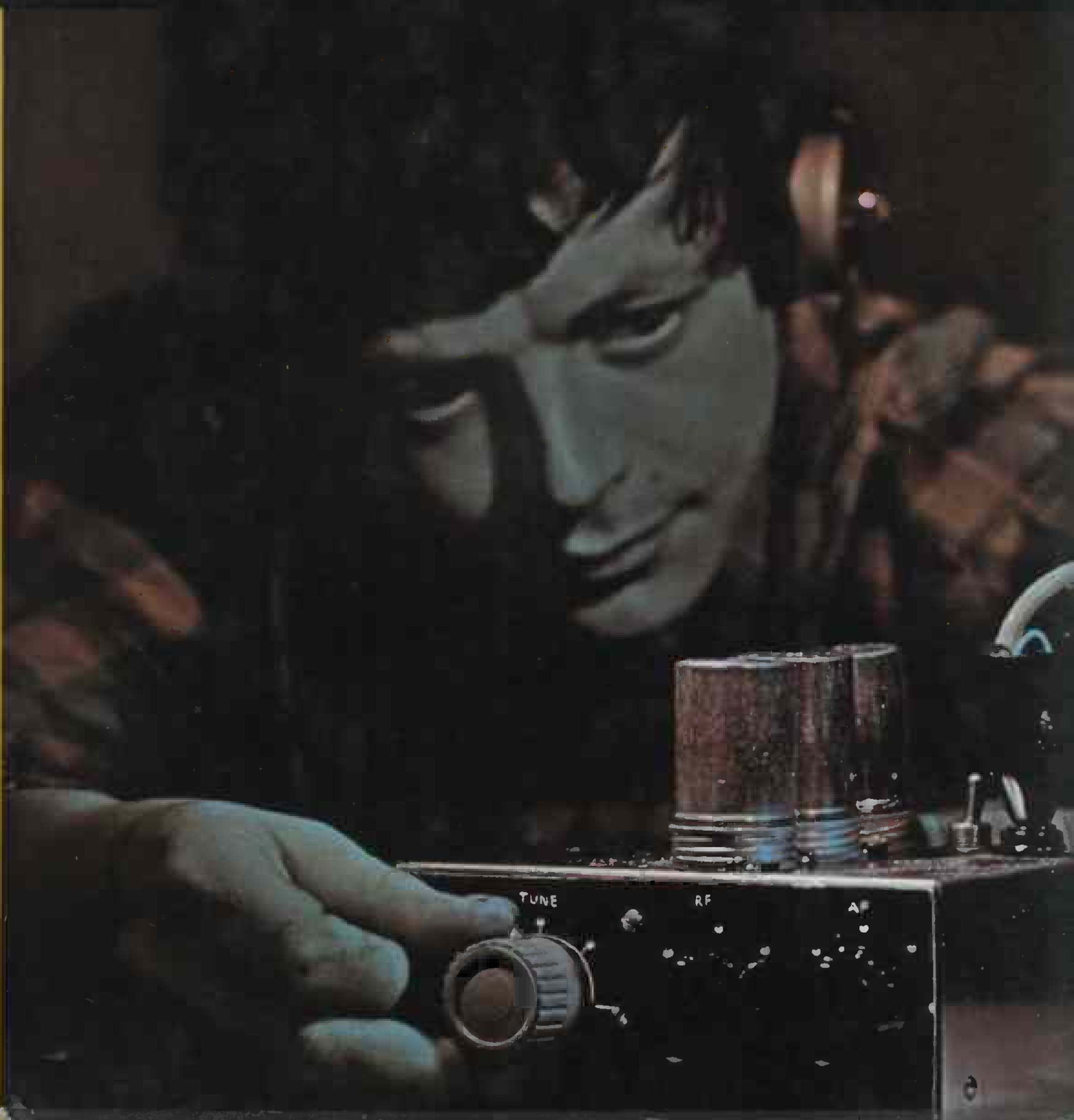
Radio

David Gibson

Illustrated Teach Yourself



How to make three different receivers, from crystal set to superhet, and a transistorized amplifier, with step-by-step instructions

NET IN U.K.

Radio

Illustrated Teach Yourself

editor
Dorothy Ward

designer
Gerald Wilkinson

David Gibson

Illustrated Teach Yourself Radio

Brockhampton Press

SBN 340 0369 5
First Published 1968

Photographs by Peter Goodliffe
Printed in Great Britain by Fletcher & Son Ltd. Norwich

Brockhampton Press Ltd. Salisbury Road, Leicester

ERRATA

p. 35 ~~Line 11 should read (see page 22)~~
p. 55 ~~Figures 1 and 2 transposed~~
p. 66 ~~Line 1 should read '3,000pF (0.003mF).~~
p. 69 ~~Line 14. The three trimmer capacitors are 30pF and one each wired in parallel across VC1/VC2/VC3.~~
p. 77 ~~Amateur licence now £3~~
p. 79 ~~Line 34 should read 4 metres (70 Mc/s)~~
p. 80 ~~Mobile licence now 30s~~
p. 83 ~~Line 16 for 'thick' read 'dotted'.~~

Contents

1 Radio Components

All electronic and radio circuits have one thing in common – they depend on electricity. This comes from a variety of sources, but we will consider only two of them. First, the electricity which comes to us from the mains, and second the battery, used in torches, transistor radios and so on.

The exact nature of electricity is still being debated, but we do know quite a lot about it. We know that all material things are made of atoms, and that atoms are made up of positive, negative and neutral charges.

If we take two magnets and arrange them so that the North pole of one is touching the South pole of the other, they will stick to each other. There is a definite force, an attraction, which holds them together. If we orient them so that both the South poles are touching, they will not stick together but will try to push themselves apart. Thus we can state that like poles repel, unlike poles attract.

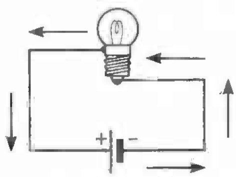
Atoms confirm what the magnets tell us. An atom is arranged like a miniature solar system. Just as the earth rotates around the sun, so the electrons, minute negative charges, rotate around the nucleus. The nucleus has a positive charge and, due to its attraction to the electrons, holds these negative charges in orbit around it. So we can see that unlike charges attract, just as the magnet proved. The whole atom is neutral, the amount of positive charge in the nucleus is exactly balanced by the sum of the negative charges orbiting around it.

If we can apply a force of sufficient intensity, we can dislodge electrons from their orbit and cause them to move away from their atom. In some materials atoms do not part with their electrons unless a tremendous force is applied; these materials are called insulators. In others, the good 'conductors', we do not need very much force at all. Copper, for instance, is very happy to part with its electrons and is thus a good conductor.

This is why copper wire is used to wire radio sets. The force we use is the battery.

In copper the 'free electrons' as they are called, wander aimlessly about. If we connect a battery and a bulb to each other with copper wire, these free electrons in the wire all rush in the same direction as shown by the arrows in figure 1, that is, anti-clockwise. The bottom symbol is a battery, the top one is the bulb. The lines connecting them represent the copper connecting wire which completes the circuit. An electron is a negative charge and the negative side of the battery, shown with a minus sign, will repel or push them anti-clockwise. Similarly the positive side of the battery, shown with a plus sign, will attract or pull them; remember – like charges repel, unlike charges attract.

Figure 1/1

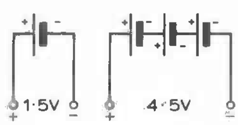


Electricity therefore, is a movement of electrons in a definite direction, flowing from negative to positive.

Batteries

A battery is simply a device which has a surplus of electrons at its negative terminal and a deficit of electrons at its positive terminal. The battery thus acts as a force because it will ***force*** electrons round a circuit. This force is referred to as an E.M.F. – Electro-Motive Force, but its more usual title is ***voltage***. Normally, a single-cell battery has a potential force or voltage of 1·5 volts. It may be large or small, but if it is a single cell, it will still give approximately 1·5 volts regardless of its size. If we want more than 1·5 volts we can connect a number of cells in series. In figure 2 we have a single cell giving 1·5 volts and next to it are three such cells wired in series, thus giving three times the voltage, i.e. 3 × 1·5 = 4·5 volts. Manufacturers often wire up several cells and put them in a single case with the voltage marked on it. The electricity or the current driven by a battery is called direct current or d.c., because it flows in one direction only, from negative to positive.

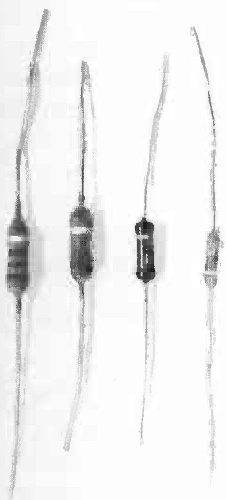
Figure 1/2



Alternating current

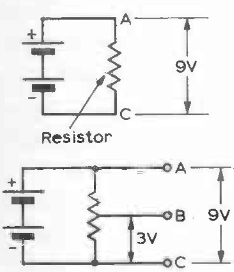
The other source of electricity referred to earlier is called a.c., standing for alternating current, because the current travels first in one direction and then in the other, i.e. it reverses or alternates. First one end of the circuit is positive, then it changes to negative so that the current still flows from negative to positive. By the same token the voltage alternates too.

Resistance



small fixed resistors

Figure 1/3

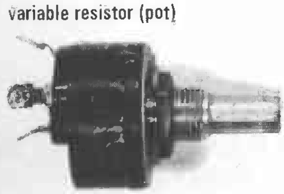


As its name implies, a resistor is a device which resists the flow of electrons. It is commonly made of carbon, but sometimes special resistance wire is used wound into a little coil.

If we have a radio set and one part needs 9 volts while another part needs only 3 volts, we have to find some means of dropping the voltage from 9 to 3 volts. It would not be economical to use a different battery for each particular voltage we needed. This is where the resistor comes in. In figure 3 we have a 9-volt battery and a resistor connected with wire to form a complete circuit. The battery will cause the current to flow from its negative terminal to its positive terminal through the resistor. If we could measure the voltage between the middle of the resistor and one end, we would find that it was less than the battery voltage. As we moved our ***tapping point*** up and down the resistor the voltage would be 9 volts between points A and C and would get progressively less as we moved down to point C (figure 3b). Thus by choosing our tapping point correctly, we could obtain our 3 volts from a 9-volt battery.

Resistance is measured in Ohms after a German scientist who discovered the law relating resistance, voltage and current. Current is measured in Amperes, but in low-power circuits we use milliamperes (abbreviated to milliamps or simply mA). One mA is one thousandth of an Ampere. Ohm's Law states that the voltage is equal to the current in Amperes (or Amps.), multiplied by the resistance in Ohms. Mathematically stated, $V = I \times R$. We use I as a symbol for current because C is already used as a symbol for capacitance which we will learn about later. Since $V = I \times R$, simple algebra allows us to say that $R = \frac{V}{I}$, and that $I = \frac{V}{R}$. Thus if we know any two of these quantities we can calculate the third. Let us take an example. We have a radio set which is powered by a 9-volt battery. We want 5 volts for part of the circuit which will draw 5 mA. Here we need to know

variable resistor (pot)



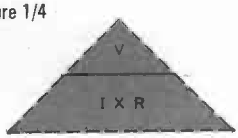
Ω

the value of a resistor which will drop 9 volts to 5 volts, i.e. will drop 4 volts (9 − 5 = 4 volts) when 5 mA is flowing through it. Ohm's Law tells us that $R = \frac{V}{I}$, so by substituting we have $R = 4/5/1000 = 4 \times 1000/5 = 800$ Ohms. We use the Greek letter omega for Ohms, so our result would be written 800Ω.

Again, if we have 100 volts and the resistance is 500Ω. The current flowing through this resistor would be, using Ohm's Law, $I = \frac{V}{R} = \frac{100}{500} = \frac{1}{5}$ Amp. = 200mA. (Multiply by 1000 to convert Amps to mA).

In order to assist in memorizing Ohm's Law, the triangle shown in figure 4 was designed. Cover the factor you wish to find with your finger, and the correct formula is left exposed. For instance, to find voltage, cover the V and read Ohm's Law I × R. To find resistance, cover R and read $\frac{V}{I}$.

Figure 1/4



Wattage

Wattage fixes the power the resistor can safely dissipate. When current flows in a resistor a certain amount of voltage is lost or dropped across it. The power lost is dissipated in the form of heat. Resistors are rated in Watts and if this rating is exceeded the resistor could easily over-heat and destroy itself. To find the Wattage we multiply the current flowing through the resistor by the voltage dropped across it. Thus in the case above we had 100 volts across a resistor with $\frac{1}{5}$ Amp flowing through it. Therefore $V \times I = 100 \times \frac{1}{5} = 20$ Watts. Resistors sometimes have their values in Ohms written on their bodies, but usually a colour code is used. This takes the form of three little bands of colour. The colour code is shown in figure 5. Always start reading the colour code from the end of the resistor nearest to the coloured bands. The first band gives the first digit, the second band the second digit, and the third band tells how many noughts or zeros to put after the first two digits. If the coloured bands were green, blue and orange, this would be a 56,000Ω resistor, i.e. first digit green band = 5, second digit blue band = 6, orange band = 3 zeros. A fourth band indicates the resistor's tolerance to this value.

Once we reach 1000 the letter k is used to signify × 1000. This saves us writing all those noughts.

Colour of band	digit or no of zeros
Black	0
Brown	1
Red	2
Orange	3
Yellow	4
Green	5
Blue	6
Violet	7
Grey	8
White	9

resistor colour code

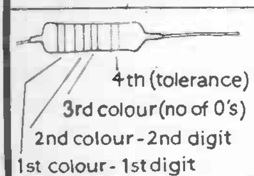


Figure 1/5

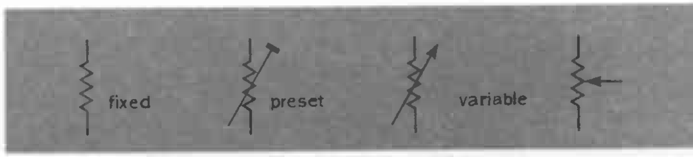


Figure 1/6

Our 56,000Ω resistor would be written 56kΩ. Again, 120,000Ω would be written 120kΩ. When we reach a million we use the letter M standing for Mega. Thus 1,000,000Ω would be written 1MΩ (1 Meg-Ohm). Note that we could write 500,000Ω as 500kΩ or 0·5MΩ.

Resistors can be made variable so that we can vary the amount of resistance in circuit. These variable resistors are called potentiometers or 'pots'. They usually consist of a block of carbon or sometimes resistance wire, with a little sliding metal finger which makes contact with the block. A volume control is an example of this and is shown in figure 6.

The circuit symbol for a fixed-value resistor is a zigzag line and when it is variable it has an arrow through it. Sometimes we wish to vary a resistor for the best result and then leave it set in a final position. Here we used a pre-set resistor or pot. These are really potentiometers, but to differentiate between them in circuits we use a fixed-resistor symbol with a little T across it.

Capacitance

In radio, a capacitor or condenser is rather like a storage jar or jug, but instead of liquid it holds or stores charges of electricity. Jugs are rated by how many pints of fluid they can hold; similarly capacitors are rated not in pints but in Farads. The Farad is such a large unit (imagine a million-pint jug), that micro-farads are more commonly used. A micro-farad is one millionth of a Farad and is written μF or occasionally mF. Even this is too large a unit for some circuits and we have to use micro-micro-farads which is a million millionth of a Farad and written μμF (mmF) or sometimes pF standing for pico-farad. Note that a 100pF capacitor and a 100μμF capacitor are both the same value.

μF
pF

A capacitor usually consists of two metal plates separated by an insulator so that there is no direct electrical connection between them. If we connect the two plates of a capacitor to the two terminals of a battery, the capacitor will charge up. The plate

Figure 1/7a

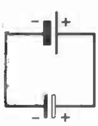


Figure 1/7b

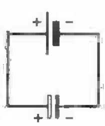
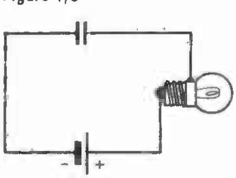
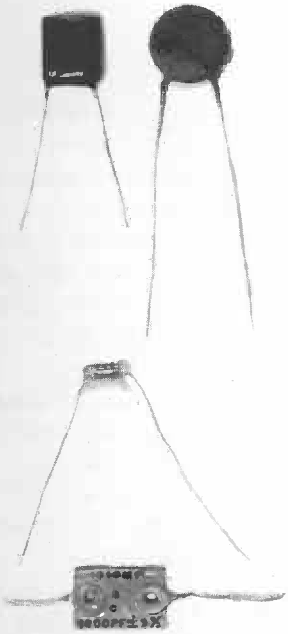


Figure 1/8

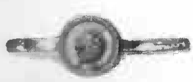


connected to the negative side will be rich in electrons, while the other plate will be starved of them. Immediately the battery is connected there will be a very brief flow of current (electrons), but this will cease as the plates become charged. Since no direct current can flow through the capacitor, the charges stay on the plates under each other's influence across the insulator which separates them. Also, the negative terminal of the battery has many surplus electrons, but since the negatively charged plate of the capacitor already has many electrons due to the capacitor charging up, these electrons tend to repel further electrons from the negative terminal of the battery; remember – like charges repel. As far as d.c. is concerned, the capacitor is a break in the circuit and thus no continuous current can flow.

With a.c. the voltage is alternating; positive, then negative, then positive again and so on (see page 16). If we connect our battery and capacitor as before and continually change over the wires to the positive and negative terminals of the battery, the plates of the capacitor would be alternately positive and negative. In figure 7a the current will flow very briefly to charge up the capacitor. If, when it is charged, we connect the battery round the other way as shown in figure 7b, then another current will flow in the opposite direction charging up the capacitor again. If we put a light bulb in the circuit (figure 8) and leave the battery connected as it is, the bulb will not light. The current which flows immediately the battery is connected is so brief (a fraction of a second), that the filament of the bulb will not have time to heat up and light. Now, if we keep on alternating the wires to the battery from positive to negative, the current will flow continuously from one plate of the capacitor to the other and back again. Since the current is now continually flowing backwards and forwards, and since to get from one plate of the capacitor to the other it must pass through the bulb, the bulb will light. For this reason we say that a capacitor is an open circuit to d.c. and can therefore block or stop it from passing, but will allow an a.c. signal to pass because of this charging and discharging procedure. This property is very useful in radio sets,

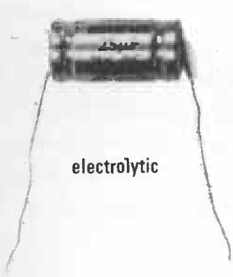


fixed capacitors



trimmer

trimmer compressor
postage stamp type



electrolytic

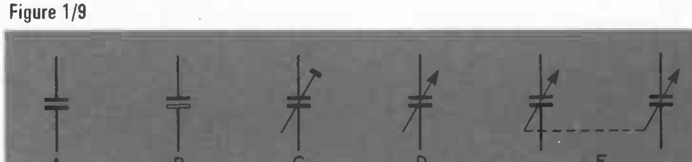
permitting us to pass on an a.c. signal but block any d.c.

Capacitors come in all shapes, sizes, and constructions. The smaller ones, which may be tubular or even flat like thin toffee, usually have their values marked on their bodies. The manufacture varies; some have plates of very thin metal foil interleaved with waxed paper and then all rolled up into a cylinder like a cigarette.

Another important type of capacitor is the electrolytic. It has its plates separated by a thin film set up by an internal chemical action. These electrolytic capacitors are marked negative at one end and positive at the other, although sometimes only one end is marked either with a colour – red for positive and blue or black for negative – or a plus and/or minus sign. It is very important that these capacitors are connected into the circuit the right way round (in the correct polarity). With ordinary capacitors this does not matter, but if electrolytics are connected the wrong way round, the voltage applied could easily puncture the thin insulating film and impair the capacitor. The circuit symbol for ordinary capacitors is two solid black bars. The symbol for an electrolytic is shown below. The hollow bar is the positive terminal, and the solid bar the negative one.

The value marked on a capacitor remains fairly constant and it is thus termed a fixed capacitor. Sometimes it is necessary to vary the capacitance and in these cases we use a variable capacitor, the symbol for which is shown in figure 9. A variable capacitor has two sets of plates, one set is fixed or stationary, while the other set can be rotated in continuous degrees, so that they interleave but do not touch the fixed plates, thus giving variable capacitance. Sometimes we want to vary a capacitor and when we have found the best value leave it set there. This type of capacitor is called a preset or sometimes a trimmer.

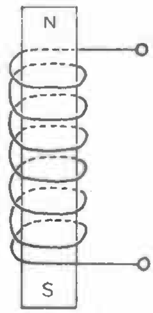
Figure 1/9



fixed | fixed (electrolytic) | variable preset | variable | twin gang variable

Inductance

Figure 1/10



If direct current (d.c.) is passed through a coil of wire round an iron former (core), the iron will become magnetized. Faraday discovered that the reverse was also true. If we take a hollow coil of wire and push a bar magnet into it, a current will flow through the coil and a voltage will appear across its ends. This is because the magnetic field surrounding the magnet interacts with the wire on the coil. We say that the lines of force or flux of the magnet 'cuts' the wire on the coil.

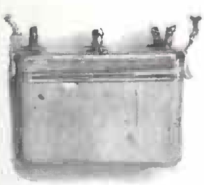
When the magnet comes to rest, after we have pushed it into the coil, we find that no current flows and thus no voltage is present across the ends of the coil. If we now pull the magnet out of the coil, again, current will flow and a voltage will be present. This time the current will flow in the opposite direction and the voltage across the coil will also reverse, the current flowing from negative to positive. Only when the magnet is moving will the current be induced and we could make current flow continuously by pushing the magnet rapidly in and out of the coil. In other words, the field or flux must be alternating.

Now imagine two coils wound very close together or even on top of each other. If we apply an alternating current to one coil, its magnetic field will be continually alternating. The lines of force set up by this coil will 'cut' the wire of the second coil and induce a current in it which will flow even though it is not connected to any source of power. This principle is used in transformers. The coil to which energy is supplied is called the 'primary', and the coil in which current is induced is termed the 'secondary'. If we wound ten times the number of turns on the secondary as there were on the primary, then feeding 10 volts a.c. to the primary winding would result in 100 volts a.c. across the secondary winding. In this case we would have a 'step-up' transformer. Similarly, by using a suitable number of turns on each coil we could have a step-down transformer. Note that transformers do not work on d.c., the current in the primary must be alternating.

