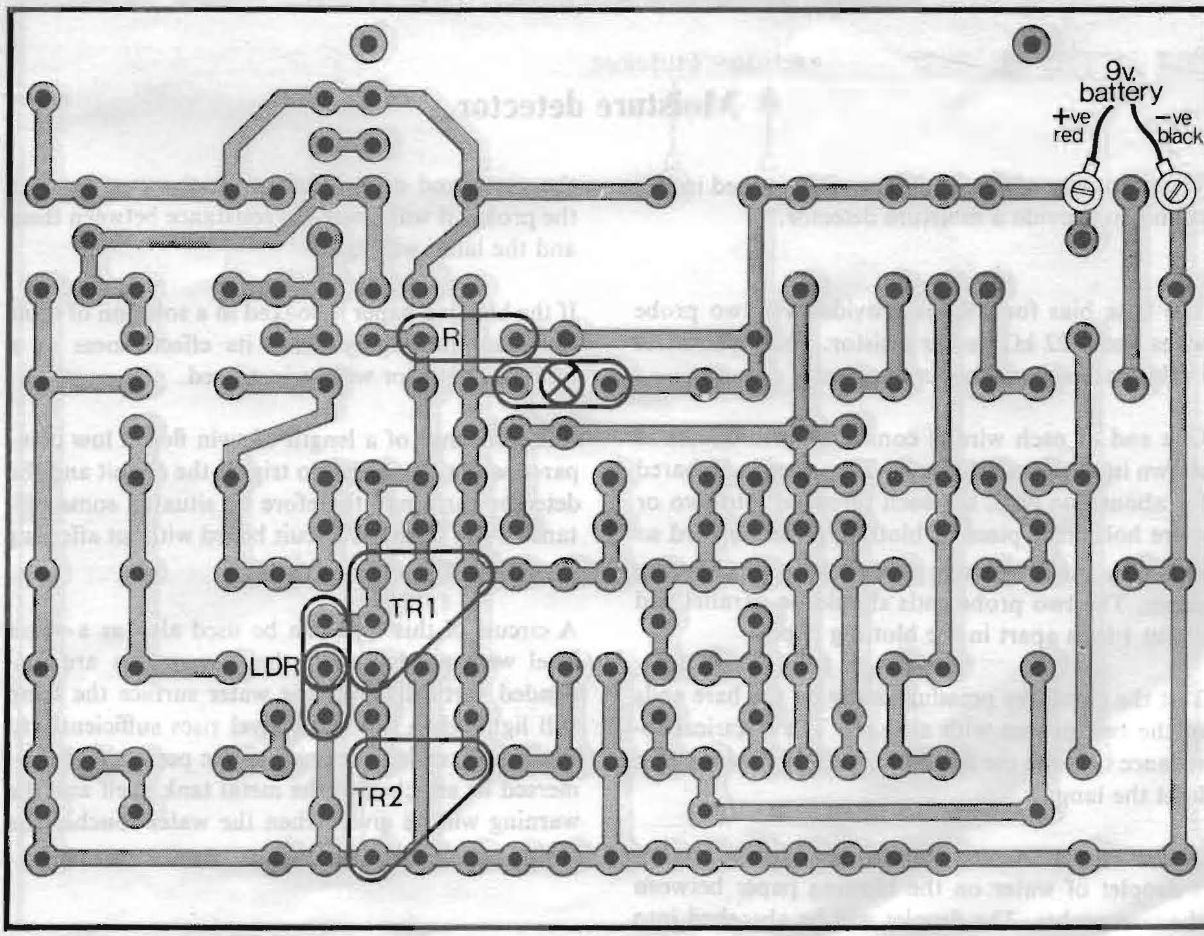
Neglecting the LDR for the moment it is clear that TR1 can be biased into conduction by a suitable value of resistor R. The current through R can be determined by Ohms Law and it will be drawn via the emitter/base junction of TR1. This will produce a collector current through TR1 of β times the base current (β = approx. 100) and this current too will have to come through TR1's emitter/base junction. However, all the current through TR1 emitter has to come through the emitter/base junction of TR2 and constitutes the base current of TR2. The collector current of TR2 is of course β (approx. 100) times its own base current and is therefore $\beta \times \beta$ = say 10,000 times the base current of TR1. Thus the Darlington Pair may be considered as a single transistor of extremely high gain and great sensitivity. Another feature is that when very large currents have to be controlled TR2 can be a 'power' transistor while TR1 which controls it can be a small transistor capable of carrying say only one hundredth of the current through TR2.

In the particular application described in this experiment the current through the Darlington pair is determined by a potential divider consisting of a resistor R in the upper section and the LDR (photocell) in the lower. The value of R will depend on the light conditions in which the circuit is operated and should be the lowest at which the lamp definitely remains 'out' when the resistor is inserted. 22 kΩ will probably suit most conditions.

To test the 'parking light' system, connect up the circuit as shown and select the most suitable resistor, so that the lamp normally remains out but lights when the LDR is screened with the hands. In daylight, drawing the curtains should light the lamp. At night, extinguishing the room lights will put the lamp 'on', even with an R value of 2 or 3 megohms.


lamp
6V 40mA
R
TR1
TR2
LDR
9V
+
−

11·1


9v.
battery
+ve
red
−ve
black
R
TR1
LDR
TR2

Experiment 12

Moisture detector

The sensitivity of the Darlington Pair is used in this circuit to provide a moisture detector.

The base bias for TR1 is provided via two probe wires and a 22 kΩ limiter resistor. The probe wires in this case act as moisture probes.

One end of each wire is connected into circuit as shown in the layout diagram. The other ends, bared for about one inch, are each threaded into two or more holes in a piece of blotting paper or card so that they make effective contact with the blotting paper. The two probe ends should be parallel and about ¼ inch apart in the blotting paper.

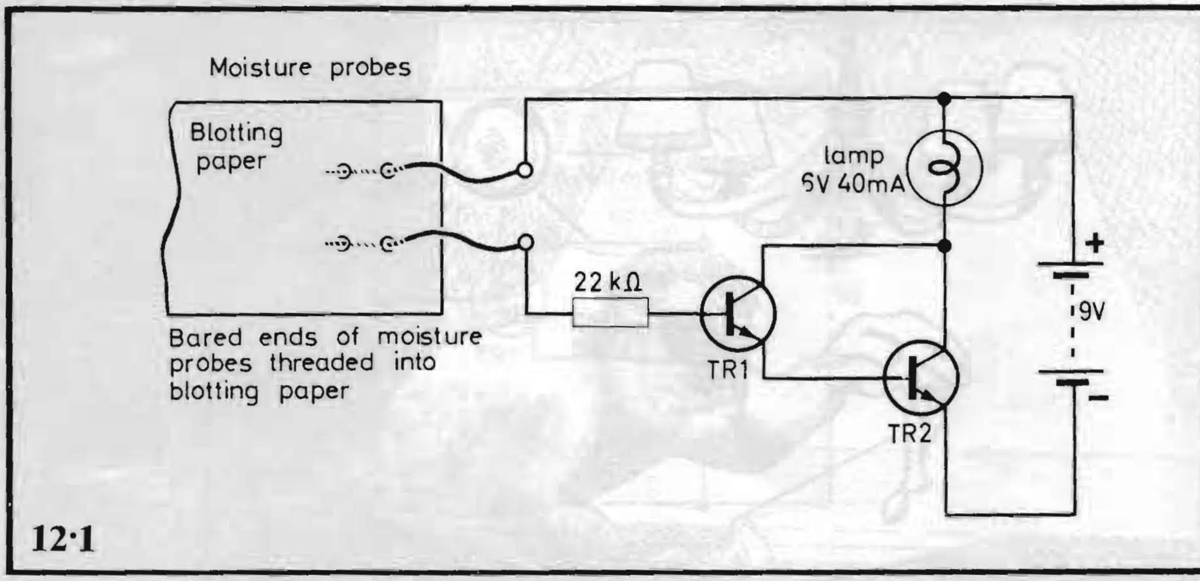
Test the circuit by pressing gently on the bare ends of the two probes with a finger. The electrical resistance through the finger should be low enough to light the lamp.

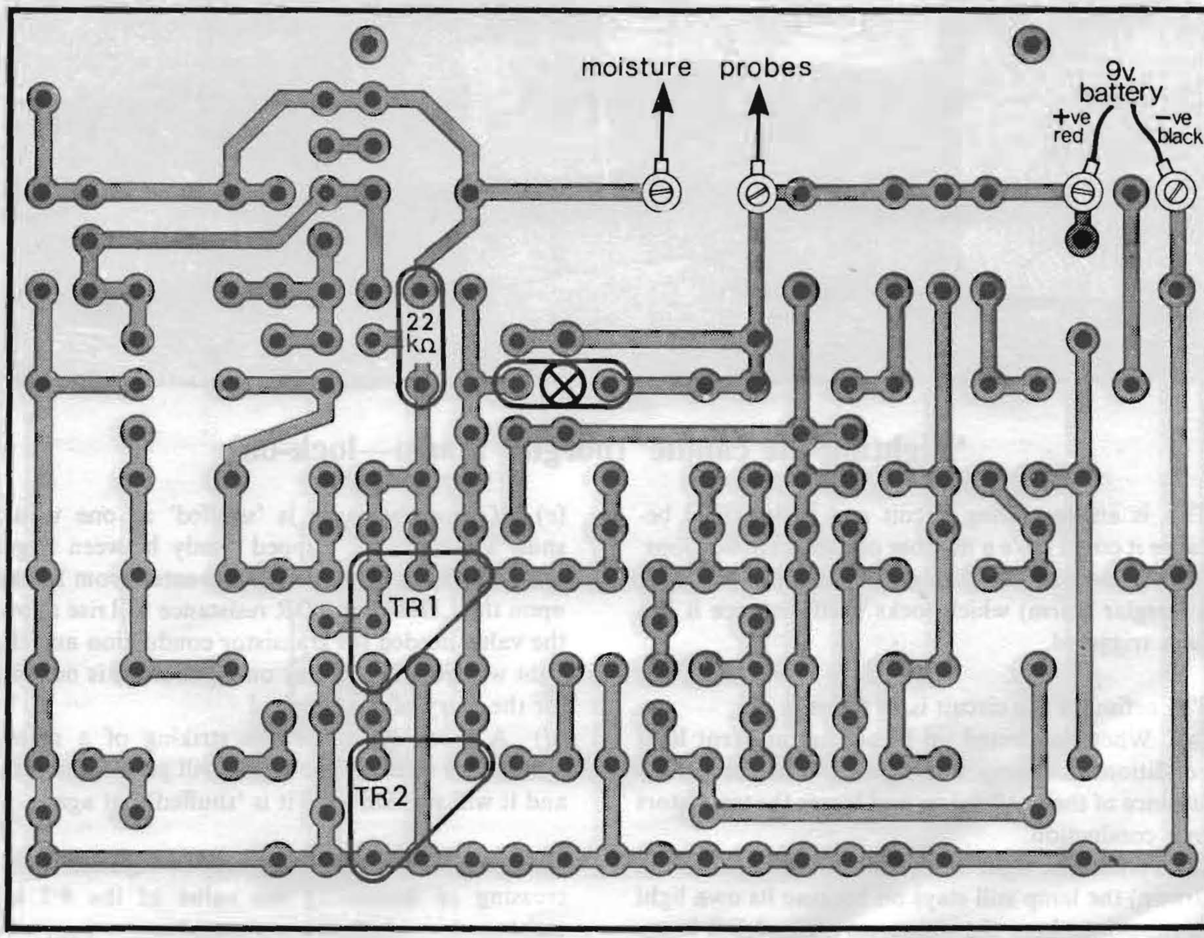
The moisture detector can then be tested by placing a droplet of water on the blotting paper between the two probes. The droplet will be absorbed into the paper and as it diffuses over the area between the probes it will lower the resistance between them and the lamp will light.

If the blotting paper is soaked in a solution of table salt and thoroughly dried its effectiveness as a moisture detector will be increased.

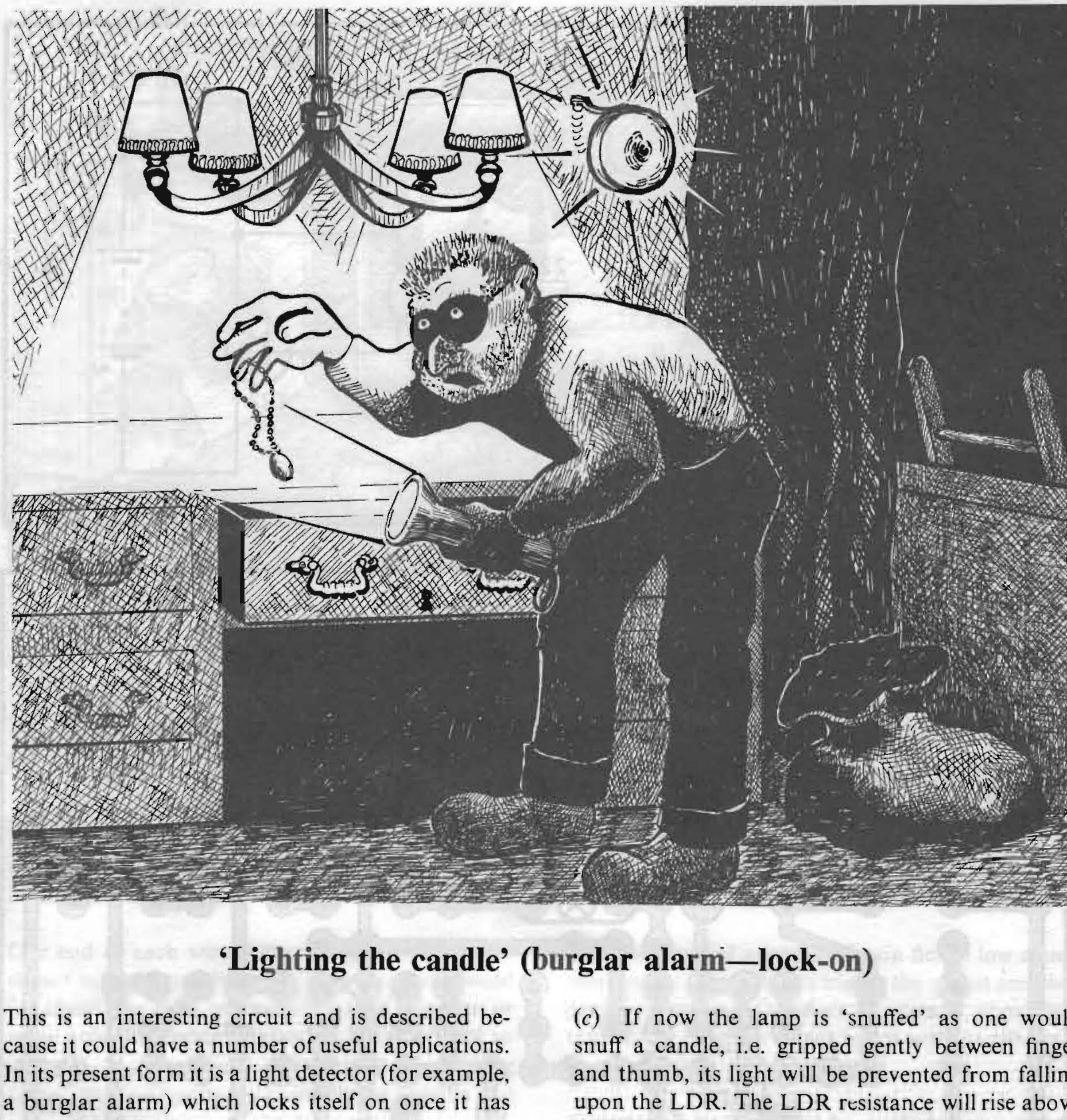
The resistance of a length of twin flex is low compared with that needed to trigger the circuit and the detector card may therefore be situated some distance away from the circuit board without affecting its efficiency.

A circuit of this type can be used also as a water level warning device. If the two probes are suspended vertically over the water surface the lamp will light when the water level rises sufficiently to touch both ends. One end may be permanently immersed or attached to the metal tank itself and the warning will be given when the water touches the other.


Moisture probes
Blotting paper
Bared ends of moisture probes threaded into blotting paper
lamp
6V 40mA
22 kΩ
TR1
TR2
+
9V
-
12·1


moisture probes
9v. battery
+ve red
−ve black
22 kΩ
TR1
TR2

Experiment 13

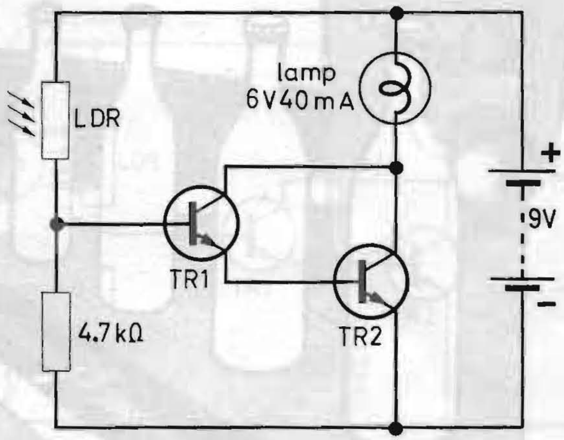


'Lighting the candle' (burglar alarm—lock-on)

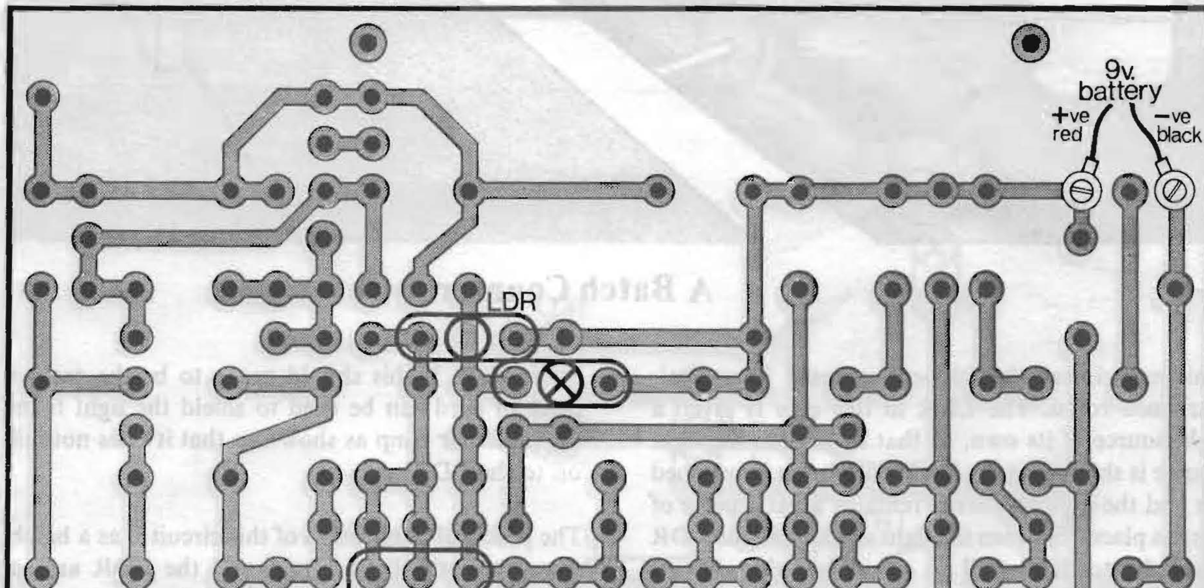
This is an interesting circuit and is described because it could have a number of useful applications. In its present form it is a light detector (for example, a burglar alarm) which locks itself on once it has been triggered.

The action of the circuit is as follows:
(*a*) When connected up in normal ambient light conditions the lamp will light up because the resistance of the LDR is low and biases the transistors into conduction.
(*b*) When the light is turned off (or curtains are drawn) the lamp still stays on because its own light is enough to keep the resistance of the LDR low.
(*c*) If now the lamp is 'snuffed' as one would snuff a candle, i.e. gripped gently between finger and thumb, its light will be prevented from falling upon the LDR. The LDR resistance will rise above the value needed for transistor conduction and the light will go out and stay out. The stage is now set for the entry of the burglar!
(*d*) A torch beam, or the striking of a match within 3 or 4 feet of the LDR, will put the lamp on and it will stay on until it is 'snuffed' out again.

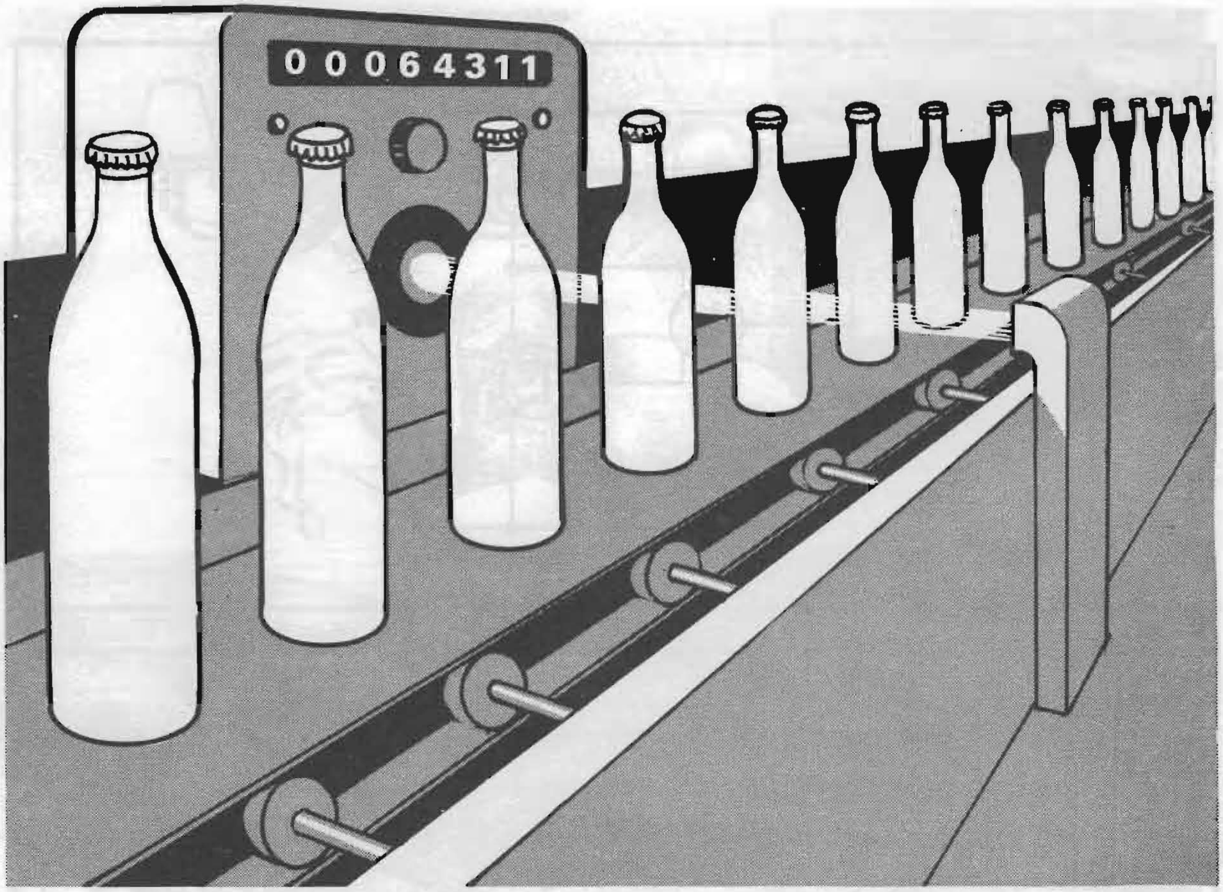
The sensitivity of the circuit may be adjusted by increasing or decreasing the value of the 4·7 kΩ resistor.


lamp
6V40mA
LDR
TR1
TR2
4.7kΩ
+
9V
−

13·1


9v.
battery
+ve
red
−ve
black
LDR
TR1
4·7
kΩ
TR2

Experiment 14

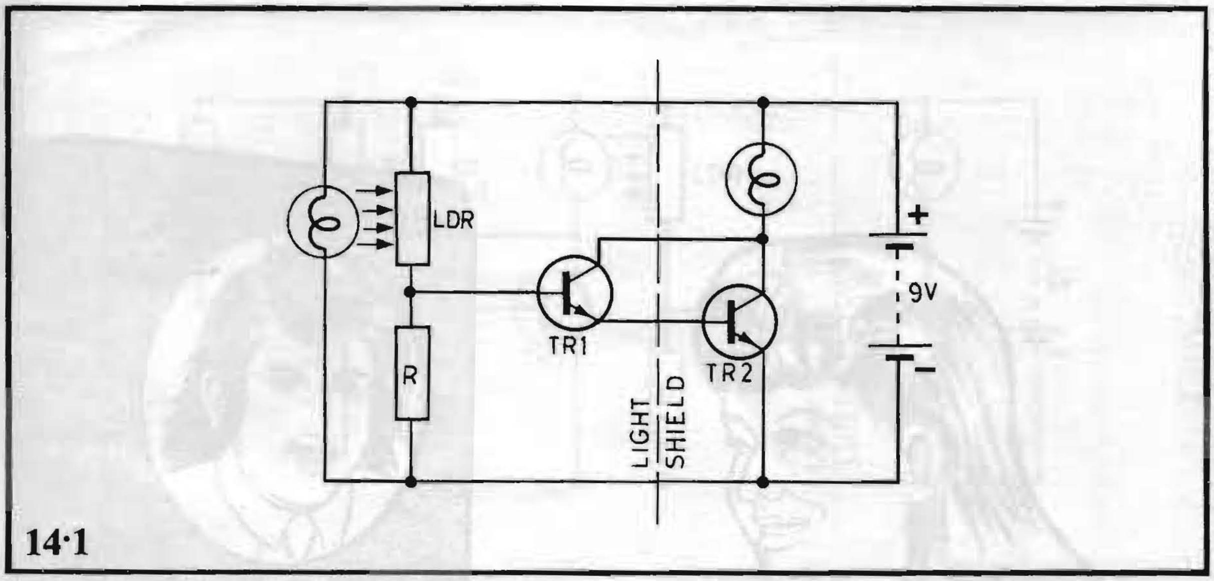


A Batch Counter

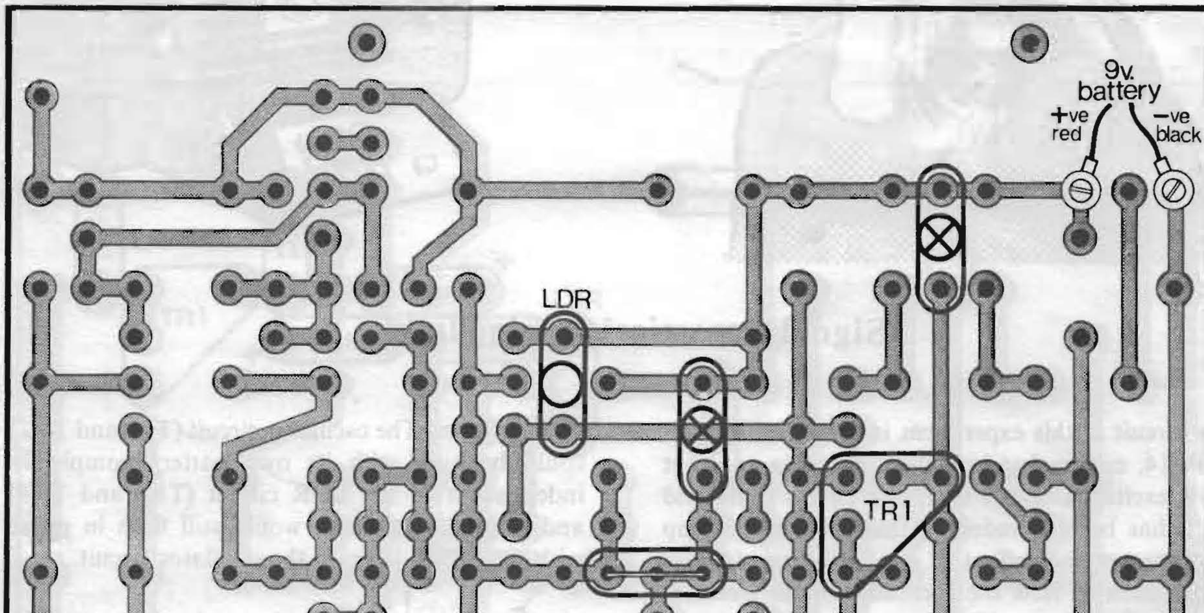
This experiment should be conducted in a semi-darkened room. The LDR in this case is given a light source of its own, so that as long as the light source is shining on the LDR, the circuit is switched on and the indicator lamp remains lit. If a piece of card is placed between the light source and the LDR the indicator lamp will go out. When the piece of card is removed again, the indicator lamp lights again.

