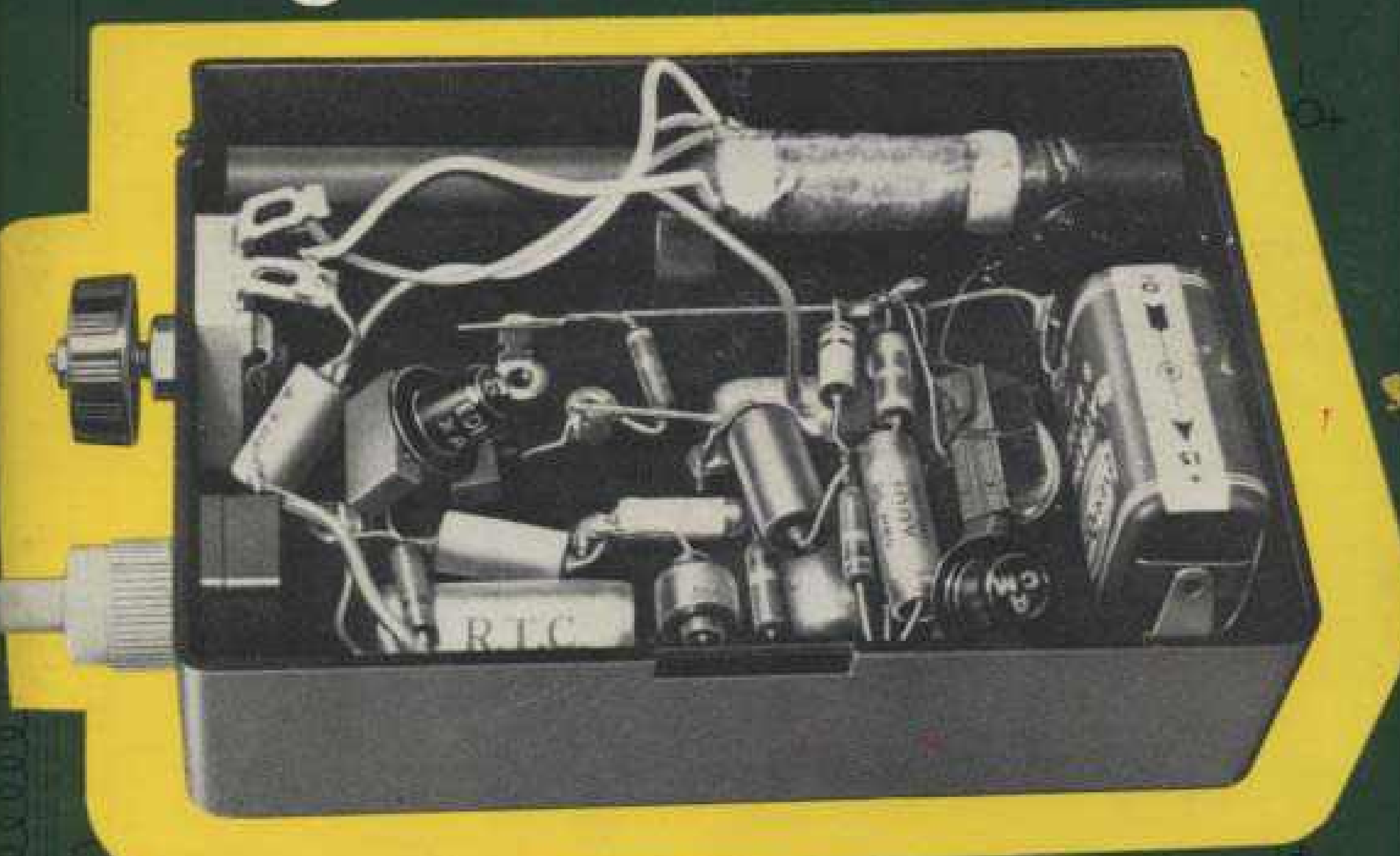
MAKING TRANSISTOR RADIOS

A Beginner's Guide



R.H. Warring

This book covers just about every type of transistor radio receiver which the amateur can tackle, and develops these from the basic crystal set to the advanced superhet model. The receivers described have been confined entirely to the transistor type, as valve sets are now quite out of date and furthermore have the disadvantage of requiring mains' voltage.

The author has made a great point throughout the book of not being too technical for the beginner, and has been eminently helpful with such difficult problems as the interpretation of circuit diagrams and the soldering together of components. There are also innumerable valuable tips to the reader on how to achieve the best results without recourse to any elaborate or expensive equipment. The final chapter dealing with printed circuit sets will also make this more advanced process fully intelligible to the beginner.

Each and every stage has been carefully illustrated with the author's own line drawings in order that the reader may *visualize* all his problems before he sets about resolving them. The keen beginner should therefore be in a position to become completely expert at building a variety of different types of receivers during the course of working through this instructive book. To be able to build a working radio receiver provides a first-class pastime – and a very rewarding one – and this is the book which will enable you to get the most satisfaction out of this particular hobby.