A voltage is also induced across a single coil when a.c. is passed through its windings. The wire of the coil is 'cut' by the flux which the coil itself is producing.

coil with no core

coil with core



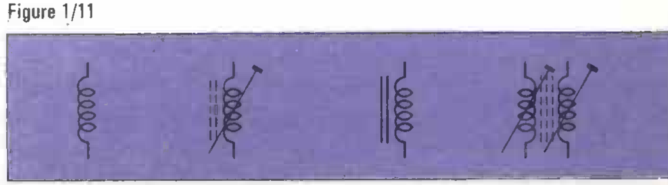
I.F. transformer

This self-induced current and voltage will always try to oppose the original current and voltage which caused it. If the original voltage makes the original current flow through the coil in one direction, then the induced voltage will force the induced current to flow through the coil in the opposite direction, thus opposing it. This induced voltage is referred to as a 'back e.m.f.' This property of coils is often used in radio to 'smooth' a.c. A choke (coil of wire) will pass direct current without hindrance because the direct current is not alternating and thus does not create a back e.m.f. to oppose it. However, a.c. will cause a back e.m.f. and as the a.c. tries to grow so the back e.m.f. will try to prevent this by causing a current to flow in the opposite direction. As the a.c. tries to get less or diminish in value, the choke or coil will give back some of the energy it has to try and make up the a.c. which is diminishing.

Coils are made in different sizes and wound with different thicknesses of wire and on different types of former, dependant upon the sort of circuit they are intended for. Some coils have no core at all, being wound on a hollow former. Others, called 'air-wound', do not have a former, the turns of wire being self-supporting. Mains transformers used in power circuits are wound on metal cores or formers.

Coils are often called 'inductors' because they all possess inductance. As the units for resistors are Ohms, and the units for capacitors are pF and μF, so the units for coils are 'Henrys'. This is a very large unit and milli-Henrys are often used – that is one thousandth of a Henry. In radio circuits we use an even smaller unit, a millionth of a Henry or micro-Henry abbreviated to μH.

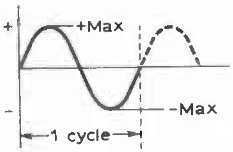
Figure 1/11



coil with no core | coil with core | coil with iron core (choke) | two coils coupled together with adjustable cores (I.F. transformer)

Frequency

Figure 1/12



c/s
Hz

An a.c. signal starts from zero, rises to a maximum positive value, decreases to zero again, goes down to a maximum negative value, then rises to zero. It continues this cycle of events for as long as energy is supplied. Starting from zero, after the signal has passed through one positive and one negative maximum and finally returned to zero, we say that it has passed through one complete cycle. The number of complete cycles per second is called the frequency. (see figure 12).

As with resistance, we use k to mean × 1000 and M for × 1,000,000. Thus 10 kc/s would be 10,000 c/s, the c/s in each case standing for cycles. Again, 5·5 Mc/s would be 5,500,000 c/s. The term c/s is now being replaced generally by the term Hz or Hertz. Whichever notation you come across, c/s and Hz mean exactly the same thing. You might see 780 kc/s which is exactly the same as 780 kHz or 780,000 c/s.

Most communications receivers have their dials marked in kc/s and Mc/s, but nearly all entertainment types are marked in metres. To convert one to the other we use the formula: Metres $= \frac{300{,}000{,}000}{\text{frequency in c/s}}$ i.e. the wavelength in metres is equal to 3 hundred million (the approximate speed of light and of electromagnetic waves) divided by the number of cycles per second. For example, on Long waves, the BBC radiate a programme on 1,500 metres. To find this in kc/s we rearrange the formula thus: 300,000,000/metres = c/s. Therefore, $\frac{300{,}000{,}000}{1{,}500}$ = 200,000 c/s or 200 kc/s (200 kHz).

The air is full of radio signals, that is, ac signals at a frequency too high for our ears to detect. If we erect an aerial, say 30 ft of wire hung between the house and a convenient tree, then these high frequency a.c. signals will induce a small voltage in the wire, causing minute currents to flow which can be detected at the end of the aerial by our radio set which converts them into a lower frequency which our ears can detect. Since there are many signals, we use a coil and a capacitor wired up together in parallel as a means of sorting them out.

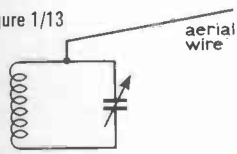
Reactance

When a.c. flows in a coil of wire it induces a voltage and current which tend to oppose the original voltage and current; this might be called a form of resistance. To distinguish from ordinary resistance like that of a resistor, we use the term ***reactance*** and it is also measured in Ohms. With a coil, as the frequency of the a.c. signal rises so the reactance of the coil rises.

A capacitor also has reactance, but here we find that as the frequency rises so the reactance of the capacitor decreases. If we wire a coil and capacitor in parallel as shown in figure 13, then at one particular frequency the reactance of the coil and that of the capacitor will be equal and opposite and will thus tend to cancel each other. When this happens we say that the circuit is ***resonant.*** The energy stored in the coil and that in the capacitor combine at resonance. The circuit now behaves something like a pendulum. If we push a pendulum it will swing from side to side, but eventually it comes to rest. If, however, we continued to give it a little push at just the right moment, it would not stop swinging. We would say that the pendulum was oscillating and that we were sustaining oscillations by supplying a short pulse (or push) of energy to keep it going. This is what happens at resonance in our parallel tuned circuit. The oscillations are started by the a.c. signal induced in the aerial and passed on to our tuned circuit. The current flows from one plate of the capacitor, through the coil to the other plate and then back again. Just like the pendulum, it is reinforced by another little push from the a.c. signal induced from the aerial. Other signals which we do not want to listen to are still inducing a.c. in our aerial, but it is the wrong frequency, the little pulses from these signals arrive at the wrong time and their effect on the tuned circuit is thus minimized.

By making the coil or capacitor variable, we can tune in different stations by tuning our circuit to different frequencies. It is usual to make the capacitor variable and keep the coil at a fixed value. Sometimes a number of variable capacitors are coupled together so that their capacitance can be varied simultaneously by rotating a common spindle. This type of capacitor is called a ganged capacitor.

Figure 1/13



2 | Semiconductors

Crystals and bonds

We said in the last chapter that the atom was electrically neutral, the net negative charge of the orbiting electrons balancing the net positive charge of the nucleus. In some substances, germanium and silicon, for example, the individual atoms are tightly bonded together in a regular pattern. In a crystal material, such as germanium, the electrons in the outermost orbits link with those in the outermost orbits of adjacent atoms, thus forming this crystal bonding. It is these linking electrons which we are interested in, since they are the ones which normally interact. The electrons orbiting each atom may have a number of different orbits, i.e. they circle their parent atom at different distances, but for our purpose we will consider the atom only with regard to the electrons taking part in these outer orbits which are called 'valence' electrons; the crystal bonds are called 'valence' bonds. Germanium and silicon each have four valence electrons and it is these two crystalline substances which are commonly used in the manufacture of diodes and transistors or semiconductors.

If we take germanium and purify it, we find that it is a near perfect insulator at zero temperature. As the temperature increases, some of the valence electrons acquire sufficient energy to break away from their atoms, and if a voltage is present across the crystal a current flows. We think of current in semiconductors as flowing both ways, from negative to positive and from positive to negative.

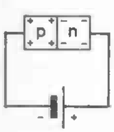
Current-flow

Imagine a crystal structure composed of many atoms. Suppose the first atom loses an electron. Since that atom was electrically neutral, it now acquires a charge equal and opposite to the electron it has lost. A positive hole appears in the structure where the electron was and it will readily attract and accept an electron from a neighbouring atom; this will make it neutral again, but now the second atom will have acquired a positive hole. The second atom in turn can take an electron from a third atom and so the positive hole will be transferred down the line. You will see that as electrons are travelling one way, positive holes are apparently travelling in the reverse direction. We talk of current carriers being negative, when the current is formed by the passage of electrons, or positive when the current is considered as a flow of positive holes.

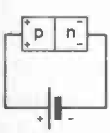
Depending on whether there is a predominance of electrons or holes, the semiconductor material is termed n-type or p-type. In order to ensure this predominance, the germanium (or silicon) is first purified, and then very minute quantities of a special type of impurity are purposely added. This is called 'doping'. Both germanium and silicon have four valence electrons. Indium has only three, so if we dope the pure germanium with a minute quantity of indium we will alter the crystal structure. The indium will form bonds with the germanium but, since it only has three electrons, it is one electron short and as a result of this we have electron deficit, there is a predominance of positive holes and the material is thus termed p-type. Likewise, other substances have five valence electrons, and if our otherwise pure material is doped with one of these, there will be surplus electrons and the material will be n-type.

Figure 2/1

a



b



In figure 1 we have a p—type and an n-type material which have been fused together to form what is called a p-n junction. In figure 1a, we have wired a battery as shown. Since unlike charges attract, the surplus electrons in the n-type material will be attracted to the positive terminal of the battery. Likewise, the positive holes in the p-type material will tend to be attracted by the negative terminal of the battery. Thus no appreciable current will flow through the diode and across the junction between the two types of material. Therefore the junction behaves like a very high resistance, so high that in practice we often consider it as an open circuit.

If we reverse the battery leads as shown in figure 1b, the reverse will happen. The negative terminal of the

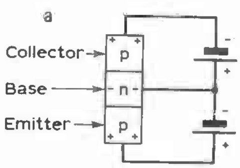
The diode

battery repels the electrons in the n-type material driving them towards the p-n junction. On the other side, a similar opposition or stress is experienced by the positive holes due to the repulsion from the positive terminal of the battery. As a result, the electrons and positive holes combine at the junction, a current flows and the junction behaves like a low resistance. We say that when the junction acts like a high resistance, then the diode is reverse biased, and when it acts like a low resistance, i.e. it conducts, the diode is forward biased. The circuit symbol for a diode is shown here.

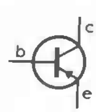
If we take two diodes wired up back to back, that is two p-n junctions, make these up as a single unit and wire up two batteries as shown in figure 2, the diode formed by the lower junction between the sections marked emitter and base is forward biased, that is, the junction will pass current. The top diode, the junction of the base and collector is reverse biased and thus acts as a very high resistance. Since the emitter-base is forward biased, then current will flow, positive holes flowing from the emitter into the base region which is made very thin. A few electrons flow from the base to the emitter, but these are kept low by the doping. As a result, many of the positive holes injected or emitted into the base by the emitter are drawn straight across the base region and are collected by the collector which is supplying positive holes as fast as it can to the negative terminal of the battery. A very small base current, has quite a large effect on the collector current, and thus we have amplification where a small quantity controls larger charges in another. The two p-n junctions shown in figure 2a constitute a transistor, the circuit symbol for which is shown in figure 2b.

Figure 2/2

a



b



The transistor

Manufacturing diodes and transistors is a very highly specialized process; it is not just a case of getting a piece of p-type material and a piece of n-type material and sticking the two together. For example, the melting point of indium is very much lower than germanium. Thus a small bead of indium is laid on a thin slice of germanium, and the two are heated until the indium melts and starts to dissolve some of the germanium with which it is in

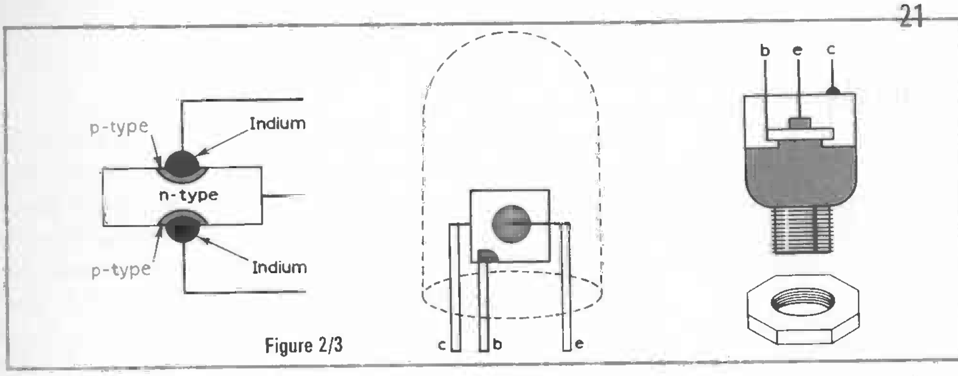


Figure 2/3

contact. The two are then allowed to cool and the germanium-indium junction reforms into the crystal lattice forming a diode junction. This process is called alloying. It is also possible to heat the base material almost to melting point in a gas which contains the doping element. As a result, the impurity is diffused into the surface of the base material and a junction is formed. Similarly, in transistors, the base material is again treated for the other junction. Some of these points are illustrated in figure 3.

The circuit diagram

Let us take our first look at a circuit diagram. There are basically three ways of wiring a transistor into a circuit. In figure 4 we have the circuit diagram of a simple transistor amplifier. The circle represents the transistor, the base being drawn as a vertical bar or line, while the emitter and collector are drawn as lines coming from the base at an angle. The emitter is identified by a little arrow head. There are two types of transistor in common use. The type shown in figure 4 is a p-n-p type, signified by the fact that the head of the arrow is pointing inward towards the transistor. If the arrow head was pointing outward, then the transistor would be an n-p-n type. In order to avoid confusion, only p-n-p types have been used in the circuits shown in this book. The The zigzag lines are resistors. The fixed resistors are described in Chapter 1, and the two other components marked C1, and C2 are capacitors; they are electrolytics, shown by one bar of the symbol being hollow.

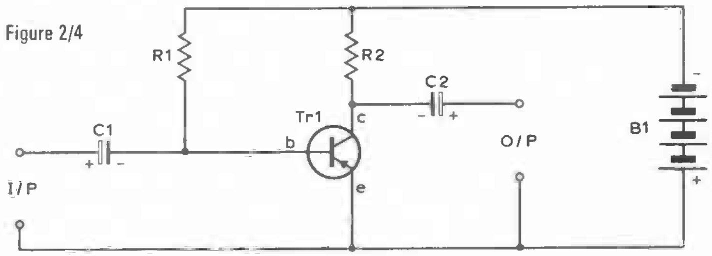
As shown, the transistor is said to be in the common emitter configuration. This is because the signal coming into the amplifier is applied between base and emitter, and the output or amplified signal is taken from the collector and emitter, the emitter thus being common to

I/P
input

both input and output. The two other circuit configurations are common base and common collector. Again, in order to make things simple, the circuits in this book have been resistricted only to the common emitter type, which is the configuration most generally used anyway. In the circuit in figure 4, the signal we wish to amplify comes in, or, is fed to the input connections marked I/P. Since the signal is varying in strength or amplitude, it is in fact an a.c. signal. When the a.c. signal arrives at CI, it can pass on to the base of the transistor. A capacitor is an open circuit to d.c. and cannot pass it, but a.c. can flow because of the charging action of the capacitor (see page 11).

The d.c. bias voltage applied to the base is obtained by R1. The base will draw very little current, but it will draw some and since the current, to get to the base, must pass through R1, then R1 will have a voltage dropped across it. The exact voltage will depend on the current and the value of R1. In this way, we can arrange for the voltage at the base to be some value in between that at the collector and that at the emitter. The amplified signal arrives at the collector and here we need R2. If the collector were connected straight to the negative supply, there would be nothing for the signal to develop across, and the capacitor C2, being also connected to the negative supply line in our mythical circuit, would not pass on any signal because the negative line is d.c. and the capacitor will not allow d.c. to pass. If we put in resistor R2 as shown with C2 in figure 4, things will alter dramatically. The signal input at the base first causes the collector current to increase and then to decrease. Since the current flowing either to or from the collector must also flow through the resistor R2, because they are wired in series, then the current through R2 will also vary in sympathy with the collector current. As a large variation in current passes through the resistor, a large voltage difference will appear across the ends of the resistor, a small variation will produce a small rise or fall in voltage. So, as the current rises and falls, i.e. alternates, so this produces an alternating voltage across the resistor R2 and we have an a.c. signal which the capacitor C2 can pass on to the next stage.

Figure 2/4



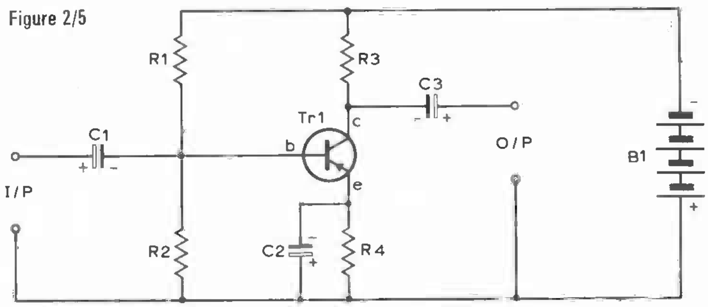
Note in our circuit of figure 4 that the capacitors are electrolytics. This is an indication that the circuit is intended to amplify low frequencies, such as audio frequencies (abbreviated to a.f.).

Some transistor amplifiers are designed to amplify signals, such as those used in broadcasting, whose frequency is very high indeed, way above the range of the normal ear's response. These radio frequencies (r.f.) can only be heard by using a radio receiver, which converts the r.f. into a.f. or alters the frequency to a lower one which is in the range of our hearing.

Thermal runaway

The simple circuit in figure 4 has certain disadvantages, although it can be made to work in practice. One of the problems with a transistor is that it is sensitive to heat. The trouble with this heat problem is that as the transistor gets warmer it passes more current which in turn makes it hotter still, until eventually the transistor could destroy itself. This condition is known as thermal runaway. If the battery supply is kept very low and the transistor is not stood in the sun or exposed to any great source of heat, then thermal runaway is remote. However, it is sometimes necessary to operate transistors in places where there are wide ranges of temperature. In these instances we use a different bias system which helps to discourage thermal runaway by contributing a measure of compensation.

Figure 2/5

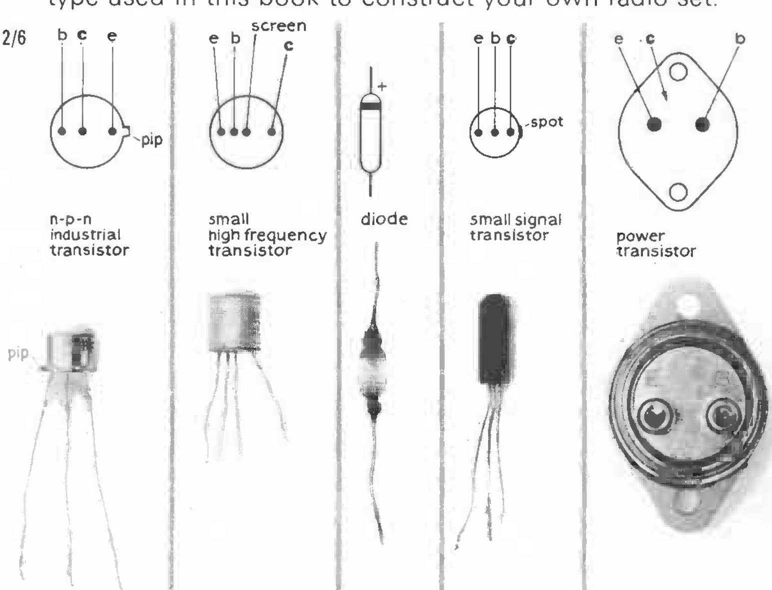


Potential divider Look at figure 5. Here we have the input capacitor C1 which is letting the a.c. signal through and blocking the d.c. Also, there is a resistor, R3, which acts as a load, or something for the output amplified signal to develop across. We have C3, which passes on the amplified signal and again blocks the d.c., so these three components are doing exactly the same job as their counterparts in figure 4. In addition we have wired an extra resistor, R2, from the junction of the base and one end of R1, to earth or positive. We also have a resistor and capacitor wired in parallel, and then both wired between the emitter and earth line. If we ensure that R1 and R2 have a fairly low resistance, then the current passing through these resistors will be high, certainly much higher than the small current passed by R1 in figure 4. The arrangement of R1 and R2 in figure 5 is called a potential divider. By varying the values of the two resistors, we can vary the voltage available at the base connection within the limits of the battery voltage. Since now the current flowing through R1/R2 is large, then the very small base current which flows through R1 will not affect the voltage drop across R1 to any great extent, and the voltage at the base connection will remain almost constant. It will tend to remain steady, no matter how much the bias current passing through the transistor base may increase. Since the resistor R4 is in series with the emitter lead, then any current which passes through the emitter or collector, must flow through R4.

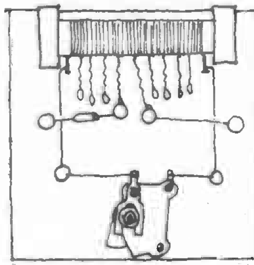
Let us suppose that heat tries to make the transistor pass excess current through R4. Immediately the current through R4 increases, so the voltage across it is greater and there is less voltage between the emitter terminal and the base terminal, the voltage on the base being kept constant by the potential divider R1/R2. With this decrease in voltage between emitter and base, there is a corresponding decrease in collector current, and so the transistor can now protect itself against thermal runaway.

Construction Transistors come in varying shapes and sizes. Some have a metallic case, while others have a plastic covering or encapsulation. Some are very small; usually these are the ones which handle low power. Others are larger, some $\frac{7}{8}$in in diameter and $\frac{1}{2}$in deep. These large power types are sometimes mounted directly to a metal plate which helps conduct heat away from the transistor. The plate is sometimes finned, and is called a heat-sink. Many power types have only two pins or leads, the third connection being the actual metal casing of the transistor. Again, to ensure that the leads are identified, manufacturers often mark the body with a small dot of paint. Others arrange the wires in a certain pattern so that the different leads may be identified. Yet others make the shape of the case tell where to start. In figure 6 are some transistors and base connections, mostly of the type used in this book to construct your own radio set.