The value of 'R' in the circuit should be adjusted until the circuit works properly in the light of conditions prevailing. A value of the order of 4·7 kΩ will probably be suitable. It is possible that the light from the indicator lamp may upset the experiment. If this should prove to be the case, a piece of card can be used to shield the light from the indicator lamp as shown so that it does not fall on to the LDR.

The practical application of this circuit is as a batch counter. If the light source and the LDR are so arranged that a succession of objects can pass between them as shown in the illustration at the top of the page, the circuit will be alternately switched on and off, as the light to the LDR is interrupted. Instead of using an indicator lamp, some form of counter would be used, which when a certain pre-set number of objects had passed on an assembly line, for instance, would switch the conveyor belt off, so giving a batch of objects.


LDR
TR1
TR2
R
LIGHT SHIELD
+
9V
−

14·1


9v. battery
+ve red
−ve black
LDR
TR1
R
TR2

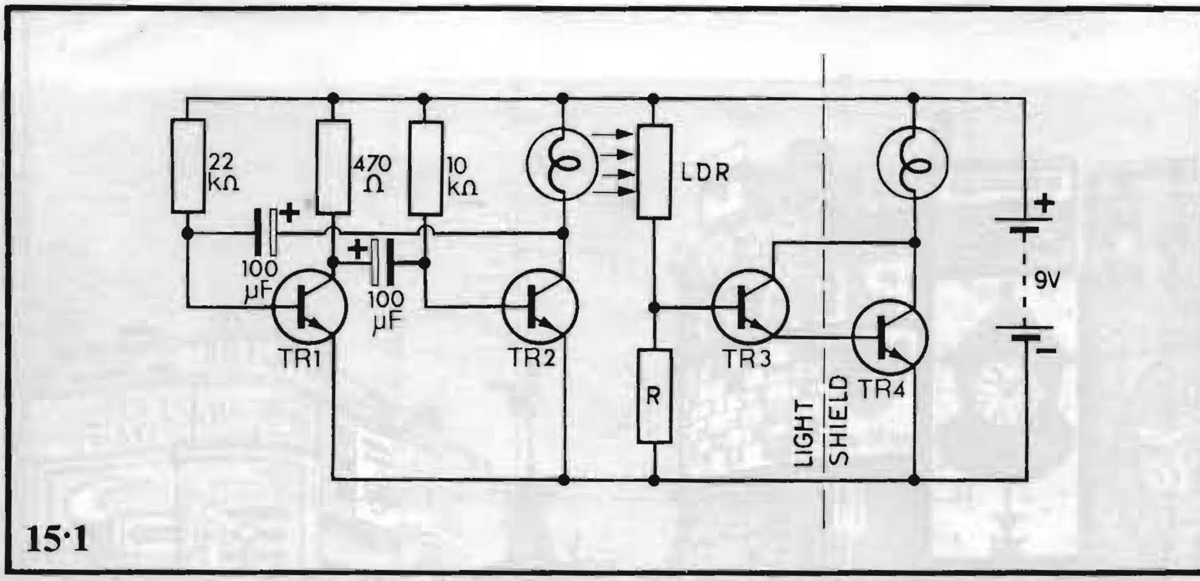
Experiment 15

Signal transmission using light

The circuit in this experiment is similar to Experiment 14, except that instead of having a constant LDR exciter lamp, an oscillator circuit (TR1 and TR2) has been included so that the exciter lamp switches on and off at a set frequency. (A full explanation of how the oscillator circuit works is given in Experiment 17.)

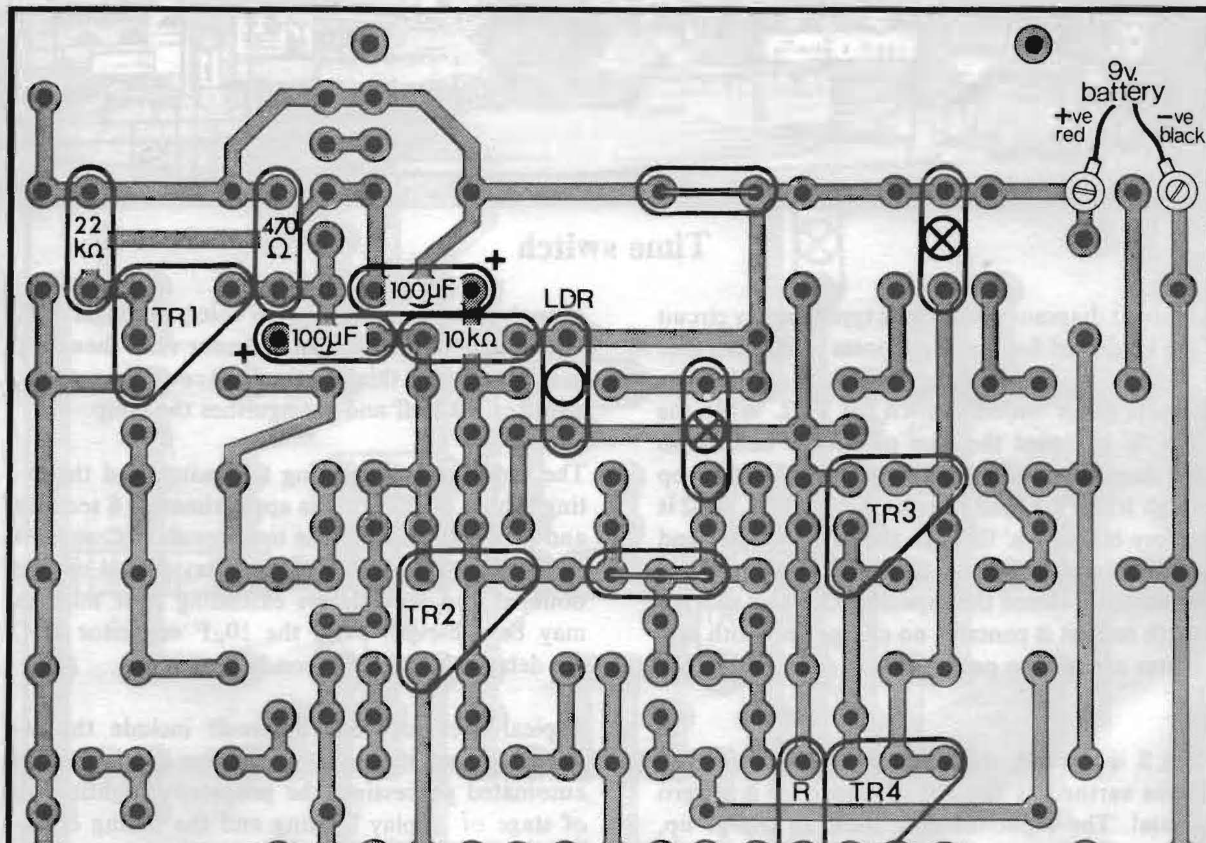
The importance of this circuit lies in the fact that the indicator lamp flashes in phase with the exciter lamp even when there is no electrical connection between them. The oscillator circuit (TR1 and TR2) could be built with its own battery completely independent of the LDR circuit (TR3 and TR4) and the indicator lamp would still flash in phase with the exciter lamp in the oscillator circuit.

It is now possible to send signals along a cable using light pulses instead of electrical current and this facility could well be used in conjunction with such devices as the 'Visiphone' shown in the illustration at the top of this page.



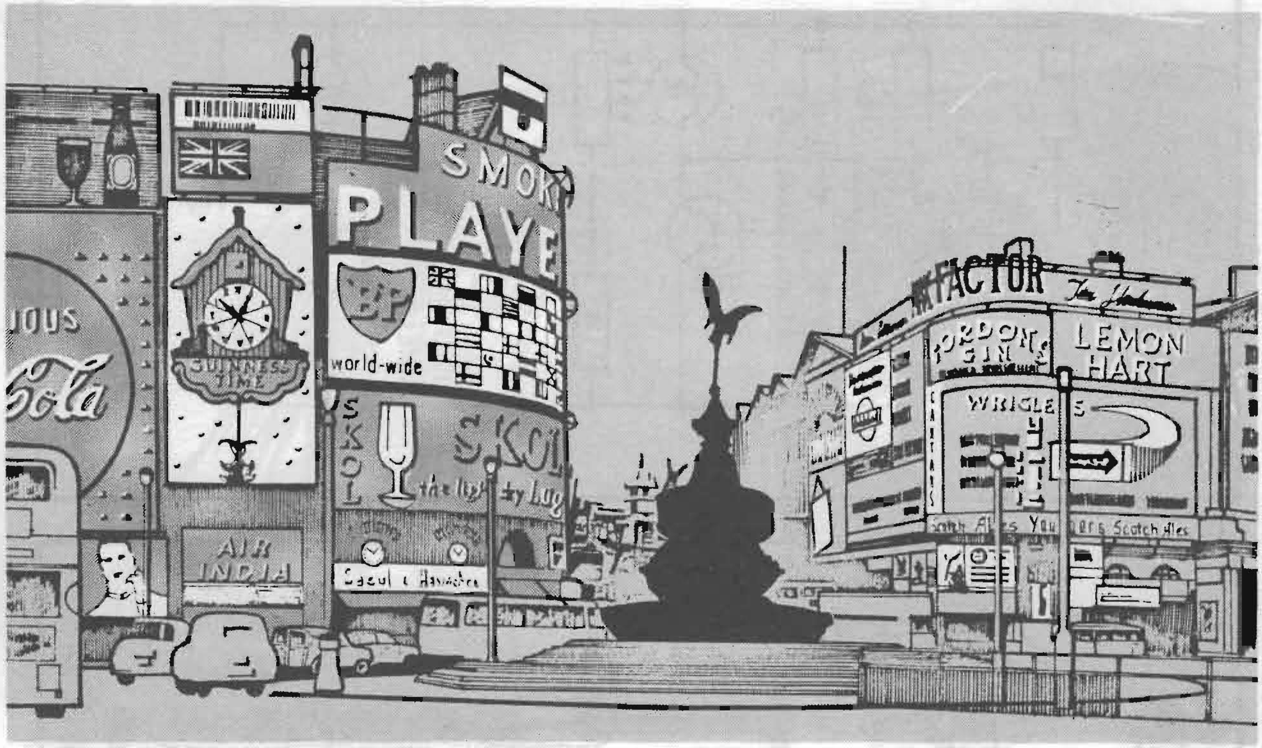
22 kΩ
470 Ω
10 kΩ
LDR
100 µF
100 µF
TR1
TR2
TR3
TR4
R
LIGHT SHIELD
9V
+
−

15·1



9v. battery
+ve red
−ve black
22 kΩ
470 Ω
TR1
100µF
LDR
100µF
10kΩ
TR2
TR3
R
TR4

Experiment 16



Time switch

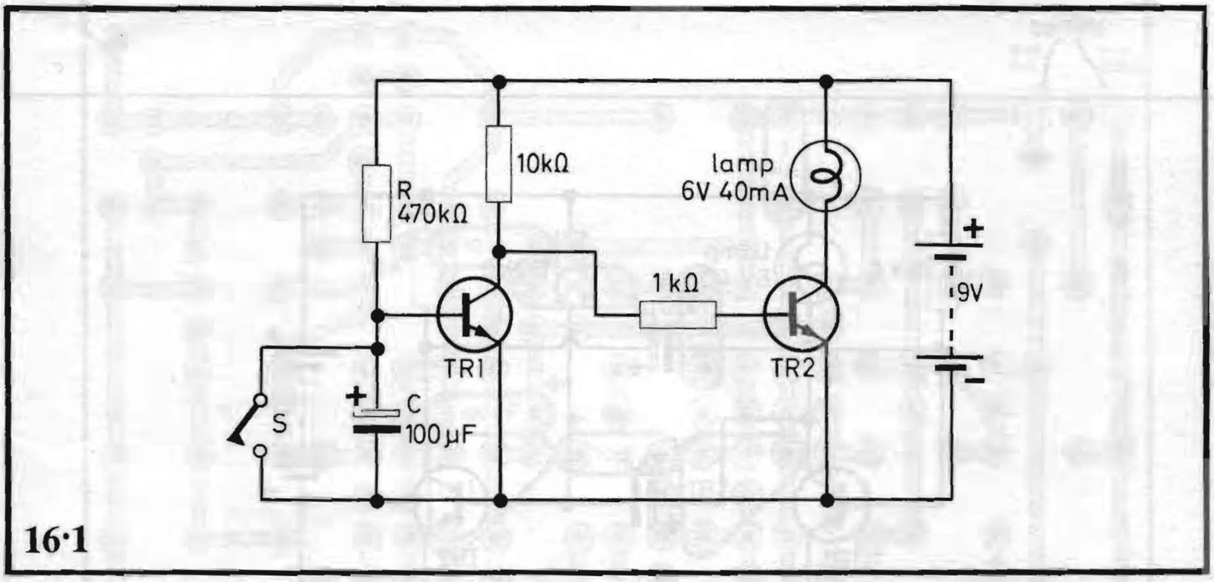
The circuit diagram illustrates a typical delay circuit of the kind used for many purposes in modern life.

TR1 acts as an 'on/off' switch for TR2. When the switch 'S' is closed the base of TR1 is earthed so that it does not conduct and there is no voltage drop through its 10 kΩ load resistor due to TR1. TR2 is therefore biased 'on' through the 10 kΩ resistor and the 1 kΩ coupling resistor and the lamp lights up. With switch S closed the capacitor C is also shorted to earth so that it contains no charge and both sets of plates are at zero potential.

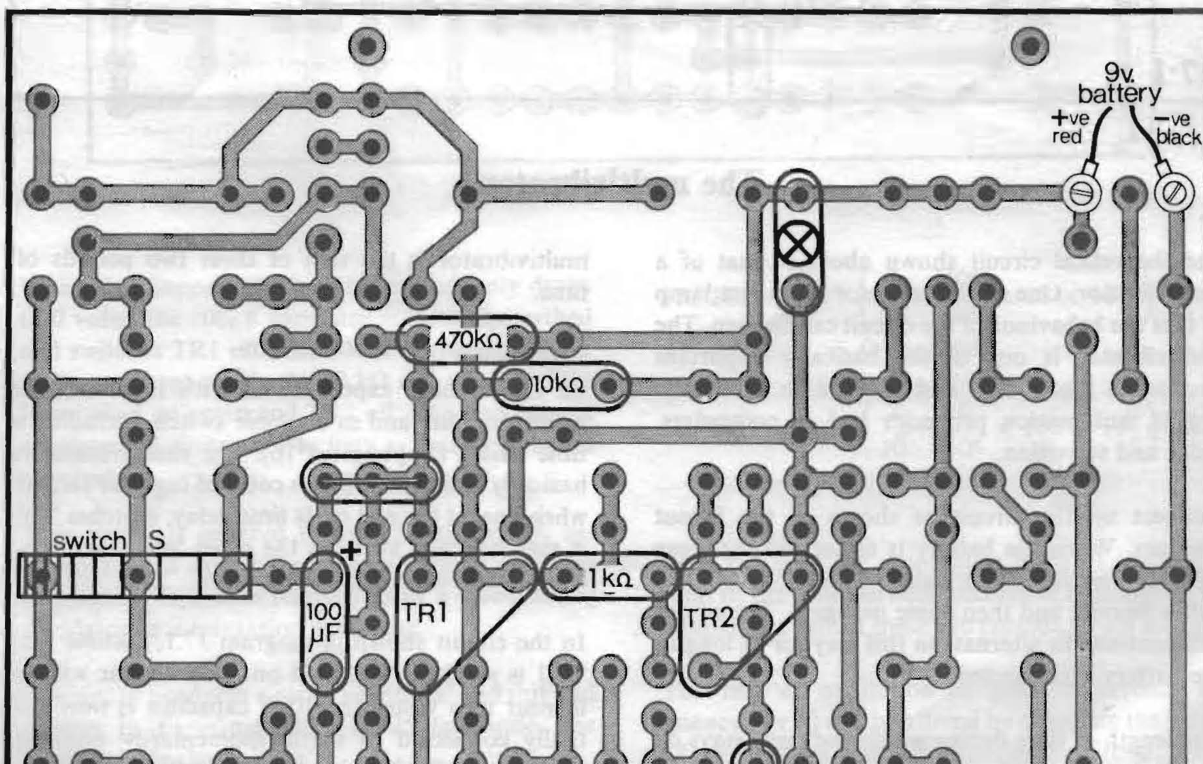
When S is opened, the base of TR1 momentarily remains earthed as the 100 μF capacitor is at zero potential. The capacitor now starts to charge up, however, via the 470 kΩ resistor R, and as it charges its voltage slowly rises making the base of TR1 progressively more positive until it becomes positive enough (at approximately 0·6 volts) to trigger TR1 into conduction. The TR1 collector volts then drop to near zero and this, via the 1 kΩ coupling resistor, switches TR2 off and extinguishes the lamp.

The time between opening the switch and the extinguishing of the lamp is approximately 6 seconds and is proportional to the time constant C × R. If either C or R is doubled the delay period will be doubled and long delays extending over minutes may be achieved. With the 10μF capacitor at C the delay is about 0·6 seconds.

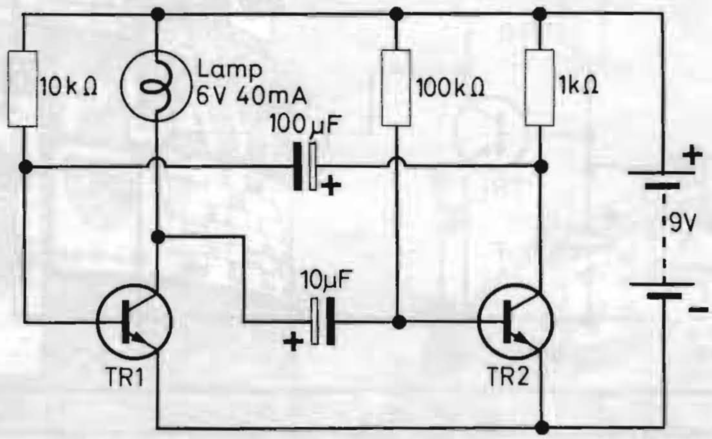
Typical uses for such a circuit include the sequencing and timing of successive operations in automated processing, the progressive lighting up of stage or display lighting and the timing of exposures in photographic printing. In the latter case, the resistor R could be variable so that any required exposure time could be pre-selected.


10kΩ
lamp
6V 40mA
R
470kΩ
1kΩ
9V
TR1
TR2
S
C
100µF

16·1


9v.
battery
+ve
red
-ve
black
470kΩ
10kΩ
switch S
1kΩ
100
µF
TR1
TR2

Experiment 17



17·1

The multivibrator

The theoretical circuit shown above is that of a multivibrator. One of the collector loads is a lamp so that the behaviour of the circuit can be seen. The multivibrator is one of the basically important circuits in electronics and is used in electronic organs, automation processes and in computers, radar and television.

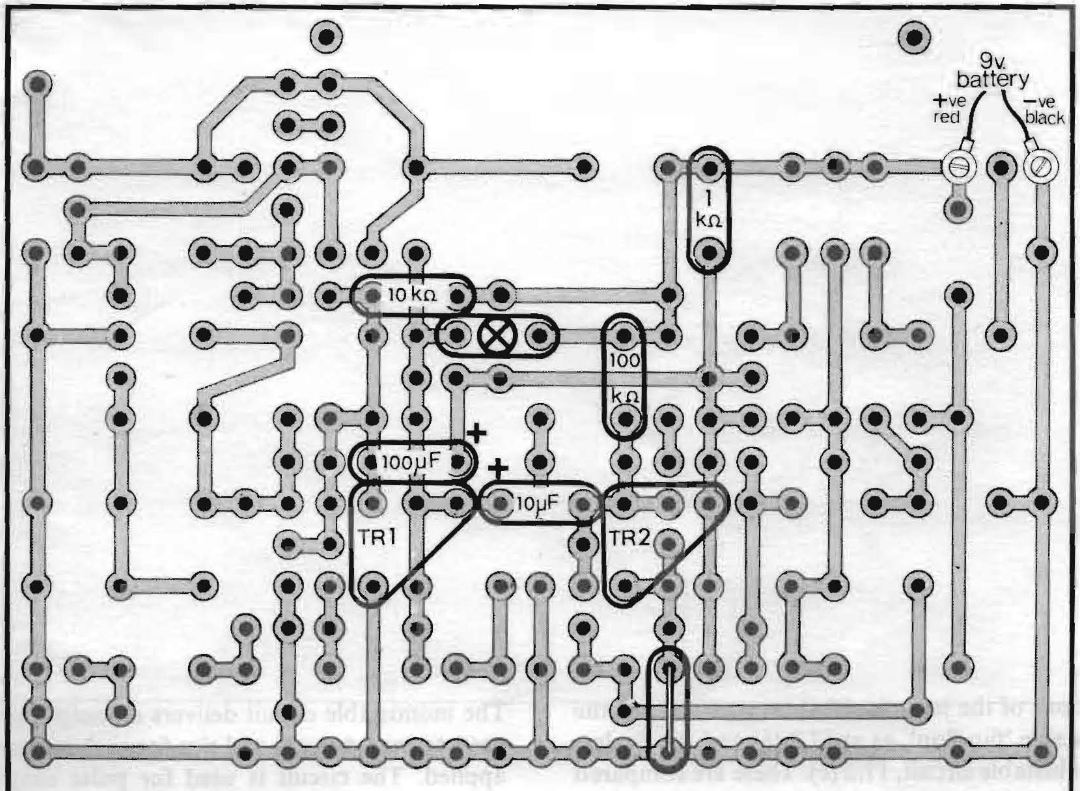
Connect up the circuit as shown in the layout diagram. When the battery is connected the lamp will light up for about half a second, go out for half a second, and then come on again. The circuit will continue to alternate in this way for as long as the battery is connected.

The length of time during which the lamp stays on can be varied by changing the values of the 10µF capacitor and the 100 kΩ resistor. Similarly the length of time during which the lamp stays out (or, the length of time TR2 stays on) can be varied by altering the values of the 100µF capacitor and 10 kΩ resistor. The length of one complete cycle of the multivibrator is the sum of these two periods of time.

Explanation

So far we have experimented with the transistor as an amplifier and as a simple switch, including a time switch (Experiment 16). The multivibrator is basically two time switches coupled together so that when one, at the end of its time delay, switches 'on' it automatically switches the other 'off'. This process repeats itself indefinitely.

In the circuit shown in diagram 17.1, assume that TR1 is suddenly switched on. Its collector will go to near zero volts. The 10µF capacitor is thus virtually connected to earth, momentarily earthing the base of TR2 which is thus switched off. The 10µF capacitor then charges up slowly with current via the 100 kΩ bias resistor from the positive rail. The voltage on the capacitor goes increasingly positive until it reaches the point at which TR2 will conduct.



When this happens TR2 collector suddenly drops to 0 volts; the 100μF capacitor is virtually earthed and switches TR1 off. The 100μF capacitor in turn starts to charge up via the 10 kΩ resistor until TR1 is switched on again and TR2 off. This process will continue indefinitely for as long as battery power is supplied.

This circuit is referred to as a multivibrator, because it has a square wave output which is rich in harmonics. It is also referred to as a free-running oscillator or a relaxation oscillator.

The circuit produces a series of 'pulses' and this and circuits in Experiments 18 to 25 fall under the heading of 'pulse circuits'.

The time taken for one of the transistors in a multivibrator to switch itself on depends on the values of its bias resistor R and input capacitor C and is approximately 0·7 CR seconds.

For TR1, it is: $\left(\frac{7}{10} \times \frac{100}{10^6} \times 10 \times 10^3 \right)$
$= 0{\cdot}7$ seconds

For TR2, it is: $\left(\frac{7}{10} \times \frac{10}{10^6} \times 100 \times 10^3 \right)$
$= 0{\cdot}7$ seconds

Thus the time for a complete cycle of the circuit (that is, the time between successive lightings of the lamp) is the sum of these two periods, or 1·4 seconds.

The rate of oscillation or pulse recurrence frequency (p.r.f.) can be altered by changing the values of the resistors and capacitors in the circuit. When the values of the bias resistors, load resistors and coupling capacitors are the same for both transistors, the circuit is said to be 'symmetrical', the output is a 'square' wave (equal on and off periods) and the complete cycle takes 1·4 CR seconds.

Experiment 17

Variations of the basic multivibrator circuit are the monostable 'flip-flop', as at 17.2 (*b*) and the Eccles-Jordan bistable circuit, 17.2 (*c*). These are compared with the multivibrator at 17.2 (*a*).

In the monostable circuit at (*b*), one of the coupling capacitors of the multivibrator circuit has been replaced by a resistor R2. In the normal state, TR1 is biased on and is conducting. Its collector is at near-zero volts and this, through the coupling resistor R2, keeps TR2 biased 'off'. If a negative pulse is applied to its base TR1 is cut off. Its collector suddenly goes positive and this applies a positive bias to the base of TR2, via resistor R2. TR2 'flips' into conduction, its collector going to near-zero volts. This negative movement holds TR1 off via the coupling capacitor C. The capacitor then charges up, via TR1 base bias resistor R1, until the base of TR1 becomes sufficiently positive to enable TR1 to 'flop' back into conduction again, switching TR2 off via R2 as it does so. The circuit remains in this state, TR1 conducting, until some external pulse triggers it over again.

The time during which TR1 remains 'off' is governed by the values of C and R1 and is approximately 0·7 CR1 seconds.

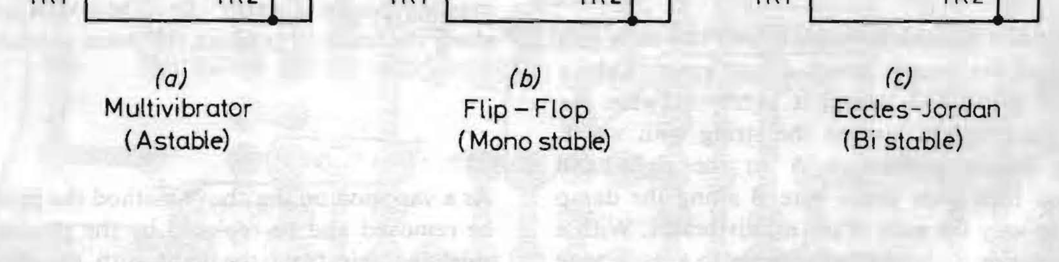
The monostable circuit delivers an output pulse of predetermined shape and size for each trigger pulse applied. The circuit is used for pulse shaping or amplification or for introducing a delay in passing on a pulse. Experiment 21 uses a 'flip-flop' circuit.

In the Eccles-Jordan bistable circuit at (*c*), both coupling capacitors of the multivibrator circuit at (*a*) have been replaced by coupling resistors.

If TR1 is initially conducting its collector is at near-zero volts and this, via the coupling resistor R2, holds TR2 off.

A negative input pulse on the base of TR1 will switch TR1 off. Its collector will go positive and this, via R2, will switch TR2 into conduction. TR2's collector will then go negative to near-zero volts and this, via R1, will hold TR1 off. The circuit will remain in this new state indefinitely, until a further input pulse causes it to change over again.

Thus *two* input pulses will cause the circuit to go through a complete cycle and, if the output is taken from either collector, will give *one* output pulse. Thus the output is half the input and this circuit is the basis of binary counting and of digital computers. Experiments 22, 23, 24 and 25 use a bistable circuit.