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Written and illustrated by
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INTRODUCTION

THE home construction of radio receivers used to involve large aluminium chassis, valves, a cumbersome mains' transformer, a collection of other large components and an extensive wiring up job. The finished job may have looked impressive as an example of working electronics, but pretty 'messy' unless enclosed in a cabinet. Today similar—or even better—performance can be realized with transistor receivers, taking up no more volume than a pack of cigarettes.

Transistors, in fact, have revolutionized amateur radio construction. Although one still finds designs for valve circuits published from time to time, they are quite out-dated—museum pieces rather than present-day projects. Transistors make radio receiver construction so much simpler—and cheaper. And, of course, they have the advantage that they work off low voltages, readily supplied by small dry batteries.

This book covers a fairly extensive *practical* course in transistor radio receiver construction. Theory is not all that important. Any radio receiver can be split up into separate stages, and there are basic practical requirements for getting each stage to work—the types and values of components required, and how they should be connected. The most important thing about the end product—the finished receiver—is that it should work, and give a satisfactory performance.

No previous knowledge of radio is needed to build successful receivers to the various designs given, although for the absolute beginner it is recommended that a start be made with the very simplest type, the crystal set (Chapter 4). Certain techniques have to be mastered, however—especially the art of successful soldering (which is really very simple, provided you go about it the right way). The first three chapters, therefore, are devoted to principles and techniques, and are important.

The remaining chapters then describe designs of the various different types of transistor radio receivers, virtually in increasing order of complexity. Each circuit is treated in a practical manner, but with descriptions of how and why each works. Regard each as a practical project well worth attempting—and the background descriptions a 'painless' introduction to receiver design theory! You should, in fact, end up as quite an expert on amateur receiver design and construction, for the coverage offered by this book is quic comprehensive as far as receiver types are concerned; and the subject is a fascinating one for anyone who likes making things that work.

R.H.W. 1970

CHAPTER 1

HOW RADIO WORKS

EVERYONE is fairly familiar with the idea of sound waves radiating from a source—rather like the spread of ripples on the surface of a still pond after a stone is dropped into it. Like ripples on water, however, sound waves are only able to travel for relatively short distances since the energy associated with the passage of the sound wave through the air is 'damped' or dissipated by the resistance of the air.

This is illustrated diagrammatically in Fig. 1, the ripples representing the sound wave (or series of waves), decreasing in 'height' (or amplitude to use the technical description). The actual waveform is represented by a section through the 'ripples' taken along a particular direction, and it is quite noticeable how this decreases in amplitude with distance. The amplitude represents the energy content of the wave, and at a distance from the source this becomes too small to be audible.

The only way in which this limitation can be overcome—i.e. to make the sound audible at a greater distance—is to increase its volume, or make the amplitude greater to start with. This is the principle behind the loud-hailer, or public address system, which *amplifies* or magnifies the original sound. But again there are obvious limits to what can be done in this respect.

The other thing about sound waves is that they are affected by wind. A following wind will increase the distance over which a given sound can be heard, and a head wind has the opposite effect. Another factor which can be significant is the presence of other sounds (from other sources), which can mask the original sound in which we are interested.

To transmit sound over long distances some other method is obviously necessary. One method is to turn the sound waves into electrical waves which can be transmitted along a length of wire—Fig. 2. This is the principle of the telegraph or telephone. There are several immediate advantages. The transmission is completely free from wind effect, and from external sounds (provided these do not reach the microphone), although there may be some 'noise' generated in the electrical circuit

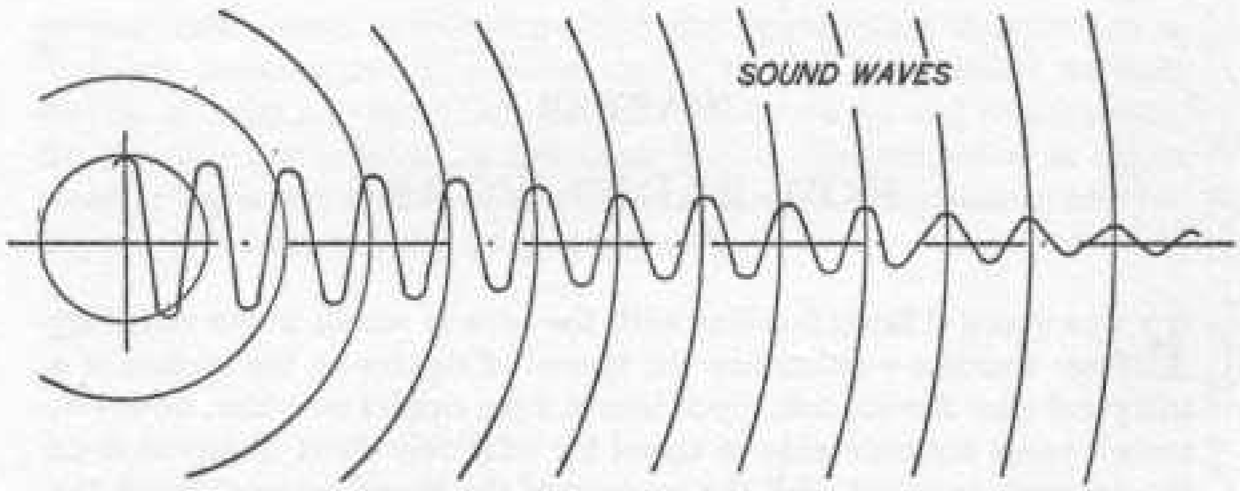

Fig. 1. *Diagrammatic representation of sound waves, showing fall off in energy with distance*