Figure 2/6



3 | The Crystal Receiver



This type of receiver is just about the simplest and cheapest there is. It is practically foolproof too, since a mistake in the wiring will simply prevent the set from functioning properly, but it will not damage any of the components. The wiring fault will usually show itself as (*a*) the receiver not working at all or (*b*) the receiver functioning at greatly reduced volume.

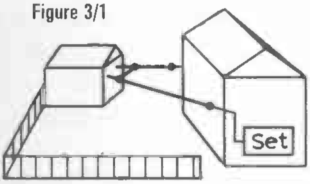
Propagation

A wave of radio energy can travel to us in one of two ways; either straight towards us, following the earth's surface or up into the air until it reaches ionized layers in the atmosphere and is reflected back down to earth again. In the case of very high frequencies, say television, the waves strike the atmosphere in such a way that they pass right through and travel out into space. This is why television is normally restricted to line-of-sight type of distances, whereas ordinary short waves, which are lower in frequency, can be made to travel all round the world by reflection from the ionosphere. Sometimes both the ground-wave and the reflected sky-wave are picked up by the receivers. If they both arrive at exactly the same time, they will reinforce each other and the signal strength will apparently increase, but if they arrive at different times, then they are said to be out of phase, and the signal strength will tend to decrease or fade.

The crystal receiver pays for its simplicity in that it will only work, in normal circumstances, with a very good aerial and/or when it is reasonably close to the transmitter, about 60 miles being considered the maximum distance by some. You notice I say 'in normal circumstances' and that 'about' 60 miles is considered maximum. There have been occasions when the simple crystal set has received signals at far greater distances.

The aerial First, then, the type of aerial. Generally, as long as possible and as high as possible is the rule. Supposing the garden is only 30 ft long and the garden shed is 18 ft from the house. Buy 50 ft of insulated wire, the type sold in chain stores for bell wire will do. It has a single centre conductor, or sometimes a number of thinner wires, and an outer protection of insulating plastic. (This wire is ideal for wiring up the set, too.) Run the wire from the house to the shed, which will give 18 ft; hold it in place by wrapping it round a nail. Across the shed now and round another nail, say another 4 ft, that makes it 22 ft long so far. Now run the aerial back to the house (another small nail) this will give us another 18 ft or a total length of 40 ft. This length doesn't include the rest of the wire which must be taken into the house to plug into the aerial socket on the set. You will now see that even in a limited space we can still get quite a long aerial out. Sometimes the most unlikely things work as aerials. The bed-springs, for instance, could be tried. The guttering also might work, while the prototype set worked very well when a short wire was connected from the aerial socket to the wire fence running down the garden.

Figure 3/1



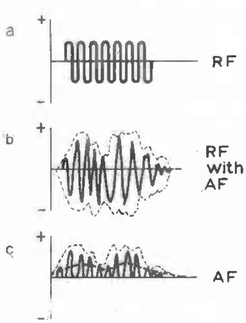
The earth Another requirement of the crystal set is a reasonably good earth. ***Do not*** take earth leads to odd metal pipes in the house in the belief that they will go outside underground and thus offer a superb earth. It is far safer to take a length of wire from the earth terminal of the set, out of the window, and connect it to a piece of metal pipe driven into the ground. You could drill a hole in the pipe for a small nut and bolt, and fasten the earth wire to the rod this way.

In the last chapter we described how the a.c. voltages and currents of the radio waves affected the aerial. We said that the radio waves induced an a.c. current into the aerial wire, and that since there were many radio stations and therefore many radio waves, then we must have some means of tuning into the one we want and rejecting all others. The way we did this was with a coil and a capacitor wired in parallel.

So now we have four things on the list for our crystal set. An aerial, an earth, a coil and a capacitor. We will also need some headphones in order to hear the signal because headphones respond to a.f. (audio or audible signals). Headphones are composed of a magnet with a coil of wire wound round it. In front of the magnet is a disc of metal which is attracted or repelled by the magnet depending on the signal flowing through the coil. The disc fluctuates in sympathy with the a.f. voltage or current applied to the coils. The discs movement causes a similar movement of the air creating sound waves, and thus we can 'hear' these alternating voltages. Headphones thus convert electrical energy into sound energy which our ears can detect quite easily.

One small snag remains. The radio wave which we have tuned by our tuned circuit is r.f. and our headphones can only detect a.f., so we need some means of converting the r.f. signal into a similarly fluctuating a.f. signal.

Figure 3/2



In figure 2a we have a symbolic drawing of a radio wave. It is simply an r.f. wave. A Morse signal consists of a wave like this, the wave being interrupted or broken up into dots and dashes. In figure 2b we have an r.f. wave with some modulation. This is really a wave as shown in figure 2a, but the speech or music has been used to alter the amplitude of the wave, so that some of the peaks of the wave are high and others low. The frequency remains the same, only the amplitude varies in sympathy with the speech or music, thus this type of wave is called amplitude modulated. Unfortunately neither our headphones nor our ears can follow the very high (r.f.) frequency of these signals.

We know that a diode has a very low resistance when current tries to pass in one direction, and has such a high resistance in the other direction that it might even be considered as an open circuit. This property of the diode is used in our crystal set to convert r.f. signals into a.f. signals which our headphones and ears can appreciate. If we wire our diode into the circuit so that any current flowing to the earphones must flow through the diode, we find that the current will only flow one way. When the diode is forward biased it will allow current to flow with little hindrance. When it is reverse biased it will not allow current to flow. In this way we end up with the waveform shown in figure 20. Here the wave is still varying in sympathy with the a.f., but it starts from zero and increases in various intensities, without going below zero. Our headphones still cannot vibrate at such a high frequency, but whereas before (figure 2b) the wave peak in the positive direction had its effect cancelled almost immediately by a negative peak in the other direction, now, the peaks are always positive to a greater or lesser degree and our head-phone can thus follow the average level shown by the dotted line in figure 2c, which provides the type of variation which they can act on.

Figure 3/3

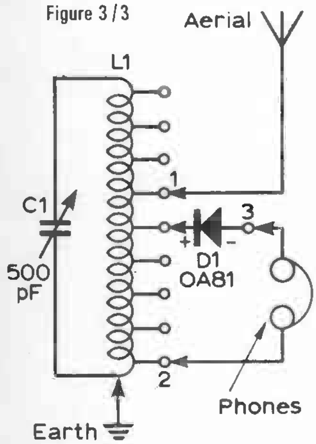
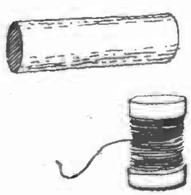


Figure 3 shows a circuit diagram of a crystal set. C1 is a variable capacitor, used to tune in the stations. L1 is a coil of wire which has inductance; together with C1 it forms a tuned or resonant circuit and thus works efficiently at the frequency to which it is tuned or resonant. The aerial and earth terminals are anchoring posts for these two wires. D1 is a diode; note it has a positive and a negative end, rather like the electrolytic capacitor. The positive end sometimes has a ring nearest to it, and sometimes is marked with a red dot or red colouring. The other end is automatically taken as negative.

Construction

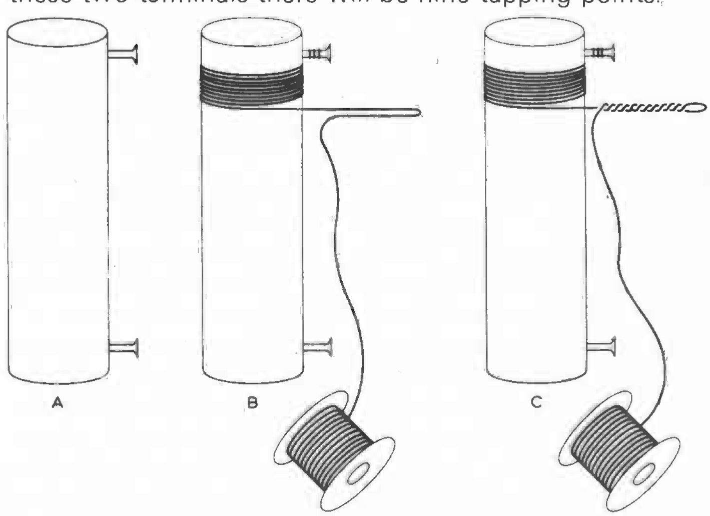
Our set is constructed on a piece of hardboard measuring 5 × 5 in. First drill or file a $\frac{3}{8}$ in diameter hole for the tuning capacitor. It has a threaded shank and a brass nut for mounting it to the hardboard as shown in the photograph.

It is possible to buy ready made coils for crystal sets, but the coil in the prototype gave superior results to the bought one. To make the coil you will need a piece of wooden broom handle 1 in diameter and $3\frac{1}{2}$in long for the former. A 2 oz reel of 24 s.w.g. (standard wire gauge) enamelled copper wire. The smaller the number is, the thicker the wire. Drive two copper nails into the

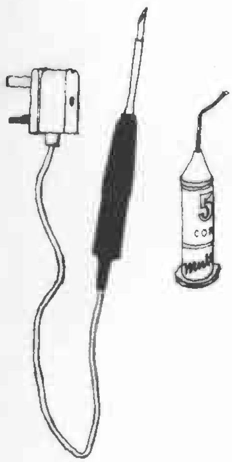


wooden former $\frac{1}{4}$in from each end. The wire is soldered to these nails at the beginning and end of the completed coil.If you make the coil former $\frac{1}{2}$ in longer at each end, then you can use brass drawing pins as anchor points and solder directly to them. Having positioned the two end terminals or anchor points, we now have to wind a coil of 100 turns of wire close-wound. This means that the turns are touching side by side. The copper has a coat of enamel which insulates it. We are also going to arrange the coil so that we can have a tapping point every tenth turn. Starting at one end, we first solder the very end of the wire to the end pin or terminal. Then we wind on ten turns, after which we make a 2 in loop of wire and twist it to form a little loop at the end of a twisted piece of doubled wire. (figure 4.) We continue in this way until we have made 100 turns. There will be two terminals, one at each end, to which the beginning and end of the coil is soldered. In between these two terminals there will be nine tapping points.

Figure 3/4



Soldering The copper wire is insulated by the coating of enamel, so when you want to solder it you must first remove the enamel coating. For this it is best to use a small piece of emery cloth, although sand paper will do at a pinch. Gently draw the wire between the sides of the abrasive; this will expose the bright copper underneath. Make sure that there is no enamel left on the wire where you



intend soldering it. It is always advisable to 'tin' (coat with solder) both things you wish to solder together. Make sure that the iron is hot and that the tip is clean. If it isn't, give it a rub with some steel wool, emery cloth, or sand paper, and touch the solder on to it for a nice bright clean silver surface. Always use resin-cored solder as the resin acts as a flux and makes any other flux unnecessary. To tin the terminals at the ends of the coil, touch the end of the iron with solder, put the iron in good contact with the terminal and touch the solder on to the terminal. As soon as it melts, remove the solder and then the iron. You should now have a nice clean coating of solder on the terminal pin. This procedure is repeated with the other terminals and the cleaned end of the enamelled wire you intend using on the coil. The tinned end of the wire is now wound twice around the terminal and the hot iron applied. Touch the tinned wire and terminal with the resin-cored solder, which should melt almost at once. Remove the solder and then the iron. The soldered joint should cool to a bright metal and if it is dull or lumpy it is possible that you have a bad joint, often called a dry joint. If this happens re-apply the iron until the solder melts and then remove it again.

When the complete coil is wound it is necessary to clean the little loops at the end of the taps on the coil. This is again done with an abrasive cloth or paper making sure that the inside of each loop is quite clean and free from enamel, after which each loop end is tinned.

Having wound the coil, take two small squares of soft wood $1\frac{3}{8}$ in square × $\frac{3}{8}$ in thick. These are fixed at each end of the coil and are used to mount the coil itself to the hardboard. One small nail is sufficient to hold the small squares of wood to either end of the coil. Two small nails are driven from the front of the hardboard into the edges of the soft wood squares (see photograph page 33).

Having mounted the variable capacitor and the coil, push six drawing pins into the hardboard to act as soldering points. (Even if you do not possess a soldering iron you can still wire up a crystal set by winding two

Components

C1. 500pF variable capacitor
 – Jackson Dilecon
L1. Coil see text
D1. Diode – Mullard type OA81
High resistance headphones
 (4000 Ohms)
wire for aerial and earth
hardboard 5 × 5in
6 drawing pins
card for dial, knob
2oz reel of 24swg enamelled
 copper wire
1in dowel diameter $3\frac{1}{2}$in long
wood $1\frac{3}{8} \times 1\frac{3}{8} \times \frac{3}{8}$in (two)
resin cored solder
2 copper tacks
2 half-inch nails

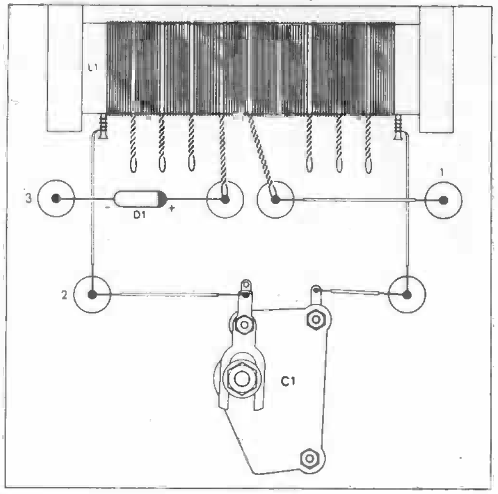
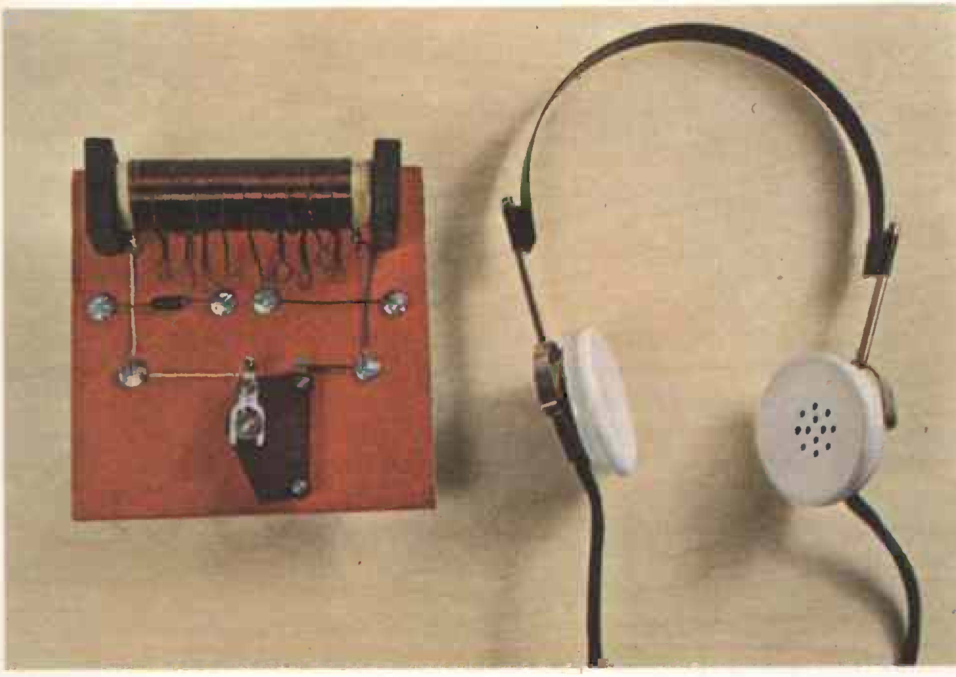


Figure 3/5

turns of the wire around the drawing pin before pushing it into the hardboard). Use a plastic covered wire for wiring up, removing a small amount of insulation from each end of the wire where you want to solder. When you wire up the crystal diode, hold the wire you are soldering with a pair of pliers. Semiconductors don't like heat, which can easily change their working characteristics. By holding the diode in place with a pair of pliers around the wire lead, the heat travelling up the wire from the soldering iron will be conducted away from the diode itself by the large metal expanse of the pliers (see also page 37).

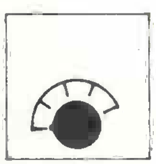
When all the wiring is completed the only thing left to decide is the best tapping point for the aerial and diode respectively. In the prototype, the best positions were, starting from the earth end as 0, diode tapped in at 40 turns, and aerial tapped in at 50 turns. Experiment with these points and see which combination gives you the best volume and station separation.

With the values given for the coil and capacitor, the set tunes the medium waveband.



The crystal receiver and headphones

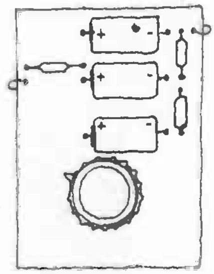
Connect the aerial wire to point 1 in figure 5, and the earth lead to point 2. Now connect your headphones between points 2 and 3. This means that you will have two connections to point 2, one of the headphone leads and the earth lead. Now tune the variable capacitor until a station is heard. Rotate it further to see if you can pick up any other stations. Now is the time to experiment with the tapping points, since you do know the set is working.



The front of the set has a small white knob which is fitted to the spindle of the variable capacitor. The dial was made out of scraper board (obtainable from most stationers and art shops) which is a white chalk-board with a matt-black coating. By scraping or scratching this black surface with the special nib provided, the white shows through. The smallest packet, which contains ample board, costs 2/6d.

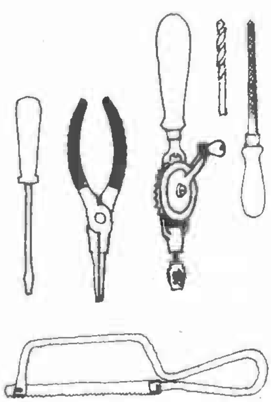
In the next project we are going to use two transistors and make a small two-transistor amplifier. We will be able to use it as an amplifier for the crystal set or either of the other two sets shown later in the book.

4 Transistor Amplifier



In this chapter we are going to build a two-transistor audio amplifier. In order to make the most use of our components, the amplifier has been designed especially so that it will allow you to plug the simple crystal receiver into it and thus amplify the signals sufficiently for them to be heard on a small loudspeaker. The amplifier may further be used with the other two receivers described later on.

Tools



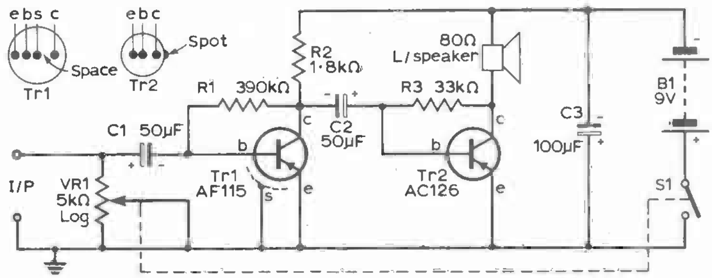
Some tools are necessary right from the start. You will need a good electric soldering iron with a small pencil bit, and a reel of resin-cored solder. Flux is present in the core of the solder and helps to prevent oxidation which would otherwise ruin a good joint. The tools I used in building the amplifier are as follows; electric soldering iron and resin-cored solder, small screwdriver, pair of long-nosed pliers, fretsaw with metal cutting blades, hand drill, $\frac{3}{8}$in twist drill, $\frac{1}{4}$in dia. round file. These tools are the bare minimum for the projects described in this book. The soldering iron is essential, and though it might be possible to scrape by without the other tools, this would make construction very difficult.

Before starting to build any project, always check the components list to make sure that you have everything. Carefully check all the values, especially of resistors, if you are not used to the colour coding.

Circuit diagram

The circuit diagram of our amplifier is shown in figure 1. The two points marked I/P (input) are where we feed the signal in from our receiver. The volume control is marked VR1 and varies the amount of signal fed into the amplifier. When the slider (shown by the little arrow) is at the top of the resistor, i.e. nearest to the capacitor C1, then the signal is shorted to earth and so no signal is fed in at all. When the slider is at the other end, it

Figure 4/1



doesn't short out any of the resistor VR1, and thus all the signal is fed into the amplifier, corresponding to maximum volume. Capacitor C1 will allow the a.c. signal to pass on, but will prevent any d.c. passing which might upset the voltage on the base of transistor Tr1. Note that this capacitor is an electrolytic and must be connected the right way round. The positive end will either be marked with a + sign, or will have a red dot.

The base current passes through R1 and thus by choosing a suitable value for R1 we can adjust the voltage applied to the base (see page 22). Resistor R2 forms the collector load and allows the signal to develop across it. The varying (a.c.) amplified signal at the collector is passed, via C2 (capacitor), to the base of the second transistor Tr2. Again, the capacitor's function is to pass the a.c. signal and block the d.c. which would otherwise flow from the negative supply lead, through R2 and on to the base of Tr2. The 33 kΩ resistor R3 supplies the correct base voltage to Tr2 in the same way as R1 did for Tr1. The collector load of Tr2 is the loud-speaker which allows us to hear the amplified a.c. and thus our amplifier is complete.

The capacitor C3 serves to 'decouple' the supply voltage. Some of our input signal might sneak through into the negative supply line, and to prevent this happening we put a large value capacitor directly across the supply line. This will allow any a.c. signal to pass and will promptly short it straight to the positive earth line. To the 9 volts d.c. it makes no difference at all, because, like all capacitors, it is an open circuit to d.c.

You will notice that there is a dotted line shown from the on/off switch to the volume control VR1. This means that the two components are one. The switch is built into the volume control. When two components are controlled by one thing we say that they are 'ganged'.

Construction

Take the strip of veroboard and cut off a piece $2\frac{1}{2}$ in long. The rest can be kept for other projects. Drill a hole in one end for the volume control and on/off switch as shown in figure 2. Enlarge the hole you have drilled with a round file until it is $\frac{3}{8}$in in diameter. The filing should be done carefully so as not to crack or break the veroboard. Now mount the control VR1 on to the board with the crimped washer between the control and the board. Put the nut on and tighten it up firmly. The spindle on the control can be cut down to 1 in with a fret-saw fitted with a metal cutting blade. You can buy a little bundle of blades from most hardware or tool stores.