(a)
Multivibrator
(Astable)

(b)
Flip – Flop
(Mono stable)

(c)
Eccles-Jordan
(Bi stable)

17·2

Experiment 18

Electronic violin

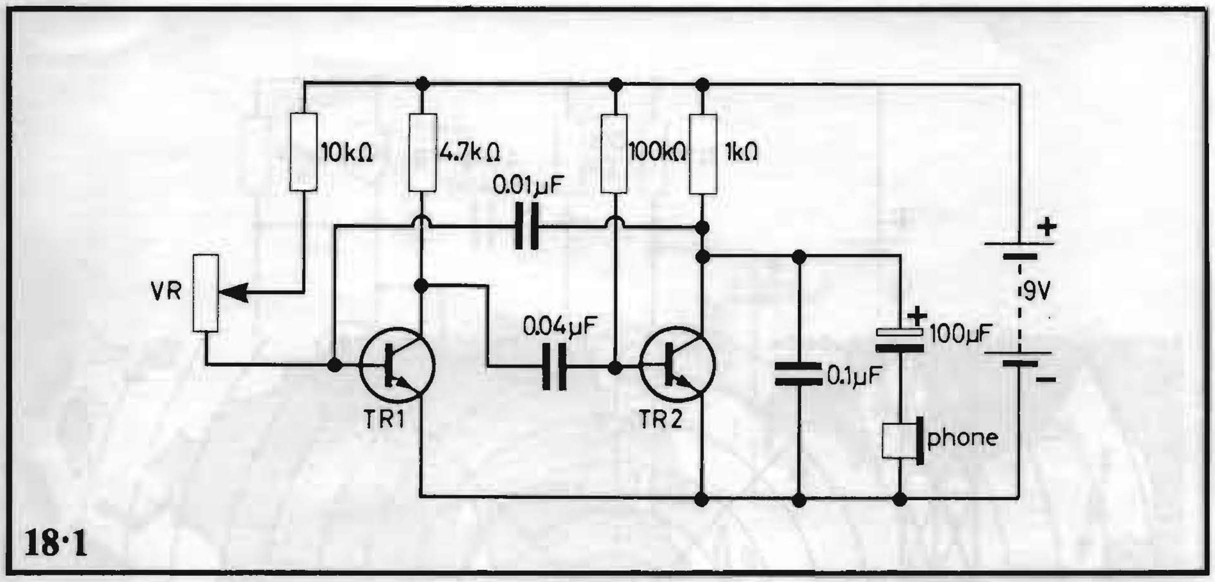
The multivibrator circuit is adapted here to produce electronic music.

The circuit is similar to that of the preceding circuit. The main difference is that the TR1 base bias resistor is made variable. The 10 kΩ resistor in series with this variable resistor is a safety device to ensure a minimum value of base bias resistance.

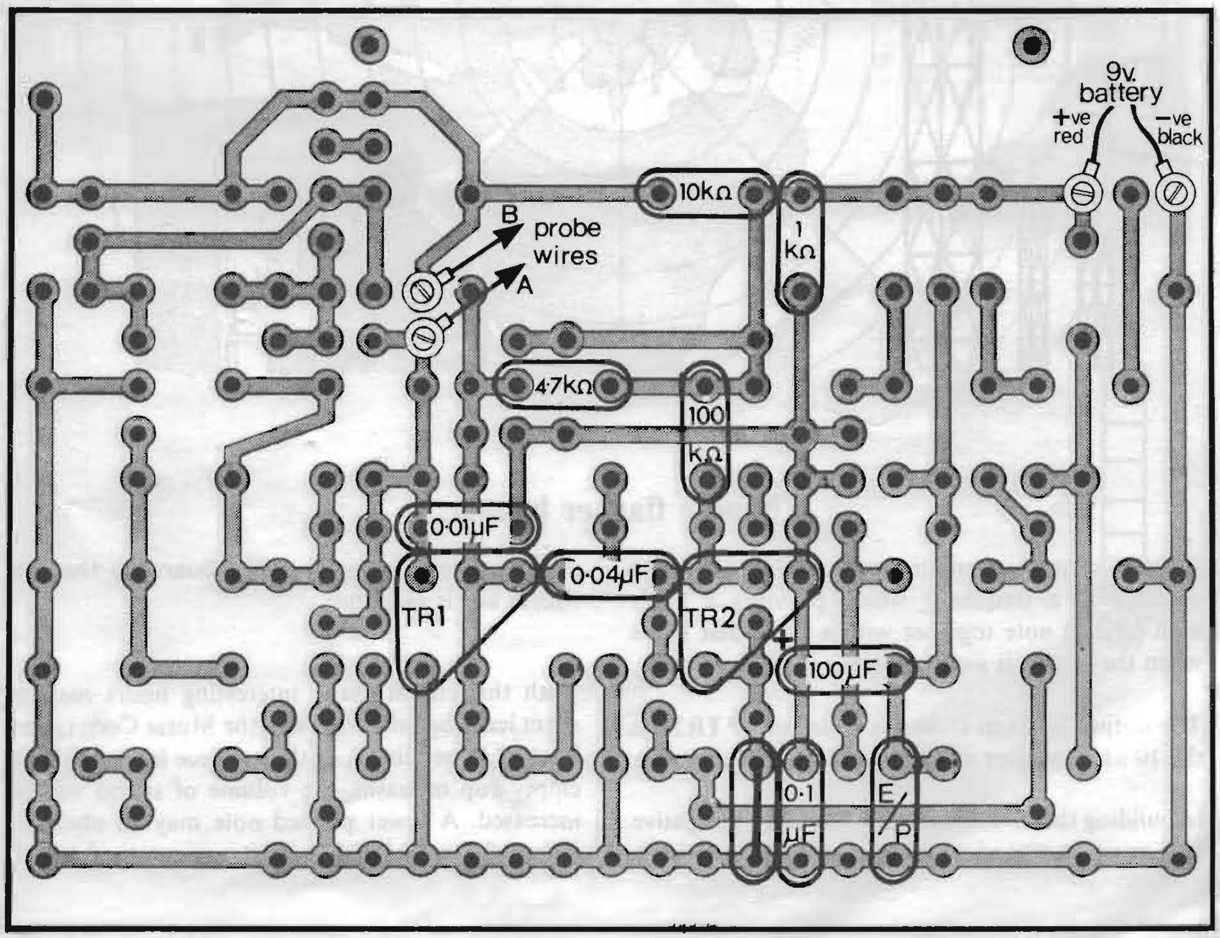
To provide a variable resistance drive two nails into a piece of dry board, about a foot apart. Take a piece of string and stretch it tightly between the nails. Thoroughly dampen the string with water. Firmly attach probe-wire A to the right-hand nail and then slide probe-wire B along the damp string to vary the note of the multivibrator. With a little practice it should be possible to play a tune on this 'electronic' violin. A tremolo effect may be obtained by moving the probe to and fro along the string about the mean point of the note being played.

An alternative method of producing a variable resistance is to make a carbon track with a piece of cardboard and a soft lead pencil. Draw two parallel lines across the sheet of cardboard about a quarter of an inch apart and some six inches long. *Heavily* shade in between the lines with the pencil. Attach probe A to the right-hand end of the carbon track so that it makes electrical contact, e.g. use a large drawing pin or a paper clip. Then slide probe B along the track to produce the notes required.

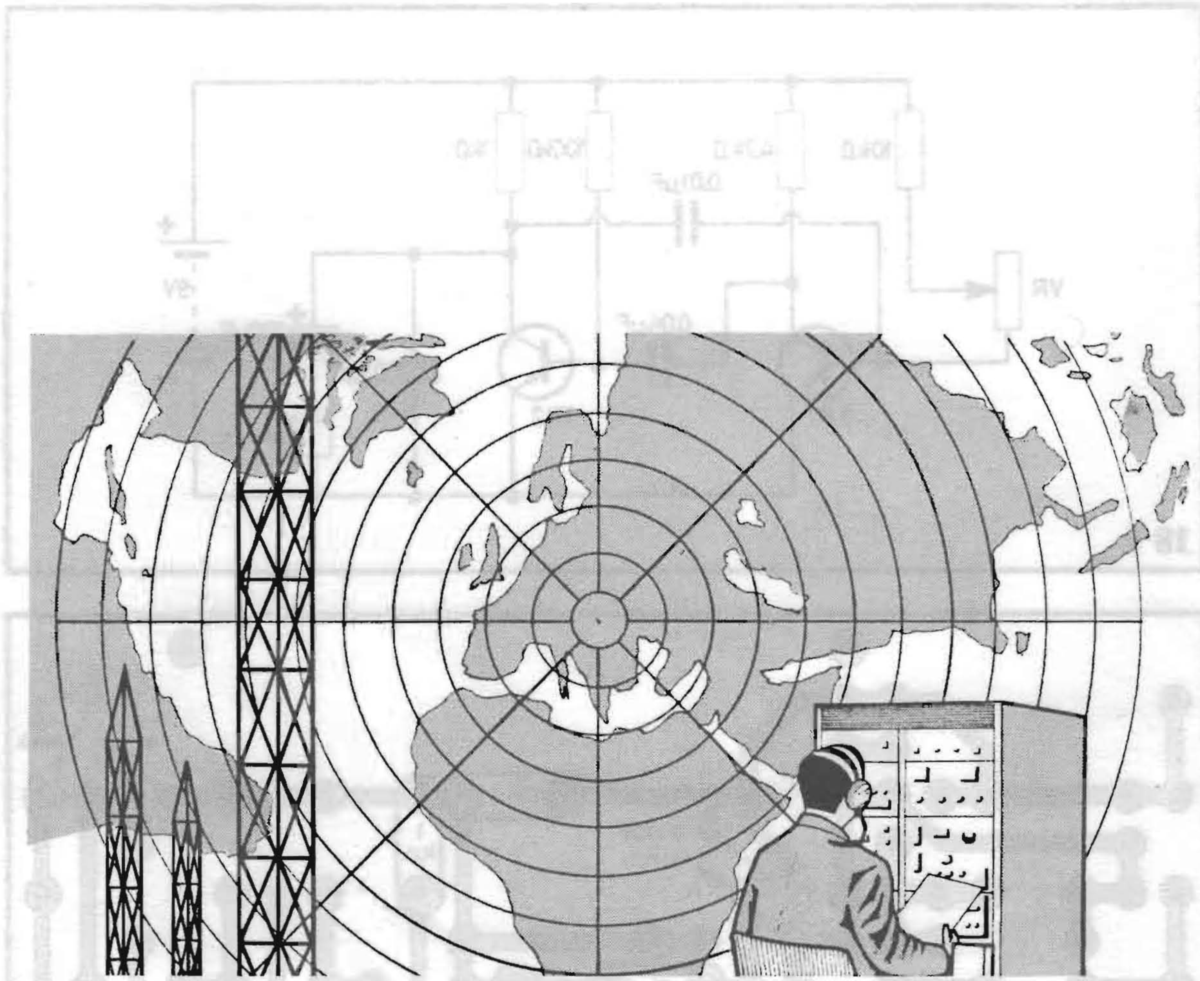
As a variation on the above method the probes can be removed and be replaced by the photocell. By shielding this from the light with the hand, the resistance can be varied. With practice and appropriate shielding and illumination of the LDR a tune may be played merely by moving the hand in the air.


10kΩ
4.7kΩ
0.01µF
100kΩ
1kΩ
VR
0.04µF
TR1
TR2
0.1µF
100µF
9V
phone

18·1


9v.
battery
+ve
red
−ve
black
10kΩ
1
kΩ
B
probe
wires
A
4·7kΩ
100
kΩ
0·01µF
0·04µF
TR1
TR2
100µF
0·1
µF
E/
P

Experiment 19



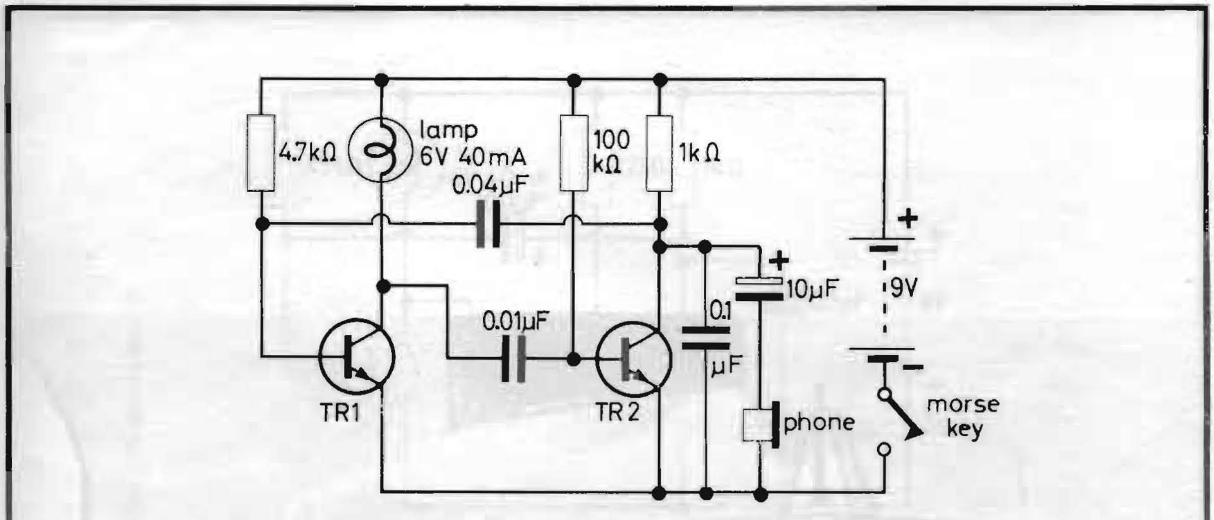
Morse flasher buzzer

In this circuit, a multivibrator is designed to oscillate at a frequency which provides a fairly high-pitched note together with a lamp that lights when the circuit is switched on.

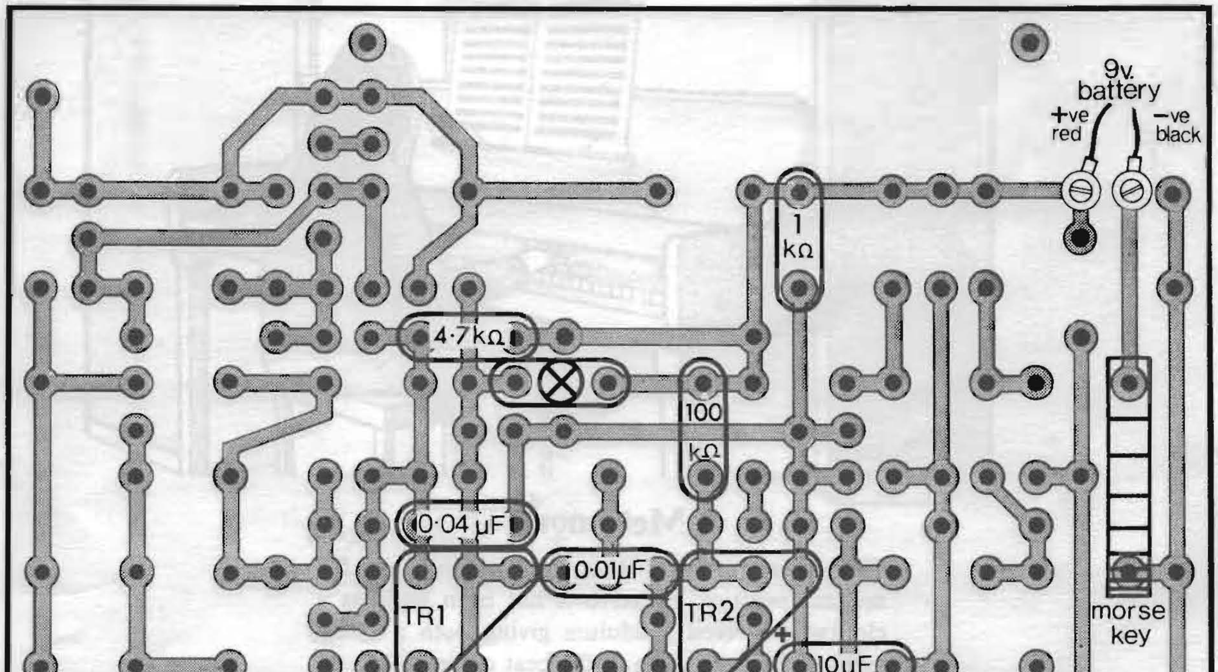
The output is taken from the collector of TR2 via the 10 μF capacitor and the earphones to negative.

In building this circuit note that the battery negative lead must be moved over to the top of the middle conductor on the right of the board so that the Morse key is in circuit.

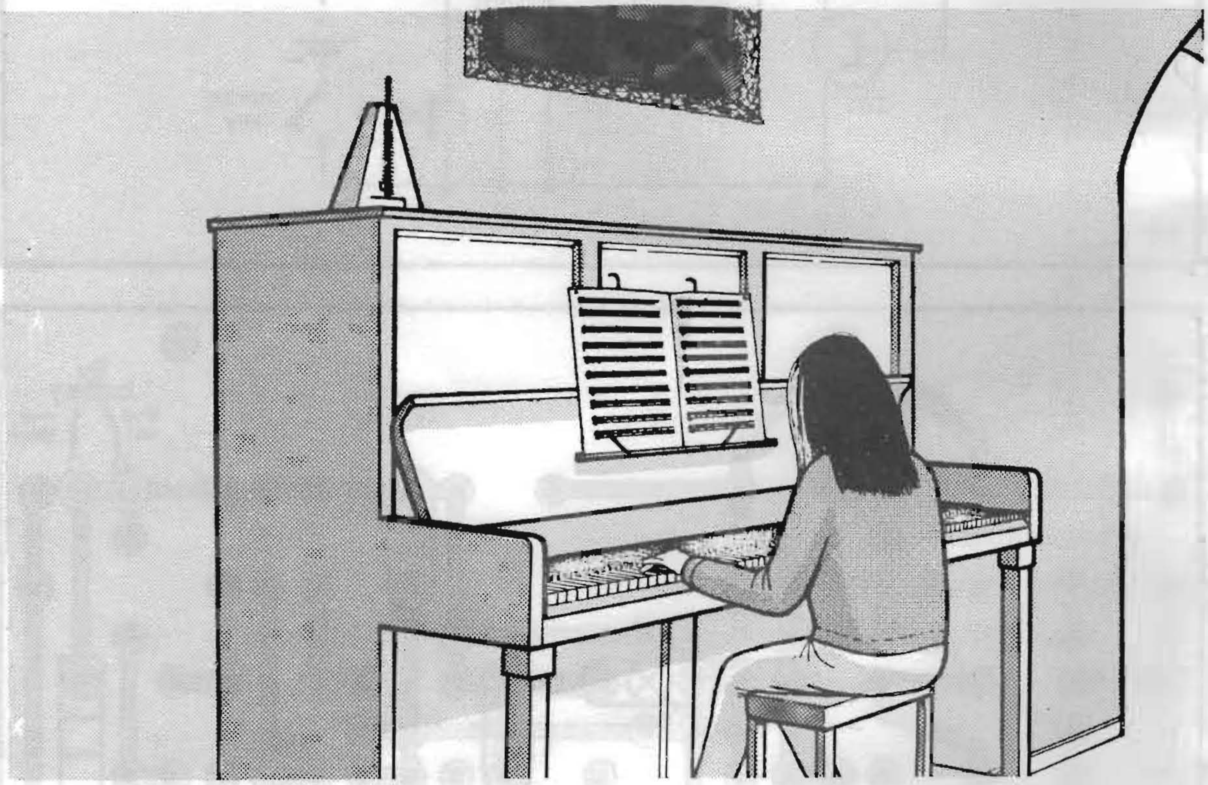
With this circuit many interesting hours may be spent learning and practising the Morse Code (given later in Appendix C). If the earpiece is placed in an empty cup or basin, the volume of sound will be increased. A lower pitched note may be obtained if the 0·01 and 0·04 μF capacitors are interchanged.


4.7kΩ
lamp
6V 40mA
0.04μF
100
kΩ
1kΩ
+
10μF
9V
0.1
μF
0.01μF
TR1
TR2
phone
−
morse
key

19·1


9v.
battery
+ve
red
−ve
black
1
kΩ
4·7kΩ
100
kΩ
0·04μF
0·01μF
TR1
TR2
+
10μF
0·1
μF
E/
/P
morse
key

Experiment 20

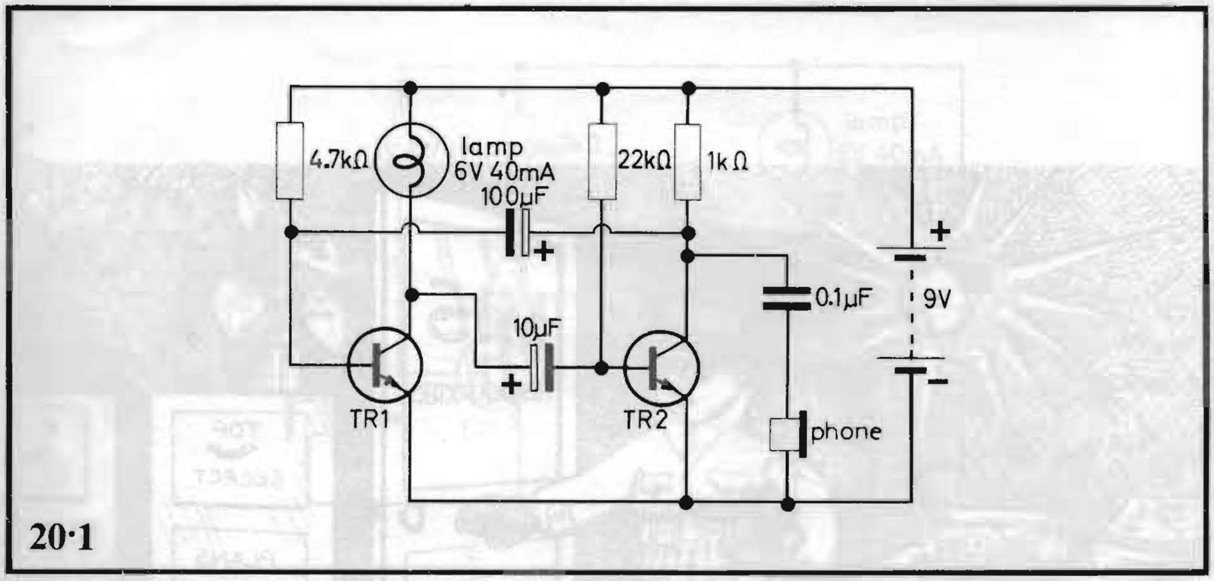


Metronome

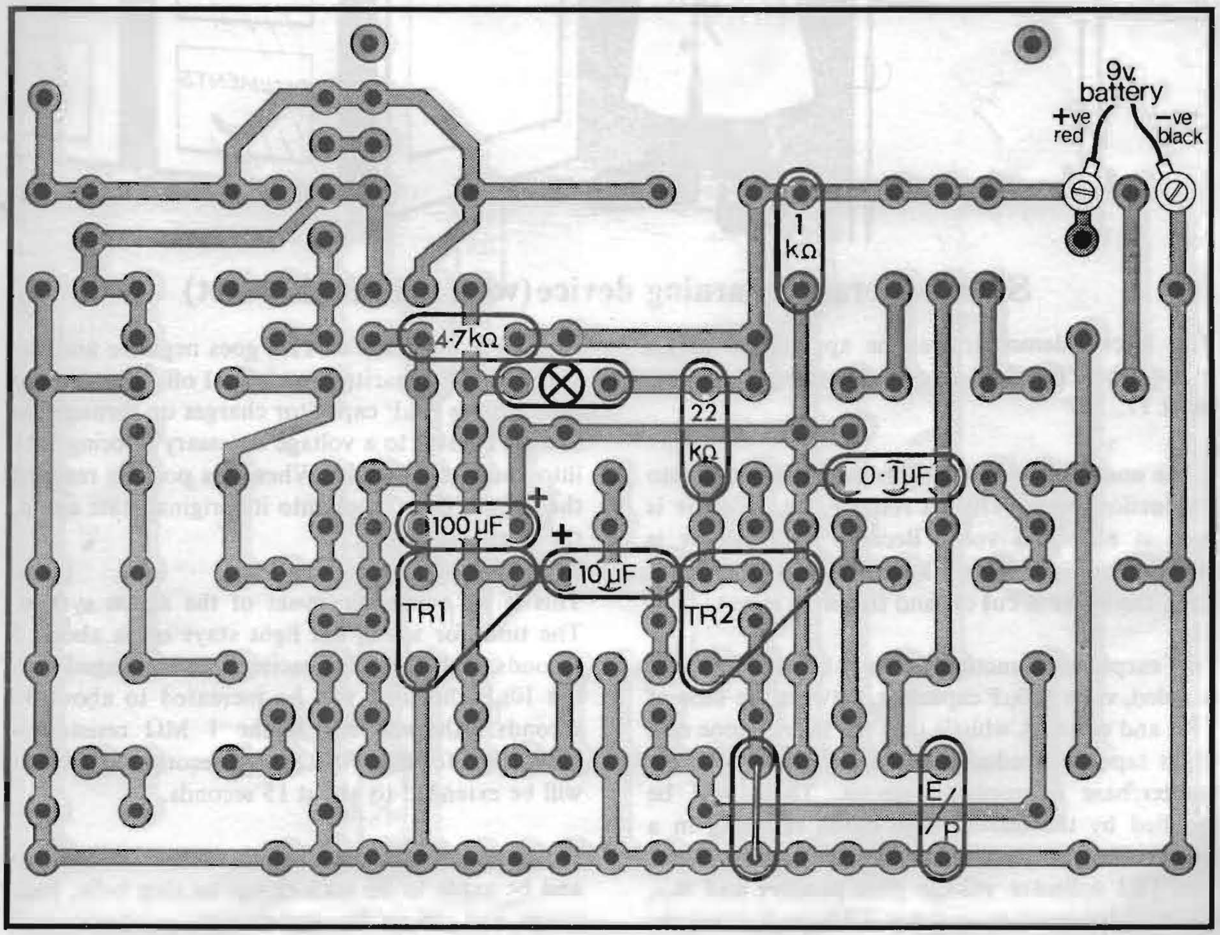
The metronome is a device for beating time for musical practice. Hitherto it has been built as a clockwork driven pendulum giving both a visual and audible indication of the beat or time.

In this circuit these functions are performed electronically by a multivibrator circuit. The frequency of the beat is approximately once every half second.

The speed can be halved by substituting a 10 kΩ resistor for the 4·7 kΩ; or it can be doubled by substituting a 10 kΩ for the 22 kΩ resistor.


4.7kΩ
lamp
6V 40mA
100µF
22kΩ
1kΩ
0.1µF
9V
10µF
TR1
TR2
phone

20·1


9v.
battery
+ve
red
–ve
black
1
kΩ
4·7kΩ
22
kΩ
0·1µF
100µF
10µF
TR1
TR2
E/P

Experiment 21

Sound-operated warning device (with automatic reset)

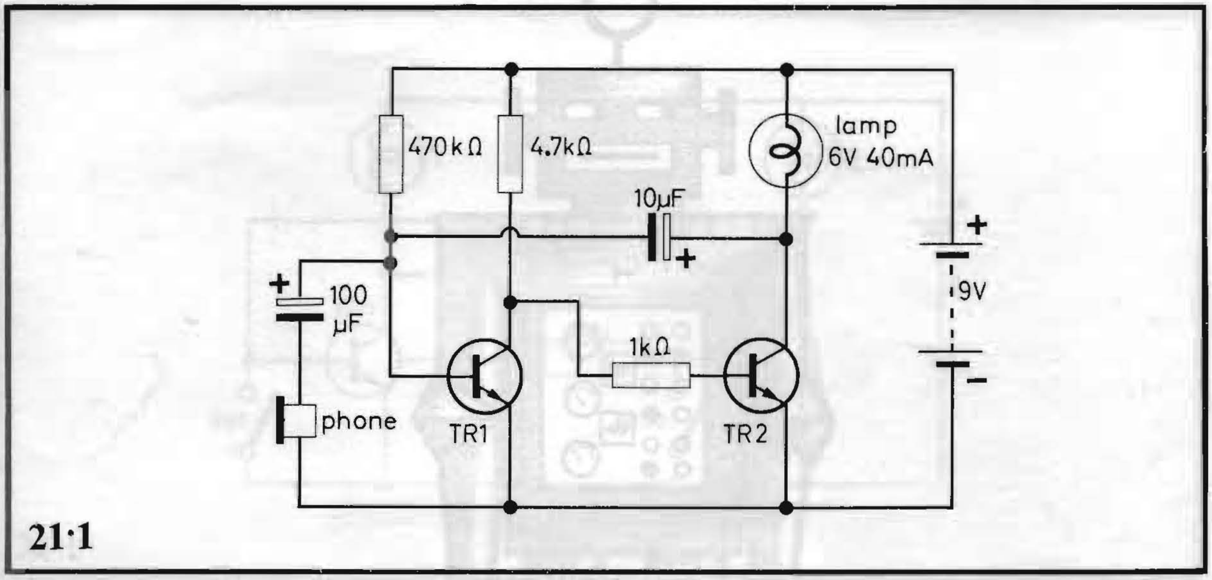
This circuit demonstrates one application of the monostable 'flip-flop' circuit described in Experiment 17.