itself. Also, to carry the sound over a great distance, it is only necessary to increase the length of the wire. There will be some loss of energy, due to the electrical resistance of the circuit, but this can be overcome by inserting another unit to boost or amplify the electrical waves, if necessary. And electrical waves are easy to boost in this manner, whereas sound waves are not.

The other alternative is to turn the sound waves into electrical energy which is then transmitted through the air, rather than along a wire. These waves can then be picked up by a distant receiver, which

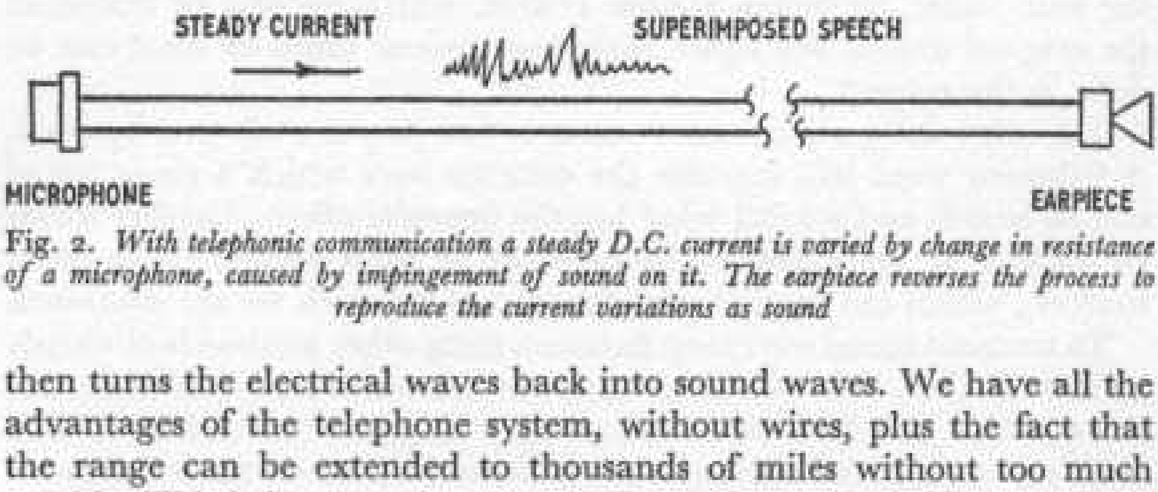

Fig. 2. *With telephonic communication a steady D.C. current is varied by change in resistance of a microphone, caused by impingement of sound on it. The earpiece reverses the process to reproduce the current variations as sound*

then turns the electrical waves back into sound waves. We have all the advantages of the telephone system, without wires, plus the fact that the range can be extended to thousands of miles without too much trouble. This is because electrical waves transmitted through air suffer very little loss of energy, and in fact do not need air at all to conduct them. They will travel just as well through empty space.

Another important difference, compared with sound waves, is that electrical waves are much more closely spaced together, or have a higher *frequency*, than sound waves. Sound waves range in frequency from about 30 cycles per second* (a very low note) to about 16,000

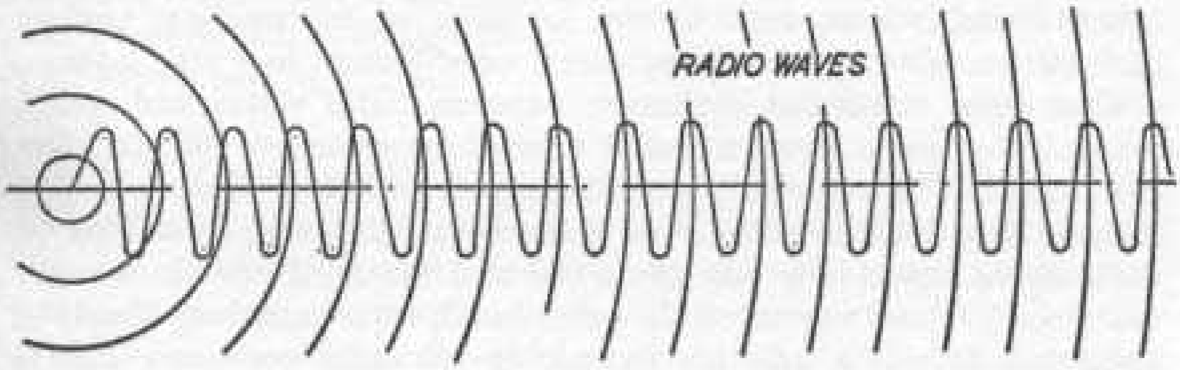

Fig. 3. *Diagrammatic representation of radio waves. The frequency is very much higher than sound waves, and the power very much less*