The next step is to mount the three resistors and three capacitors roughly in the position shown in figure 2. All these components are mounted by bending their leads at right angles, and pushing them through the holes in the board. Once the resistors and capacitors are mounted on the board, leads from these components, which are joined together and soldered, are twisted together once and the excess wire cut off. This will be sufficient to hold the individual components in place on the board. Where a single lead is needed as a terminal, the wire from the relevant component is brought back up through an adjacent hole. This is the case with R2, of which one end goes to join 390 kΩ resistor, C2 and the collector lead from Tr1. The other end joins the negative lead from C3, and this junction is a terminal to which is connected the battery negative lead and one of the loudspeaker leads (see figure 4). In figure 3 the underside or wiring side of the board is shown, and when you have finished wiring up the components compare your board with figure 3. If all is well you can now wire in the transistors.

Soldering in transistors

Care is needed when wiring in semiconductors, which is why we leave them until last. One great danger is the heat while soldering. If you apply a hot soldering iron to one of the leads of a transistor and leave it there for any length of time, the heat from the iron will travel up the lead and into the transistor itself until it arrives at the p-n junctions. Too much heat at one of these delicate

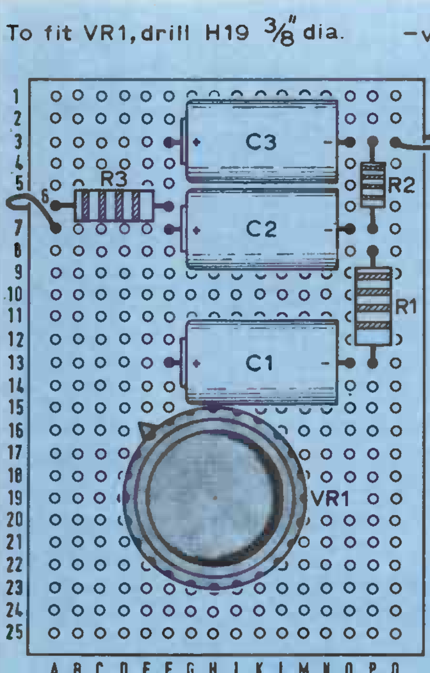


Figure 4/2

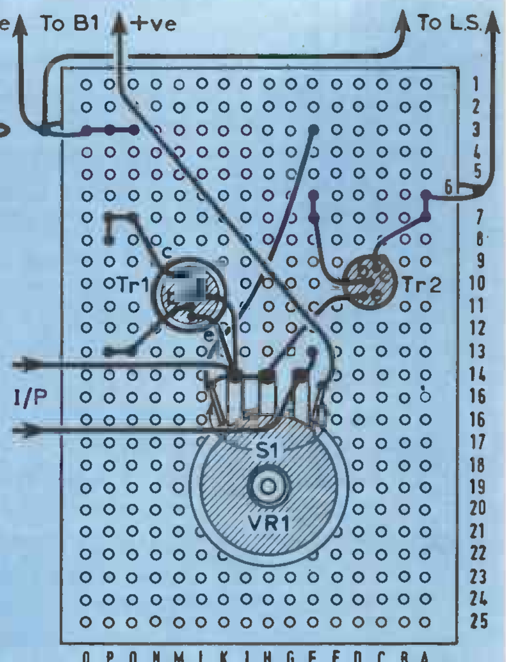


Figure 4/3

Figure 4/4

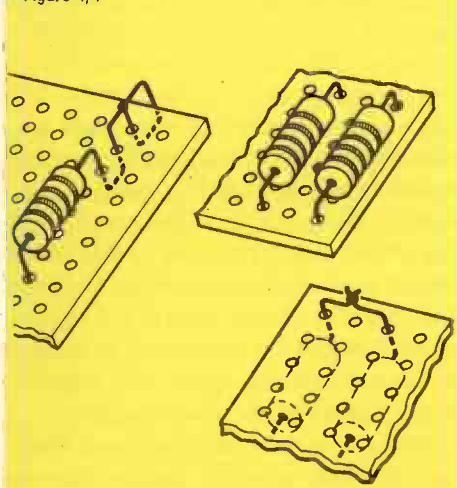
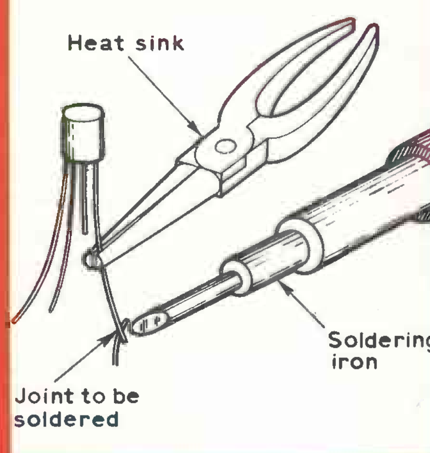


Figure 4/5



junctions can ruin the transistor. The wiring-in of transistors should therefore be left to the very last, as it is all too easy to touch the leads with the soldering iron accidentally when soldering in another component.
To safeguard against damaging the transistor we use a 'heat shunt', so called because it 'shunts' some of the heat away from the transistor.

If we grip the transistor lead with our long-nosed pliers when we solder it into circuit, the metal pliers will conduct away most of the heat (figure 5). By gripping the lead you are soldering about $\frac{1}{4}$ in up, you can then put the lead to the point where it is to be connected and solder it into the circuit without worrying too much about the safety of the transistor. When the joint is soldered, remove the soldering iron tip, but keep hold of the lead with the pliers. A metal-soldered joint can store up quite a lot of heat, and it is best to keep the pliers in position for at least twenty seconds after the iron tip is removed. The heat travelling up to the p-n junction might not be sufficient to ruin the transistor completely, but it might easily be enough to alter the internal workings, causing instability, or more usually lack of gain, so that the transistor will not amplify as it should.

Tr1

Before connecting the transistors it is very important to identify the leads. In our amplifier one transistor has four leads and the other has three. The transistor types were purposely chosen so that there would be no difficulty in differentiating between Tr1 and Tr2. Transistor Tr1 is the one with four leads. Looking at the bottom of Tr1 as shown in figure 3, you will see that the four leads are in line, but that there is a large gap. Three leads are close together and the fourth one, much farther away, is the collector lead. Immediately next to it is the screen, then the base, and finally on the left-hand side is the emitter. The screen is shown in the circuit diagram as a dotted line between base and emitter leads, and is connected internally to a screen between the junctions. In order to make the lead identification a little easier, it is a good idea to mark the case of the transistor with a thick pencil line on the side next to the collector lead. The transistors in our amplifier are wired in upside down so that the position of the leads can be seen at all times.

Orient the transistor Tr1 so that the emitter lead is nearest to the volume control. The emitter lead and the screen lead are then both connected to the left-hand upper terminal. The volume control has five tags or terminals, two thin wire ones at the bottom, and three thicker tags at the top. The bottom two tags are the switch connections, while the top three thick terminals are the potentiometer tags. The base lead is bent down carefully and soldered to the juntion of C1 and R1. When bending the leads, it is advisable to grip the wire about a quarter of an inch from the transistor case with the pliers and then bend the lead by hand. This will take any strain off the lead-in wires where they enter the transistor. The collector lead is now bent and soldered to the junction of R1, R2, and C2, while the base goes to junction of R1/C1.

Transistor Tr2 can now be soldered into the circuit making sure that it is oriented as shown, with the emitter lead nearest to the volume control, and the collector towards the terminal formed by one end of the 33 kΩ resistor R3. Note the new collector lead is the one nearest to the spot on the case. This junction forms a terminal for connexion to one side of the loudspeaker.

Tr2

Now connect the loudspeaker to the two terminals as shown in figure 3. It doesn't matter which lead of the speaker goes to which terminal. Having done this, check the whole circuit carefully, following it round by comparing it with figure 1. Then check your wiring against figure 3. If all is correct you can now connect the battery, making sure it is the right way round. The negative terminal of the battery should go to the 1·8 kΩ resistor R2 where it joins the negative side of C3. This point is easy to locate because one side of the loud-speaker also goes to this point, which is on the left-hand side of the board shown in figure 3. The positive battery terminal lead will be connected to the right-hand bottom switch tag of the volume control. Check the battery wiring again and make doubly sure that it is correct. If it is connected the wrong way round, you could easily ruin both transistors.

The battery specified is a special long-life battery which is more expensive than some other types. If you prefer, of course, you can use one of the cheaper types. The battery terminals consist of two little clips which plug into the battery. One is male and the other female so that it is almost impossible to plug them into the battery the wrong way round. The two wires leading from these terminals are a red positive and a black negative lead.

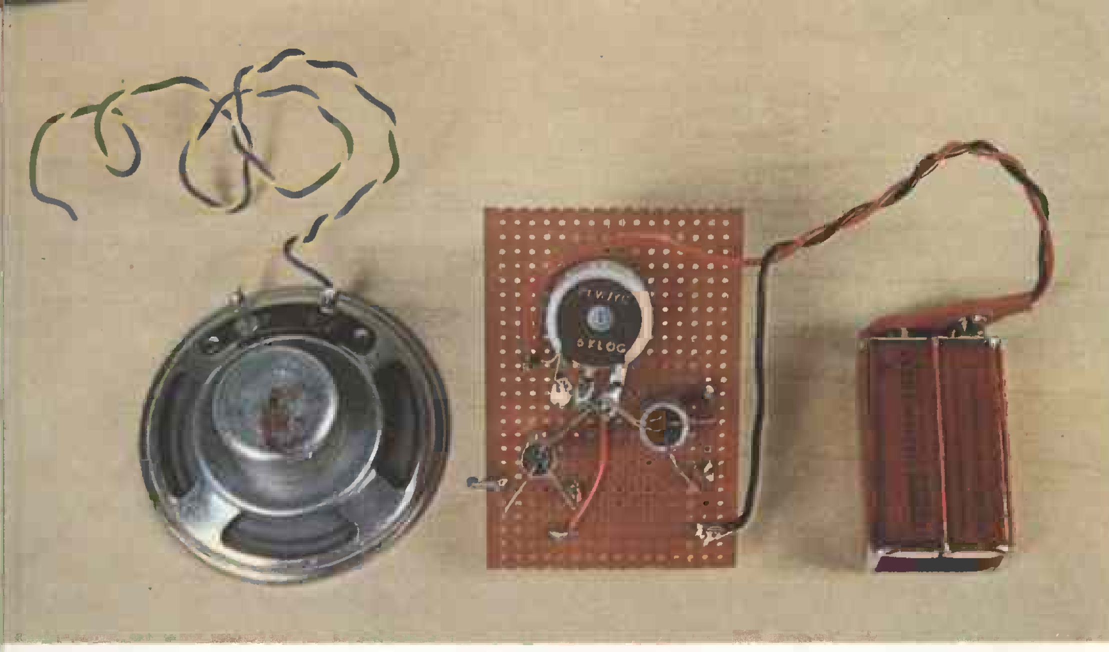
Testing

Turn the volume control fully anti-clockwise. As it goes into this position you will hear a little click as the on/off switch turns to the off position. Connect the battery plugs to the battery and turn the volume control clockwise slightly. Again you will hear a click as the on/off switch goes into the on position. If you touch the right-hand top terminal of VR1 (this is the tag which is soldered to the positive side of C1), you should hear a buzzing sound in the loudspeaker. If this is not so, switch off and recheck the wiring.

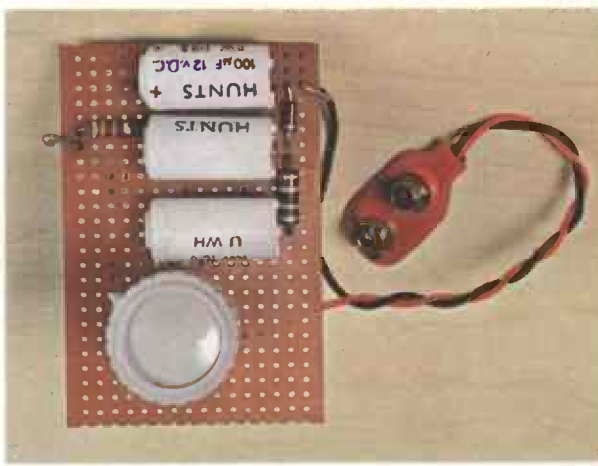
Connecting the crystal set

To connect the amplifier to the crystal receiver you will need two wires, preferably of different colours and about 6 in long. Twist them together and connect one from the earth (terminal 2) of the crystal set to the earth (or positive line) of the amplifier. The other wire connects the terminal 3 on the crystal set, which comes from the negative end of the crystal diode, to the right-hand top tag of VR1. Disconnect the headphones, fit a suitable knob on to the shaft of VR1 and the project is complete.

It should now be possible to hear the stations received on the crystal set at loudspeaker strength. If the signal sounds very loud and distorted, turn the volume control down by rotating the shaft clockwise. This is purposely the opposite direction of rotation normally used. If the amplifier switch is left on unintentionally, it does not harm the crystal set, but the amplifier battery is being run down unnecessarily so to avoid this, the position of maximum volume coincides with the maximum degree of rotation before the on/off switch goes into the off position. Thus when switching off it is very easy to hear when the amplifier is off.



two-transistor amplifier: above with loudspeaker and battery



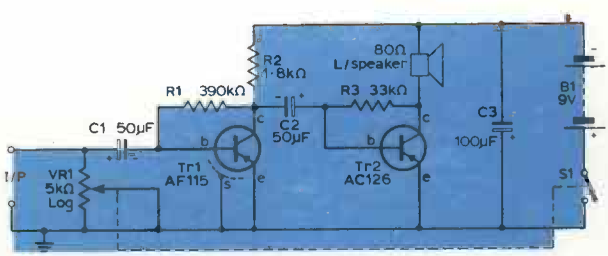
Components

Resistors (all $\frac{1}{8}$ watt)
R1 390kΩ
R2 1·8kΩ
R3 33kΩ
VR1 5kΩ log. pot. (with switch)

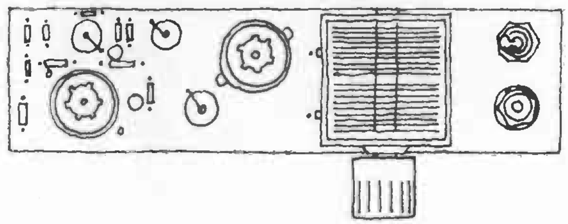
Capacitors
(all electrolytic)
C1 50μF 12V
C2 50μF 12V
C3 100μF 12V

Semiconductors
Tr1 AF115 Mullard
Tr2 AC126 Mullard

Loudspeaker, 80 ohm
plain veroboard $2\frac{1}{2} \times 1\frac{3}{4}$ in
9 Volt battery and clips
wire for wiring up
resin cored solder
knob



5 | Two-Transistor Receiver

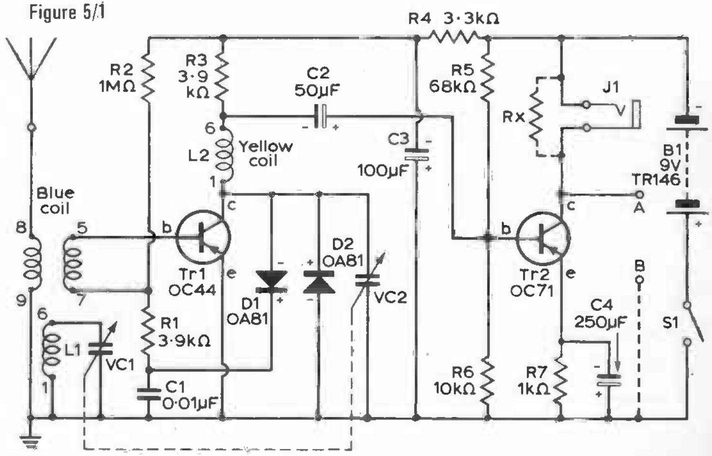


If you have built the simple crystal receiver, you will realize that although it can give reasonable results, it does have some drawbacks. It needs a very good aerial and earth and it needs to be in an area of good signal strength, i.e. not too far away from the station you wish to receive. In this chapter we will examine details of a receiver which uses four semiconductors, two transistors and two diodes. Here we have a circuit which will receive stations under conditions where the simple crystal receiver might not receive anything at all or at best very weakly.

The Circuit

Looking at the circuit of figure 1 let's follow the path that the incoming signal from our aerial will take on its journey through the set to the headphones. The r.f. (radio frequency) signals from the aerial are connected to the coil marked L1. There are three separate coils on one coil former wound close together, and each of these coils is inductively coupled to the other so that an alternating current or voltage in one of them

Figure 5/1



will induce an alternating current or voltage in the others. Our radio signal, being an alternating signal, is applied to the first coil between points 8 and 9 on L1. The coil between points 1 and 6 form a tuned circuit together with VC1 which is one gang of a two-gang variable capacitor. Thus by varying VC1, we can alter the frequency to which the circuit responds and thus 'tune-in' our stations. The a.c. signal also induces a voltage in the third coil between points 5 and 7, and from this winding the signal is passed for amplification to the base of Tr1. Transistor Tr1 amplifies the r.f. signal and this appears at the collector where the fun really starts. Coil L2 is tuned by VC2 and is resonant at the signal frequency. This means that the coil will present a very large impedance or opposition to the signal so it will not be able to pass L2 and get to R3. It can get past the diodes D1 and D2 but, as in the crystal receiver, the diodes will rectify the signal and it now starts to look like an a.f. signal (audio frequency). This a.f. signal is fed back again to the base of Tr1 via D1 and R1. Here, Tr1 now amplifies the signal again, this time at a much lower frequency (a.f.), and it once more appears amplified at the collector of Tr1. Last time it arrived it was a high radio frequency and coil L2 would not let it pass, but now it is a low frequency audio signal and the coil L2 allows it to pass unhindered. This low frequency a.c. signal develops its amplified voltage across the 3·9kΩ resistor R3, and C2 passes this a.f. signal on the base of Tr2. This second transistor is a simple audio amplifier, amplifying the signal which appears at its collector and is fed to the headphones via the jack socket J1.

You will notice that the audio amplifier stage (Tr2) has a different circuit configuration from the ones used in both stages of our simple two-transistor amplifier in the previous chapter. The bias voltage for the base of Tr2 is derived from a potential divider R5 and R6. There is also a resistor and capacitor in the emitter circuit (see Chapter 2). As in the transistor amplifier in Chapter 4, we have a large value decoupling capacitor C3 wired in across the negative supply line to Tr1, and earth.

Coils The coils used for the receiver are plug-in coils, wound on a former with pins protruding from the base. These coils are made to plug in to a valve holder type B9A. Thus all the wiring is connected to the valveholder tags, and the coils are just plugged in, no actual soldered connexions being made to the coil or its pins. The coils are also wound on different coloured formers, so it is an almost fool-proof method of ensuring that the right coil is plugged into the right valveholder. This receiver also has a separate on/off switch marked S1 in figure 1, and a jack socket to plug the headphones into marked J1. A jack plug is soldered on to the end of your headphone leads.

Before starting to construct the receiver, it would be a good idea to check the semiconductors. Both the transistors should have a red spot on one side, and the wire nearest to this spot is, in both cases, the collector lead. The diodes too, should have one end marked either with a + sign or a band or dot. This is the positive end and, just as with the transistors, these diodes must be properly connected. The positive and negative ends are marked on figure 1. If you are in any doubt at all, it would be advisable to check this with your supplier, or your local radio shop.

The receiver is constructed in a similar manner to the amplifier previously described, in that the wire ends of the components are pushed through the holes in the veroboard and soldered directly together on the reverse side in accordance with figures 1 to 4. The electrolytic capacitors are mounted vertically in this circuit and not horizontally as they were in the two-transistor amplifier.

Construction First cut a piece of veroboard 6½ in long and drill or file the holes for both B9A valve holders (for plugging in the coils) plus the two small 6BA holes for the nuts and bolts which will hold the valve holders to the veroboard. Next drill and file the two holes at the end of the board for the on/off switch and the headphone jack. Finally, drill two holes for the two 4BA bolts which will hold the two-gang variable capacitor to the board (VC1/VC2). The positions of all these holes are shown in Figure 2. The position of the remaining components

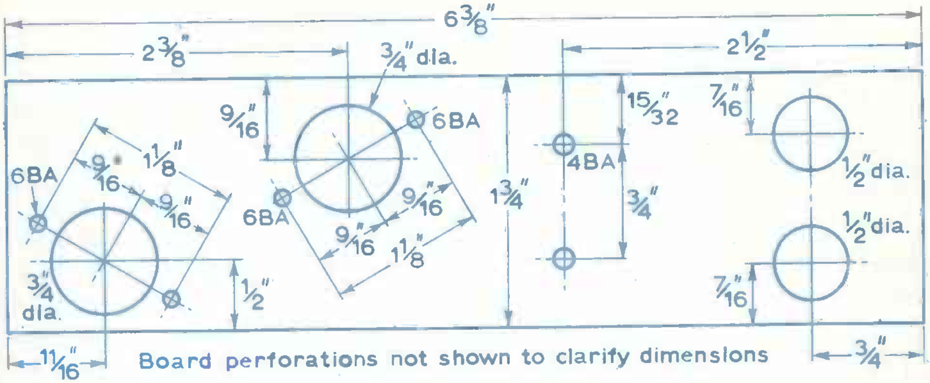


Figure 5/2

is shown in figure 3. The two 4 BA bolts for securing the two-gang capacitor should not exceed $\frac{5}{16}$in in the actual length of the threaded portion measured from the underside of the head. If it is longer than this it will touch the vanes of the capacitor and short them out or damage them. If, like me, you are only able to buy bolts which are too long, then you must remove the excess length with a fret-saw fitted with a metal-cutting blade. Screw a nut onto the bolt first, then cut off the excess portion and unscrew the nut from the bolt, to allow the nut to re-form any burr caused by the fret-saw blade. If this is not done, and the burr left on, it will prove difficult to screw the shortened bolt into the threaded hole in the bottom of the tuning capacitor. The 6BA and 4BA brass nuts and bolts are obtainable from toolshops and some ironmongers, or chain stores sell them too. They can be bought in little packets of a dozen or so. The three electrolytic capacitors C2, C3 and C4 are mounted on their ends because on their sides they would take up too much room. The wire from the positive end is bent over and runs flush down the side of each electrolytic and is then pushed through the relevant hole in the veroboard, as is the negative wire lead which is merely straightened out in line with the body of the capacitor.