In the normal state the TR1 transistor is biased into conduction by its 470 kΩ resistor. Its collector is thus at near-zero volts. Because its collector is directly coupled by the 1 kΩ resistor to the base of TR2, the latter is cut off and the lamp is out.

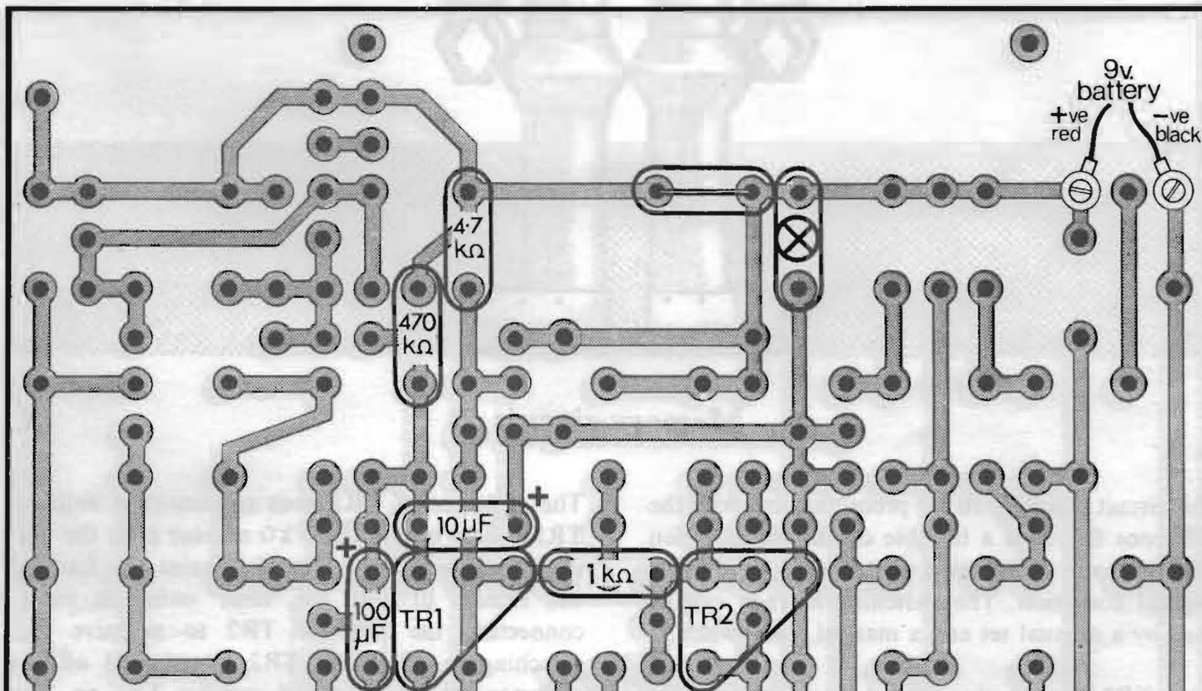
The earphone, functioning as a microphone, is coupled, via a 100μF capacitor, between the base of TR1 and earth. A whistle into the microphone or a slight tap will produce alternating currents in the emitter/base microphone circuit. These will be rectified by the emitter/base diode resulting in a negative pulse on the base of TR1, switching it off. The TR1 collector voltage goes positive and this, via the 1 kΩ resistor, switches TR2 on, lighting the lamp. The collector of TR2 goes negative and this via the 10 μF capacitor, holds TR1 off. TR1 will stay off until the 10μF capacitor charges up through the 470 kΩ resistor to a voltage necessary to bring TR1 into conduction again. When this point is reached the circuit 'flops' back into its original state again, the lamp going out.

This is an automatic re-set of the alarm system. The time for which the light stays on is about 5 seconds. If the 100μF capacitor is interchanged with the 10μF the time will be increased to about 40 seconds. Alternatively, if the 1 MΩ resistor is substituted for the 470 kΩ, the 5 second time period will be extended to about 15 seconds.

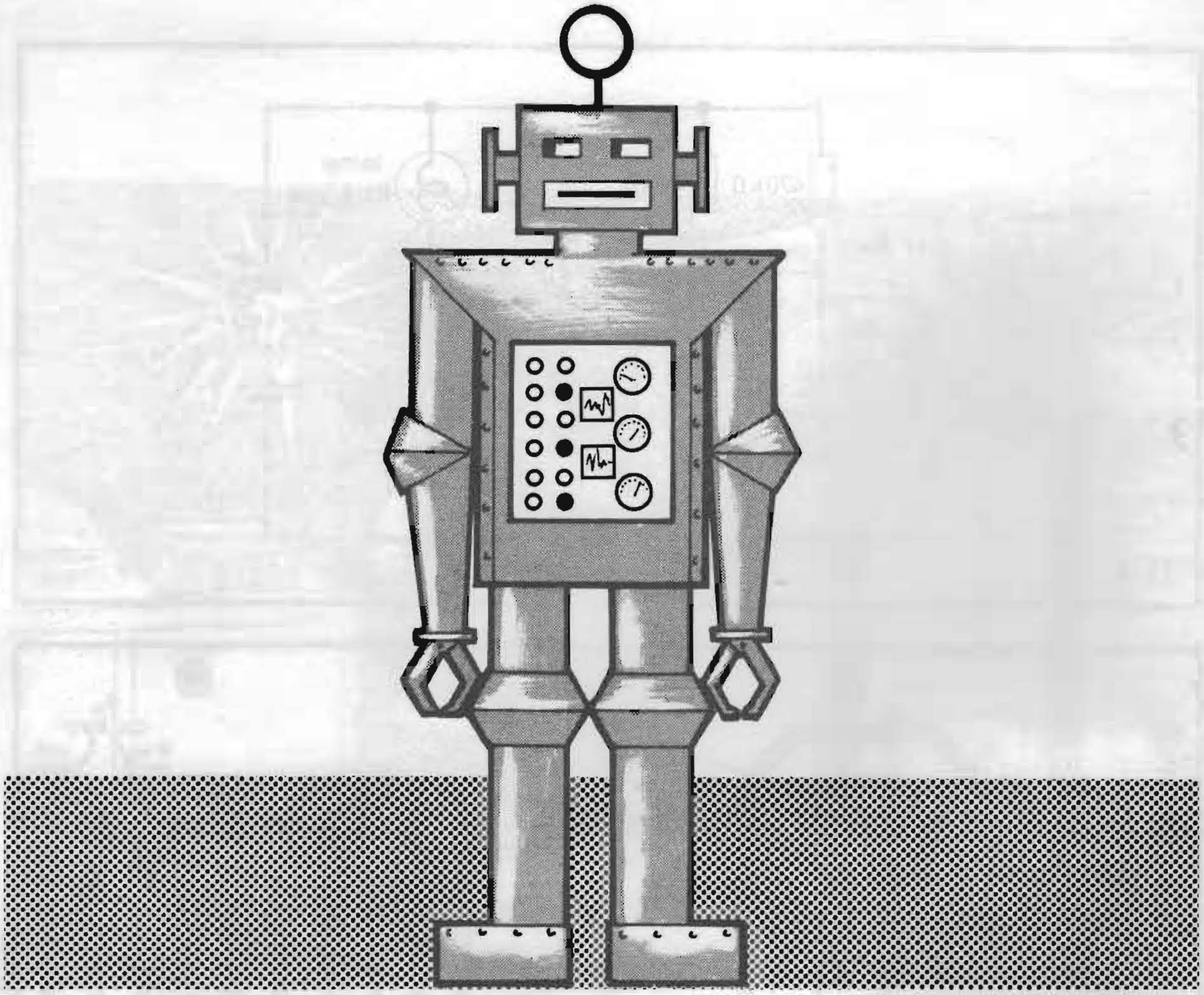
A relay could, of course, be substituted for the lamp and be made to do such things as ring bells, lock doors, and put on floodlights.


470kΩ
4.7kΩ
lamp
6V 40mA
10µF
+
100
µF
9V
1kΩ
phone
TR1
TR2

21·1


9v.
battery
+ve
red
−ve
black
4·7
kΩ
470
kΩ
10µF
1kΩ
100
µF
TR1
TR2
E/P

Experiment 22



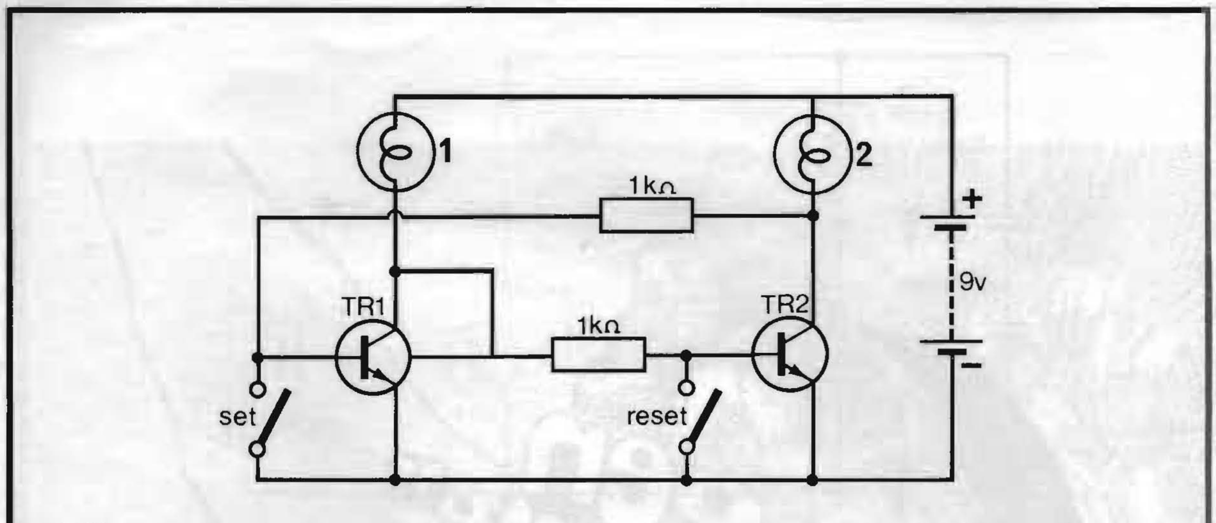
Memory circuit

This circuit is similar to the preceding one, with the difference that it is a bistable circuit which, when switched over, will remain so until it is reset to its original condition. The switching in each case is done by a manual set and a manual reset switch.

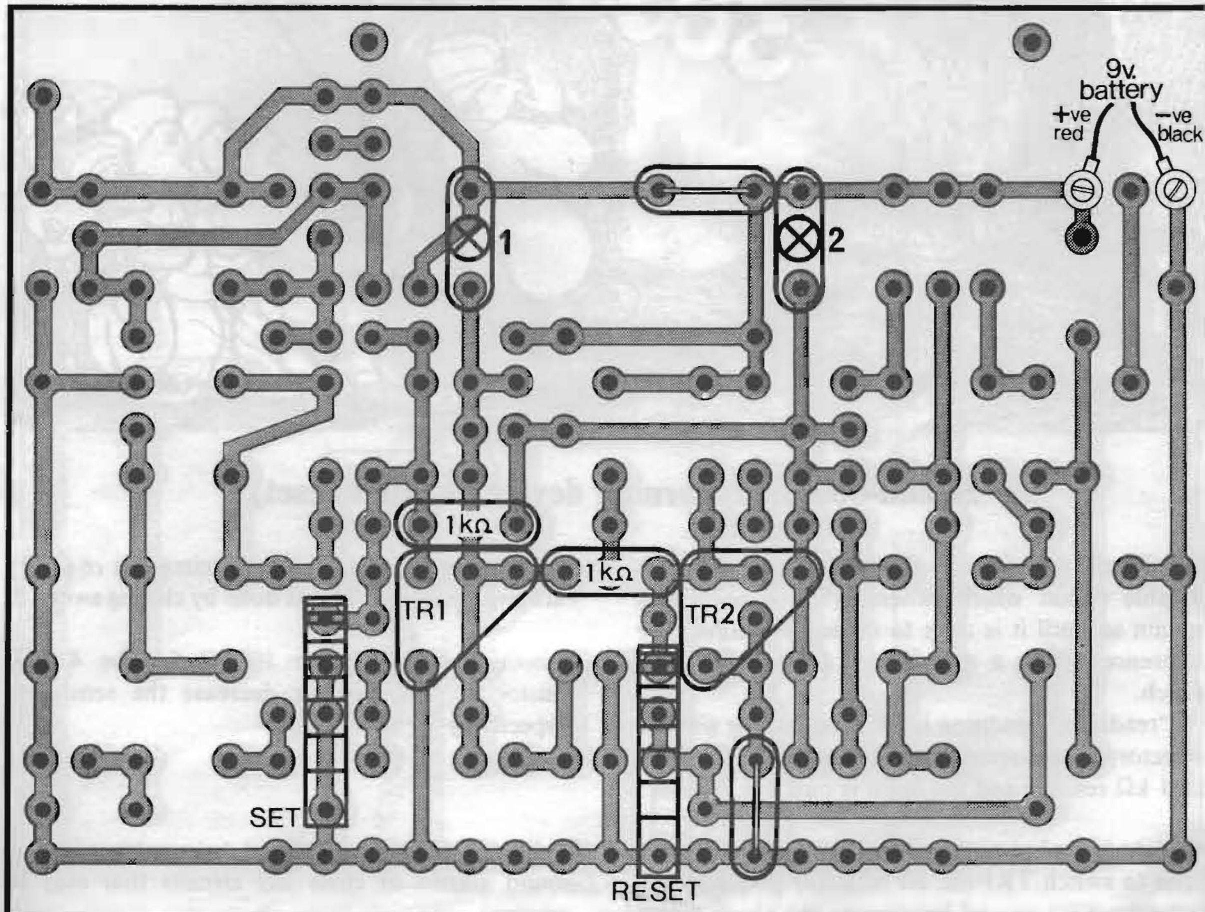
When TR1 is conducting, lamp 1 is on. The collector is at near-zero volts, so holding TR2 off via the 1 kΩ resistor. So lamp 2 is out.

When the 'set' switch is pressed, the base of TR1 is connected to negative, switching TR1 off. The collector of TR1 goes positive which switches TR2 on via the 1 kΩ resistor and thus lamp 2 lights. The collector of TR2 goes to near-zero volts so TR1 is held off via the 1 kΩ resistor after the 'set' switch is released and lamp 1 remains out. Lamp 2 will remain lit until the 'reset' switch is made, connecting the base of TR2 to negative and switching it off. When TR2 is switched off, its collector goes positive and switches TR1 on. The circuit has thus returned to its original state.

This circuit relies on an external signal (pressing the 'set' or 'reset' switch) to change its state. It can be used, therefore, as a memory circuit in a computer, because it will maintain the same signal indefinitely until it is cancelled.


1
2
1kΩ
TR1
1kΩ
TR2
+
9v
−
set
reset

22·1


9v.
battery
+ve
red
−ve
black
1
2
1kΩ
1kΩ
TR1
TR2
SET
RESET

Experiment 23

Sound-operated warning device (manual reset)

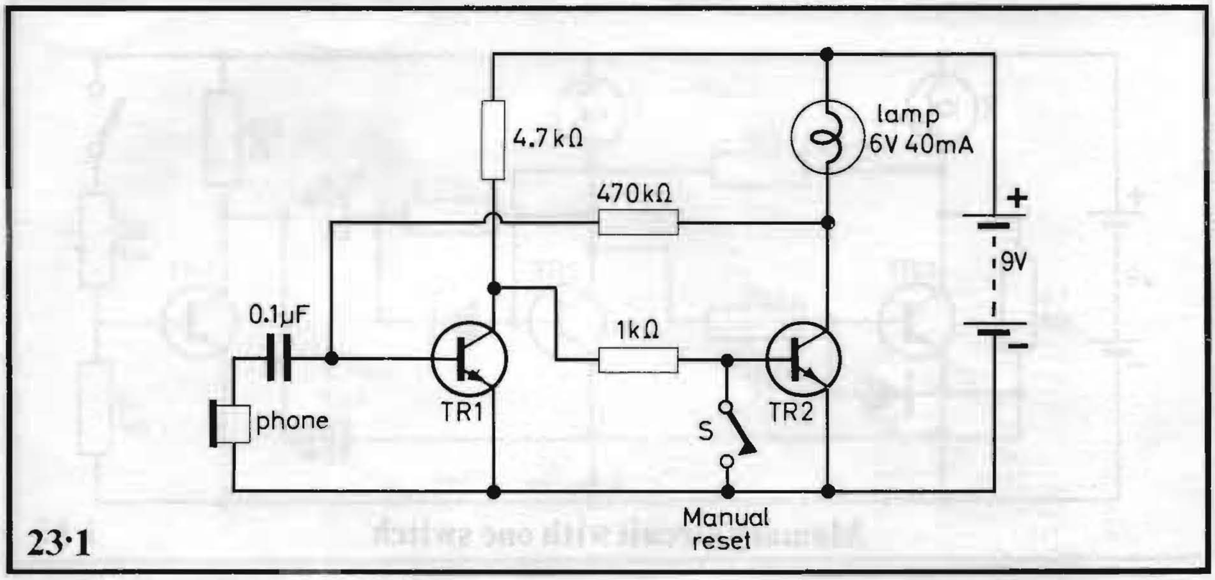
This circuit is similar to the preceding one with a bistable circuit which, when switched over, will remain so until it is reset to its original state. The difference is that a microphone replaces the 'set' switch.
The 'readiness' condition is TR1 conducting with its collector at near-zero volts. This holds TR2 off via the 1 kΩ resistor and the lamp is out.

A slight whistle into the earphone will provide a pulse to switch TR1 off. Its collector goes positive switching TR2 on and lighting up the alarm lamp.

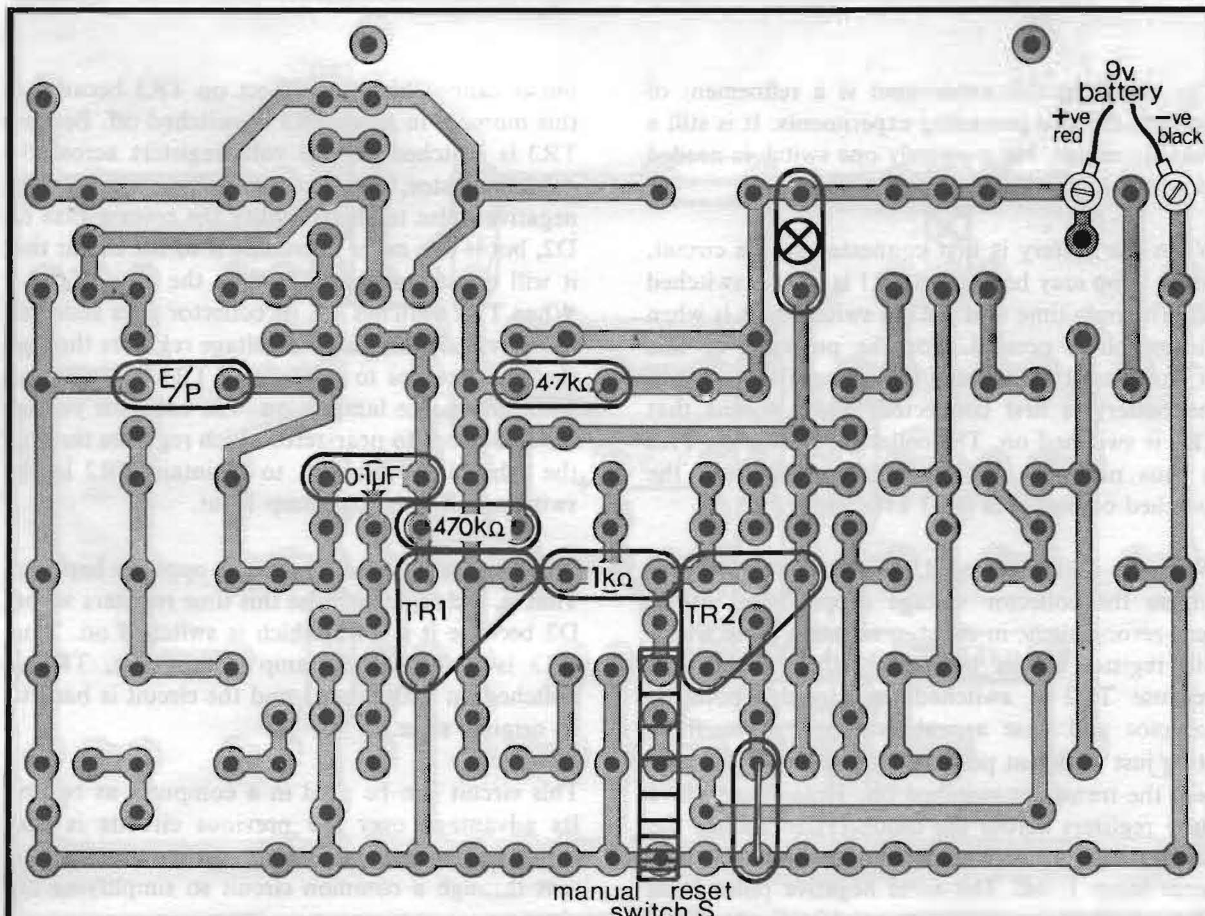
The lamp will stay on until the circuit is re-set by earthing TR2 base. This is done by closing switch S.

Substituting a 1 MΩ or 100 kΩ for the 470 kΩ resistor will increase or decrease the sensitivity respectively.

The lamp could be replaced by a relay wired to sound alarms or close any circuits that may be required.


4.7kΩ
lamp
6V 40mA
470kΩ
+
9V
−
0.1µF
1kΩ
phone
TR1
TR2
S
Manual
reset

23·1


9v
battery
+ve
red
−ve
black
E/P
4·7kΩ
0·1µF
470kΩ
1kΩ
TR1
TR2
manual reset
switch S

Experiment 24

Memory circuit with one switch

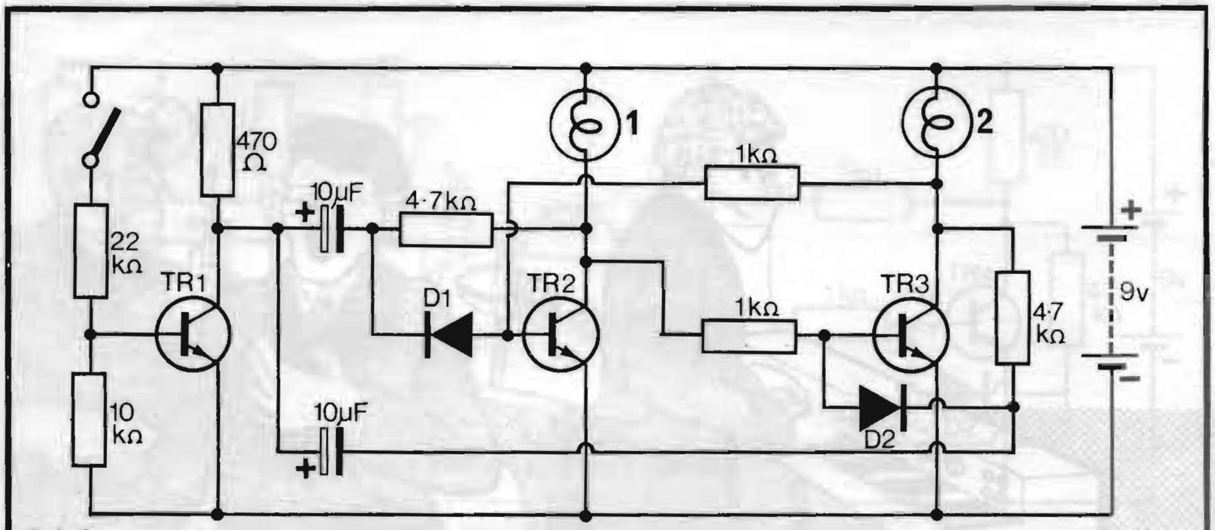
The circuit in this experiment is a refinement of those in the two preceding experiments. It is still a bistable circuit, but now only one switch is needed to switch from one state to the other.

When the battery is first connected to the circuit, either lamp may be on, but TR1 is always switched off. The only time that TR1 is switched on is when the switch is pressed. For the purposes of this explanation it is assumed that lamp 1 lights when the battery is first connected, which means that TR2 is switched on. The collector voltage on TR2 is thus near-zero, which maintains TR3 in the switched off state via the 1 kΩ resistor.

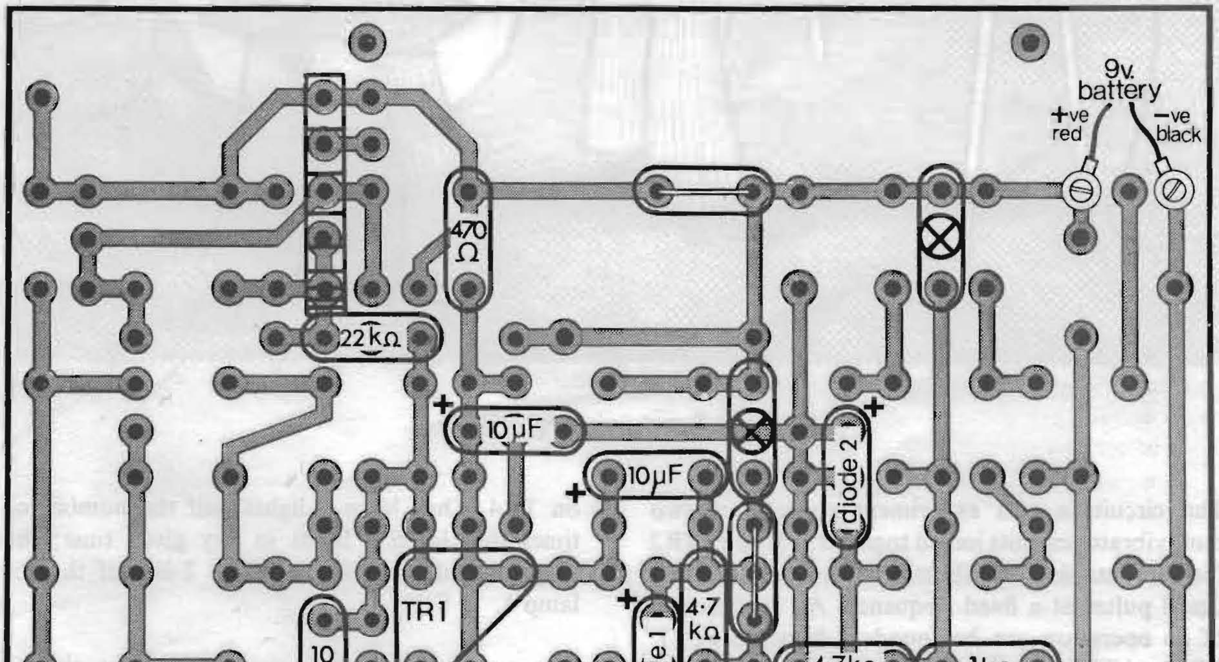
When the switch is closed, TR1 suddenly switches on, so the collector voltage drops from +9 to near-zero. This is, in effect, a negative pulse which will register across both the 10μF capacitors. Because TR2 is switched on already, both its collector and base are at near-zero volts, there being just sufficient positive voltage on the base to keep the transistor switched on. Thus the negative pulse registers across the diode D1 to reduce the base voltage on TR2 sufficiently to switch it, and hence lamp 1, off. The same negative pulse from TR1 registers across the second 10 μF capacitor, but it cannot have any effect on TR3 because at this moment in time, TR3 is switched off. Because TR3 is switched off +9 volts registers across the 4·7 kΩ resistor, to reverse-bias the diode D2. The negative pulse tends to nullify the reverse bias on D2, but it can never overcome it to the extent that it will register across D2 on to the base of TR3. When TR2 switches off, its collector goes suddenly to +9 volts. This positive voltage registers through the 1 kΩ resistor to the base of TR3, so switching TR3, and hence lamp 2, on. The collector voltage on TR3 drops to near-zero, which registers through the other 1 kΩ resistor, to maintain TR2 in the switched off state and lamp 1 out.