cycles per second* (which is a very high pitched note and about the upper limit for audibility). Electrical waves within this frequency range can be transmitted *along a wire*, so that a telephone is a simple and uncomplicated converter of sound into electrical waves, and vice versa. But to be capable of radiation *through the air* the electrical waves must be of much higher frequency. The latter type are known as *radio waves* and may have frequencies ranging from about 150,000 cycles per second up to several hundred *million* cycles per second (see Fig.3). Sound frequencies are known as *audio frequencies* (AF); and radio frequencies as *radio-frequencies* or RF.

It also follows that radio waves are of much too high a frequency to be heard—the upper limit of frequency for audibility being only about

* A 'cycle' means a complete wave 'up and down'. The rate at which these waves vibrate or oscillate is known as the frequency, expressed as so many cycles per second. In the case of radio waves, the frequency is normally specified in *kilocycles* per second (1 kilocycle being equal to 1,000 cycles); or *megacycles* per second (1 megacycle being equal to 1,000,000 cycles). To conform to international standards the term 'cycles per second' (or c/s, as an abbreviation), is now replaced by the single word 'Hertz' (abbreviated Hz). Kilocycles per second thus become kiloHertz (kHz), and megacycles per second megaHertz (mHz).

16 kilocycles per second. Radio transmission thus involves the complication of first turning sound frequencies (AF) into radio frequencies (RF) for transmission; and then reconverting radio frequency signals (RF) into audio frequencies (AF) at the receiving end. The first is done by a radio transmitter; and the second by a radio receiver. There are also other complications, such as the necessity of transmitting various different sounds simultaneously, which we will come to a little later.

One other important difference between radio waves and sound waves is that radio waves travel at a very high velocity—186,000 miles per second, which for all practical purposes means that radio waves take no time at all to travel from one point on the earth to another (a radio signal would only take about one and one-third seconds to reach the moon). Sound waves, on the other hand, travel relatively slowly—about one-fifth of a mile per second, or 720 miles per hour. This is because they are *pressure waves*, whereas radio waves are *electromagnetic waves*. We can hear (and feel) pressure waves (i.e. sound), but not electromagnetic waves.

We have mentioned the wide range of RF frequencies in use. These can be divided into various 'bands', viz:

Long wave—150 to 500 kHz (kilocycles per second).
Medium wave—500 to 1500 kHz (kilocycles per second).
Short wave—1·5 to 30 mHz (megacycles per second).
VHF (very high frequencies)—above 30 mHz (megacycles per second).

The descriptions 'Long Wave', 'Medium Wave' and 'Short Wave' stem from the original method of designating a broadcast frequency by the *wavelength* of the signal—in fact, tuning dials on radio receivers are still more commonly marked in wavelength than frequency.

We can convert from wavelength to frequency, or vice versa, by using the simple relationship:

wavelength × frequency = velocity (of electromagnetic waves).

However, wavelength is always given in metres, so we must also express velocity in similar units, i.e. 300,000,000 metres/second. Thus:

wavelength (in metres) × frequency (cycles per second) = 300,000,000
or wavelength (in metres) × frequency (in kHz) = 300,000
or wavelength (in metres) × frequency (in mHz) = 300

The corresponding wavelengths for the various bands mentioned above are thus:

Long wave—2,000 to 600 metres Medium Wave—600 to 200 metres Short Wave—200 to 10 metres VHF—less than 10 metres	Note: if talking in terms of wavelength only these figures would normally be quoted the other way round, as the band range, e.g. Long Wave 600 to 2,000 metres.

Each radio transmitting station has its own particular RF frequency (or equivalent wavelength), allocated by international agreement. Any one station always operates on this frequency (although it may also put out the same programme on other frequencies in different bands). A radio receiver is made 'tunable' over a range of frequencies, so that it can be adjusted to pick up the transmissions of a number of different transmitting stations. Due to technical difficulties, it is virtually impossible to make a receiver tunable over the whole range of RF frequencies from 150 kHz to over 30 mHz, and so separate tuning stages are provided for each band. Some receivers may have only two tuning bands—Long Wave and Medium Wave. Others may also include a Short Wave band, and possibly a VHF band. More specialized receiver designs may cover only the Short Wave and/or VHF bands; and split these bands into still further sub-bands for ease of tuning.

The same principle applies throughout, however. A radio receiver is made tunable to a range of RF frequencies (or equivalent wavelengths). That in itself is quite a simple process, involving only a minimum of components. The snag lies in the fact that the RF signal picked up by the receiver is completely inaudible—it is well above the range of audible frequencies. It is necessary to modify the RF signal in some manner so that it can transmit speech and music, i.e. audio frequencies, capable of being decoded and put out *as* AF by the receiver via an earphone or loudspeaker.