It is best to mount the two valveholders for the coils, the tuning capacitor, the on/off switch and the headphones jack on to the board first. Following this, the remainder of the components, with the exception of the transistors, are mounted in their respective holes, their wire leads being bent down at right angles to allow this except in the case of the leads of the three electrolytics explained earlier. Note that the rear bolt holding the tuning capacitor has a wire connected to it which connects the frame of the tuning capacitor to earth. If this lead is omitted, some rather strange effects can occur. One is that when a hand is brought near to the capacitor to tune it, the station will get louder or softer. This is because the human body has a certain capacity to earth and thus bringing the hand close to the tuning gang will have the effect of coupling the capacity of the body to the tuned circuits. This is often referred to as 'hand-capacity effect'. It is very annoying in a receiver, so remember to connect the earth wire to this bolt in the capacitor frame.

Hand capacity effect

When wiring of the components is completed, the diodes may be inserted in the board. Make sure that they are connected the right way round and check all the wiring especially the valveholders. Remember that the tags or pins are numbered from the gap counting clockwise round when viewed from the underneath or tag side of the valveholder. This is shown on the wiring diagram in figure 4 anyway, but make sure that you did, in fact, count in a clockwise direction. On the twin-gang tuning capacitor you will find two soldering tags on either side which are connected to the fixed plates. Only the two tags on the left-hand side are used, the other two are ignored.

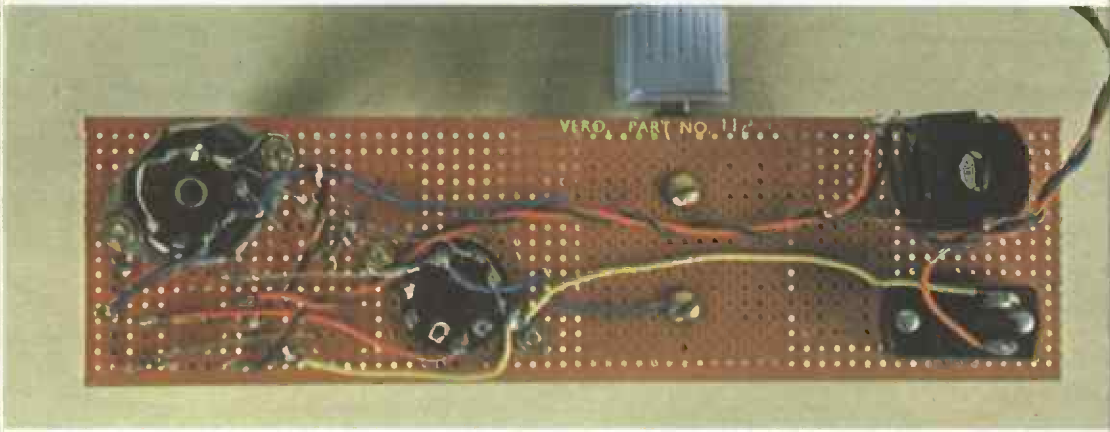
Transistor wiring

Having checked the wiring so far, the next step is to wire in the two transistors. Confusion might arise here and it would be easy to make a mistake because the two transistors are not interchangeable. They are both about the same size, cylindrical, black cased, and they both have a red spot on one side of the case to mark the collector lead. Wire in the OC45 (Tr1) first, pushing the three leads through the relevant holes in the board. The collector lead is nearest to the diode, and the emitter lead nearest the large electrolytic capacitor C4. Again the precaution of using a pair of pliers as a heat-shunt is strongly advised. Now wire in the OC71 audio amplifier transistor (Tr2), observing the same precautions.

Bell wire, ideal for wiring jobs, comes in several colours from many electrical shops and chain stores and usually costs only a few coppers per yard. It is sometimes one single strand of wire or several thinner strands covered with a coloured plastic insulating sheath. A choice of two or three colours is useful so that the battery leads, for instance, could be colour-coded to avoid connecting the battery terminals round the wrong way. If the positive lead is made red, which is usual practice, and the negative lead any other colour, it is unlikely that a mistake will be made. Remember that transistors expire very rapidly if the battery is connected the wrong way round.

Having completed all the wiring, check all connexions carefully, making sure that there are no badly soldered joints presenting a path of high resistance (see page 31). Check the wiring of your receiver with the wiring shown in figure 4.

Plug in the two coils, making sure that they go in their correct positions. They should be oriented correctly, the larger gap in the pin spacing on the coils corresponding to the similar spacing in the valveholder. The blue coil plugs into the valveholder on the left-hand side of the board, the yellow coil goes in the other valveholder nearest to the tuning capacitor. The coils may not push in easily at first and may have to be eased in by rocking them too and fro very gently; if the coil pins get bent, they will not push in at all and may suffer permanent damage. At the top of the coil is an insulated nut the same colour as the coil former. This is only used when the coil is to be mounted directly to the chassis or board and held in position by this nut. Protruding from the top centre of each coil is a threaded brass shaft with a small slot in its end. This is connected to a core of compressed iron dust or ferrite. By unscrewing or screwing up this thread, the position of the core inside the coil former is altered. This has the effect of varying the inductance of the coil. It is best, in this circuit, to unscrew the brass thread of both coils until $\frac{1}{4}$ in of brass thread is protruding from the coloured former. Normally, these cores would be used for accurately setting up the two tuned circuits L1/VC1 and L2/VC2, but in this receiver no



two-transistor receiver

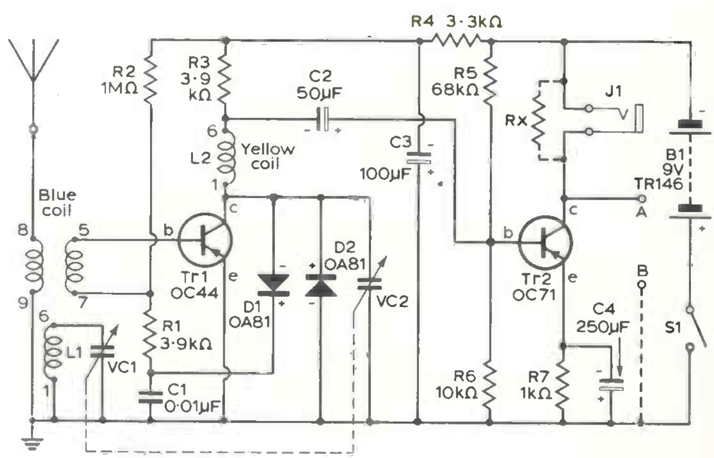
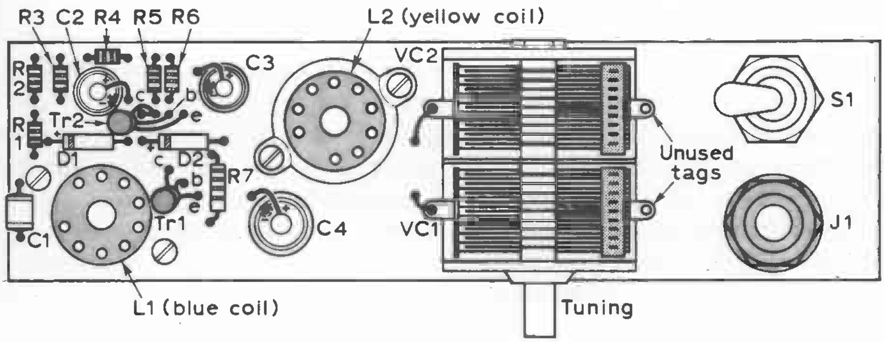
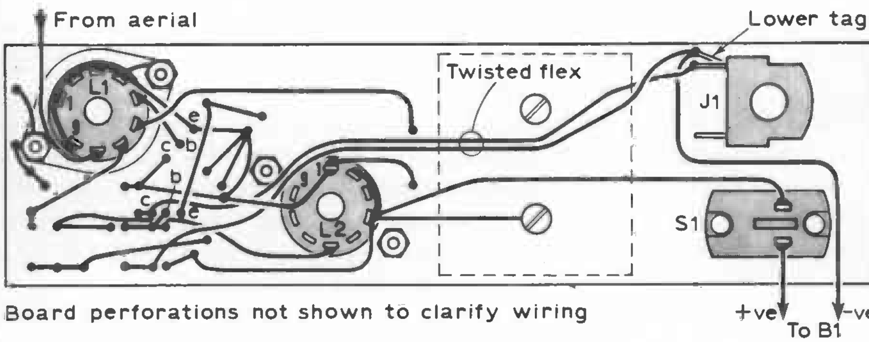


Figure 5/3 and 4





Board perforations not shown to clarify wiring

Components

Resistors
(all $\frac{1}{8}$ w)
R1 3·9kΩ
R2 1MΩ
R3 3·9kΩ
R4 3·3kΩ
R5 68kΩ
R6 10kΩ
R7 1kΩ

Capacitors
C1 0·01µF miniature
C2 50 µF }
C3 100 µF } 12V electro-lytic
C4 250 µF }
VC1 }
VC2 } 2 gang 500pF variable cap-acitor – Jackson

Semi-conductors
Tr1 OC45 }
Tr2 OC71 }
(or OC81 } Mullard
D1 OA81 }
D2 OA81 }

Coils
L1 Denco mini-ature transistor plug-in, blue range 2T
L2 As L1 but yellow

Phone jack
on/off toggle switch
9V battery
plain veroboard
$1\frac{3}{4}$ × 13in
two B9A valve holders
battery clips (red wire positive, if attached)
four 6BA nuts & bolts
two 4BA bolts
jack plug

careful adjustment is necessary other than to set in the cores as advised.

Plug the headphones into the jack socket J1, connect the battery to the battery terminals – make sure that the leads are connected correctly – and switch on. Connecting a suitable aerial to pin 8 of L1 and an earth to the positive or earth line should allow stations to be received.

In areas of poor signal strength, a good aerial will be needed together with a good earth. In areas of high signal strength, almost anything will do. The remarks regarding aerials in the chapter on the crystal receiver (page 27) are also applicable here.

For those who like to experiment, various positions of the cores in the coils might be tried. This will not harm the set in any way and the cores can always be returned to their original positions if no worthwhile improvement is effected. However, in the original, even when the two tuned circuits were accurately aligned with the aid of special equipment, no great increase in volume was apparent.

This little receiver is excellent as a bedside set, and if the type of battery specified is used it should last for a very long time as the receiver only draws about 2 milliamperes, giving a battery life of about 12 months if the set were used constantly for an hour every single night of the year. Any 9 volt battery would do which will accept the terminal clips. The EverReady PP3 or the Vidor VT2 will also work well but will not last so long.

Adding the amplifier

The receiver may be plugged into the two-transistor amplifier described in Chapter 4, provided a very simple modification is carried out. If we unplug the headphones, then there is no collector load for Tr2 across which the amplified signals can develop. To overcome this we can wire in a $4{\cdot}7k\Omega$ $\frac{1}{8}$ Watt resistor between the two headphone contacts, i.e. across the jack socket as shown by the resistor Rx and wires in dotted lines in figure 1. Having supplied Tr2 with a load, we now connect a lead from the positive or earth line of the receiver to the positive or earth line of the amplifier. A second lead goes from the collector of Tr2 to the input terminal of the amplifier, i.e. to the right-hand top tag of VR1 on the amplifier. These two leads are shown in figure 1. The one marked A goes to VR1 on the amplifier, and the dotted line marked B is connected to the amplifier earth or positive line. This wiring up will also give us the added luxury of a volume control (VR1).

If the signal sounds loud and distorted, then the volume control on the amplifier should be turned down, as too big a signal is being fed into the amplifier, and is driving the input transistor into a non-linear state. When we say an amplifier is linear we mean that the output is an amplified but otherwise exact replica of the input. When it is non-linear, it means that distortion has crept in and that the output signal is now no longer a faithful reproduction of the original input signal.

When you have built this receiver and got it working, then you might like to use your skill at construction and make a different and very superior type of set – a 'superhet'. Just why the superhet is superior and how to build one is described in the next chapter.

6 | Superhet Receiver

The t.r.f. The previous transistor receiver described is called a 'straight' receiver or a t.r.f. standing for tuned radio frequency. This implies that the signal is received at a certain frequency dependent upon the setting of the tuning capacitor and then amplified at this same frequency until it is converted into audio, again amplified and fed to a pair of headphones. If we wanted to discuss a circuit without drawing the whole thing out with all the components, we would use a thing called a 'block diagram' or 'block schematic' which would show the general scheme of things quickly. A t.r.f. receiver could be drawn out in this way as shown in figure 1. Here, the signal comes in at the aerial on the left and goes to an r.f. amplifier stage. It then goes to the detector stage shown by the next box or block, it is converted to a.f. or audio frequencies, and finally the signal goes to the audio frequency amplifier, the last block, and from here it passes on to the headphones.

The superhet There is another type of receiver which can give very superior results to the t.r.f and this type is called a 'Superheterodyne' or superhet. One of the problems with a t.r.f. is that there is a limit to the number of tuned circuits that can be tuneable. On our crowded wavebands all the stations are close together, sometimes so close that a simple t.r.f. cannot separate them. What we need here is more selectivity and we can achieve this with more tuned circuits – lots of coils all tuned by a variable capacitor with lots of sections or gangs on it. However, it would be very difficult to make sure that all the different sections were exactly tuned to the same frequency, and it would be almost certain that the whole set-up would become unstable and very difficult to control. We might make the tuned circuits tune to just one frequency and screen them from each other, but we want to be able to tune our receiver over many frequencies

and wavebands, and it would be difficult mechanically to screen all those gangs on the capacitor and the coils. Fortunately the superhet offers a way round the problem.

Look at the block diagram of figure 2. This is how the superhet principle works. Note that the last two boxes are marked exactly the same as the t.r.f. block diagram in figure 1. They do, in fact, perform the same functions, the detector 'detects' the a.f. from the r.f. signal fed into it, and the a.f. amplifier amplifies this a.f. and feeds it to the headphones. Sometimes there is more than one a.f. stage when it is required to make the audio signal even louder to operate a loudspeaker, as happened in our two-transistor amplifier. A block diagram of the transistor amplifier discussed in Chapter 4, if drawn correctly, should resemble figure 3. In our superhet receiver, (figure 2,) the signal comes in via the aerial as shown and is fed to the mixer stage, this is the box marked mix. The principle of operation is the same no matter what the frequency of the signal, but it will be simpler to explain mathematically if we assume for the moment that the station we are receiving is transmitting a signal on 1,000 kc/s. Accordingly, our first tuned circuit is tuned to 1,000 kc/s. If the mixer were a straightforward r.f. amplifier, then at its output it would present an amplified signal of the same frequency. The box marked osc is an oscillator and is, in fact, a midget transmitter in its own right. It generates a signal whose frequency is controlled by the tuning capacitor VC2. By altering the number of turns on the coil L2 (altering its inductance), we can alter the frequency of our oscillator. We could use exactly the same coil and capacitor values as L1/VC1, and in this case both circuits would always tune together to the same frequency dependent upon the position or rotation of the variable capacitor VC1/VC2. If we altered the coil L2 so that when VC1/L1 tuned to 1,000 kc/s, VC2/L2 tuned 2,000 kc/s, then the oscillator would always be 1,000 kc/s above the frequency to which VC1/L1 was tuned, because the two capacitors are ganged together and will thus alter the tuning of both coils by the same amount. We could chose any combination of frequencies we liked. If VC1/L1 was tuned to, say 3,000 kc/s, and we arranged VC2/L2 to tune 7,000 kc/s, then the oscillator whose frequency is controlled by VC2/L2 would always be 4,000 kc/s higher than the frequency to which VC1/L1 was tuned. Once we have settled this difference frequency, this difference will hold over the tuning range of the variable capacitor because the two sections are ganged together and both tuned circuits will alter by the same amount.

Going back to figure 2, we have our signal coming in at 1,000 kc/s from the aerial to the mixer, and also fed into the mixer is a signal from our oscillator at 1,460 kc/s. The mixer does just what the name implies – it mixes. At its output you can find four frequencies present. There will be the two original frequencies, 1,000kc/s and 1,460kc/s, and there will be the sum and the difference of these two. The sum will be a signal at 2,460 (1,000kc/s + 1,460kc/s) and the difference

FIGURES 1 and 2 Transposed.

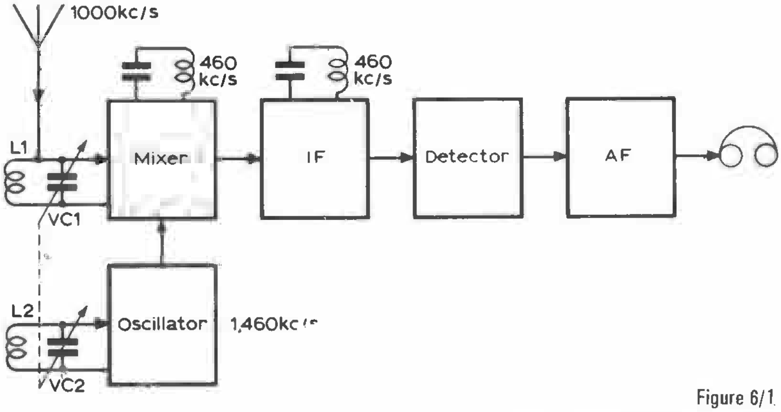


Figure 6/1

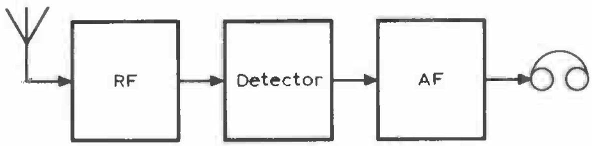


Figure 6/2

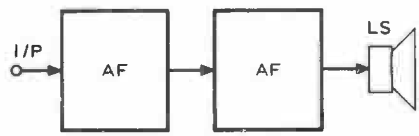


Figure 6/3

signal will be 460kc/s (1,460kc/s − 1,000kc/s).

As with the aerial (page 27) we use a simple tuned circuit to select the signal we want from all those present. The combination of a coil and a fixed capacitor tuned to the difference frequency – 460 kc/s will allow the 460 kc/s signal to pass and will reject the others. The capacitor is fixed because there is only one frequency to tune to. As the oscillator is always higher than the incoming signal by the same amount, no matter where we tune in the waveband, there will always be a signal at the output of the mixer at 460kc/s. The tuned circuit we use here is called an intermediate frequency transformer. We can use very small coils and fixed capacitors in this position and in fact, we use two tuned circuits (both tuned to 460kc/s) and inductively couple them together. As they are small, we put them in a metal box to screen them and protect them from external magnetic fields and pick-up. The 460kc/s signal (i.f.) is fed to an i.f. amplifier which amplifies it. The two circuits tuned to the i.f. and screened in a metal can is called an i.f. transformer or i.f.t. Again in our i.f. amplifier we can use two tuned circuits because we have only one frequency to bother about. From the i.f. stage the signal is fed to the detector to convert it to audio, and it then goes to the a.f. amplifier to be amplified and fed to the headphones. The important thing is that we can have all those tuned circuits for our selectivity without the bother of ganging.

Circuitry

The circuit diagram of a transistor superhet receiver is shown on page 58. It is a five-stage receiver using four transistors and a diode, capable of giving excellent results, not only on medium waves but on the Trawler band and short waves. It will receive at least two amateur or 'Ham' bands and can be used on long waves as well. At first it might look rather complicated, but really it is very simple. Each transistor with its relevant components is a stage, rather like a one transistor receiver. If you can build a one transistor circuit – then all you have to do is just that – four times.

Circuit action

The incoming signal first arrives at the aerial terminal. This is the point marked 8 on L1. This coil is the same coil as used in the first stage of the two transistor t.r.f receiver in Chapter 5. Again we have a tuned circuit inductively coupled to the other windings to select the signal we want to hear and reject the others. The coil between points 5 and 7 on L1 inductively couples this selected signal to the base of Tr1. This transistor is a radio frequency amplifier, or straight r.f. amplifier, and an amplified replica of the signal appears at the collector where it causes an a.c. current to flow in sympathy in coil L2 between points 8 and 9. Again we have a tuned circuit which selects the frequency we want, and another coil marked 5 and 7 to feed this signal to the base of Tr2. The tuned circuits formed by VC1/L1 and VC2/L2 are both adjusted to tune to exactly the same frequency. The resistors R1/VR1 supply the base voltage for Tr1, but notice that the lower resistor is made variable. If we turn this resistor right down to minimum, the base will be connected to the earth line and this will cut off

Tr1, i.e. prevent it from amplifying. In this way we have control over the magnitude of the signal fed to the rest of the receiver. Since this control is in the r.f. stage, it is called an r.f. gain control. The capacitor (C1) wired across the r.f. gain potentiometer is used to by-pass any varying signal voltage which might develop across VR1. If this were allowed to happen, then any varying voltage would vary the gain of the stage giving a very unwelcome effect.

Having fed our amplified signal to the base of Tr2, its amplified replica would normally appear at Tr2 collector, however, Tr2 is our mixer stage. The coil L3 has a main winding tuned by the third gang of our variable tuning capacitor VC3. The two other coils connected to the collector and emitter respectively are coupled inductively to each other and to the main winding. This coupling causes energy to feedback between collector and emitter in such a way that the whole circuit oscillates. The frequency of oscillation is controlled by VC3 and the coil it tunes. The coil in this case is arranged to tune (with the aid of VC3) to a frequency of 465kc/s above the frequency to which the first two coils are tuned. This means that no matter what signal we tune VC1/L1 and VC2/L2 to, VC3/L3 will always be tuned 465kc/s higher. As a result we select this different frequency with a circuit tuned to 465kc/s in the collector of Tr2, Tr2 is made to function as both mixer and oscillator. Note that the tuned collector load of Tr2 takes the form of two tuned circuits inductively coupled together to give even greater selectivity. The dotted line around the two circuits means that they are enclosed in a screening can.