If the switch is pressed again, the opposite happens. That is, the negative pulse this time registers across D2 because it is TR3 which is switched on. Thus TR3 is switched off, lamp 2 goes out, TR2 is switched on with lamp 1 and the circuit is back to its original state.

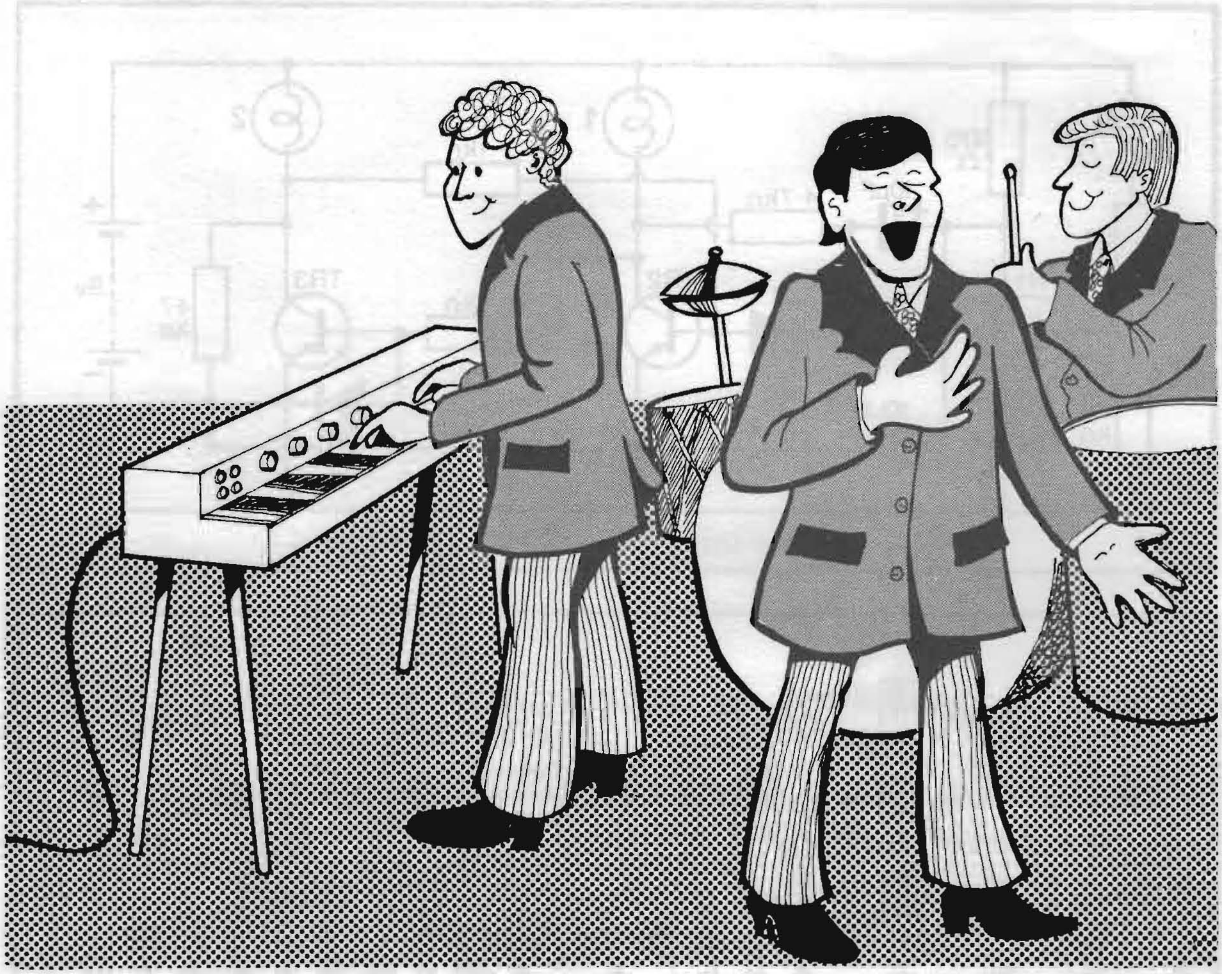
This circuit can be used in a computer as before. Its advantage over the previous circuits is that cancelling instructions to change its state can be sent through a common circuit so simplifying the circuitry.


470 Ω
1
2
1kΩ
10µF
4·7kΩ
22 kΩ
TR1
D1
TR2
1kΩ
TR3
4·7 kΩ
9v
10 kΩ
10µF
D2

24·1


9v. battery
+ve red
−ve black
470 Ω
22 kΩ
10µF
10µF
diode 2
diode 1
4·7 kΩ
TR1
10 kΩ
4·7kΩ
1kΩ
1kΩ
TR2
TR3

Experiment 25

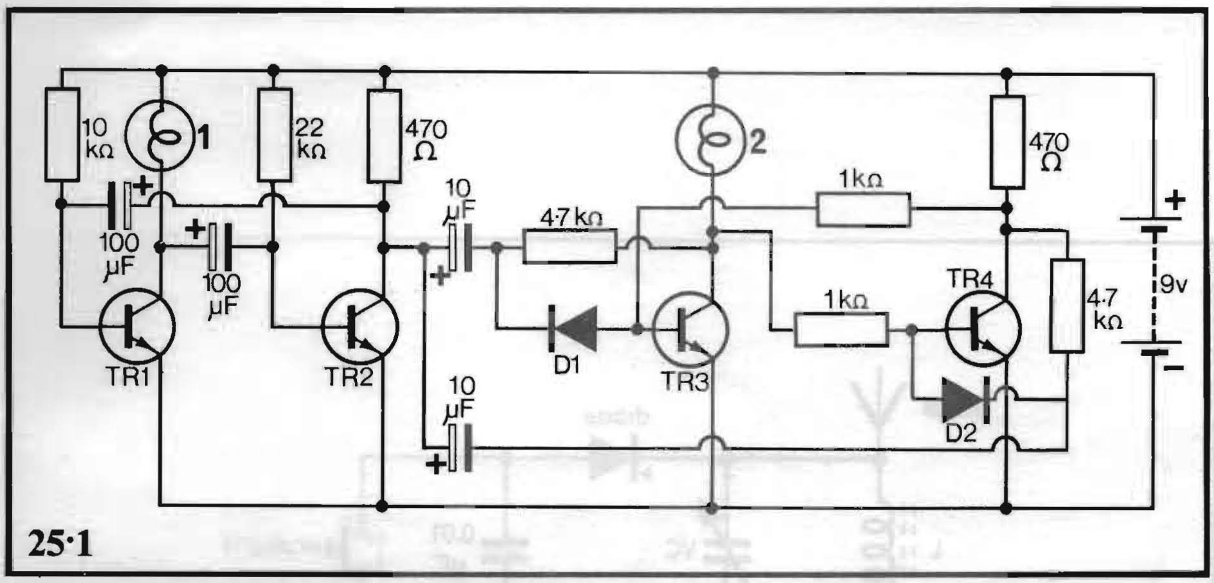


The frequency divider

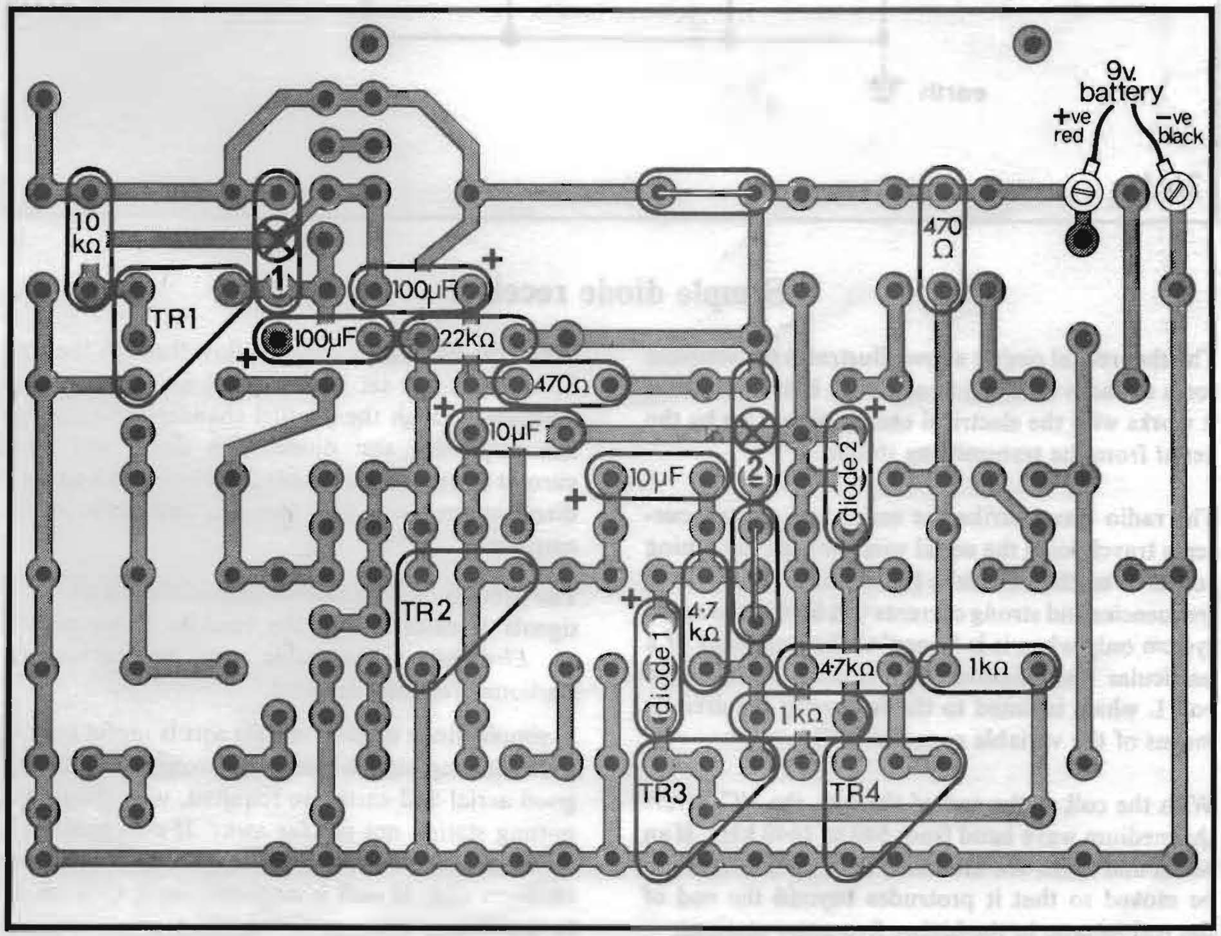
The circuit in this experiment consists of two multivibrator circuits joined together. TR1 and TR2 form an astable multivibrator to provide a series of timed pulses at a fixed frequency. An explanation of its operation can be found in Experiment 17. TR3 and TR4 form a bistable multivibrator as used in Experiments 22, 23 and 24.

TR1 and TR2 are switched on alternately. A negative pulse is sent to the bistable part of the circuit when TR2 is switched on, which is when lamp 1 goes out. Lamp 2 lights when TR3 is switched on, which is for every other pulse from TR2, the alternate pulse being directed to switch on TR4. Thus lamp 2 lights half the number of times that lamp 1 lights in any given time; the frequency of operation of lamp 2 is half that of lamp 1.

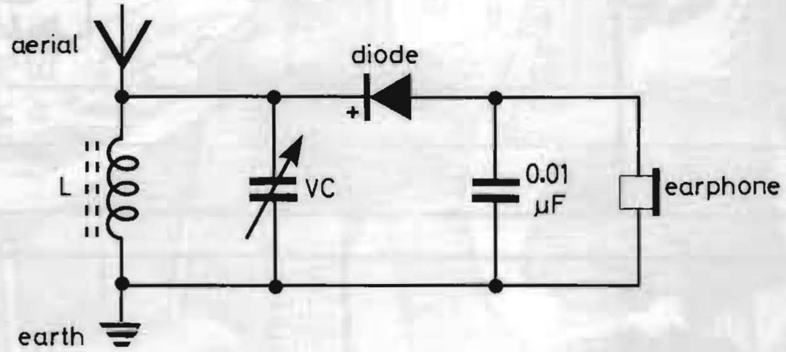
One application of this circuit is in the electric organ, where use is made of the fact that the frequency of the note, middle C for instance, is exactly half the frequency of the note C an octave up. Thus if the frequencies of all the notes in the top octave on the organ are halved by using frequency dividers, the next octave down is produced. This process can be repeated until the bottom octave on the organ is reached.


10
kΩ
1
22
kΩ
470
Ω
100
µF
100
µF
TR1
TR2
10
µF
4·7 kΩ
D1
10
µF
2
1kΩ
TR3
1kΩ
470
Ω
TR4
4·7
kΩ
9v
D2

25·1


9v.
battery
+ve
red
−ve
black
10
kΩ
TR1
1
100µF
100µF
22kΩ
470Ω
10µF
10µF
2
diode 2
470
Ω
TR2
4·7
kΩ
diode 1
4·7kΩ
1kΩ
1kΩ
TR3
TR4

Experiment 26



26·1

Simple diode receiver

The theoretical circuit above illustrates the simplest form of radio receiver. It needs no battery because it works with the electrical energy picked up by the aerial from the transmitting station.

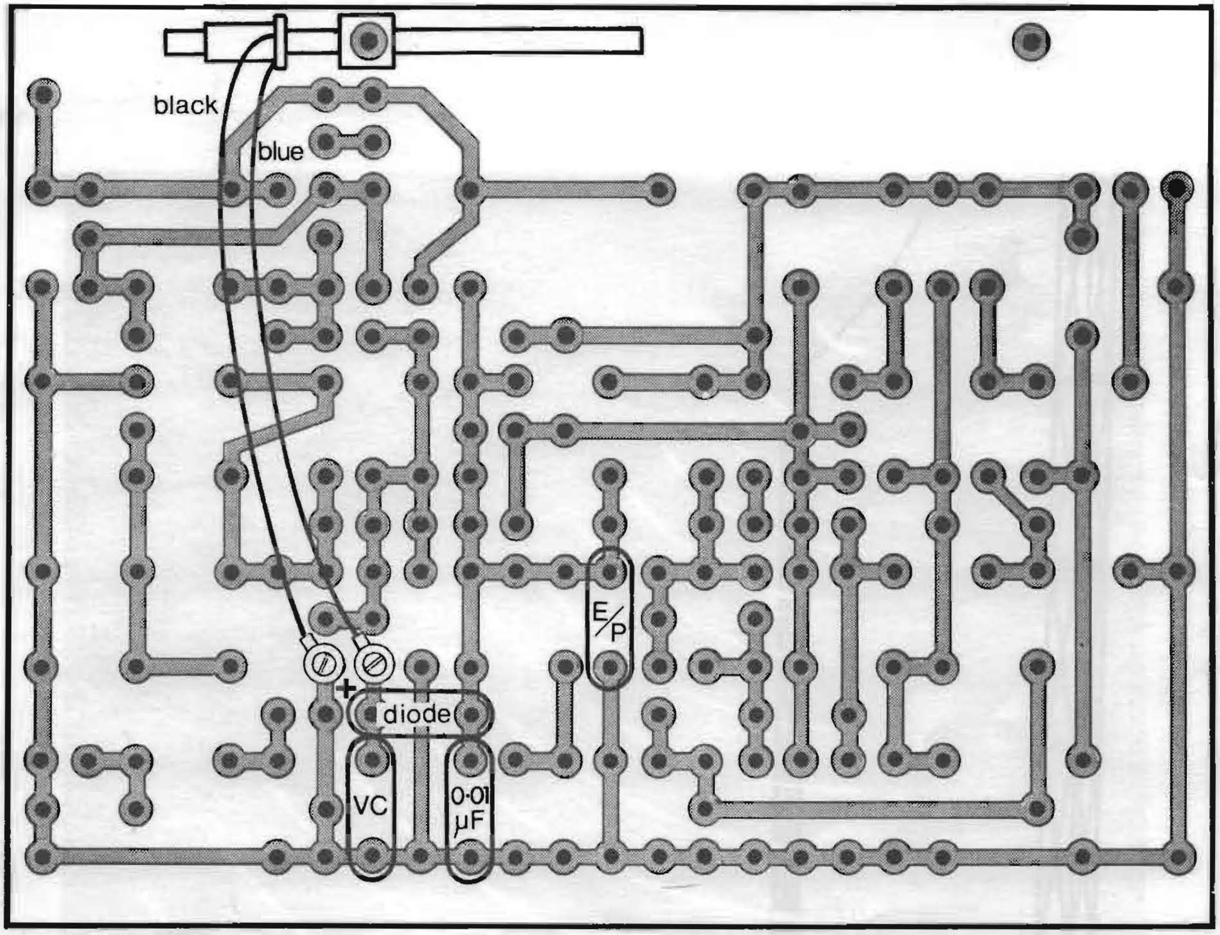
The radio waves strike the aerial and electric currents travel down the aerial wire through the tuning coil L to earth. The air is full of radio waves of all frequencies and strong currents will flow in the aerial system only when it is 'tuned' to the frequency of a particular transmission. This is done by having a coil L which is tuned to the frequency required by means of the variable capacitor VC.

With the coil at the end of the rod, the VC covers the medium wave band from 540 to 1640 kHz. If an aerial and earth are attached, the coil may have to be moved so that it protrudes beyond the end of the rod to tune in the higher frequency stations.

When the oscillatory currents flow through the coil L, voltages are set up across it and these create currents through the parallel channel presented by the earphones and diode. The diode will pass current in one direction only, and uni-directional or direct current will flow through and activate the earphones.

The process of detection or demodulation of radio signals is described in the booklet *Fundamentals of Electricity*, obtainable on application to Radionic Products Limited.

A simple diode receiver of this sort is useful only if the incoming signals are very strong. Normally a good aerial and earth are required, with the transmitting station not too far away. If no signals can be received in your area, start with one of the later receivers and, as skill is acquired, work backwards to this one.



Aerial

The type of aerial required depends on the wavelengths to be covered and the distance from transmitters.

A simple aerial consists of, say, six feet of insulated wire hung more or less vertically over the set from the ceiling or picture rail.

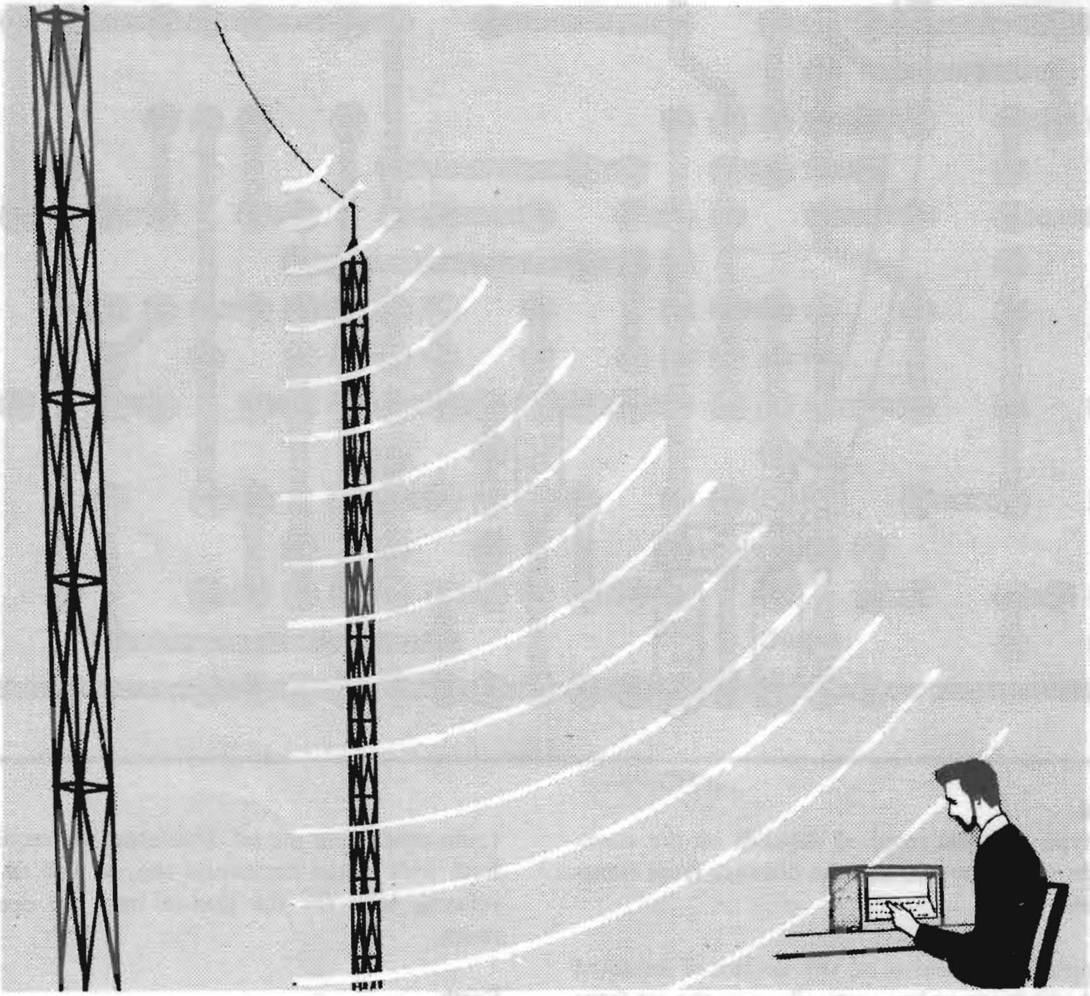
An indoor inverted 'L' type can consist of about 12 feet of wire strung horizontally across the room with a six-foot down-lead to the set.

An outdoor aerial might consist of 60 feet of stranded copper wire strung between a tree and a chimney stack with a 30-foot down-lead into the room containing the set. Insulators are required at both ends of the horizontal run, as well as an insulating tube for the lead-in into the operating room.

Earth

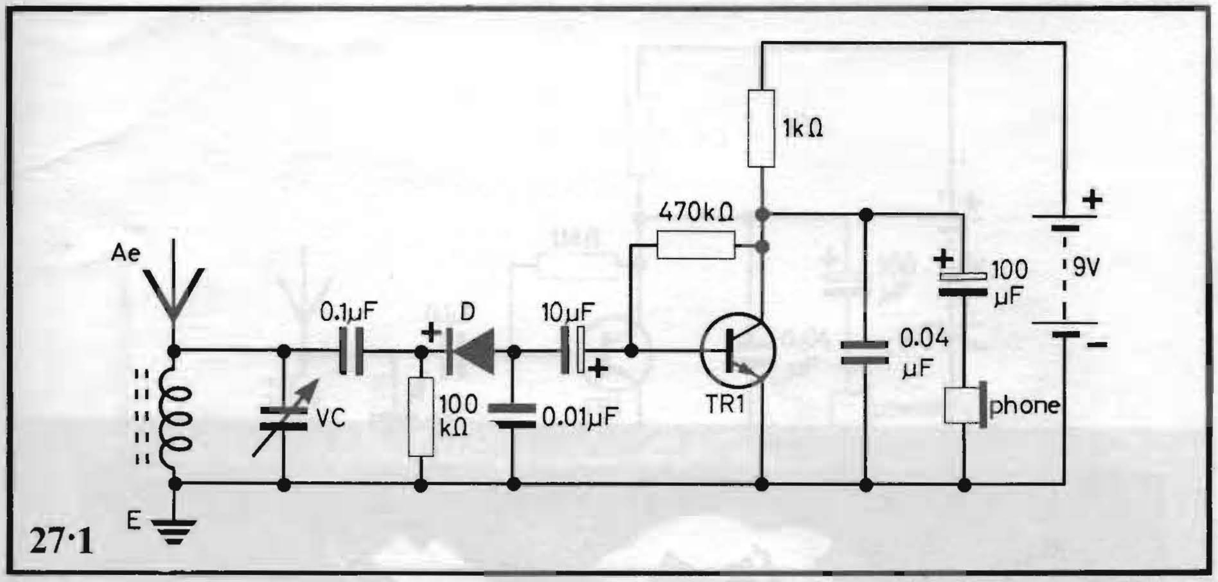
The earth lead should be as short as practicable and should be of low resistance wire, such as double flex. The remote end can be connected to a copper earth tube driven two or three feet into moist earth or can be soldered to a metal plate or biscuit tin buried two or three feet underground. Alternatively, a good electrical connection to the household cold water system or even to the central heating system may serve reasonably well.

Experiment 27



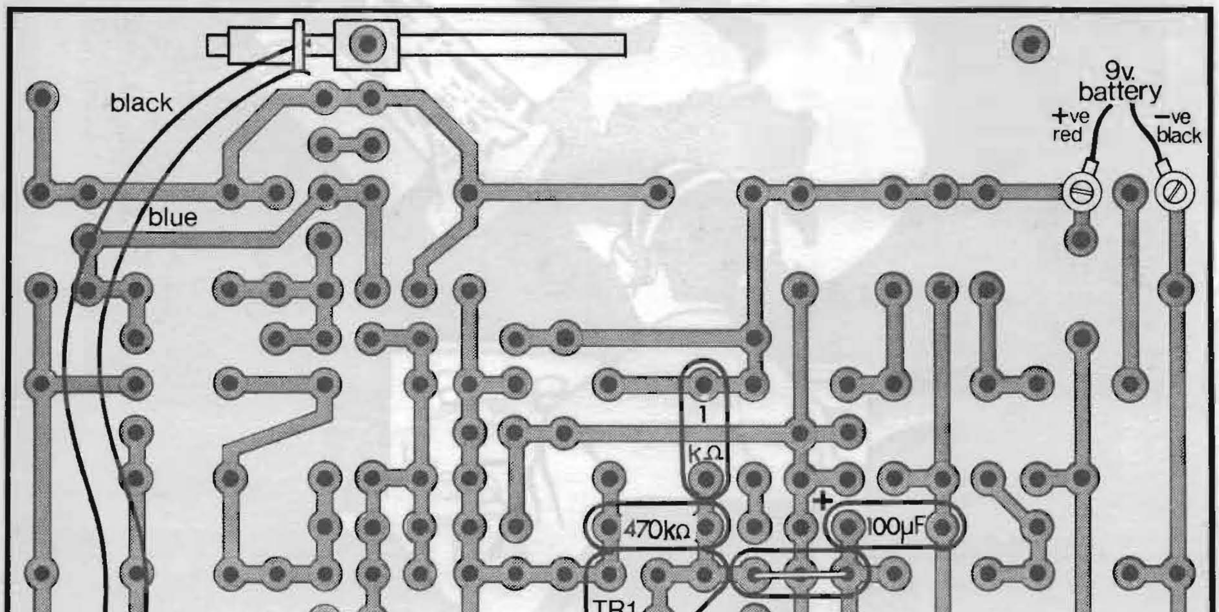
Diode receiver with audio amplifier

This circuit is basically the same as the preceding one, but a stage of audio amplification is added to increase the strength of the signals detected by the diode. The tuned circuit is coupled to the diode via the 0·1μF capacitor and a 100 kΩ resistor provides the diode with a d.c. (direct current) path to earth. An aerial and earth are required as before but in strong signal areas the results can be quite good.