The manner in which this is done is as follows. The RF signal transmitted by the radio station is of fixed frequency, equivalent to a single 'note', but of far too high a pitch to be heard. The AF content of the programme to be transmitted is superimposed on this fixed frequency signal, causing it in effect to 'warble' *at audio frequency*.

Technically this is called *modulation*. The fixed frequency RF signal is called the *carrier*, so that when the AF content is superimposed the actual signal put out is *modulated RF*. Fig. 4 shows this diagrammatically. With the transmitting station switched on, but not actually broadcasting, just the carrier signal is being put out. Once the station starts to transmit speech or music, the signal turns into modulated RF. The *RF frequency* remains unaltered, so a receiver adjusted to the same frequency will remain tuned in; but additional components in the receiver can now demodulate or detect the RF component of the signal, extract it from the carrier, and feed it to headphones or a loudspeaker to transform it back into audible sound.

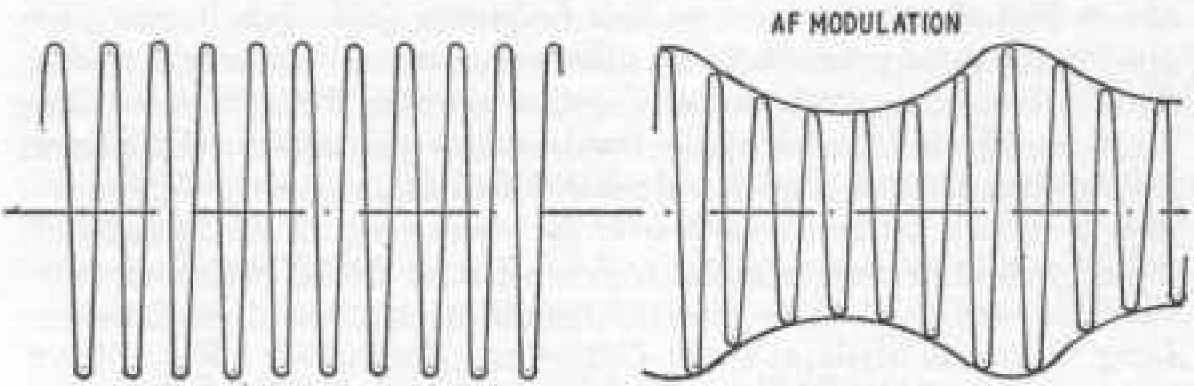

Fig. 4. *Basic radio wave* (left)*; and the modulation produced by a single note* (right)

That is really all we need to know about the process. All the necessary modulation is done by the transmitting station. The receiver merely has to be made tunable to the carrier frequency and given the ability to extract the AF component of the modulated signal. We might, however, have a look at the two different methods of modulation employed, as these will affect the design of the receiver.

The type of modulation shown in Fig. 4, where the carrier remains at the same frequency, but its *amplitude* is varied by modulation, is known as amplitude modulation (AM). This is used on the Long, Medium and Short wave-bands. In fact, the form of the modulated wave shown represents modulation by a single AF note. In practice many different AF notes will be involved in superimposing speech and music on the carrier, so that the actual shape will be very much more complex, and continuously varying, e.g. *see* Fig. 5. This does not affect the issue at all, as demodulation by the receiver remains basically straightforward.

The other type of modulation is known as frequency modulation (FM). This has a number of technical advantages over AM, but also necessitates the use of a much higher carrier frequency. FM is thus restricted to the VHF bands, usually from about 50 mHz upwards. It also involves the use of a different type of receiver design which is considerably more complicated and generally outside the scope of straightforward amateur construction, as most VHF receivers are.