From the second tuned circuit of the i.f.t. (intermediate frequency transformer) the signal is fed to the base of Tr3. This transistor receives base bias voltage from the potential divider arrangement of R6 and R7. Transistor Tr3 amplifies the 465kc/s signal and this is selected at its collector by a second i.f.t. again a double tuned circuit for even greater selectivity. From a tap on the second coil of i.f.t.2., the signal goes to a diode detector and the resultant a.f. signal develops a voltage across VR2. If we set VR2 to minimum, then we will

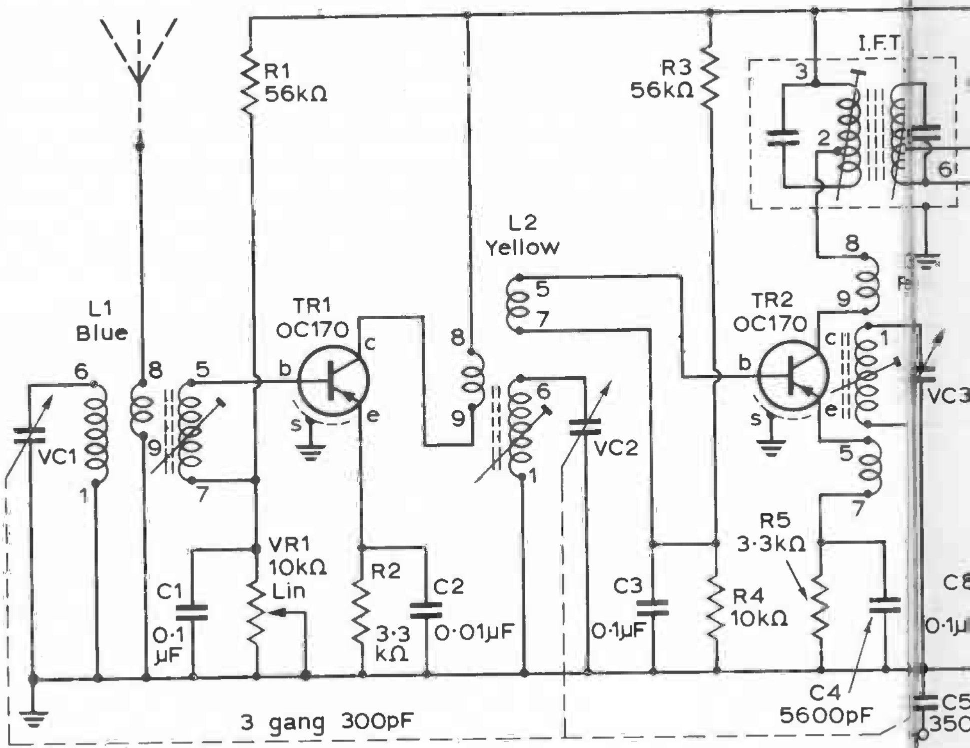
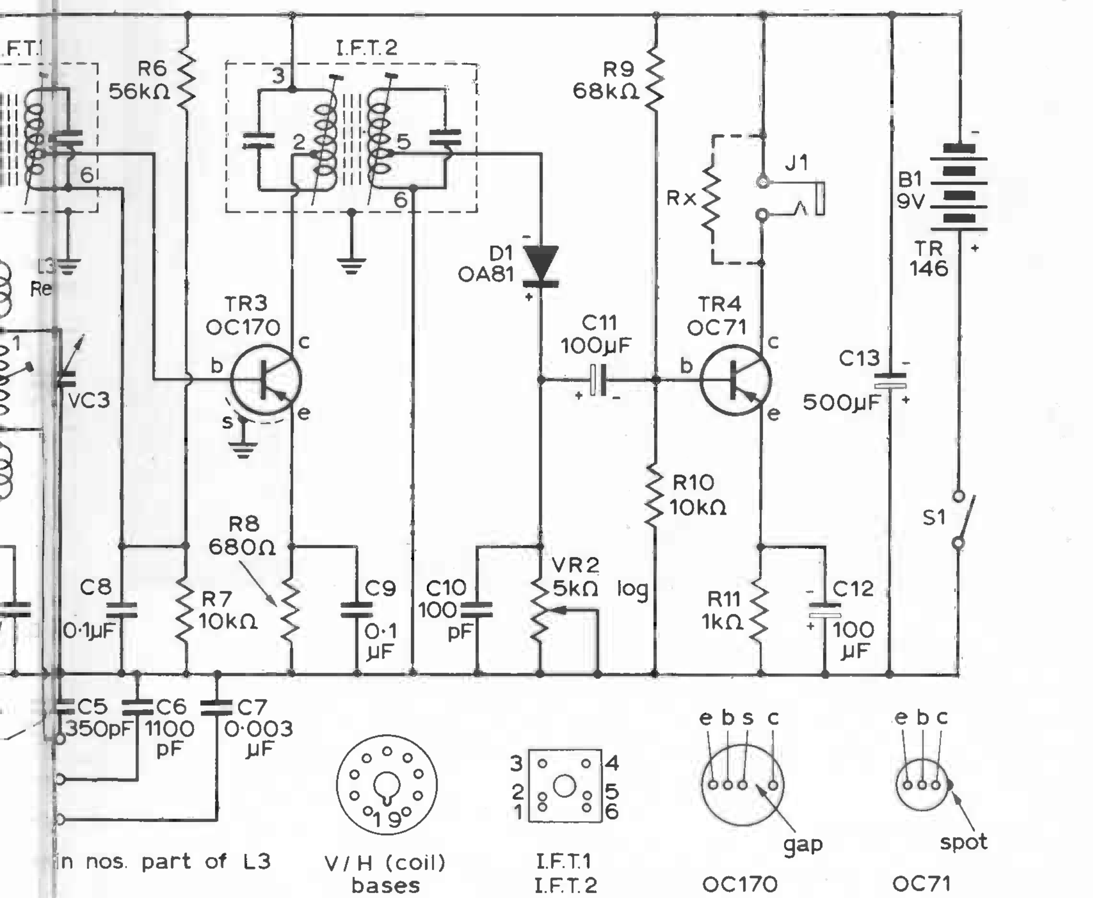


Figure 6/4

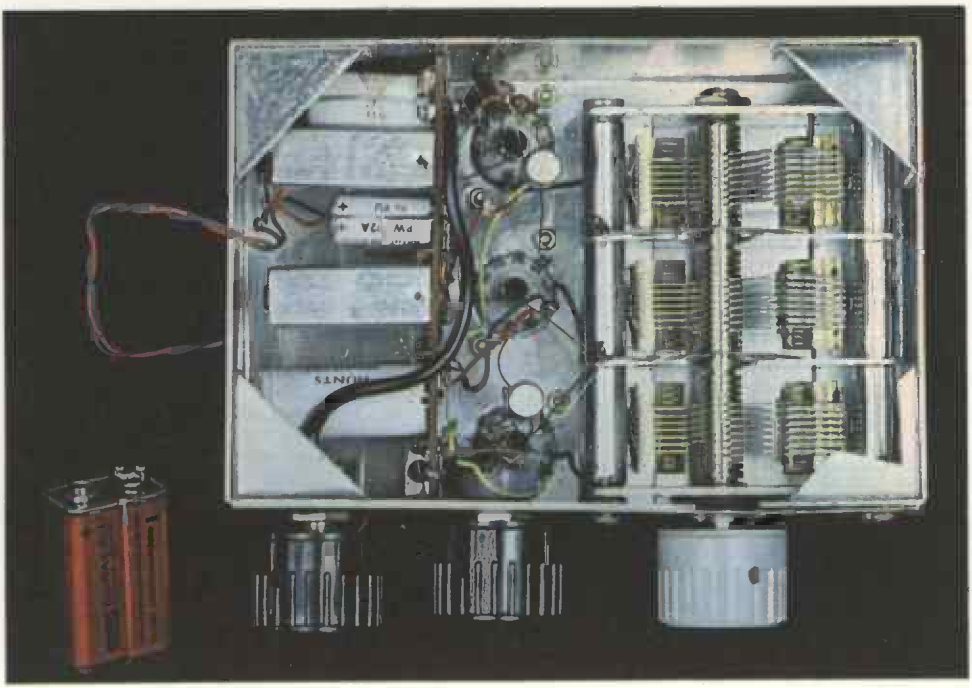
short out the whole resistance and there will be nothing for the signal to develop across and thus no signal will will be fed on the a.f. amplifier Tr4. VR2 varies the amount of audio signal available for amplification and is thus termed the a.f. gain control, sometimes referred to as the volume control.

Capacitor C11 is necessary because otherwise the base of Tr4 would be shorted to earth through the diode and the winding on the i.f.t.2., and through VR2. The amplifier, Tr4, has the usual potential divider R9/R10 to supply the base bias voltage and this time its collector load is made up by the resistance of the headphones



which plug into the jack socket J1. A separate on/off switch S1 breaks the positive lead to the battery when the set is off. Capacitor C13 is used from the negative supply rail to earth to short to earth any a.c. signals which might find their way on to the supply line.

Notice how many tuned circuits we have in our superhet. Counting from VC1/L1 there are six altogether, four of these are i.f.t.'s and the others are VC1/L1 and VC2/L2. The tuned circuit VC3/L3 is used only to control the frequency of the oscillator and therefore does not add directly to the selectivity.



Components

Resistors (all $\frac{1}{8}$ watt)

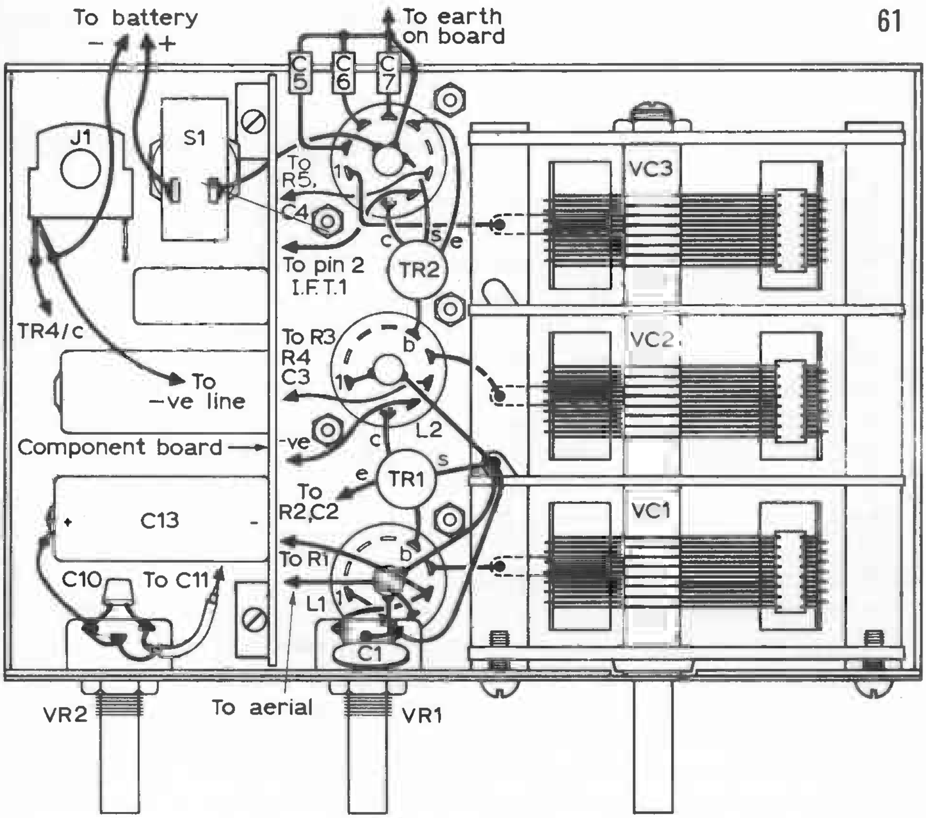
R1	56kΩ
R2	3·3kΩ
R3	56kΩ
R4	10kΩ
R5	3·3kΩ
R6	56kΩ
R7	10kΩ
R8	680Ω
R9	68kΩ
R10	10kΩ
R11	1kΩ
VR1	10kΩ lin pot.
VR2	5kΩ log. pot.

Semiconductors

Tr1	OC170	Mullard
Tr2	OC170	Mullard
Tr3	OC170	Mullard
Tr4	OC71	Mullard
D1	OA81	Mullard

Capacitors

C1	0·1μF
C2	0·01μF
C3	0·1μF
C4	5600pF
C5	350pF (330 + 20pF)
C6	1100pF (1000 + 100pF)
C7	3000pf (0·003μF)
C8	0·1μF
C9	0·1μF
C10	100pF
C11	100μF 12V electrolytic
C12	100μF 12V electrolytic
C13	500μF 12V electrolytic
VC1	3-gang 310pF variable capacito Jackson
VC2	3-gang 310pF variable capacito Jackson
VC3	3-gang 310pF variable capacito Jackson



Coils

L1 Range 2T blue
L2 Range 2T yellow
L3 Range 2T red
} Denco miniature transistor plug-in
IFT1 Denco type IFT18/465
IFT2 Denco type IFT18/465

Note The range 2T quoted for the coils will give medium wave coverage. For the other ranges see text

Strip of plain veroboard $3\frac{7}{8} \times 1\frac{3}{4}$in
three B9A valve holders
9V battery—Mallory TR146 or similar
wire for wiring up, battery clips
three knobs, scraper board
four 4BA bolts
Ten 6BA bolts, twelve 6BA nuts

jack socket, jack plug,
on/off toggle switch
aluminium chassis 6 × 4 × 2in
In case of difficulty the chassis may be obtained from Messrs H.L.Smith, 287, Edgware Rd, London W2

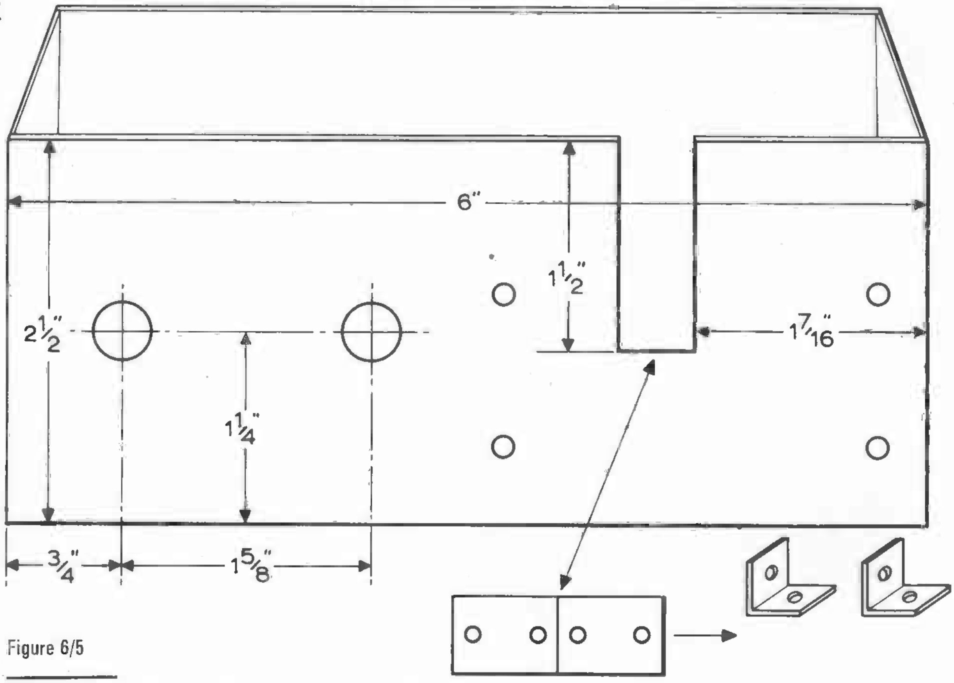
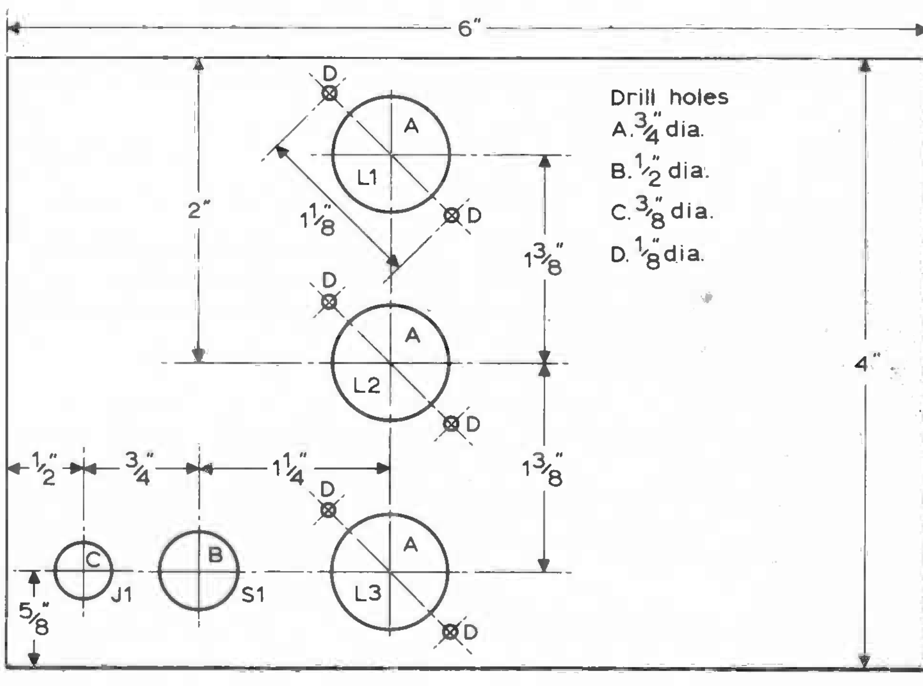


Figure 6/5

Figure 6/6



Tools required In addition to the tools on page 34, you will need: twist drills – 4BA and 6BA clearance, round file – $\frac{1}{8}$in diameter, half-round file – $\frac{5}{8}$in diameter.

Construction First make sure that you have all the components as specified in the components list. You will need to drill the aluminium chassis to accommodate the three controls on the front panel, and the three valveholders to take the plug-in coils. The drilling details are given in figures 5 and 6. We are going to use the chassis as a case to protect the components when the set is built, and to screen the whole receiver too. Be careful when you cut out the strip of aluminium to allow the tuning capacitor access into the chassis. You will need to cut this little strip into two and drill it to make two small feet with which to mount the veroboard to the chassis later.

Cut a piece of veroboard $3\frac{7}{8}$in long and carefully drill two holes in the corners for the two metal angle brackets you have made. Bolt these to the bottom two corners of the board with 6BA nuts and bolts. Now put the veroboard in the position it will occupy in the chassis. With the front of the chassis towards you, the veroboard will be $1\frac{3}{4}$in from the left-hand side, and the two metal angles should protrude towards the left-hand side. Mark the position of the holes for the brackets and drill the chassis accordingly. Check all holes and remove any burr with a file, running the drill through again afterwards if necessary. The three-gang capacitor and the a.f. gain potentiometer may now be mounted. Do not mount the r.f. gain potentiometer yet or it will be very difficult to mount the veroboard when it is wired.

The three coils are packed in cans by the manufacturers and these cans are used to screen the coils. The lids of the cans are cut as advised by the manufacturer in information supplied free with each coil. The lid is cut and drilled and then mounted between the valveholder and the chassis in each case. The remaining portion of the can may then be screwed into the lid already held in place.

Take the piece of veroboard and make two sets of cut-outs for the i.f.t.'s as shown in figure 7. Do not mount the i.f.t.'s yet. Now fit the remaining small components, except the transistors, on the board positioned as shown in figure 8. With the exception of the three electrolytic capacitors, all these components (resistors and capacitors) have their wires bent down at right-angles and pushed through the holes in the board. The electrolytics are mounted upright, their positive ends at the top, and the wire from the positive end running flush down the side of the capacitor. The wiring of the underside of the board is shown in figure 9. Mount the i.f.t.'s held in position by bending the two lugs on the side of the screening can over when they protrude through the holes in the board. Complete only the wiring which is confined to the board. When the board is completely wired as shown in figure 9, put it on one side and start wiring the chassis-cum-case components. These are the valveholders for the coils, and the three-gang capacitor. You will be soldering in two transistors here to the tags on the valveholders. Leave the transistor leads the length they are and remember to use long-nosed pliers for a heat shunt as advised in earlier chapters. This part of the wiring is shown on page 61.