Ae
0.1µF
D
10µF
470kΩ
1kΩ
+
100
µF
9V
−
0.04
µF
phone
TR1
VC
100
kΩ
0.01µF
E

27·1



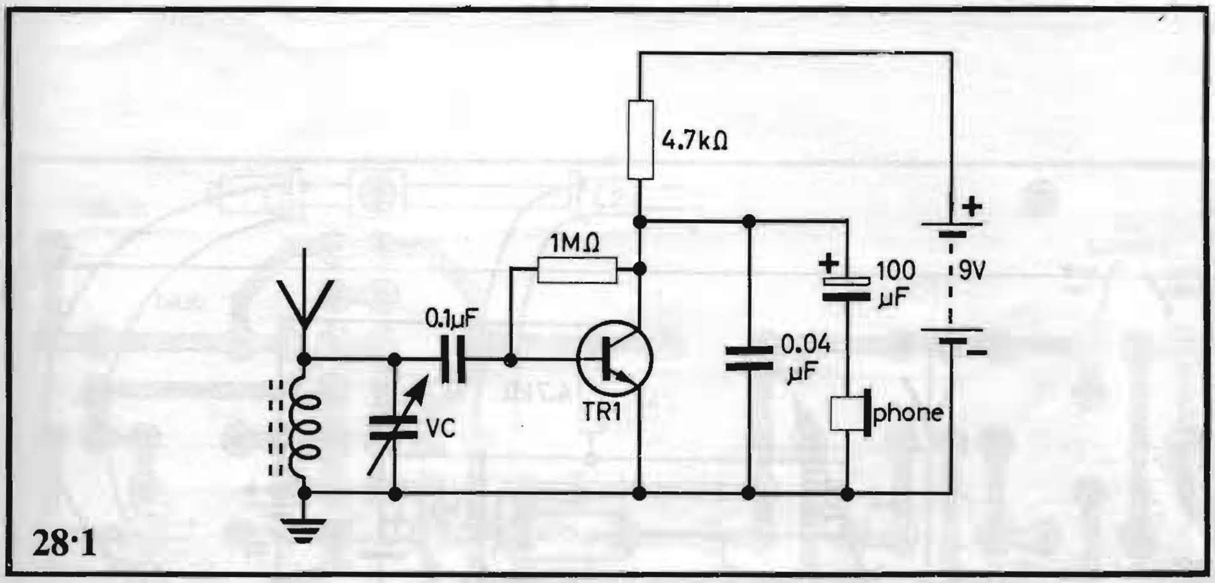
black
blue
9v.
battery
+ve
red
−ve
black
1
kΩ
470kΩ
100µF
TR1
10µF
diode
0·1µF
VC
100
kΩ
0·01
µF
0·04
µF
E
P

Experiment 28

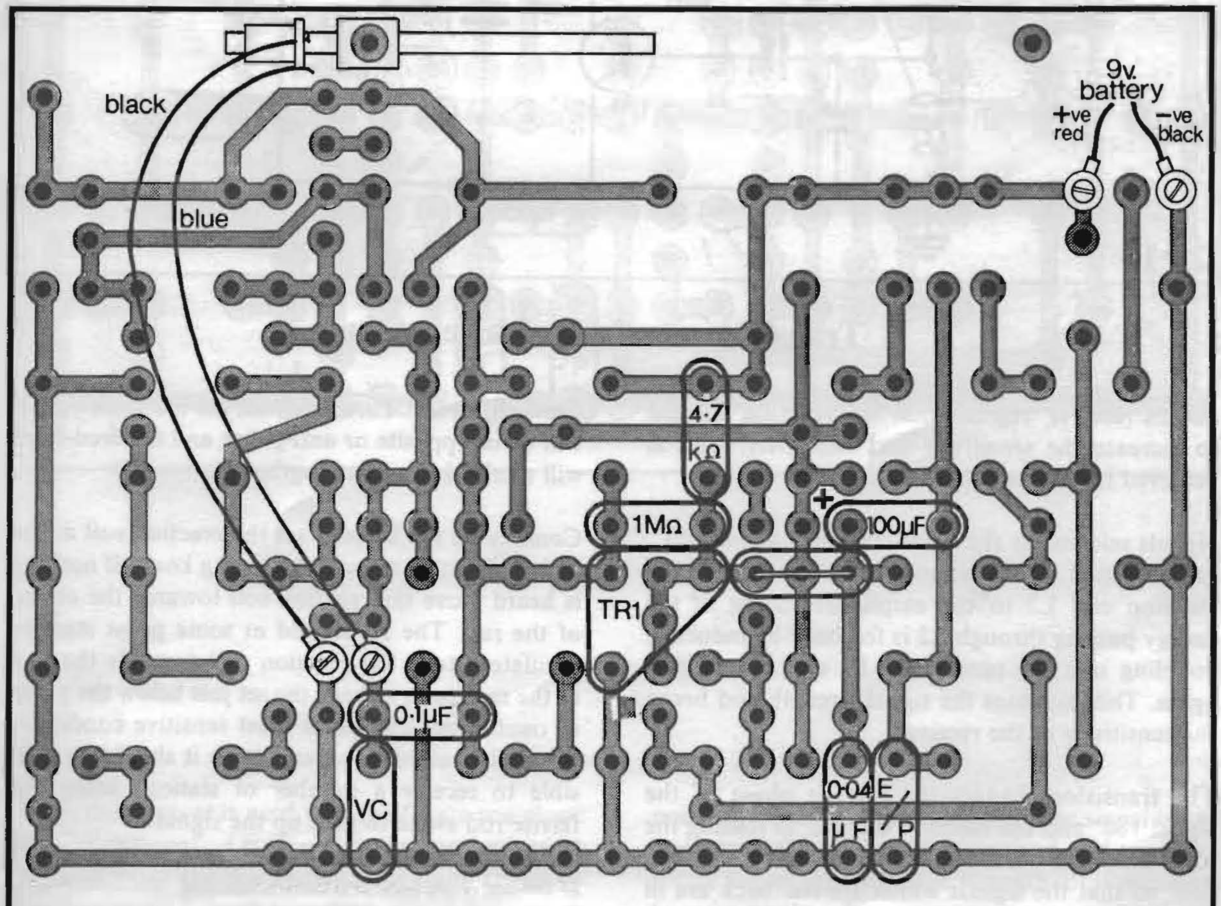
Simple transistor receiver

This receiver differs from the preceding ones in that no diode is used and demodulation is effected by the emitter/base junction of the transistor. The transistor also amplifies the audio signals thus produced.

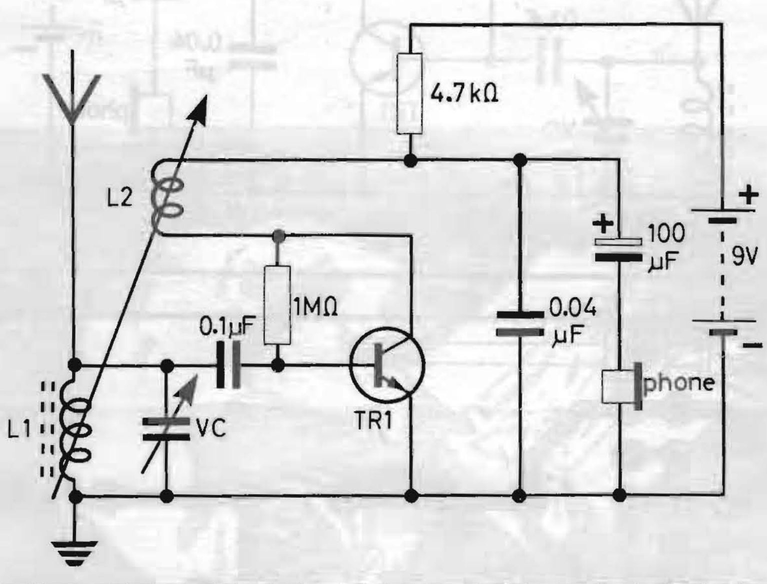
Being a high-frequency transistor, some of the radio frequency signals are also amplified, but these are by-passed to earth through the $0{\cdot}04\mu F$ capacitor. The amplified audio frequency signals are passed through the earphones via the $100\mu F$ capacitor.


4.7kΩ
1MΩ
100
µF
9V
0.1µF
0.04
µF
VC
TR1
phone

28·1


9v.
battery
+ve
red
−ve
black
black
blue
4·7
kΩ
1MΩ
100µF
TR1
0·1µF
VC
0·04
µF
E
P

Experiment 29



29·1

Transistor receiver with reaction

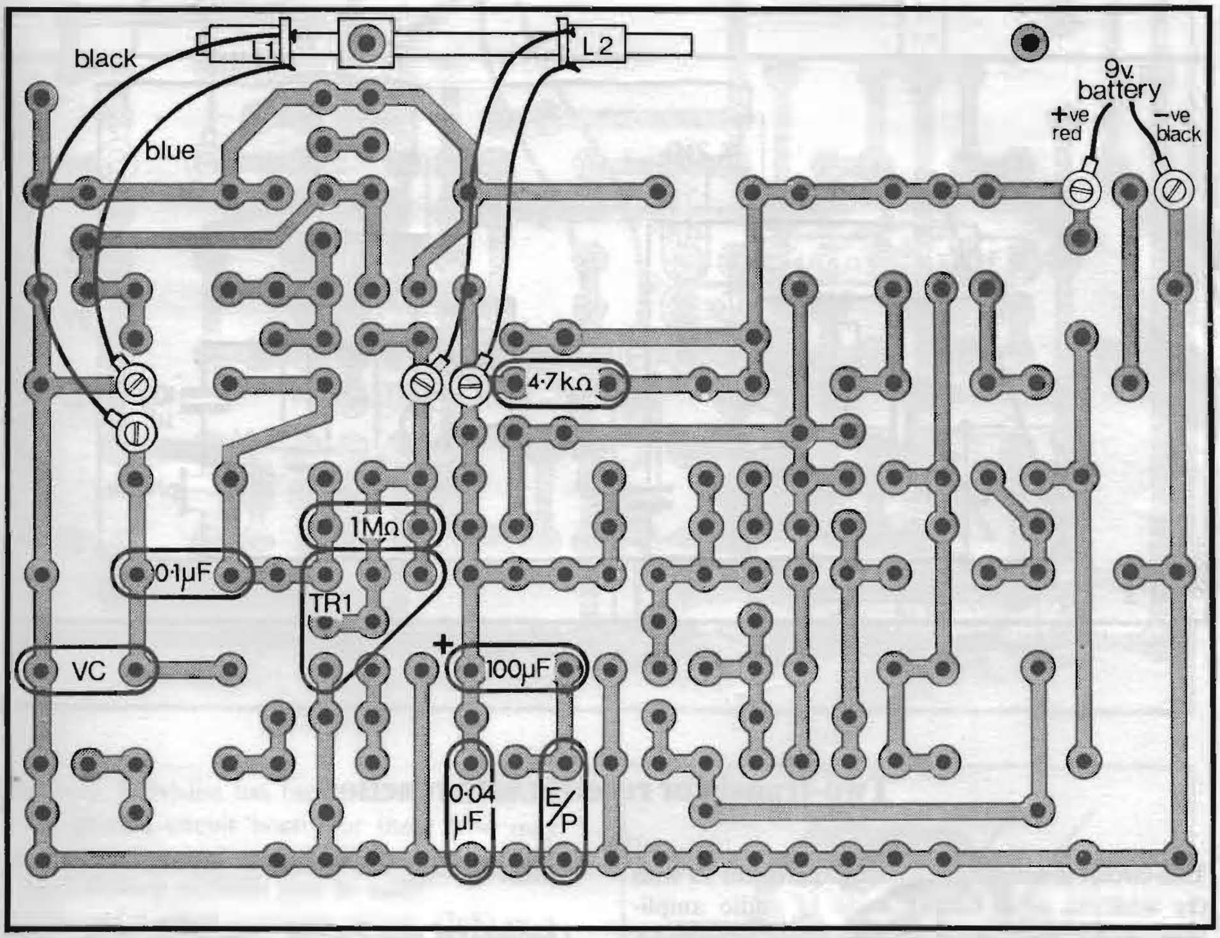
In this receiver 'regeneration' or 'reaction' is used to increase the sensitivity and selectivity. This is achieved by means of the reaction coil L2.

Signals selected by the tuned circuit L1 and the VC, are amplified by the transistor and passed via the reaction coil L2 to the earphones. Some of the energy passing through L2 is fed back by inductive coupling into the tuning coil L1 and is amplified again. This increases the signal strength and hence the sensitivity of the receiver.

The transistor changes the voltage phase of the signal 180° and the reaction coil L2, in feeding the signals back into L1, changes the phase by a further 180° so that the signals which are fed back are in phase with and reinforce the original signals. If the connections to L2 are reversed, the fed-back signals will be in opposite or anti-phase and the feed-back will diminish signal strength.

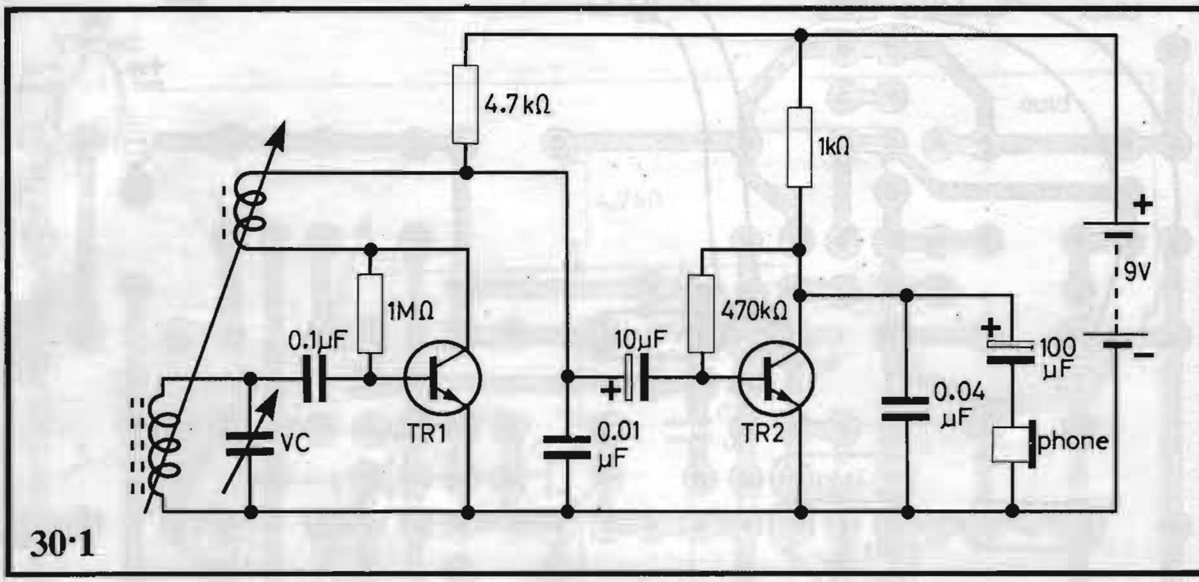
Connect up the battery, set the reaction coil at the end of the rod, and turn the tuning knob. If nothing is heard move the reaction coil towards the centre of the rod. The set should at some point start to oscillate. Move the reaction coil towards the end of the rod again to keep the set just below the point of oscillation. This is its most sensitive condition. Even without an aerial and earth it should be possible to receive a number of stations using the ferrite rod alone to pick up the signals.

If the set does not oscillate when the reaction coil is moved towards the tuning coil, reverse its leads.



When the receiver is used with the ferrite rod alone it is 'directional', i.e. a station is received most strongly when the ferrite rod is at right angles to the direction of the transmitter. When the rod is pointing end-on to the transmitter the signal is at a minimum. Once a signal is received and tuned in, rotate the set for maximum strength (or if necessary to reduce volume).

Experiment 30



30·1

Two-transistor receiver with reaction

This circuit is similar to that of Experiment 29 with the addition of a further stage of audio amplification. A large number of stations can be received using the ferrite rod aerial alone, particularly after dark.

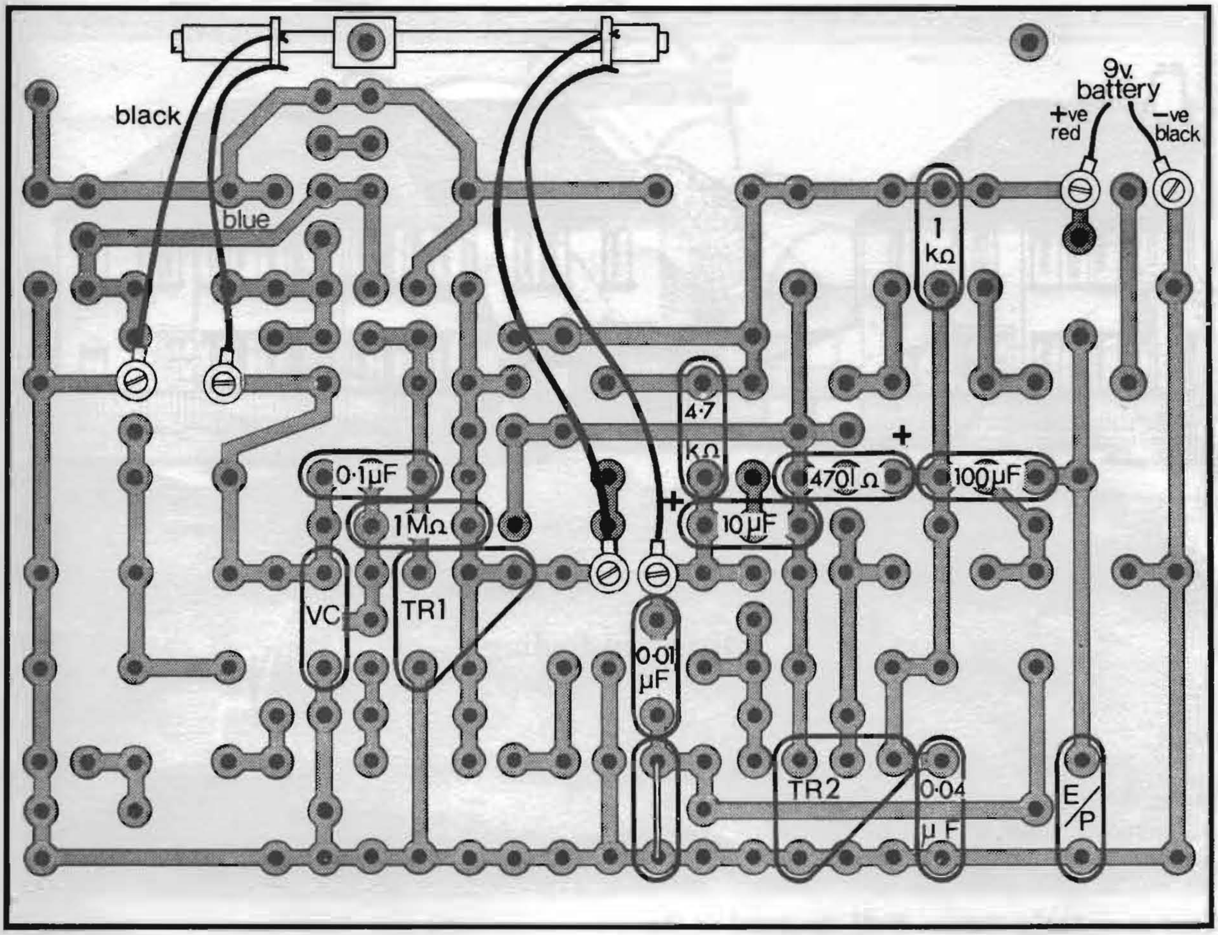
Although only a medium wave coil is provided with this kit, this circuit will give excellent results on both long-wave and short-waves if appropriate tuning coils are used.

There is always some variation in the characteristics of individual transistors and it is possible that one transistor may perform better than the other in the TR1 position in this circuit. An interchange of transistors TR1 and TR2 will show whether this is the case.

Notes:

Loudspeaker reproduction. The audio output from the radio and amplifier circuits may be fed directly into any transistor amplifier. Remove the earphone jack from the board and connect in its place two wire leads. These go to the input terminals of the amplifier. The earth line of the circuit should preferably go to the earth line of the amplifier.

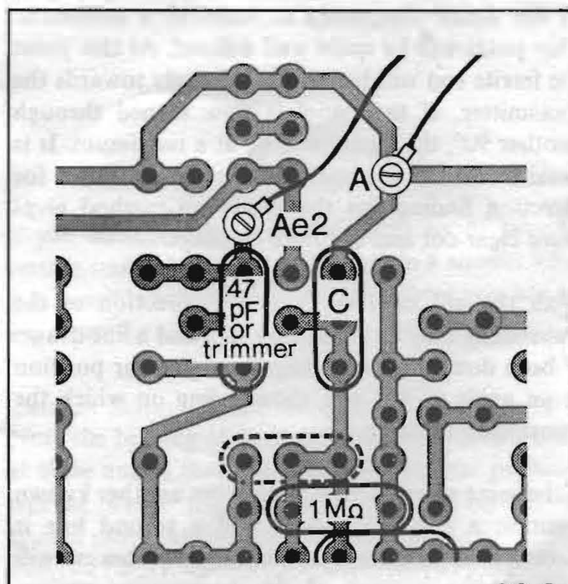
Cleaning the printed circuit board. Should this be desirable at any time, wash in warm water with soap or household detergent, rinse thoroughly under the tap and stand on edge to dry. Alternatively the board may be swabbed with surgical or methylated spirits.



Selectivity. Provision has been made in the layout of the printed circuit board for those who may require a higher degree of selectivity. One or both of the following methods may be used:

(*a*) Connect a small capacitor (about 47pF) or a 40pF or 80pF trimmer capacitor in the position shown in diagram 30.2, and connect the aerial input to Ae.2 position.

(*b*) Wind an aerial coil with a 'tapping' at about 1/6th from the earth (black lead) end. For a 60 turn MW coil take the tapping at the 10th turn; wind on 10 turns, make a loop in the wire and twist it into a lead about 4½ inches long, then continue to wind on the other 50 turns. Connect the blue and black leads in their normal positions. Clean the end of the 'loop' lead and connect it to point A in the diagram. Move the coupling capacitor C from its old (dotted) position to the new position shown in full line.



30·2

Experiment 31

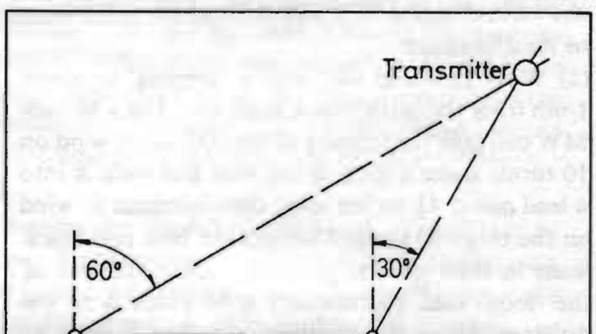
Direction-finding

Using the circuit described in Experiment 30 without aerial or earth, test out its directional characteristics.

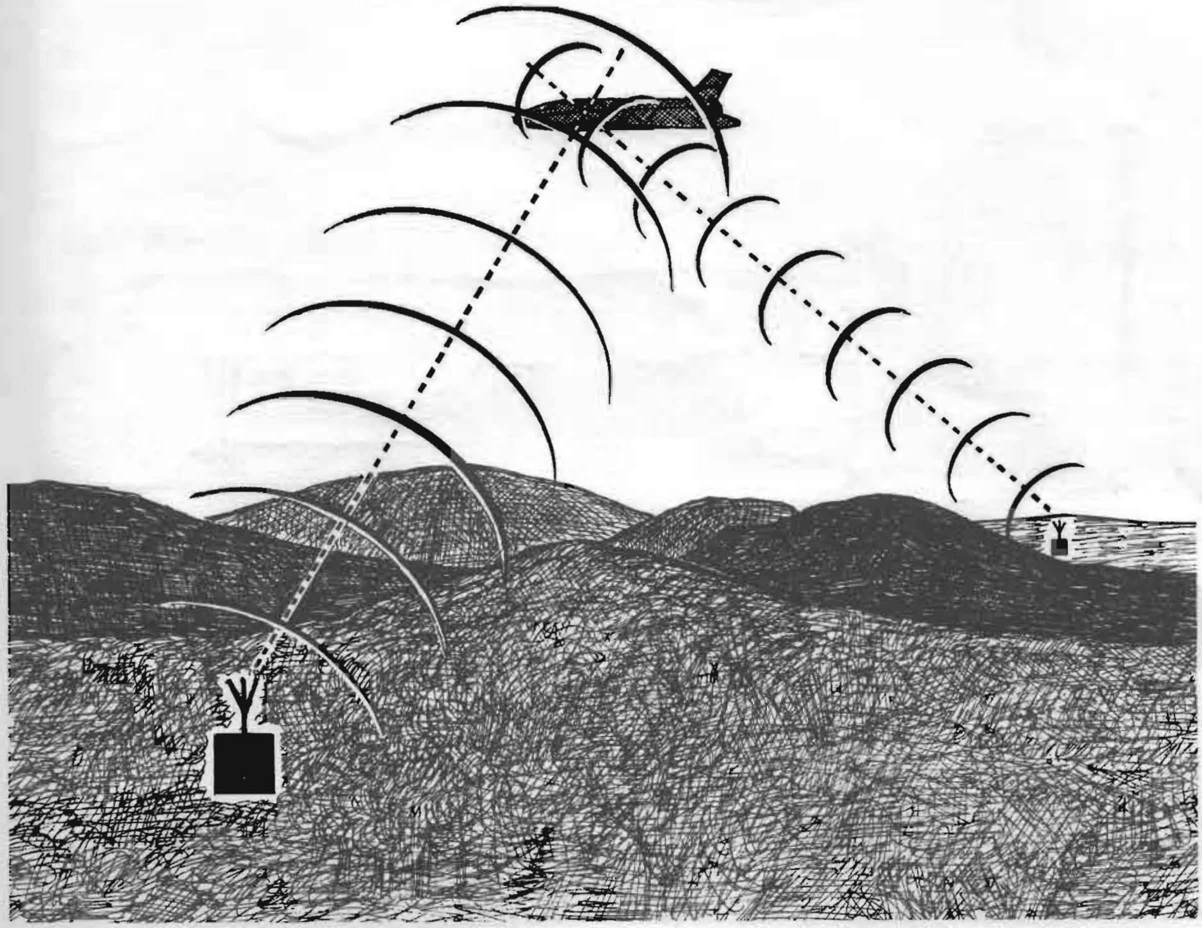
Tune in a strong station. Hold the panel in the hands, keeping it horizontal, and turn it around until the signal disappears or fades to a minimum. This point will be quite well defined. At this point the ferrite rod will be pointing directly towards the transmitter. If the panel is now turned through another 90°, the signal will be at a maximum. It is possible to use the maximum signal position for direction finding but the minimum method gives more clear-cut and accurate bearings.

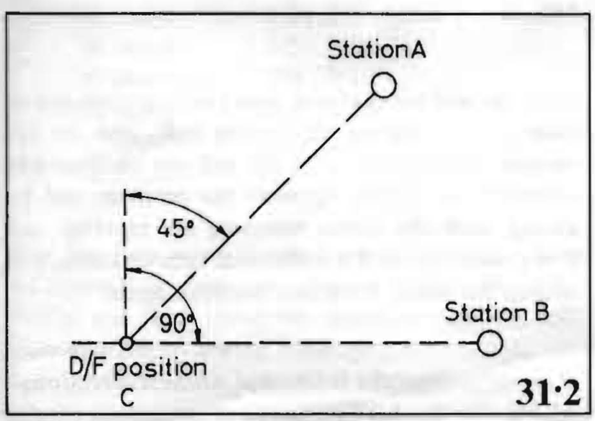
With the aid of a compass the direction of the transmitter may be noted (say 60°) and a line drawn in both directions on a map through your position at an angle of 60° will show a line on which the transmitter must lie.

If the same experiment is done from another known position a few miles away and a second line is drawn, then the point at which the two lines cut will indicate the position of the transmitting station. This is shown in diagram 31.1.



31·1





31·2

If you have a map with the positions of broadcasting stations marked on it, then in a similar way it is possible to determine exactly where you are at any time.

Tune in Station A and note its bearing (say 45°). Note the bearing of Station B (say 90°). Draw lines at these angles through A and B and your position will be where the two lines intersect (at C). A typical plot is shown in diagram 31.2.

Ships and aircraft check their positions in this way.

Experiment 32

Long wave operation

All the foregoing receivers will operate well on the long waves if a long wave coil is constructed.

A coil of 160 turns situated near the end of the ferrite rod will cover the long wave band with the 365 pF tuning condenser provided.

To make such a coil use enamelled copper wire of about 38 gauge. Wrap tightly on the ferrite rod two turns of gummed paper, 2 inches wide, gummed side to rod, and stick it to itself, but not to the rod. This is to act as spacer during the winding operation. Over this spacer wrap four further turns of gummed paper, $1\frac{1}{2}$ inches wide, gummed side away from the rod, and stick it to itself to form a tight stiff coil former. Wind on 160 turns of wire to form a coil about 1 inch in length in the centre of the former. Space the turns about $\frac{1}{8}$ inch apart to obtain a criss-cross or 'wave winding' effect with plenty of air space between the turns. Leave about 6 inches at start and finish for the connections to the circuit board.