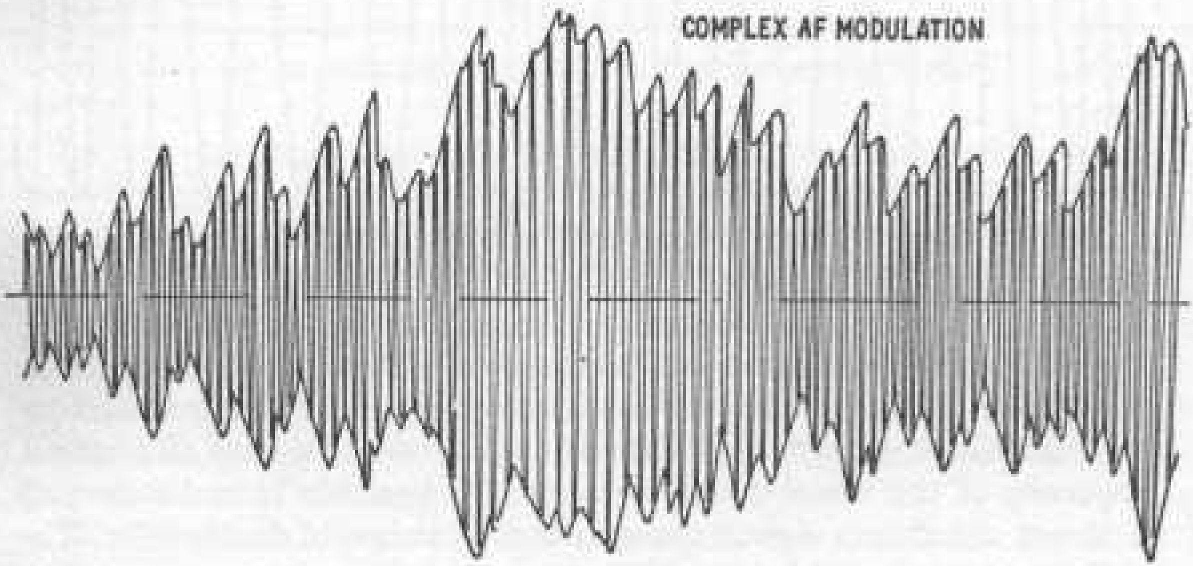

Fig. 5. *This is how a modulated RF signal would appear on an oscilloscope. The RF component being of very much higher frequency than the AF modulation, will completely 'fill' the jagged envelope and thus faithfully transmit complex sounds in the form of modulation*

For the sake of completeness, however, we will describe the system—a typical FM signal being shown in Fig. 6. It will be seen that the amplitude of the transmitted signal remains the same, but the *frequency* varies in a manner which exactly follows the superimposed speech or music (AF content). This is seen as a compression and expansion of the carrier. It is obvious that a different type of receiver is required both to stay 'in tune' with the station as its frequency varies, and to extract the AF component of the signal.

We can now set down the basic principles involved in the design of a simple radio receiver. First we need a means of picking up the transmitter signal. The simplest way of doing this is to use a piece of wire, known as an aerial. If this is cut to the same length (or a multiple or fraction of the signal wavelength) it will receive the signal at maximum possible strength. Such a fixed length of wire would, however, be tuned to a particular broadcast frequency only (although it would pick up signals of other frequencies more weakly).

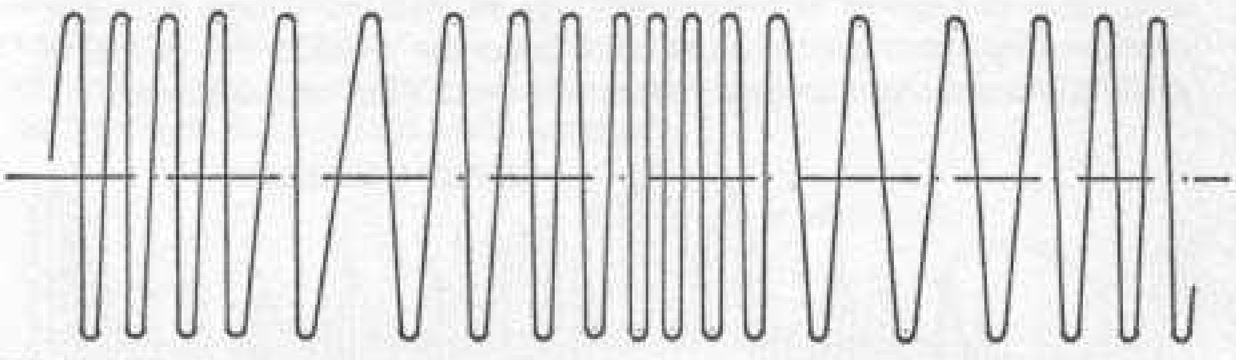

Fig. 6. *With frequency modulation (FM), the RF wave has constant amplitude but frequency is varied, as shown by the compression and expansion of the wave pattern*

To make the aerial 'tunable' we need to add a simple circuit to it, comprising basically a resistor and a capacitor, the value of one (or both) of which is variable. This will make the response of resonant frequency of the aerial/circuit combination variable in order to tune in to get maximum signal strength over a range of frequencies. The addition of this 'tunable circuit', or tuned circuit, as it is usually called, also makes the aerial length far less critical. It can be much shorter, wound in the form of a coil for convenience and become a part of the tuned circuit itself (i.e. the resistor component). An external aerial wire then no longer becomes necessary. Most modern domestic radios utilize this configuration. However, satisfactory performance in such cases depends on the tuned circuit—or more specifically the coil component in the tuned circuit—being very efficient. With less efficient coils, and particularly in areas of low signal strength, the addition of an external aerial to a tuned circuit will improve reception. More on this when we come to making up tuned circuits for simple receivers.