Padding capacitors

It is wise to mark which coil is plugging into which valveholder before starting wiring up. On the oscillator coil (red), which is the farthest one from the front, pins 2 and 3 and 4 have capacitors soldered to them. If you are only interested in medium waves, then you will only need to fit a capacitor to pin 2. This capacitor should have a value of 350pF and is fairly critical. The percentage error must not be more than 5 per cent. If this value proves difficult to obtain, then you can use two capacitors wired together in parallel. When capacitors are wired in parallel, their individual values add. In the prototype I used a 330 pF in parallel with a 22 pF and these worked very well. If you want to listen on the short-waves as well, then you should solder a 1,100 pF capacitor to pin 3 of the oscillator coil. Again, 1,100 pF is an awkward value, so I used a 1,000 pF and a 100 pF capacitor, both of which are easy to obtain. The range of the receiver was tried still higher in frequency giving quite good results. This was achieved by using another

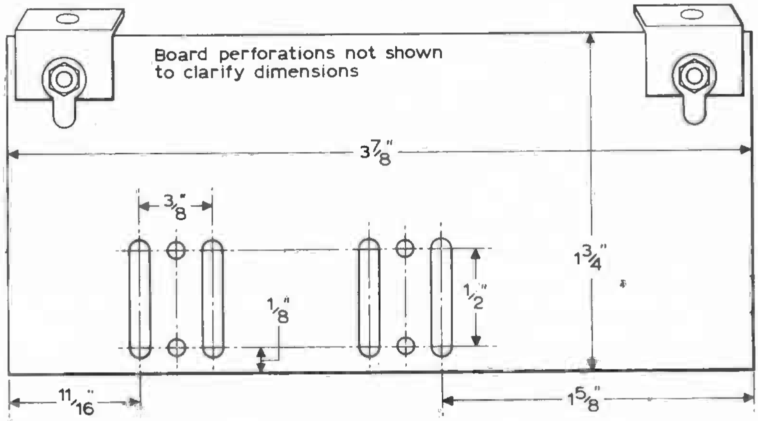


Figure 6/7

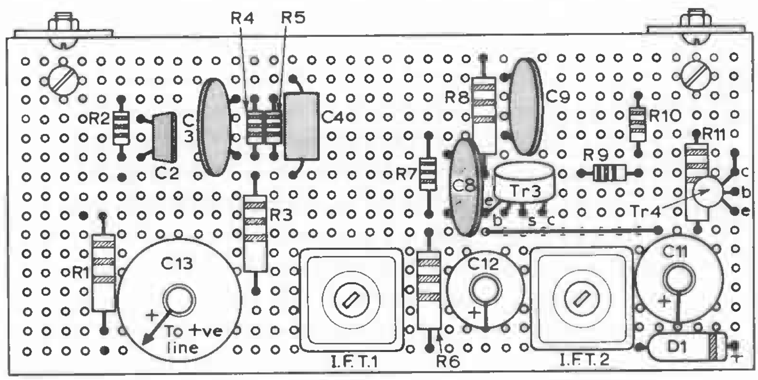


Figure 6/8

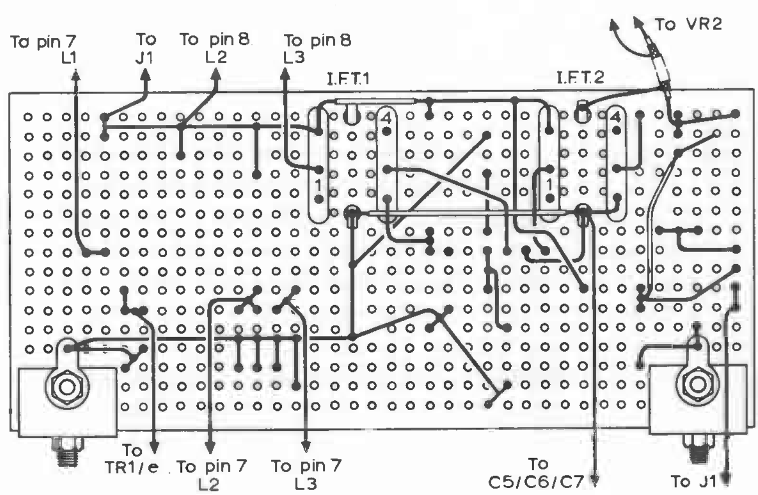


Figure 6/9

(0·003 MF)

set of coils, and wiring a 3,000 pF ~~(0·03 μF)~~ capacitor from pin 4. The other ends of all these 'padder' capacitors as they are called are joined together and taken to earth at a convenient point on the veroboard when it is mounted in position. The floating leads marked on page 61 are intended to connect to the point indicated on the veroboard.

Check that you have completed all the wiring to the valveholders and check that the transistors are wired in correctly. A diagram of their base connections is shown in figure 4. Mark their cases with pencils on the collector side as a guide when you are wiring them in. Remember that they will be inserted with the leads pointing down and thus more difficult to check. However, if you mark one side, then knowing the sequence of the leads from figure 4, you can identify individual leads by counting.

Returning to the veroboard, you should now wire in the transistors taking the usual precautions regarding correct wiring and use of a heat shunt. You should also wire in the diode if not already in circuit. The lead to the a.f. gain control is quite long (about three inches) and should be screened, or the wire might act as a little aerial and any hum or interference it picked up would be fed to the base of Tr4 and amplified as interference. The screened wire is merely ordinary plastic-covered wire around which is a sheath of woven-metal wire which is soldered to earth. Coaxial cable used for television aerial leads is like this.

You should solder wires to the jack socket and on/off switch next, after which the veroboard is ready for bolting to the chassis. Two bolts are inserted and fixed in position with nuts as shown in figure 8. The board is then placed carefully in position and two nuts applied to hold it in place. The r.f. gain control may now be fixed to the front panel.

Coverage

The coils are colour coded and this is preserved through the entire range. A set of three coils is needed for each waveband covered, thus if only medium waves are required, then only one set of coils need be purchased. The receiver has been tested on three separate wavebands and found to work well. In a set of coils there is one red, one yellow and one blue, the particular range being indicated by a number followed by the letter T. Thus, the medium waveband set are ordered as 2T – red, 2T – yellow, and 2T – blue. The range covering part of the shortwaves which included the shipping bands would be ordered as 3T – red, 3T – yellow, and 3T – blue. The prototype was tested on the following wavebands. Medium wave: 550 – 194 metres (Range 2T), Shortwave: 57 – 180 metres (Range 3T), and Shortwave 2: 60 – 20 metres (Range 4T). This coverage (which requires three sets of coils) gives entertainment on medium waves and will receive trawlers and coastal stations, a host of shortwave stations in many different countries, and also covers four 'Ham' bands – 160, 80, 40 and 20 metres.

Plug in one set of coils. The red coil always goes into the valveholder farthest from the front, the yellow coil plugs into the middle holder, and the blue coil always plugs into the front one. Drill a small hole, about $\frac{1}{8}$ in diameter, in the top of the screening cans over the coils as advised on the literature supplied with each coil.

Front panel

The black 'front panel' was made from scraper board (see page 33) which gives an opportunity for initiative in making the three dials for the front panel controls. Cut a piece to the size of the front panel, and mark out the holes you need to drill to allow the spindles of the controls to protrude. These holes will need to be drilled gently and filed very carefully because it is easy to scuff or scratch the black surface. If this is accidentally done, you can touch it in with a spot of Indian ink. After cutting the three holes, drill four others for the bolts holding the tuning capacitor. Now 'draw' your dials and mount the board on the front panel where it is held in place by the four bolts holding the tuning capacitor, and the two large nuts on the r.f. and a.f. gain controls. Now fit the three knobs and tighten up the small grub screws to hold them to the spindles of the controls.

Adding the amplifier

The receiver can be used with the two-transistor amplifier and this will allow loudspeaker reception of the more powerful stations. The same simple modification is required as was described for the two-transistor receiver. The headphones are unplugged, and a 4·7kΩ $\frac{1}{4}$ Watt resistor is connected to the two points where the headphones were, i.e. one end of the resistor to the collector of Tr4 and the other end to the negative supply rail. A lead (screened) is taken, with the braiding or screening connected to earth and the centre conductor soldered to a 50µF capacitor (positive side). The other side of the capacitor connects to the collector of Tr4 where it joins one end of the 4·7kΩ resistor Rx. At the amplifier end, the centre conductor is soldered to the right-hand upper tag on the volume control, and the earth lead to the earth of positive supply line. You will now have two a.f. gain controls because of the extra potentiometer on the amplifier. Use this control to adjust the amount of signal fed to the amplifier. The signal will be loud but very distorted if this control is turned up too much, and it should, in this case, be reduced or turned down until the distortion disappears.

The tuning scale on the prototype was not marked with the position of stations because, with three ranges covered, there just wasn't room to mark them all. You could mark the scale 0 – 10 and then draw a little graph with the stations marked on it. The more the two sets of plates on the tuning capacitor are meshed, the greater the capacitance and the lower the frequency.

If you build this receiver you will have a project which will repay the time and trouble spent on it. The whole world is no farther than the on/off switch and the different countries are all ready to talk to you – all you have to do is swing the tuning capacitor and listen.

Testing

Solder the aerial lead to pin 8 of L1 which is the blue coil, nearest to the front. Attach the earth lead to any convenient point, perhaps by a crocodile clip to the chassis. Plug in the headphones and battery, checking again that the leads are correct. Switch on and swing the tuning capacitor gently from maximum to minimum.

Assuming medium wave (2T) coils are used, if no station is heard, and this is probable, turn the vanes until they are about $\frac{7}{8}$in unmeshed. Now try to obtain a bone or plastic knitting needle and file a flat end – shaped like a screw-driver blade. Use this to unscrew the brass rod of the red coil through the hole drilled in the top of its can. If we use a metal blade we de-tune the coils slightly (see 'hand capacity effect', p. 46), so an insulated rod is necessary. At a pinch a matchstick shaped as described will do. Adjust the core until Radio 1 is heard. Now adjust the core of the yellow coil for maximum volume, and then the blue coil for the same effect. Next adjust the tuning capacitor to almost full mesh and tune in a station. Now adjust the trimmer capacitor across the red coil slightly for maximum volume, then the yellow coil trimmer and finally the blue coil trimmer. In superhet receivers, the i.f.t.'s are often adjusted, having little cores inside which are varied for maximum efficiency. However, the i.f.t.'s specified are pre-aligned at the factory and therefore need no adjustment. On no account touch these at any time.

THE THREE TRIMMER CAPACITORS ARE 30 PF, AND ONE EACH WIRED IN PARALLEL ACROSS VC1/VC2/VC3.

The remarks made on aerials in previous chapters apply equally to this receiver. The prototype was tested with a 60 ft piece of lighting flex taken from the aerial tag (pin 8 L1) through the window, round the eaves of the house to a pole in the garden. The earth was another piece of similar flex soldered to a 4 ft length of $\frac{3}{8}$in diameter copper piping driven into the ground just outside the window. Numerous stations were received on medium wave after dark.

Results

With the 3T range coils plugged in, coastal stations talking to trawler skippers were received loud and clear as well as many 'Ham' stations chatting away on top band – 160 metres. On the higher shortwaves with range 4T coils, numerous foreign stations were heard, and on the 20 metre amateur band 'Hams' from many different countries were received – America, Canada, Africa, Iceland, and from nearly every country in Europe. With this little receiver you will always find something of interest no matter what time of day or night you listen.

7 Aerials

It is usual to talk about aerials, or antennae, from a transmitting point of view. We imagine that we have a transmitting station and that we are feeding power into the aerial to make it radiate. Aerials which work well or poorly for transmission will work equally well or poorly for receiving.

What is an aerial and just how does it work? To understand this let us go back to our discussion of tuned circuits. A tuned circuit consists of inductance, usually in the form of a coil, and capacitance. Because this tuned circuit is so compact, the surrounding electromagnetic field stays quite close to the actual components and very little of this energy is radiated. If the components were made very large compared to the wavelength, then considerable radiation would take place.

Remember when we talked about an oscillator, we said that the capacitor in the tuned circuit charged and discharged through the coil, and that if we could supply a little pulse of energy at just the right moment we could make the tuned circuit carry on charging and discharging instead of dying away and stopping altogether (page 17). This is precisely what happens in an aerial because it acts like a tuned circuit which is very large compared to the wavelength.

Resonance is achieved when the reactance of the capacitor and the reactance of the inductance are equal and thus cancel each other out (page 17). At this point maximum current will flow in the circuit which will be working at maximum efficiency.

A resonant aerial is one which allows the wave to travel from one end to the other and back again in exactly one cycle. Since the charge travels the length of the wire twice, then the smallest length of wire which will be resonant will be half a wavelength long. The charge travels half a wavelength to the end of the aerial and half a wavelength back again, making a total of one wavelength. If, just as the wave returns to its point of origin we arrange for a pulse of energy to be present, then the wave will travel out along the aerial again and back to its point of origin and so on.

The length of the resonant half-wave aerial will depend upon the wavelength or frequency we are interested in.

If we accept that the charge will travel at the speed of light, which is approximately 300,000,000 metres per second, then the distance it will travel in one second or one complete cycle, will be equal to this velocity divided by the frequency. This gives us the formula: wavelength equals 300,000,000 divided by the frequency. We use the Greek symbol Lambda for wavelength and f for the frequency in cycles per second, so the mathematical equation becomes: $\lambda = 300{,}000{,}000/f$. This is rather a formidable formula to work with and even if we were to juggle it about to find the length of a half-wave aerial, it still would not take into account the 'end effect'.

Every practical half-wave wire aerial must be suspended in some way, usually the wire of the aerial is looped around an insulator at either end. This has the effect of adding a small amount of capacitance to the ends of the aerial which is called the 'end effect'. Taking this into account, the most useful and practical formula for finding the length of a half-wave aerial is: Length in ft $= \frac{468}{\text{Mc/s}}$ Let us take an example. Suppose you wanted a half-wave aerial to listen on the 7 Mc/s or forty metre amateur band. The length would be $\frac{468}{7} = 66{\cdot}85$ ft. Again if you were interested in 10 Mc/s the length would be $\frac{468}{10} = 46{\cdot}8$ ft.

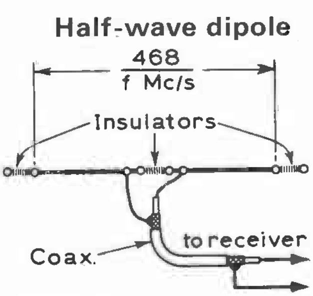


Figure 7/1

The basic aerial or antenna is the half-wave dipole. This is a length of wire or metal rod cut to half a wavelength long, and fed in the middle. (By 'fed' we mean connected to the receiver or transmitter).
In figure 1 the dipole is fed using coaxial cable or co-ax. This is the cable commonly used as the aerial lead-in for television receivers. It has a centre conductor of wire, insulated from an outer sheath of copper braid which

forms an earthing shield. A final insulated sleeving surrounds the flexible copper sheath.

The centre conductor is connected to one leg of the dipole, and the screening or braiding to the other. It is not important which way round the cable is connected at the aerial.

The half-wave dipole has one disadvantage. Although an aerial can also be resonant at odd multiples of a half-wave length, in general, the dipole is a one-band antenna, that is, it is only resonant at the particular frequency for which its length is calculated. It will work a little above and below this frequency without its performance falling off too much, but it is still rather limited because of this. Remember in our calculation, one of the items governing the formula was the frequency. If you change the frequency, then you must alter the length to retain resonance.

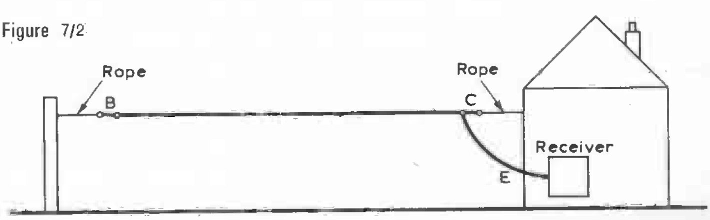
End-fed aerials

One of the simplest aerials is simply a length of wire with one end plugged into the receiver or transmitter, and the other end attached to an insulator. Just like the dipole, so the longwire can be resonant too, which means that the length should be adjusted to the frequency in use. If we have a piece of wire half a wavelength long, and we attach one end to the receiver direct, this method of feeding the antenna is called 'end-feed'.

It is not vital that the antenna should be resonant, though of course it will perform much better at the frequency for which it is resonant than when it is just some random length.

Generally speaking, the longwire should be as long as practicable, as high as permissible and as far away from earthed objects as possible. By earthed objects we mean trees, telegraph poles, houses, sheds etc., figure 2 shows a suitable arrangement for a longwire. The length B, C, E, is the actual wire comprising the aerial itself.

Figure 7/2



The length from the post or tree to the insulator can be rope, preferably weather-proofed. This also applies to the length from the other insulator to the house. Fifty feet is quite a good length to start with. It is best to keep it in a straight line but if not, try bending it around the garden. It will still work and you can bend it different ways to see which layout gives the best reception.

This fifty feet of wire will be resonant or will work most efficiently at one particular frequency, but it can be made resonant at other frequencies without altering its length (see below).

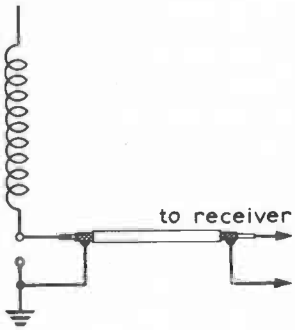
Vertical aerials

Another type of radiator which is commonly used is the vertical aerial. This is very useful where space is at a premium. A vertical aerial is exactly what its name implies, a wire or rod going straight up, like a whip aerial on a motor car. It is customary to make a vertical only a quarter of a wavelength long, but if we take a co-ax cable from our receiver and connect the inner conductor to the vertical, we can wire the braiding directly to earth. The aerial will then resonate because the earth is a conductor and behaves like a sort of mirror reflecting the quarterwave conductor, the vertical element, which is above the ground. The earth thus supplies the missing quarter wavelength and the system behaves like a form of vertical dipole fed at the centre. To calculate the length of the vertical, we find the length of a half-wave and simply divide the answer by two. For instance, if we want to listen on the 19 metre broadcast band on shortwaves, using our formula for a half-wave we get $\frac{468}{15 \cdot 8} = 29 \cdot 6$ ft. (The 15·8 is 19 metres converted to Megacycles.) This length is a half-wave, so a quarter-wave will be half this length which equals $\frac{29 \cdot 6}{2} = 14 \cdot 8$ ft.

Loading

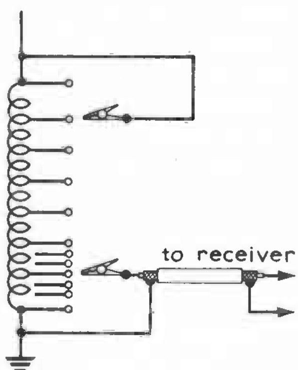
An aerial which is not resonant at the frequency we want can still be made to resonate by adding a capacitor, an inductor or both. If our garden were 43 ft long and we wanted to listen to the 7 Mc/s amateur band we would be stumped, because for the wire to be resonant at 7 Mc/s it must be 66·85 ft long. Even a vertical would need to be 33·5 ft tall. When this

Figure 7/3



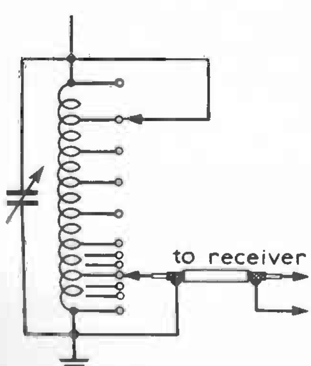
problem turns up – for instance, when we want to use one length of wire for all wavelengths – we can use a dodge called inductive loading. This impressive-sounding description merely means that we wind a coil and insert it between the end of the aerial and the receiver. Figure 3 shows what an inductively loaded vertical would be like. This dodge is very useful and is often used by amateurs when there just isn't enough room to put up a full length aerial system. A small vertical might be insulated and clamped to the side of the house, and then inductively loaded for the relevant band.

Figure 7/4



If we have, say, fifty feet of wire for an aerial, we wind one big coil to make our aerial resonate at the lowest frequency we are interested in. (figure 4). This coil is wound with a number of tapping points on it, just like the one for our simple crystal set. Now when we change bands or alter the frequency, all we have to do is to change our tapping point on the coil at point A. This tap, since it is connected directly to the top of the loading coil, will short out the excess turns between it and the top of the coil and will thus effectively vary the inductance. Likewise, the other tap B can be varied to tap the receiver load into the coil quite accurately. The good point about this is that no matter where you tap along the coil, you can't damage the receiver or the aerial. Also, you do not need any complicated instruments to adjust things to optimum. Simply experiment by tapping up and down the coil for the loudest signal at the receiver headphones or loudspeaker.

Figure 7/5

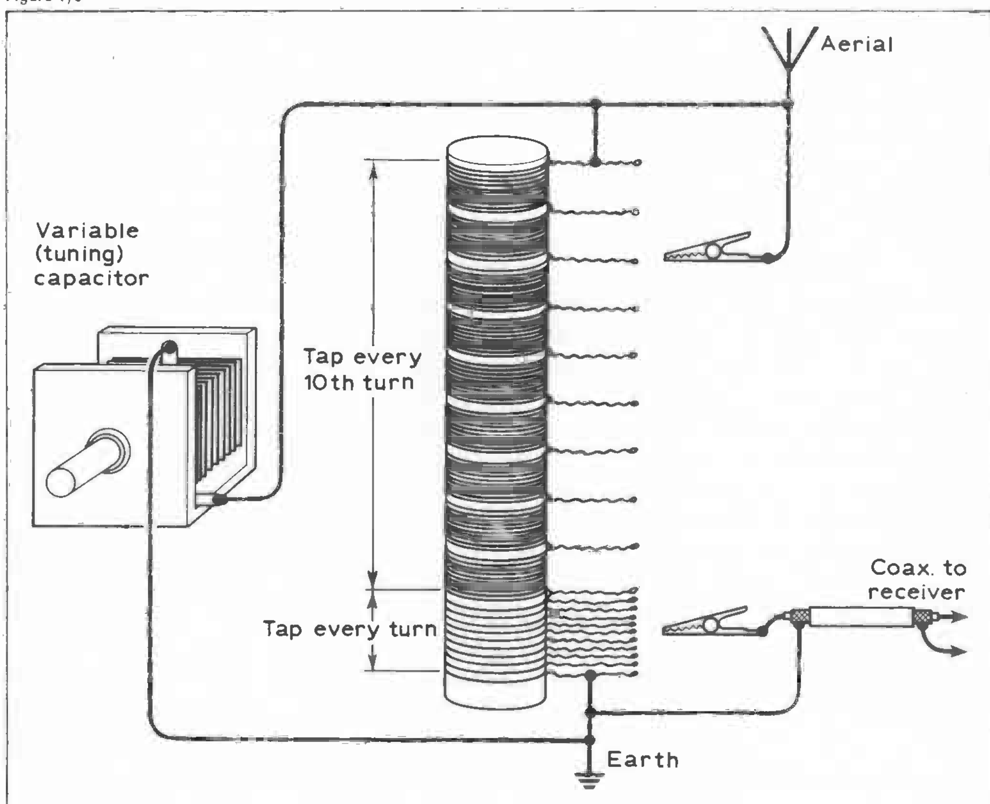


It is sometimes useful to add a capacitor as in figure 5. In this case the capacitor can be varied or tuned as well as the inductance. This coil and/or capacitor combination used in this way is called an Aerial Tuner Unit or a.t.u. It may be used with longwire aerials or verticals and a practical circuit is shown in figure 6. This coil is wound exactly as for the simple crystal set, but there are more tapping points. The capacitor could be 300μF.

Almost any wire will do for an aerial providing it is strong enough. Insulated bell wire is quite good enough to start with and it is cheap. If you use bare copper wire or wire which is not insulated, then you will need to insulate it yourself where it comes into the house to connect to the receiver. You can either buy a length of insulated sleeving to put over the wire, or you can tape the wire with p.v.c. tape where it enters the house.