When the 160 turns have been completed fix them in position with a few turns of adhesive tape.

Carefully remove the coil and the gummed paper from the rod; remove and throw away the spacer. Scrape the enamel from the ends of the wire leads, place the coil on the end of the ferrite rod and connect the coil into circuit. The start of the coil is the 'black' lead which is connected to earth and the finish (the outer end) is the 'blue' lead. The 'black' lead end should be placed nearest the centre of the rod.

If the set will not oscillate, move the reaction coil as close as possible to the tuning coil; also try reversing it on the rod. If it still will not oscillate add another one or two turns to the reaction coil by easing back the sleeve retaining the reaction coil leads, winding on the additional turn or turns, and sliding the sleeve back into position again.

Remember that the ferrite rod aerial is directional; also that a short indoor aerial may improve results.

Experiment 33

Short wave operation

The radio circuits described in the preceding experiments work very well on short waves and many fascinating hours may be spent listening to transmissions from radio amateurs, ships, aircraft and foreign short wave broadcasting stations.

Short wave coils are required and, while the construction details which follow refer specifically to the circuit in Experiment 30, the tuning coils may equally be used with the other receiver circuits.

The Amateur Bands are as follows:

160 metre	1·8– 2·0	MHz (= Mc/s)
80 metre	3·5– 3·8	,,
40 metre	7·0– 7·1	,,
20 metre	14·0–14·35	,,
15 metre	21·0–21·45	,,
10 metre	28·0–29·7	,,

The first four wave bands down to 20 metres may be covered by two coils. Placed at the end of the ferrite rod, and using the standard reaction coil, they give the following coverage:

18-turn coil	180–60 m (1·6–5·0 MHz)
5-turn coil	60–20 m (5·0–15 MHz)

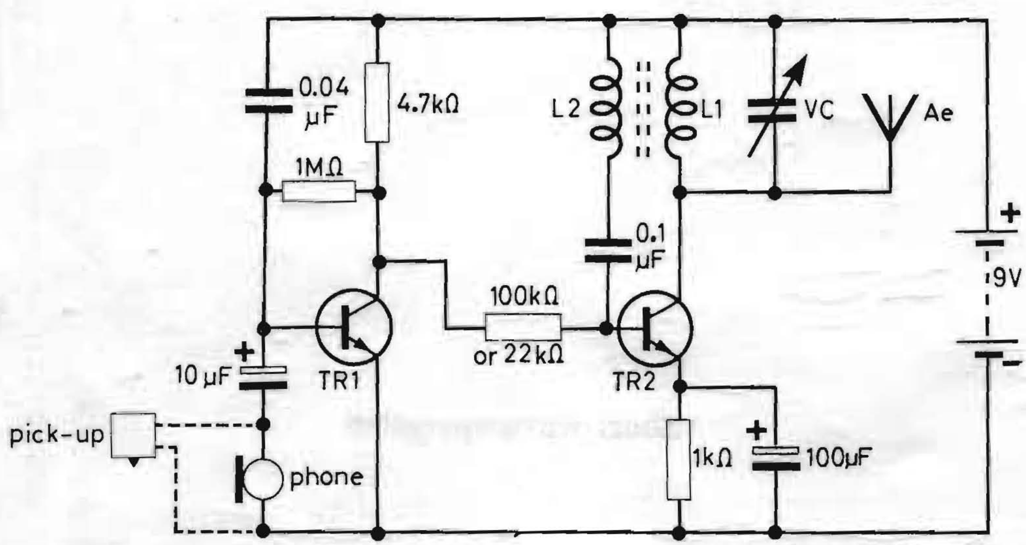
These coils should be made as single layer coils using the enamelled copper wire provided. The method of construction outlined in Experiment 32 may be used as a guide. A short vertical indoor aerial is desirable.

For reception on the 15 and 10 metre-bands, the two wire probes included in the kit may be used as aerial and reaction coils. In this case the ferrite rod is not used. The aerial coil is made by forming one of the probes into a single round loop. The ends of the probe are attached to the circuit board at the points designated for the M.W. coil black and blue leads. The loop is then shaped in a vertical plane parallel to the side of the board. The reaction coil is fitted and shaped in the same way from the reaction coil attachment points, so that two vertical loops are established in planes parallel to each other.

If the loops are inclined towards each other the set will oscillate. If it does not, reverse the reaction coil connections without turning the loop.

With these coils the aerial coil acts as a 'frame' aerial, and is directional. These coils will cover the 15 and 10 metre-bands. A small vertical indoor aerial may also improve results with these coils.

Experiment 34



34·1

Transmitter with gramophone and voice modulation

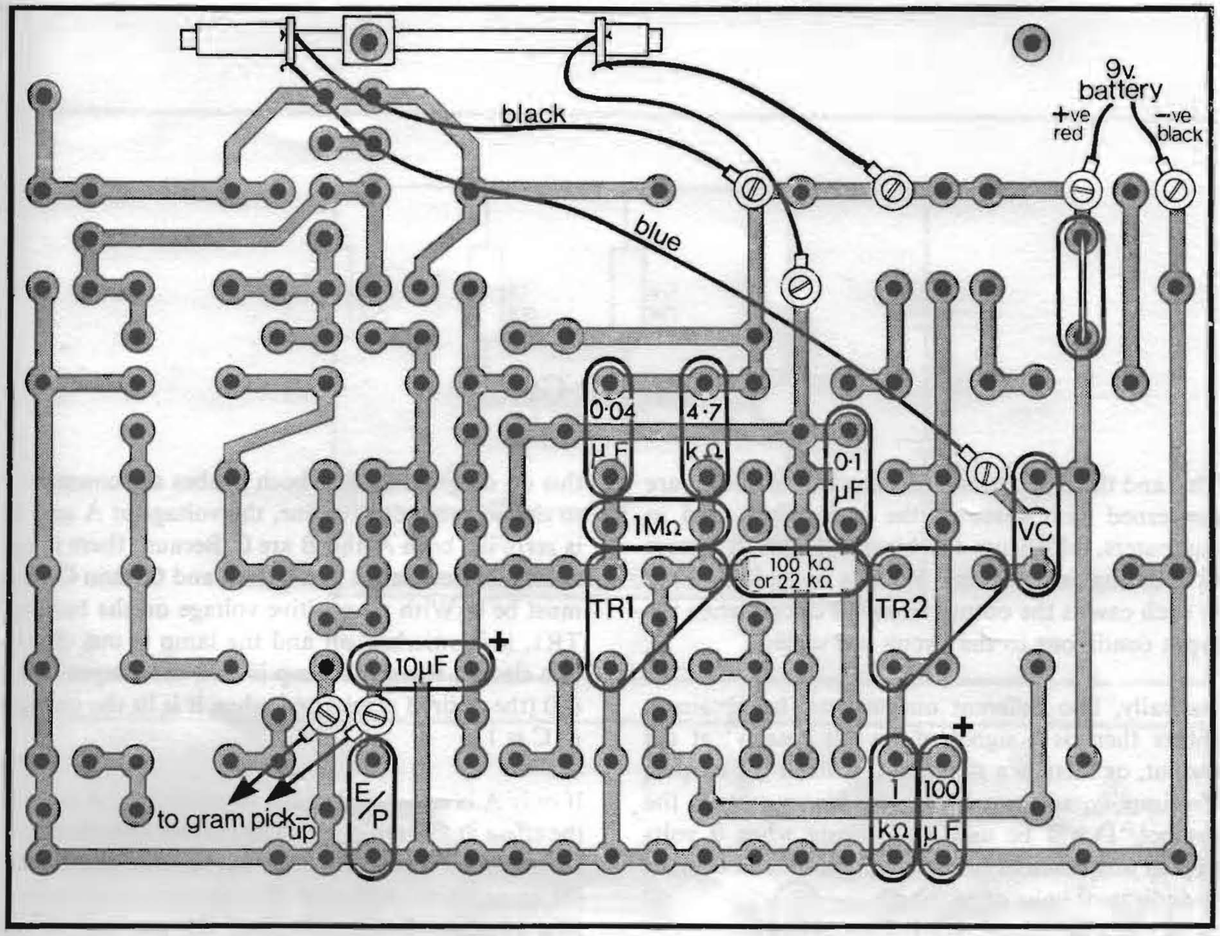
In this experiment you will see how radio broadcasts are made. The circuit above is that of a transmitter which will broadcast speech and music.

It is of course against the law to broadcast without an Amateur Radio Transmitting Licence but as the range of the transmissions from the ferrite rod aerial is so small no interference can be caused beyond the room in which the set is situated. The circuit will however transmit perfectly clearly over a distance of a few feet and will demonstrate the principles involved.

In the theoretical circuit shown here TR2 is the oscillator. The frequency is set by the tuning circuit L1 and VC in the collector circuit. The 1 kΩ resistor in the emitter circuit limits the amount of current which can be drawn by TR2 and the 100μF capacitor earths the emitter as far as alternating current is concerned and thus prevents the 1 kΩ resistor from diminishing the strength of the oscillations by 'negative feed-back'. Oscillations in the tuning circuit are picked up by coil L2 and fed back to the base by the 0·1μF capacitor to sustain oscillation. The base bias is provided by the 4·7 kΩ and 22 kΩ resistors in series.

When the battery is connected the oscillator circuit will produce a carrier wave of constant amplitude.

If the set is placed within two or three feet of a normal domestic receiver a hissing sound will be heard when the two sets are tuned to the same frequency. The receiver should be tuned to a quiet part of the dial so that the carrier wave may be noted. L2 should be placed near the centre of the



ferrite rod initially and its position adjusted later for optimum results. If the circuit can not be made to oscillate reverse L2.

TR1 is connected up as a simple audio amplifier. The earphone is connected in the emitter/base circuit and is used as a microphone. The a.c. currents produced by the microphone are applied to the base and appear in amplified form in the collector circuit. As the collector current varies so do the voltages at the collector end of the 4·7 kΩ resistor. These variations are applied to the base of TR2 through the 22 kΩ resistor and in this way they vary the amplitude of the carrier wave oscillations produced by TR2. This effect is called 'modulation' of the carrier wave.

With the transmitter tuned to the receiver the modulated signal will be received and the transmitted speech will be heard.

If a gramophone deck is available, it can be used to transmit records. Connect the two leads from the pick-up in place of the microphone and good quality broadcasts will result. Should the pick-up overload the circuit distortion will result; this can be cured by substituting a 100 kΩ for the 22 kΩ.

With a little practice you can quickly become an expert disc-jockey.

Remember that the ferrite rod is directional and the panel should be orientated with respect to the receiver until the best results are obtained.

Note: Due to local regulations, this type of equipment may not be used without a transmitting licence in the United Kingdom and in certain other countries.

Experiment 35

The OR Gate

This and the remainder of the circuits in this kit are concerned with some of the logic gates used in computers, which use the binary (1 and 0) system of counting and working. What is being looked for in each case is the output from the circuit when the input conditions to the circuit are varied.

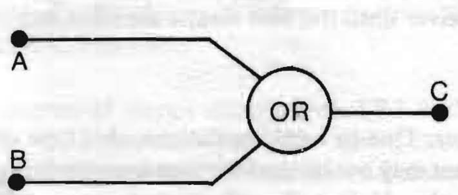
Basically, two different outputs can be obtained. Either there is a signal of 9 volts (nearly) at the output, or there is a signal of 0 volts at the output. To simplify, and to relate to the binary system, the symbol '1' will be used to indicate when 9 volts appear anywhere in the system, and '0' will be used to indicate 0 volts appearing.

In this experiment, we are concerned with the 'OR' gate. The output is at point C, shown on the theoretical circuit diagram 35.3, TR1 being used solely as a switch, and the lamp as an indicator of the output. The logic circuit is symbolised in the diagram 35.1 below.

The desired result at the output C is '0', and according to diagram 35.1 if there is a '0' at either A *or* B (or both) there will be a '0' at C. Following this on diagram 35.3, if both probes are connected to the bottom negative line, the voltage at A and B is zero, i.e. both A and B are 0. Because there is no resistance between A and C or B and C, then C also must be 0. With no positive voltage on the base of TR1, it is switched off and the lamp is out. So in this circuit, when the lamp is out, the output at C is 0 (the desired result) and when it is lit the output at C is 1.

If only A is connected to the negative line, A is 0 so the effect at C from A is 0. The current flow through the circuit is through the 4·7 kΩ resistor and diode D1 to negative. Although B is at 1, no current can flow towards C because diode D2 prevents it. B cannot have any effect on C therefore, so C remains at 0, shown by the lamp being out because TR1 is switched off. The result is similar when B is 0 and A is 1.

When both A and B are 1, i.e. neither is connected to the negative line, there is no current flow through the 4·7 kΩ resistor, and C will be at 9 volts, or 1. These results can be condensed into the Truth Table shown in diagram 35.2.

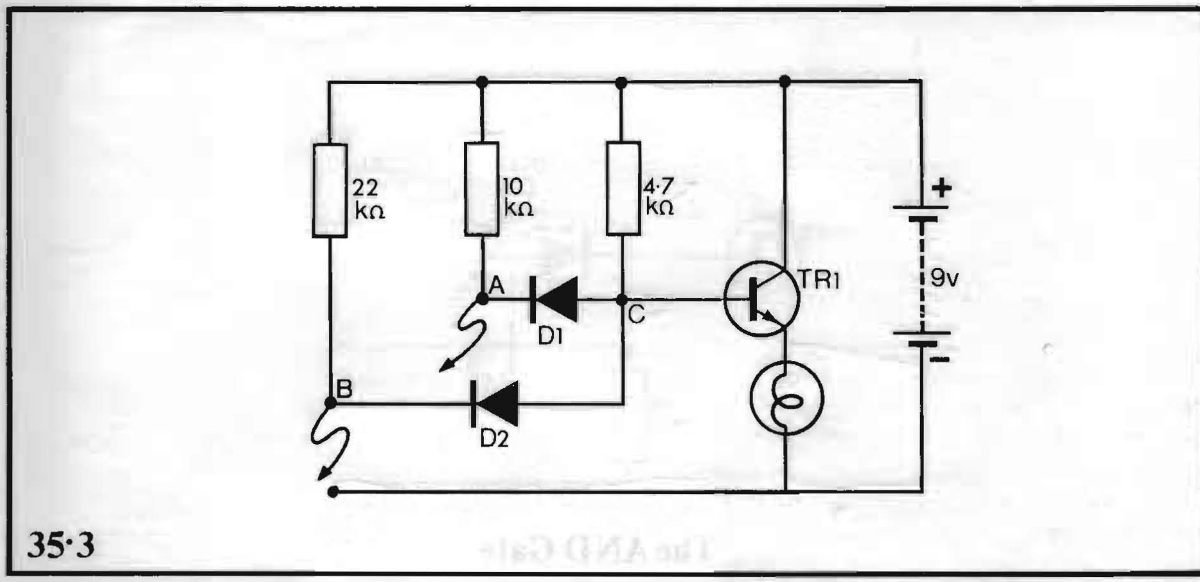


35·1

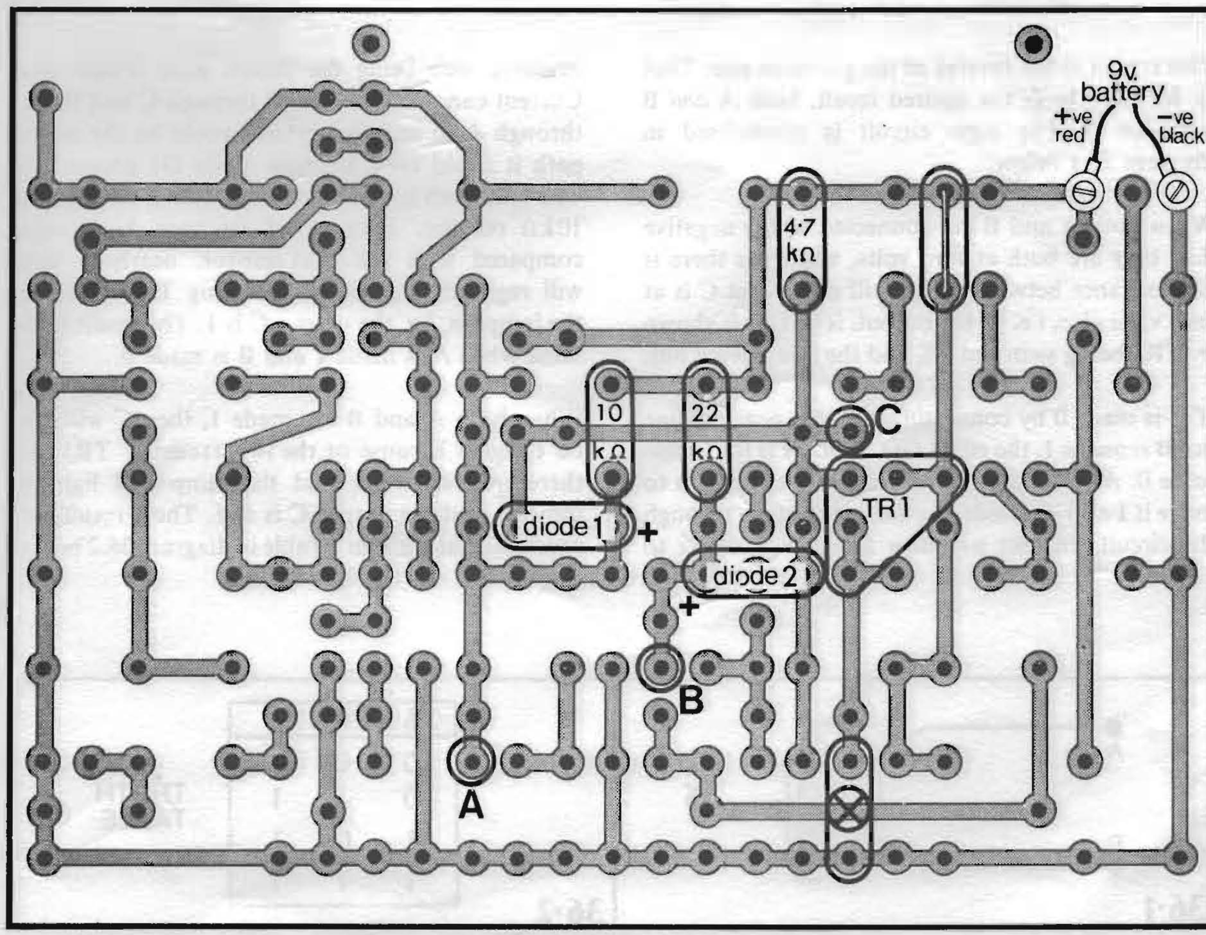
A	B	C
0	0	0
0	1	0
1	0	0
1	1	1

TRUTH TABLE

35·2


22
kΩ
10
kΩ
4·7
kΩ
A
D1
C
TR1
9v
B
D2
+
−

35·3


9v.
battery
+ve
red
−ve
black
4·7
kΩ
10
kΩ
22
kΩ
C
diode 1
+
diode 2
+
TR1
B
A

Experiment 36

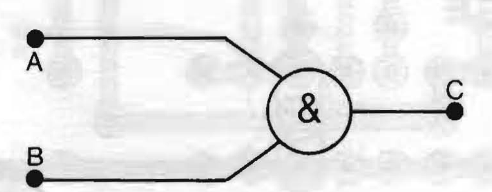
The AND Gate

This circuit is the reverse of the previous one. That is, for C to be 0, the desired result, both A *and* B must be 0. The logic circuit is symbolised in diagram 36.1 below.

When both A and B are connected to the negative line, they are both at zero volts, which, as there is no resistance between them, will mean that C is at zero volts also, i.e. C, the output, is 0. This is shown by TR1 being switched off, and the lamp being out.

If A is made 0 by connecting it to the negative line but B remains 1, the effect on C from A is for C also to be 0. As B is at 1, however, its effect on C is to make it 1 also. Considering the current flow through the circuit, current will flow through A direct to negative, this being the easiest path it can take. Current cannot flow from B through C and thence through A to negative, which would be the easiest path it could take, because diode D1 prevents it. The only path it can take, therefore, is through the 10kΩ resistor. Because of its very high value compared with the 470Ω resistor, nearly 9 volts will register at point C, switching TR1 and thus the lamp on, i.e. the output C is 1. The result is the same when A is made 1 and B is made 0.

When both A and B are made 1, then C will also be 1, again because of the 10kΩ resistor. TR1 will therefore switch on and the lamp will light to indicate that the output C is at 1. These results are condensed in the Truth Table in diagram 36.2 below.



36·1

A	B	C
0	0	0
0	1	1
1	0	1
1	1	1

TRUTH TABLE

36·2

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vents it.
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h value
9 volts
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lt is the

vill also
R1 will
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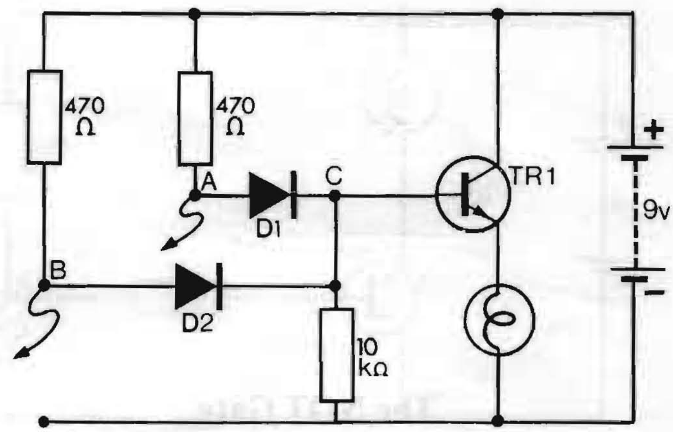
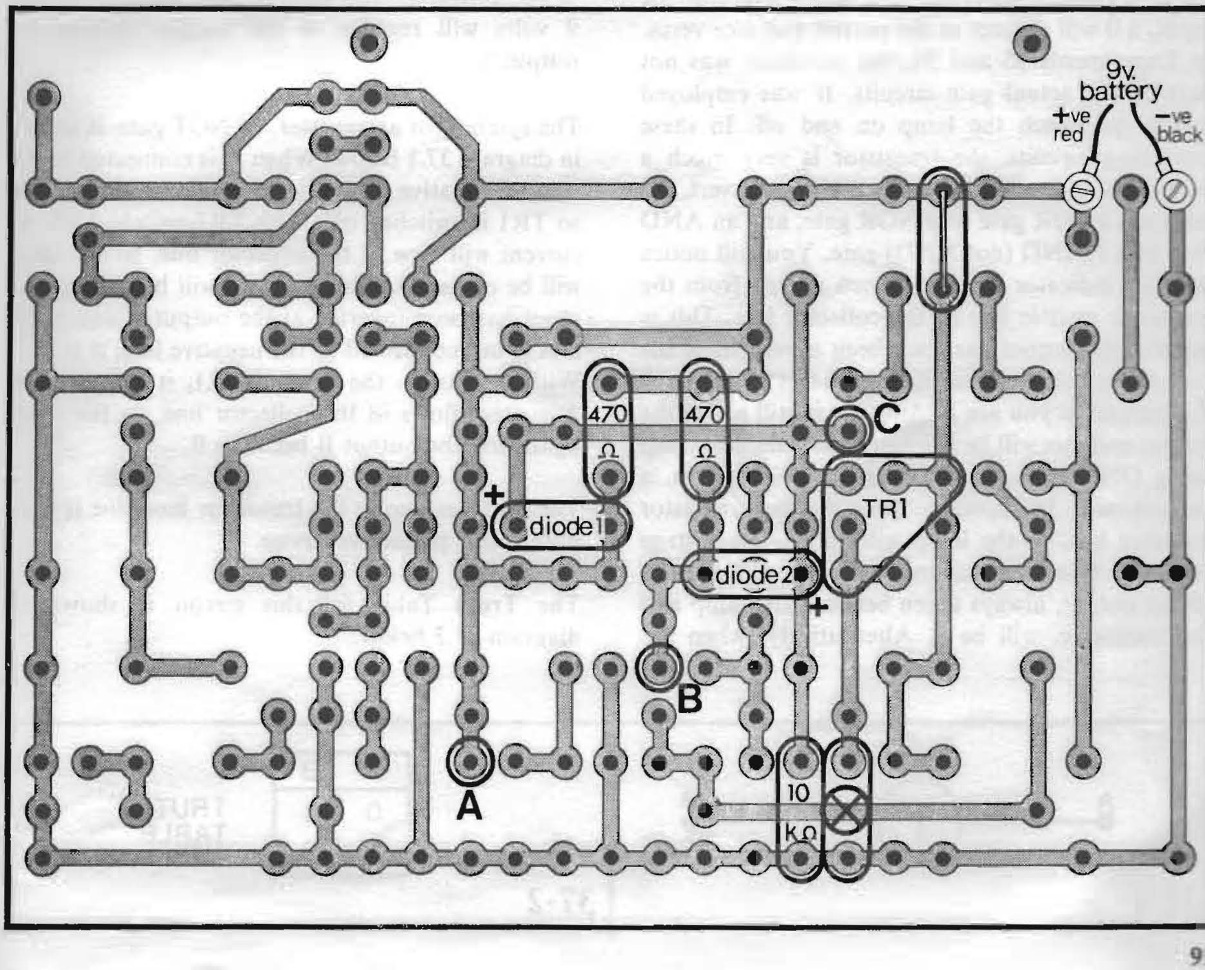
below.



36·3



Experiment 37

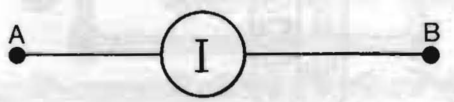
The NOT Gate

This experiment shows how the transistor can be used as an inverter. That is, if there is a 1 at the input, a 0 will register at the output and vice versa. In Experiments 35 and 36, the transistor was not part of the actual gate circuits. It was employed merely to switch the lamp on and off. In these remaining circuits, the transistor is very much a part of the gate circuits and is used to convert, for instance, an OR gate to a NOR gate, and an AND gate to a NAND (not AND) gate. You will notice that the indicator lamp has been moved from the transistor emitter line to the collector line. This is because the output has itself been moved from the base to the collector line. Except in this experiment, the indication you are looking for is still a 0 at the output and this will be shown by the indicator lamp being ON. When the transistor is switched on, a current will be flowing through the transistor collector line, so the lamp will be lit. The voltage across the transistor will drop to near zero, however, so the output, always taken between the lamp and the transistor, will be 0. Alternatively, when the transistor is switched off, no current will be flowing in the collector line. The lamp will not be lit and 9 volts will register at the output making the output 1.

The symbol for an inverter, or NOT gate, is shown in diagram 37.1 below. When A is connected to the bottom negative line, A is at zero volts (i.e. A is 0) so TR1 is switched off. With TR1 switched off, no current will flow in the collector line, so the lamp will be out and the output at B will be 1. Thus the input has been inverted at the output. Conversely, if A is not connected to the negative line, it is at 1. With 9 volts on the base of TR1, it switches on. A current flows in the collector line, so the lamp lights and the output B becomes 0.

The 1 kΩ resistor in the transistor base line is used purely as a protective device.

The Truth Table for this circuit is shown in diagram 37.2 below.