Having tuned in to the frequency required—and provided adjustment to tune into different frequencies to pick up different stations—we have 'captured' the modulated RF signal in the tuned circuit. All we then need is a detector to extract the AF component, when this can

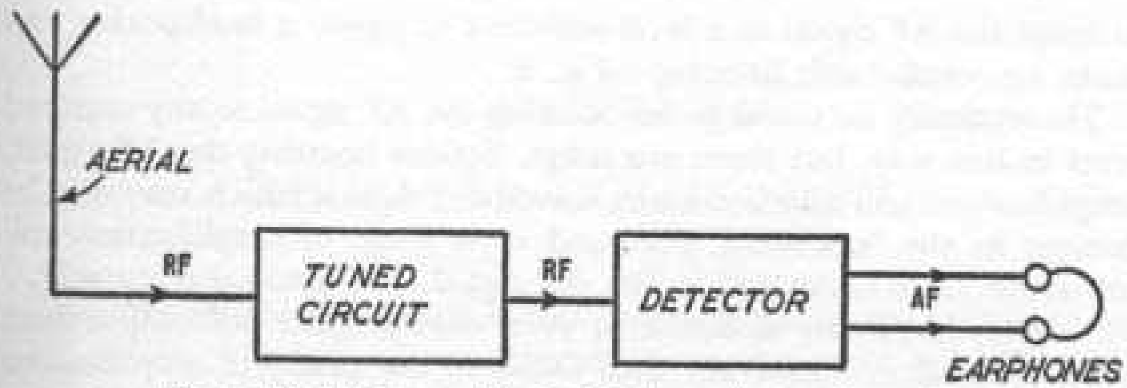

Fig. 7. *Block diagram of the simplest layout for a radio receiver*

be fed directly to earphones to make the incoming signal audible—*see* Fig. 7.

Such a very basic receiver does, none the less, have serious limitations, mainly because the actual signal level received is very low and the detector merely extracts from this and does not boost it in any way. The amount of AF volume realizable is dependent entirely on the strength of the incoming signal and the efficiency of the tuned circuit in responding to that signal. The AF output power will only be capable of driving a small deaf-aid type earpiece, and then the volume will be quite weak. Only local broadcast stations, or very powerful stations, are likely to be picked up at 'hearing level'.

Having *got* the signal into the receiver, however, and extracted the AF component, we can boost or amplify it by introducing an additional circuit into the receiver. This is known simply as an amplifier, and we can add one or more stages of amplification, as necessary, in order

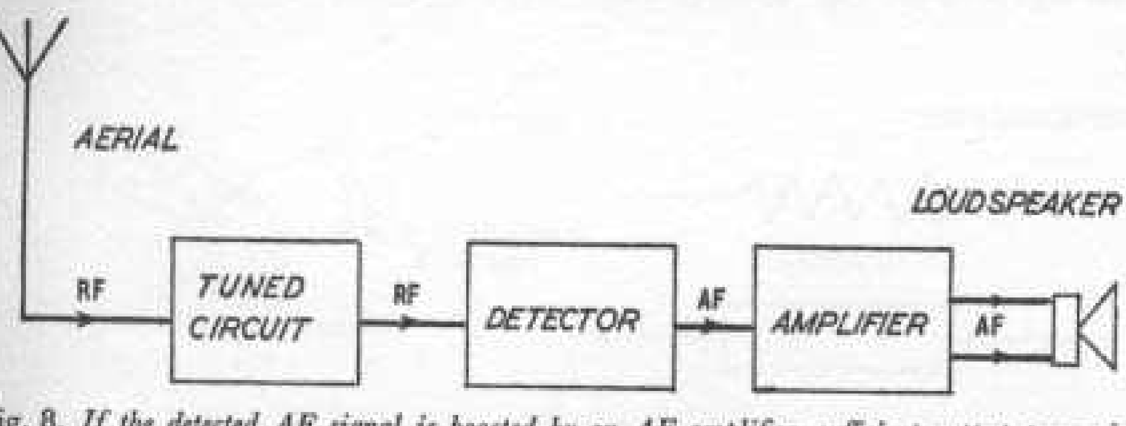

Fig. 8. *If the detected AF signal is boosted by an AF amplifier, sufficient output power is available to operate a loudspeaker*

to boost the AF signal to a level sufficient to power a loudspeaker and make for comfortable listening—Fig. 8.

Theoretically we could go on boosting the AF signal to any required level in this way, but there are snags. Besides boosting the AF signal, amplification will also boost any unwanted signals which may also be present in the 'extracted' RF, and each stage of amplification will introduce some distortion in the AF signal. We could end up with a very loud, but badly distorted or even unintelligible RF output from the loudspeaker. There are thus limits to the practical amplification which can be provided, especially with transistor circuits, but there are also other little tricks of receiver design which we can use to improve both the output and quality of the reception. These will be discussed in the descriptions of the various receiver designs which follow in later chapters.

CHAPTER 2

RECEIVER COMPONENTS

ALL the circuits described in this book are based on semi-conductor devices (diodes and transistors). Since these are miniature components, it follows logically that resistors, capacitors and other components used should also be of miniature or sub-miniature types—all of which are readily available from amateur radio supplies shops, or the larger firms of this type which specialize in mail order. A catalogue from one of these firms is, in fact, an invaluable guide in selecting—and also to a large extent, identifying—suitable components to the values (or type numbers) specified on the circuit drawings given in later chapters.

It is necessary, first, to familiarize ourselves with the shape and appearance of typical components, their electrical (or circuit drawing) symbols, and their electrical characteristics. We will thus deal with the main components under separate headings.