When you have wound your coil for the a.t.u., attach a crocodile clip to the end of your aerial and the top of the coil, and clip it to the various taps in turn. Another crocodile clip attached to a wire plugged into the receiver aerial socket will complete the job. It is only necessary to adjust the taps to get the best results.

Figure 7/6



Directivity An aerial will often transmit or receive signals in one direction but not in another. This property of aerials is called directivity. The half-wave dipole had directivity as shown in figure 7 (called a polar diagram) in which we look down from directly above the aerial. If you were to walk round a dipole at a uniform distance holding an instrument which detected and measured the strength of a signal, and at the same time you fed a steady signal into the dipole, you would get the response shown in figure 7. We can see from the polar diagram that a dipole will transmit or receive signals best when it is broadside to the station, that is in the direction marked A. If the transmitting station were situated in line with the end of the aerial in the direction marked B, then very little signal, if any, would be received. This directivity is very important when you want to listen to a station in a particular part of the world, as if your aerial is orientated incorrectly, you may not hear the station at all. Longwire aerials too have this directive property and, like all aerials, they are influenced by how they are placed, how far away they are from earthed objects which will modify their polar diagrams. It will pay to experiment with your aerial system and find which is the best direction to point it.

The vertical aerial we mentioned has a polar diagram like that shown in figure 8. It receives or transmits equally well in all directions and so is often used when all-round reception is required.

Figure 7/7

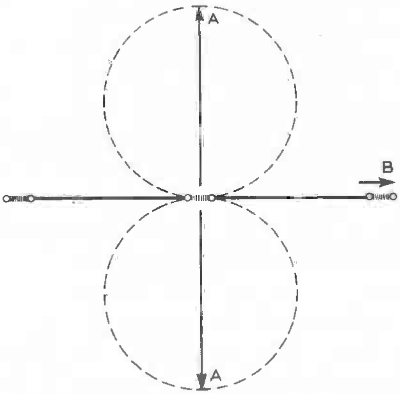
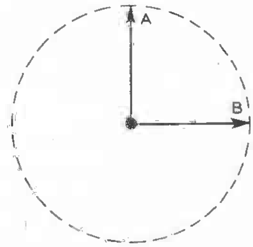


Figure 7/8



The morse code

A	· —
B	— · · ·
C	— · — ·
D	— · ·
E	·
F	· · — ·
G	— — ·
H	· · · ·
I	· ·
J	· — — —
K	— · —
L	· — · ·
M	— —
N	— ·
O	— — —
P	· — — ·
Q	— — · —
R	· — ·
S	· · ·
T	—
U	· · —
V	· · · —
W	· — —
X	— · · —
Y	— · — —
Z	— — · ·
1	· — — — —
2	· · — — —
3	· · · — —
4	· · · · —
5	· · · · ·
6	— · · · ·
7	— — · · ·
8	— — — · ·
9	— — — — ·
0	— — — — —

8 Short wave listening

Throughout the world there are hundreds of thousands of S.W.L.'s or Short Wave Listeners of both sexes, their ages varying from children to old age pensioners. This is also true of Hams or Radio Amateurs. These people have a special licence costing ~~£2~~ per year and a radio examination which permits them to hold their own callsign and operate a private transmitting station in their own homes. To become an S.W.L. you need only a suitable receiver and a reasonable aerial. -£3.

The short wave bands are split broadly into two sections as far as the S.W.L. is concerned, commercial broadcasts and amateurs or Hams. Amateurs are licenced to transmit and receive only in certain bands which are clearly defined in their licence. They must also have a frequency measuring device so that they are sure that their transmissions do not stray outside these bands. Hams are also allowed a certain set power at which their transmitters can operate. On some bands the amateurs share the band with other services. Topband (160 metres or 1·8 – 2·0 Mc/s) for instance is shared with coastal stations which talk to ships. In order to help ensure that the amateur stations do not block or jam the coastal stations, the amateur is only allowed to run his transmitter at a power of 10 watts on this band. On some other bands he is permitted to run 150 watts.

Page 85 shows a table of the amateur bands together with the powers permitted. The two numbers shown are the band edge frequencies and the amateur may transmit anywhere in between them. Thus the eighty metre band which is 3·5 – 3·8 Mc/s, the amateur may transmit on 3·501, 3·502 and so on, so you see there is quite a wide spectrum. Some of these bands get very crowded at times. This is not surprising when you consider the growth of amateur radio. There are over 13,000 licensed amateurs in Britain alone, not counting the S.W.L.'s. In America there are over 100,000 licensed amateur stations.

Callsigns

The callsign of an amateur station tells immediately which country the station is located in and once you hear it you know which part of the world you are listening to. For instance, in New Zealand the callsigns all begin with ZL. The number and letters which follow differentiate between individual stations in the same country. In England the callsigns begin with G. My callsign is G3JDG while others might be G2VVV or G3ZOZ etc. The Radio Society of Great Britain (R.S.G.B.) publish a countries list which gives the identification letters of all the countries in the world. This list is available very cheaply, and armed with this plus a good atlas one can learn quite a lot of geography in a very short time. It would be an interesting project to buy one of the big maps of the world then, when a country is heard, a coloured drawing pin could be pushed into the map. To start with a map of England might be purchased and G stations marked as they are received.

You can buy a callbook too if you wish. This is just like a telephone directory but has callsigns instead of telephone numbers. There is a G-callbook listing the callsigns, names and addresses of all British amateurs. There are others which cover all American stations while a larger volume covers the world. The latter book is rather expensive, but a British-only callsign book is reasonably cheap—less than ten shillings. You can obtain these books from the R.S.G.B.

Q Code

When one station contacts another they often promise to QSL. This is really a written confirmation that the contact took place and takes the form of a card, with the callsign of the sender printed on it, usually in bold letters. It also contains the written confirmation plus, perhaps, a few personal remarks. Thus QSL is a sort of code meaning confirmation or please confirm, I will confirm etc. The idea of using an international code is now very common and amateur stations do this frequently. This code, called the Q code, plus other amateur slang, makes it a little difficult for the beginner to understand just what it is these Hams are talking about, but are very useful, especially when sending messages in morse. Imagine

you want to know the time at the other station. This can be very different from the time in England. If you spell out this question you must send 'Can you tell me the correct time please?' This is eight words, whereas using the Q code all you need send is 'QTR?' which means exactly the same thing. In figure 2 is a list of the more commonly used abbreviations and some of the Q code. For instance you will see that QRM means interference. Thus a c.w. operator would just send 'HR QRM' and the receiving station would deduce that the other station was having difficulty in copying his signals due to some form of interference. An operator using speech might say that there was high local QRM. This would mean, perhaps, that someone nearby had an unsuppressed electric motor which was interfering with reception. Again, using c.w., a station might send '73 OM es tnx fb QSO bcnu es GN.' This would mean kindest regards Old Man, and thank you for a fine business (very nice) contact. Be seeing you and Good Night.

The morse code is a very useful thing to know. Many amateur stations, ships, commercial and news broadcasts use c.w. The c.w. stands for continuous wave, and by interrupting this continuous wave (with a morse key) we make the morse code symbols.

To obtain a full amateur licence you must pass two tests. The first test is a written paper consisting of questions of a technical nature. The second test is that you must be able to send and receive morse at not less than twelve words per minute. The minimum age for obtaining a licence is fourteen and there are a number of schoolboys who are already on the air. It is possible to get a licence by passing the technical test but not taking the morse exam. If you do this, however, you will only be allowed to use the amateur bands above 4 metres (70 Mc/s) so 70 that the lowest band you will be permitted to transmit on will be the 2 metre band – 144 Mc/s, which requires rather specialised equipment. By passing the morse test also, you may transmit on any of the amateur bands.

The morse code is shown in figure 3. Whatever you do DO NOT think of the characters as dots and dashes, think of them as dits and dahs. Thus the letter C would be thought of as dah-di-dah-dit, and D would be dah-di-dit. Perhaps you could wire up a buzzer and buy a cheap morse key to practice with. If you can find a friend who wishes to learn morse, then you could practice sending to each other once you have both committed the code to memory. Incidentally, this is where your local radio club would prove invaluable. There are always members who are willing to help with morse instruction.

Propagation

The radio waves we use for long distance communications can only get there because of the ionised layers high above the earth's surface. Unfortunately things are not constant in these layers. The degree of ionisation varies and the activity of the sun affects it. This is vividly demonstrated by sunspot activity, and conditions on the 28 – 29·7 Mc/s (ten metre) band. It has been found that the degree of ionisation is greatly affected by the number of sunspots at the time. A sunspot is a huge burst of radiation given out by the sun. The sun has an eleven year cycle regarding sunspots. They go from maximum to minimum, back to maximum again and so on, and the time between successive maximums is 11 years. During the time of a sunspot maximum the ten metre band is full of signals. At a time of sunspot minimum however, the same band is almost dead. Long periods might elapse without hearing a single station.

The height of the layers alters too and is different at night to that during the daytime. Thus the conditions on the various bands varies from hour to hour. In general, the two highest bands are the ones most affected by the sunspot count, that is 21 and 28 Mc/s. Activity can usually be found on one or more of the four lower bands at any time. Figure 4 gives some idea of the type of reception to be expected on the bands.

Mobile stations

There are some 2,000 amateurs with their radio stations in their cars. This costs an extra ~~£1~~ per year but requires 3 no further examinations. The same conditions apply regarding bands and power permitted. The main problems are that all the power must come from the car battery or

accumulator, although some mobile stations do carry an extra accumulator to run the 'rig' or station off.
Another problem is finding a suitable aerial. It is not possible to erect a large wire aerial on a motor car, so the usual procedure is to use a whip aerial with a loading coil. The whip is made as long as possible (normally between 5 and 8 feet long), and an inductance is added until the aerial is resonant on the particular band we wish to work on. A different coil is required for each separate band. A very common band for mobile stations is topband.

Radio rallies

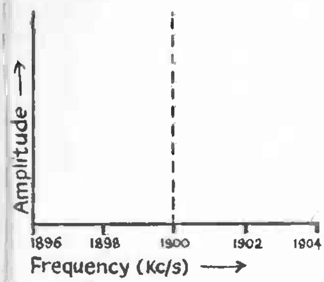
Every year, in the summer, there are a number of mobile rallies held. A talk-in station is set up, and mobile stations going to the rally can chat to each other as they travel along. If they are not sure of the way, they merely contact the talk-in station at the rally and he will talk them in. The talk-in operator usually has a very good set of maps to help him give correct directions to mobiles seeking his help. You can tell a mobile station from a fixed station because when an amateur goes mobile he must use the prefix 'stroke M' after his normal callsign to show that he is mobile. Thus when I am mobile, my callsign changes slightly from G3JDG to G3JDG/M. Mobile rallies are usually held where there is lots to do. The R.S.G.B. often runs a National rally at Woburn Abbey in Bedfordshire, while others are held at seaside resorts. Usually there are junk stalls with various radio 'bargains', lucky dips and raffles etc., besides all the local attractions. Details of these rallies are given in advance in the R.S.G.B. Bulletin or Radio Communications as it is now called.

A mobile station must be safe. It is useless, and extremely dangerous, to have a spiders web of wires running about all over the car. In my mobile installation the microphone is held round my neck by a light-weight halter. This holds the mike in position and all I have to do is talk, thus both hands are free for driving. The only control I need to touch when I am in QSO (contact) is the switch which switches my equipment from transmit to receive and vice versa. Once you know of a rally taking place, you can try to find the talk-in station on topband. You will then be able to monitor any contacts he makes, and hear all the mobile stations arriving from different directions. If you tune up and down the band, you will probably hear some of the mobiles talking to one another, giving their location etc.

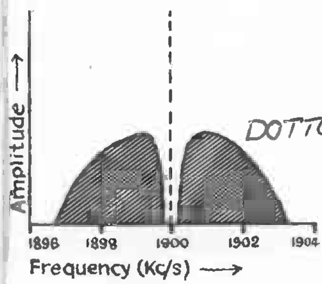
At the start of this chapter, I said that you needed a receiver and an aerial to become an S.W.L. and this is quite true. This is the first step in becoming the proud possessor of an amateur station of your own. However, it will not be long before you realise that you really need a few extra refinements.

Transmission modes

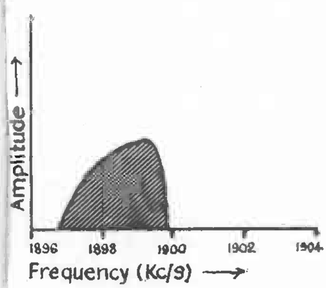
There are three main modes of transmission on the amateur bands. There is c.w., which is morse; amplitude modulation, which is ordinary speech; and a thing called single side band which is also speech but with a difference. Let us imagine that we have one each of these three types of signal and we want to resolve them i.e., make them intelligible. With c.w. we must have a thing in our receiver called a b.f.o. which stands for beat frequency oscillator. The b.f.o. is really a low-power oscillator which emits a little signal. We beat this low-power signal with the incoming c.w. signal after it has entered the I.F. amplifiers. The result is that we hear a note. Remember when we discussed mixers we said that if we fed two different signals into a mixer, the output would consist of the sum and difference of the two signals? Suppose we have a standard I.F. of 465kc/s and we arrange our b.f.o. to emit a signal at 466kc/s, that is 1,000c/s or 1kc/s higher than the incoming signal. If we now feed both these to our detector, say a diode, then the detector will act as a mixer. The output will consist of the sum and difference of the two signals we mix. Now both the original signals are R.F. and above audibility, too high for our ears to hear. Let us see what we get out of the mixer. The sum frequency will be the addition of the two frequencies, 465 plus 466kc/s which equals 931kc/s. This is even higher than either of the original frequencies and thus far too high for our ears to appreciate anything at all. The difference works out at 466kc/s minus 465kc/s which equals 1,000c/s or 1kc/s and this note is low enough for our ears to hear without any trouble at all. Most human ears can detect a



c.w. signal



a.m. signal



s.s.b. signal
(lower sideband)

frequency up to 10kc/s without any effort while some people can even hear 16-20kc/s. So the difference signal of 1kc/s we have at the detector we can hear. Thus the b.f.o. is necessary to make morse code (c.w.) in a receiver readable. With a.m. or amplititude modulation we don't need a b.f.o. so we can switch it off. We tune in a.m. until we get the best signal and leave it at that.

Now we come to s.s.b., a mode which is fast becoming the main method of speech on the amateur bands. To understand how to resolve s.s.b., let us examine this drawing of the three modes side by side. You can imagine the base line is frequency while the vertical line or axis represents the amount or amplitude of the signal. Starting with c.w., the single DOTTED ~~thick~~ line represents our carrier received, and as this carrier is unmodulated, it is a continuous wave and does not spread or take up any frequency along the bottom horizontal line which represents the frequency above and below the carrier or signal frequency we are receiving. Next we have an a.m. signal. The carrier is again centred on 1,900kc/s and on either side we have two sidebands one above and one below the carrier frequency. These sidebands contain the speech which modulates the carrier thus forming the two sidebands. If we examined these two side bands we would find that they were the same in as much as the upper sideband would be a mirror image of the lower sideband. Note that the whole signal takes up a total frequency or bandwidth along the bottom horizontal line of 6kc/s. Now if exactly the same information is carried in both sidebands we should be able to take one of the sidebands away and listen only to the other one. If we did this we would reduce the bandwidth of the signal by half and thus make room for other stations. This is what s.s.b. does, as it's name implies. It is found that the bandwidth can be further reduced to around 2kc/s and still remain intelligible. This is not Hi Fi, but it is quite good enough for communications purposes. The s.s.b. transmission also eliminates the carrier too, and so when we wish to resolve it in our receiver we must supply this missing carrier in order to make it intelligible. We can do this quite simply with our b.f.o. We tune in the s.s.b. signal for maximum noise with our b.f.o. switched off. The signal will not be intelligible at this point, sounding rather like Donald Duck talking in a gruff voice. We now switch in the b.f.o. and tune the b.f.o. pitch control, which alters the frequency of our b.f.o. slightly, until the signal becomes intelligible. If it still sounds heavily distorted, turn down the R.F. gain control.

To make a start from scratch on the short waves you could build the receiver described in Chapter 6. This will receive two amateur bands when the correct coils (range 3T) are plugged in. The two bands covered by this range of coils is 80 metres and topband – 160 metres. You should be able to hear a number of G stations on topband and some European amateurs on 80 metres. You will probably hear some mobile stations too on topband especially in the Summer months when the rally season is in full swing.

This receiver does not have a b.f.o. and so you will not be able to resolve c.w. or s.s.b. as it stands. If you would like to add a b.f.o. stage, which will consist of a single transistor and a few components, then Messrs Denco, whose address is given in the Appendix, sell a special double-wound coil complete with a suitable circuit diagram. These are shown in their Technical Bulletin DTB4 which, at the time of writing, costs 2/-. The output of the b.f.o. is taken by an insulated wire which is wrapped around but NOT directly connected to the diode detector. The receiver should pick up a very large number of stations as it stands without the addition of a b.f.o.

It is an excellent idea to join your local or nearest radio club. The name and address of the secretary may be obtained from the R.S.G.B. – don't forget a stamped addressed envelope.

The amateur bands: types of transmission and permitted power

band	power am/cw	power ssb
Topband 1·8 – 2·0 Mc/s 160 metres	10 w	26 w
Eighty 3·5 – 3·8 Mc/s 80 metres	150 w	400 w
Forty 7·0 – 7·1 Mc/s 40 metres	150 w	400 w
Twenty 14·0 – 14·35 Mc/s 20 metres	150 w	400 w
Fifteen 21·0 – 21·45 Mc/s 15 metres	150 w	400 w
Ten 28·0 – 29·7 Mc/s 10 metres	150 w	400 w

The VHF & UHF bands include 4 metres, 2 metres & 70 centimetres

Some of the Q codes and amateur abbreviations

QRG	frequency
QRK	audibility
QRM	interference
QRN	atmospherics
QRT	closing down
QRX	please wait
QSB	fading
QSL	confirmation
QSO	radio contact
QTH	location
BA	buffer amplifier
CANS	headphones
DE	from
HI	laughter
K	invitation to transmit
MOD	modulation
OM	old man
PA	power amplifier
ROGER	received and understood
RPT	report
VFO	variable frequency oscillator
XYL	wife
YL	young lady
73	kindest regards
88	love and kisses

Activity on the amateur bands

160 metres, 1·8 – 2·0 Mc/s Local G stations during daylight hours, at night, distant G stations, Europeans and sometimes American amateurs.
80 metres, 3·5 – 3·8 Mc/s Many G stations, Europeans, and when conditions are favourable, DX (long distance) stations.
40 metres, 7 – 7·1 Mc/s About the same as 80 metres.
20 metres, 14 – 14·35 Mc/s World-wide communications possible but sometimes the band closes and very little is heard.
15 metres, 21 21 .45 Mc/s Excellent at times for world-wide activity, but is sometimes very dead. Is affected by sunspots.
10 metres, 28 – 29·7 Mc/s Roughly the same as 15 metres, but very much affected by sunspots.

Appendix

In order to make the collection of components for the various circuits easier, only three sources of supply were used. This will save hunting around numerous radio suppliers trying to get different components.

The Denco coils used in the receivers may be obtained direct from the manufacturer Messrs Denco (Clacton) Ltd, 357/359 Old Road, Clacton-on-Sea, Essex.

The semiconductors, diodes and transistors, and the 80 Ohm loudspeaker are all obtainable from Messrs. Henry's Radio, 303, Edgware Road, London W.2. who specialize in semiconductors.

All the remaining components, resistors, capacitors, batteries, knobs etc., were obtained from Messrs. Electroniques Ltd, Edinburgh Way, Harlow, Essex. This latter firm holds vast stocks of components and specializes in mail order.

For those who would like to read a little deeper into the subject there are a number of books available. On transistors – *Getting Started With Transistors* by Louis E. Garner, Gernsback Library No.116 is an excellent work. Again, to follow this one, you might try the *Transistor Pocket Book* by R.G. Hibberd, published by Newnes. Your local public library can probably provide other books of interest.

For those interested in shortwave listening and amateur radio, the Radio Society of Great Britain (R.S.G.B.) have published some very useful and inexpensive books. Two of the most popular are – *A Guide To Amateur Radio,* and *Radio Amateurs' Examination Manual.* Both these are available from the R.S.G.B., 28, Little Russell Street, London W.C.1. (soon to move to 35 Doughty Street, London W.C.1) and cost less than 7/- each at the time or writing.

There are a number of publications which come out monthly. For general interest in radio, transmitting, shortwave listening etc., there is *Practical Wireless.*

For the shortwave listener and 'Ham', the ***Short Wave Magazine*** is useful. There are also some American publications which are available in this country catering for the S.W.L. and 'Ham' these are *QST, 73 Magazine,* and *CQ. The Radio Constructor* is another English magazine published monthly, while *Wireless World* tends to cater for the professional engineer rather than the beginner.

Perhaps the best advice for the beginner is to join a local radio club. Here you can ask questions and discuss problems with other members. In most clubs there are many licenced amateurs, but there is also usually a high proportion of keen S.W.L's. You will also be able to visit other members 'shacks' and see their equipment and may well become interested in setting up as a 'Ham' yourself.

Another good move is to join the R.S.G.B. There are numerous benefits and you will receive a copy of the Society's own journal free every month. This journal contains technical articles on both theory and construction, and gives information on radio contests.

Index

Illustrated Teach Yourself Books include

Soccer F.N.S.Creek

How to improve your football, to understand the rules and the finer points of play—and increase your enjoyment of the game

Show Pony
Jennifer and Dorian Williams

How to train your pony and yourself for success in the show ring and at the gymkhana

Radio David Gibson

How to make three different receivers, from crystal set to superhet, and a transistorized amplifier, with step-by-step instructions

Riding C.E.G.Hope

How to choose a pony and to judge its points; the art of stable management and of training for health and stamina; riding for fun

Photography Ron Spillman

How to choose and use a camera and teach yourself to take good pictures

Dogs as Pets C.E.G.Hope

How to find the perfect pet for fun and company: how to train, feed and keep your dog happy and healthy. With fine portraits of the best-known breeds photographed by Paul Kaye

Illustrated Teach Yourself

SBN 340 03769 5