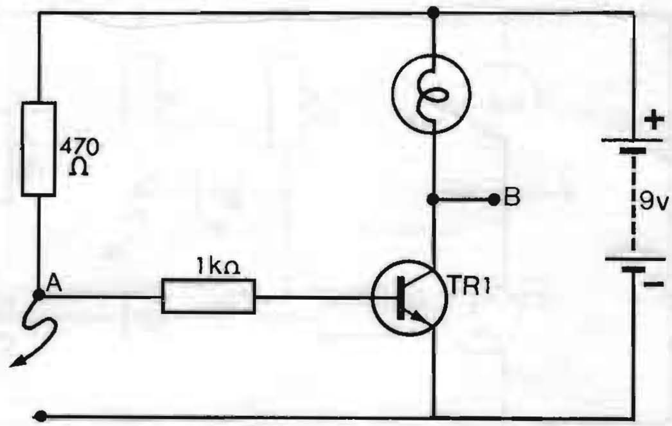


37·1

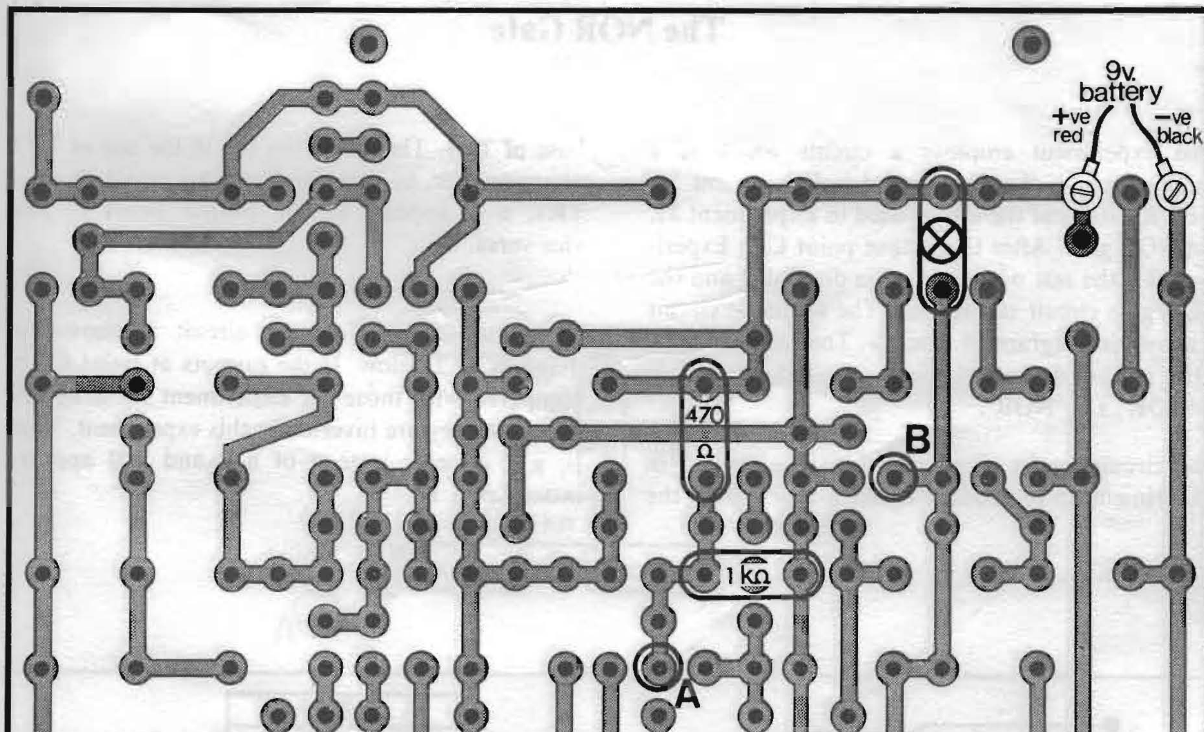
A	B
0	1
1	0

TRUTH TABLE

37·2



22·3



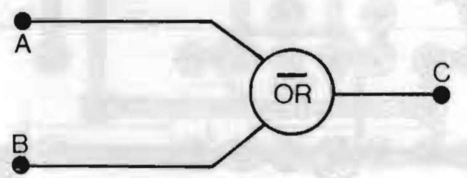
Experiment 38

The NOR Gate

This experiment employs a circuit which is a combination of the circuit used in Experiment 35, the OR gate, and the circuit used in Experiment 37, the NOT gate. After the output point C in Experiment 35, the rest of the circuit is discarded and the NOT gate circuit substituted. The symbolic circuit is shown in diagram 38.1 below. The bar above the 'OR' in this diagram indicates that the circuit is 'not OR', i.e. 'NOR'.

The circuit works in exactly the same way as in Experiment 35 to produce either a 1 or a 0 on the base of TR1. The difference lies in the use of TR1 as an inverter, so that if a 1 appears on the base of TR1, a 0 appears at the output point C and vice versa.

The Truth Table for this circuit is shown in diagram 38.2 below. If the outputs at point C are compared with those for Experiment 35, it will be seen that they are inverted in this experiment. That is, a 1 appears instead of a 0 and a 0 appears instead of a 1.

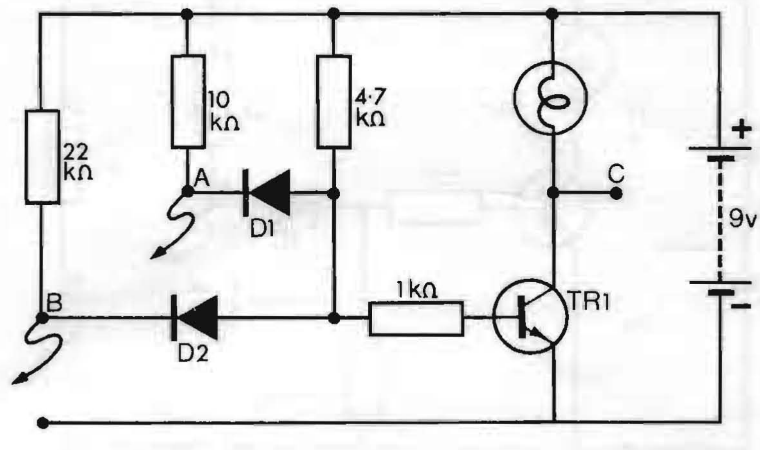


38·1

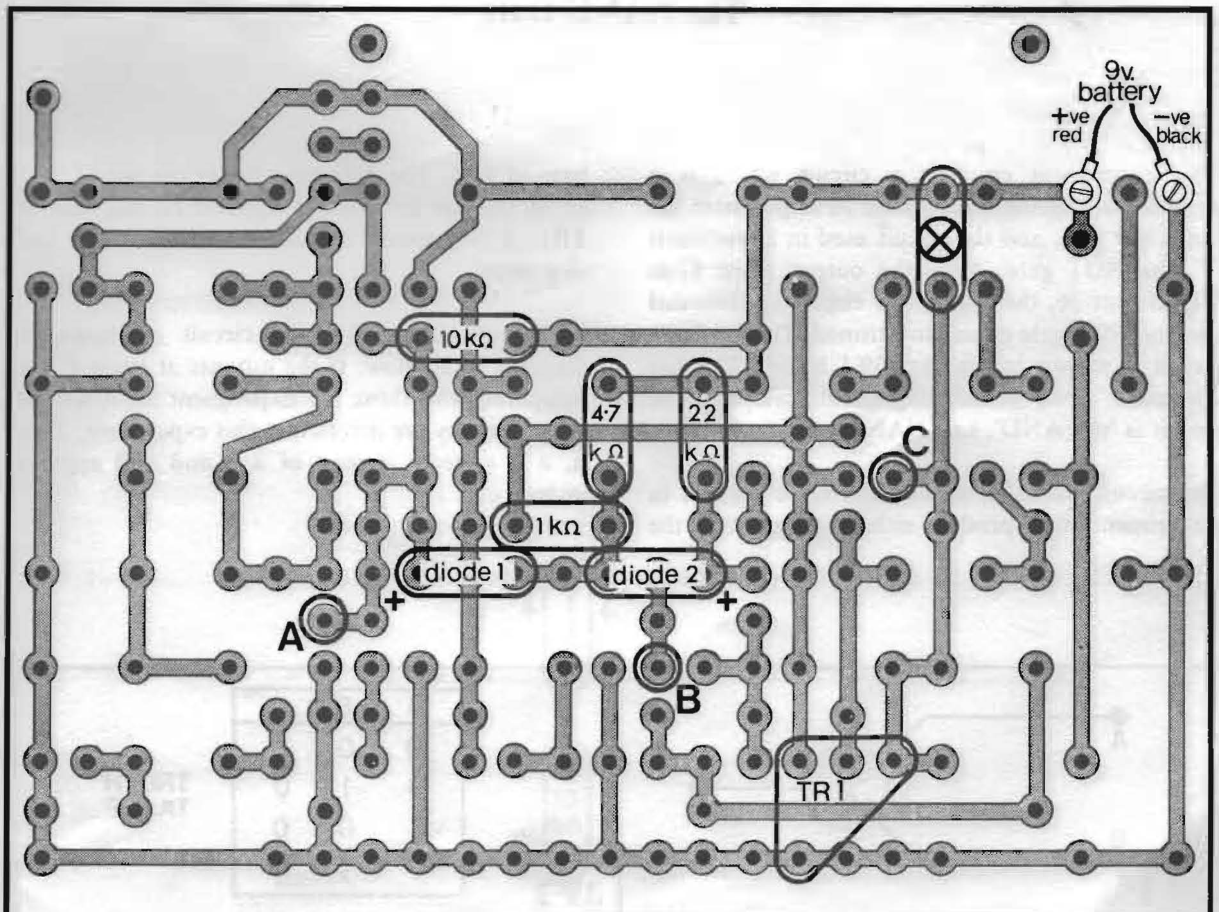
TRUTH TABLE

A	B	C
0	0	1
0	1	1
1	0	1
1	1	0

38·2


10
kΩ
4·7
kΩ
22
kΩ
A
D1
C
+
9v
−
B
D2
1kΩ
TR1

38·3


9v.
battery
+ve
red
−ve
black
10kΩ
4·7
kΩ
22
kΩ
C
1kΩ
diode 1
diode 2
+
+
A
B
TR1

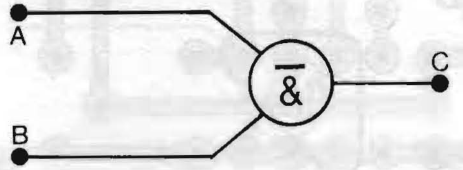
Experiment 39

The NAND Gate

This experiment employs a circuit which is a combination of the circuit used in Experiment 36, the AND gate, and the circuit used in Experiment 37, the NOT gate. After the output point C in Experiment 36, the rest of the circuit is discarded and the NOT gate circuit substituted. The symbolic circuit is shown in diagram 39.1 below. The bar above the 'AND' in this diagram indicates that the circuit is 'not AND', i.e. 'NAND'.

The circuit works in exactly the same way as in Experiment 36 to produce either a 1 or a 0 at the base of TR1. The difference lies in the use of TR1 as an inverter so that if 1 appears on the base of TR1, a 0 appears at the output point C and vice versa.

The Truth Table for this circuit is shown in diagram 39.2 below. If the outputs at point C are compared with those for Experiment 36, it will be seen that they are inverted in this experiment. That is, a 1 appears instead of a 0 and a 0 appears instead of a 1.

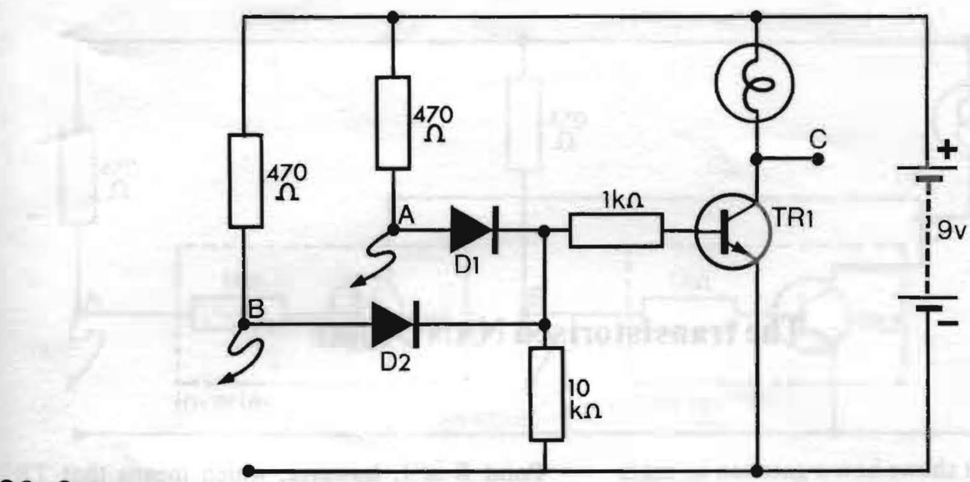


39·1

A	B	C
0	0	1
0	1	0
1	0	0
1	1	0

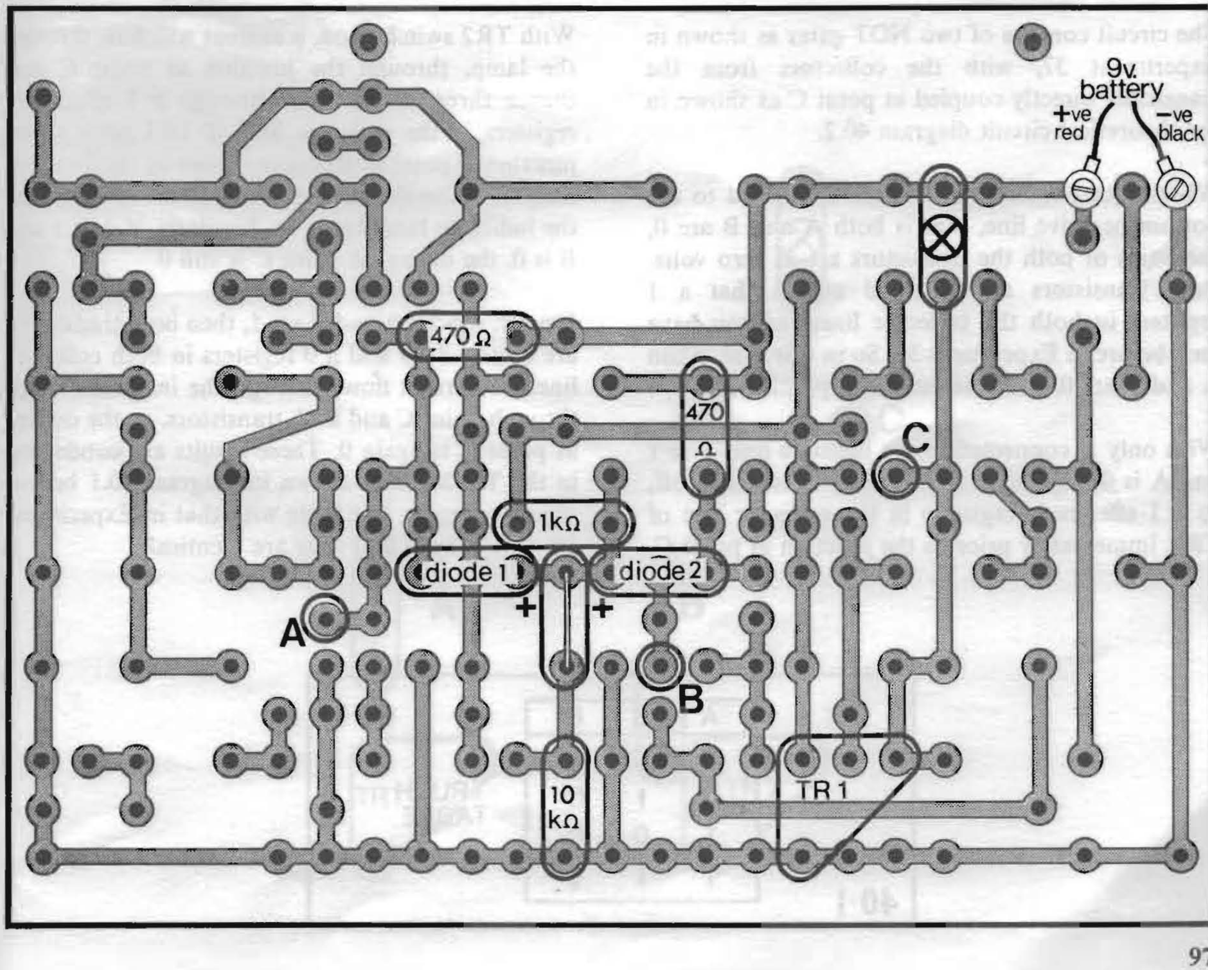
TRUTH TABLE

39·2



470
Ω
470
Ω
C
+
A
1kΩ
TR1
9v
D1
B
D2
−
10
kΩ

39·3



9v.
battery
+ve
red
−ve
black
470 Ω
470
Ω
C
1kΩ
diode 1
diode 2
+
+
A
B
TR 1
10
kΩ

Experiment 40

The transistorised NAND Gate

This last experiment shows how a gate can be made employing transistors instead of diodes, which is regular practice in modern computers.

The circuit consists of two NOT gates as shown in Experiment 37, with the collectors from the transistors directly coupled at point C as shown in the theoretical circuit diagram 40.2.

When both points A and B are connected to the bottom negative line, that is both A and B are 0, the bases of both the transistors are at zero volts. Both transistors are switched off so that a 1 registers in both the collector lines, as you have seen before in Experiment 37. So in this case, when A and B are 0, then the output at point C is 1.

With only A connected to the negative line, B is 1 and A is 0. Again, as A is 0, TR1 is switched off, so a 1 effectively registers in the collector line of TR1, immediately prior to the junction at point C. Point B is 1, however, which means that TR2 is switched on and a 0 registers in the collector line of TR2 immediately prior to the junction at point C.

With TR2 switched on, a current will flow through the lamp, through the junction at point C and thence through TR2. So although a 1 effectively registers in the collector line of TR1 prior to its junction at point C, it is over-ridden by the 0 output from TR2. So the output at point C is 0, shown by the indicator lamp being lit. Similarly, if A is 1 and B is 0, the output at point C is still 0.

Finally, if both A and B are 1, then both transistors are switched on and a 0 registers in both collector lines. A current flows through the indicator lamp, through point C and both transistors, so the output at point C is again 0. These results are condensed in the Truth Table shown in diagram 40.1 below. If you compare this table with that in Experiment 39, you will see that they are identical.

A	B	C
0	0	1
0	1	0
1	0	0
1	1	0

TRUTH TABLE

40·1

2 is
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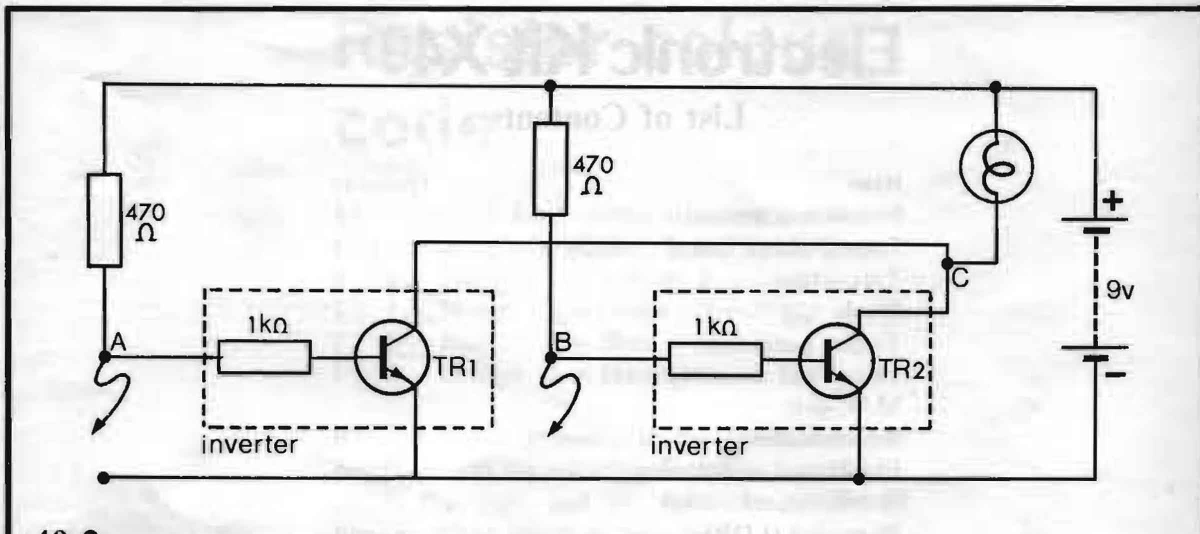
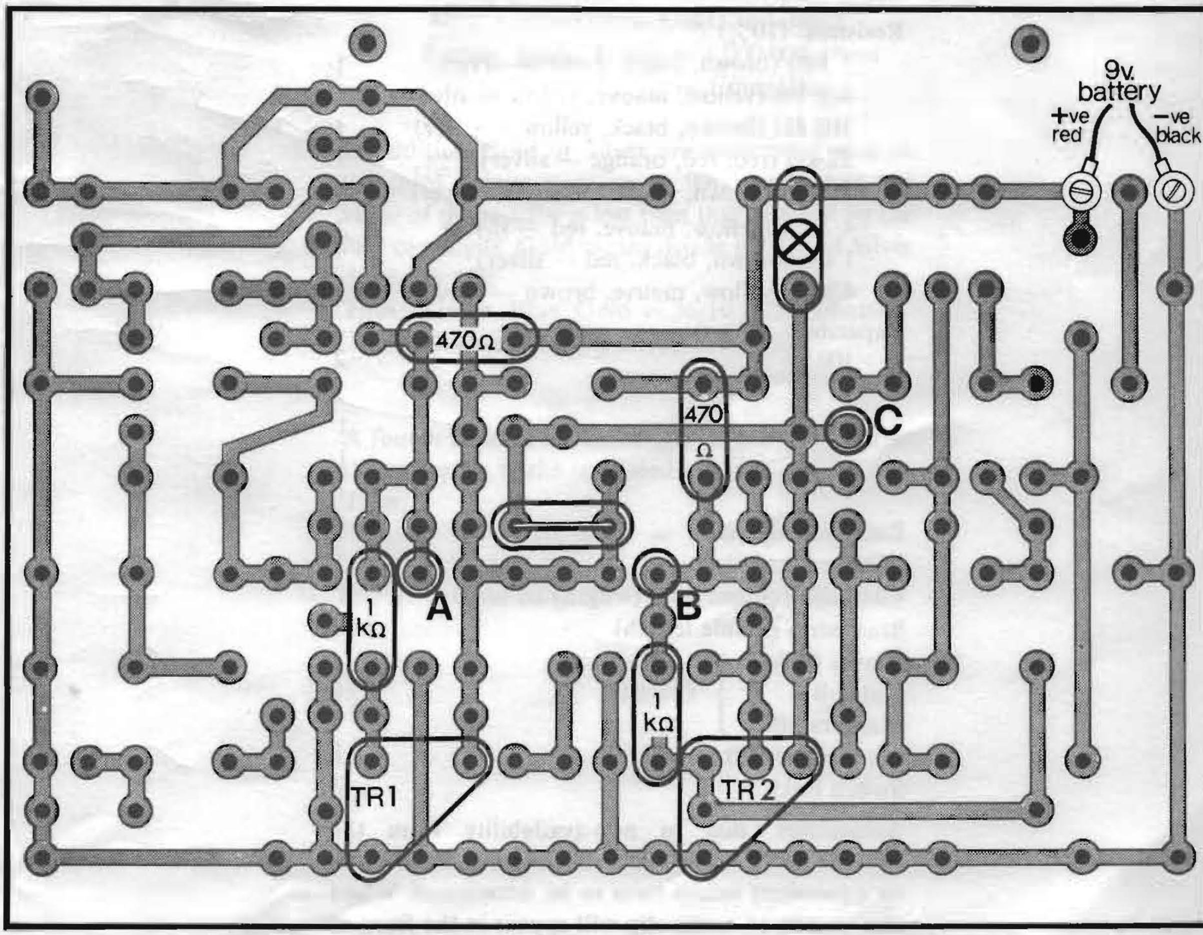


40·2



Appendix A:

Radio and Electronic Kit X40

List of Contents

Item	Quantity
Instruction manual	1
Printed circuit board	1
Transistors	4
Diode	2
Tuning condenser	1
Ferrite rod assembly	1
M.W. coil	1
Reaction coil	1
Earphone c/w jack plug	1
Earphone jack socket	1
Photo-cell (LDR)	1
Lamp 6 V, 40 mA	2
Lamp holder	2
Resistors: (10%)	
1 MΩ (brown, black, green — silver)	1
470 kΩ (yellow, mauve, yellow — silver)	1
100 kΩ (brown, black, yellow — silver)	1
22 kΩ (red, red, orange — silver)	1
10 kΩ (brown, black, orange — silver)	1
4·7 kΩ (yellow, mauve, red — silver)	2
1 kΩ (brown, black, red — silver)	2
470 Ω (yellow, mauve, brown — silver)	2
Capacitors	
100 μF	2
10 μF	2
0.1μF	1
0·04μF	1
0.01μF	1
Battery leads, pair	1
Wire probes	2
Enamelled copper wire (length)	1
Brass strip (3-hole length)	2
Screws 6BA, Nuts 6BA, Washers 6BA (packet)	1
Box spanner 6BA	1
Switch links	2

Sometimes, due to non-availability from the manufacturer, other makes of components of equal or equivalent values have to be substituted. When this occurs an errata slip will appear in the front of the handbook.

Appendix B:

Resistor colour code

The value of a fixed resistor is normally indicated by a colour code in which:

0 = Black	4 = Yellow	8 = Grey
1 = Brown	5 = Green	9 = White
2 = Red	6 = Blue	
3 = Orange	7 = Mauve	

Three colours, generally in the form of colour bands, denote the value in *ohms*. The first two indicate the digits and the third the number of noughts which follow them.

Thus: Brown, Grey, Brown = 180 ohms.
Green, Blue, Red = 5600 ohms
= 5·6kΩ (kilohms).
Brown, Black, Green = 1,000,000 ohms
= 1 megohm.

In addition Gold or Silver are sometimes used in the third colour position as 'Dividers' when the value of the resistor is less than that denoted by the first two digits. Gold means divide by 10 and Silver divide by 100.

Thus: Green, Blue, Gold = 56/10 = 5·6 ohms.
Orange, Orange, Silver = 33/100
= 0·33 ohms.

A fourth band at the other end of the body shows the tolerance in the indicated value of the resistor. Thus:

No fourth band	= ± 20%	tolerance
Silver band	= ± 10%	tolerance
Gold band	= ± 5%	tolerance

Appendix C:

Value of Capacitance

The basic unit of capacitance is the Farad, F. This is too large for normal use, so, it is expressed in the following forms:-

The Microfarad, µF	$= F \times 10^{-6}$
The Nanofarad, nF	$= F \times 10^{-9}$
The Picofarad, pF	$= F \times 10^{-12}$

i.e.

1 Farad	= 1,000,000 µF
1 µF	= 1,000 nF
1 nF	= 1,000 pF (sometimes written µµF)

Below are some examples of these units which are used on the capacitors in this Kit.

1. 0·1 µF is equivalent to 100 nF or 100,000 pF
2. 0·047 µF is equivalent to 47,000 pF
3. 0·01 µF is equivalent to 10 nF or 10,000 pF

Note:

1. Some capacitors are marked 100 n instead of 100 nF, these are direct equivalents.
2. In some kits a 0·047 µF is included instead of a 0·04 µF. There is only a slight difference between the two components and the performance of the kit does not suffer in any way.

Appendix D:

Morse code

A	. —	**N**	— .
B	— . . .	**O**	— — —
C	— . — .	**P**	. — — .
D	— . .	**Q**	— — . —
E	.	**R**	. — .
F	. . — .	**S**	. . .
G	— — .	**T**	—
H	. . . .	**U**	. . —
I	. .	**V**	. . . —
J	. — — —	**W**	. — —
K	— . —	**X**	— . . —
L	. — . .	**Y**	— . — —
M	— —	**Z**	— — . .

1	. — — — —	**6**	— . . . .
2	. . — — —	**7**	— — . . .
3	. . . — —	**8**	— — — . .
4	. . . . —	**9**	— — — — .
5	. . . . .	**0**	— — — — —

Punctuation

Full Stop	. — . — . — (Period)
Comma	— — . . — —
Question Mark	. . — — . .

Procedure

Preliminary call	. — . — . —
Invitation to transmit (K)	— . —
Start or Break Sign	— . . . —
Error	. . . .
Wait (AS)	. — . . .
Stroke (/)	— . . — .
End of Message (AR)	. — . — .
End of Work (VA)	. . . — . —
Distress Signal (S.O.S.)	. . . — — — . . .

Notes

1. If a dot is called 'di' and a dash 'dah', the correct timing of dots and dashes will be achieved.
2. One 'dah' should equal three 'di's' in time.
3. The space between parts of the same letter should be one 'di'.
4. The space between two letters should be three 'di's'.
5. The space between two words should be from 5 to 7 'di's'.