Resistors (old name '*Resistances*')

Physically, resistors are small, cylindrical-shaped objects with a length of tinned wire protruding from the centre of each end—see Fig. 9. They are actually made from powdered carbon mixed with a binder and fired in an oven to produce a hard, rigid shape. The body

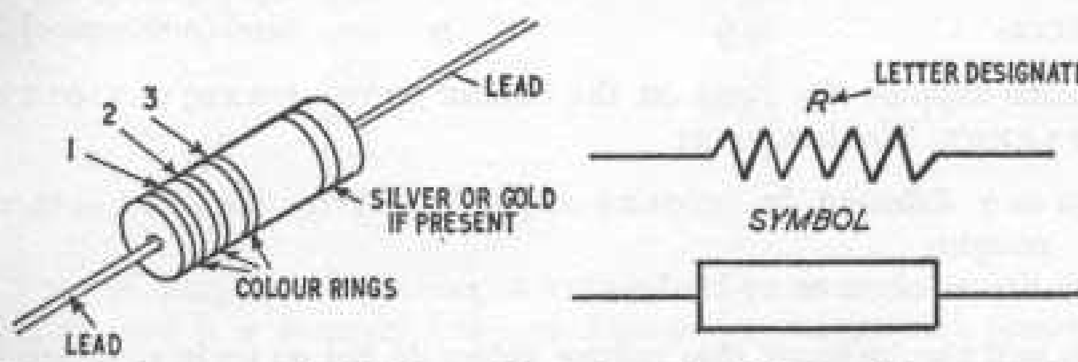

Fig. 9. *Resistors are marked (colour coded) as shown. Symbol used to designate a resistor on a circuit drawing is either a 'squiggle' or a rectangular box*

cover is usually dark brown, but this is encircled with three, or four, coloured bands. These coloured bands show the value of the resistor, according to a standard colour code.

If a resistor has four colour bands, the band nearest one end will either be silver or gold. A silver band indicates that the resistor is made to a performance tolerance within plus or minus 10 per cent of its nominal value (given by the colour code). A gold band indicates that the resistor is made to a closer tolerance of plus or minus 5 per cent. The absence of a silver or gold band simply means that the resistor is made to normal manufacturing tolerances of plus or minus 20 per cent of the nominal value.

The resistor colour code is read in the order shown in Fig. 9, i.e. starting with the colour of the ring nearest one end (or nearest the opposite end of a silver or gold band, if present). The complete colour code is as follows:

Colour	*1st ring gives first figure of resistance value*	*2nd ring gives second figure of resistance value*	*3rd ring gives number of noughts to put after first two figures*
BLACK	0	0	none
BROWN	1	1	one (0)
RED	2	2	two (00)
ORANGE	3	3	three (000)*
YELLOW	4	4	four (0000)
GREEN	5	5	five (00000)
BLUE	6	6	six (000000)**
VIOLET	7	7	seven (0000000)
GREY	8	8	eight (00000000)
WHITE	9	9	nine (000000000)

Thus suppose the rings on the resistor were—1-RED; 2-VIOLET; 3-ORANGE. We then have:

RED = 2 followed by VIOLET = 7 followed by ORANGE = three noughts
or 27,000 ohms or 27 kilohms.

It will also be found that resistor values do not go up in equal steps,

* or Kilohms ** or Megohms

but rather in *preferred* values. The following is a list of preferred values, from which it will be seen that if we wanted a resistor somewhat greater in value than 100 ohms, say, the next standard value would be 120 ohms, and the next one after that 150 ohms, not equal steps of 5, 10 or 20 ohms at a time.

Preferred values in ohms	*Preferred values in kilohms or megohms*
10	1
12	1·2
15	1·5
18	1·8
22	2·2
27	2·7
33	3·3
39	3·9
47	4·7
56	5·6
68	6·8
82	8·2
100	10
120	12
150	15
180	18
220	22
270	27
330	33
390	39
470	47
560	56
680	68
820	82
1000 (1 kilohm)	1

For the purpose of drawing a resistor on a circuit diagram, the symbol used is a squiggly line—*see* Fig. 9. In Continental practice, resistors are drawn as rectangular box shapes and this can be regarded as an alternative symbol. It is becoming increasingly common to find 'boxes' used instead of 'squiggles' for designating resistors on circuit drawings. The actual value of the resistor may be written in over the top of this symbol, or the particular resistor designated by a letter and a number. The letter R is always used in such cases. Since there will usually be a number of resistors in the complete circuit, each will be identified by the letter R and a number, R1, R2, R3, etc. This makes it easy to refer to the position of individual resistors in the circuit. The values of each of the resistors is then given separately in a components list. The word ohms is usually omitted, i.e. just the value given as a number, although the symbol Ω may be added to designate ohms. Values of 1,000 ohms or greater are designated by K or KΩ (i.e. kilohms). Thus the figure 470 appearing by a resistor would designate a value of 470 ohms; whilst 4·7K would designate a value of 4·7 kilohms or 4,700 ohms.

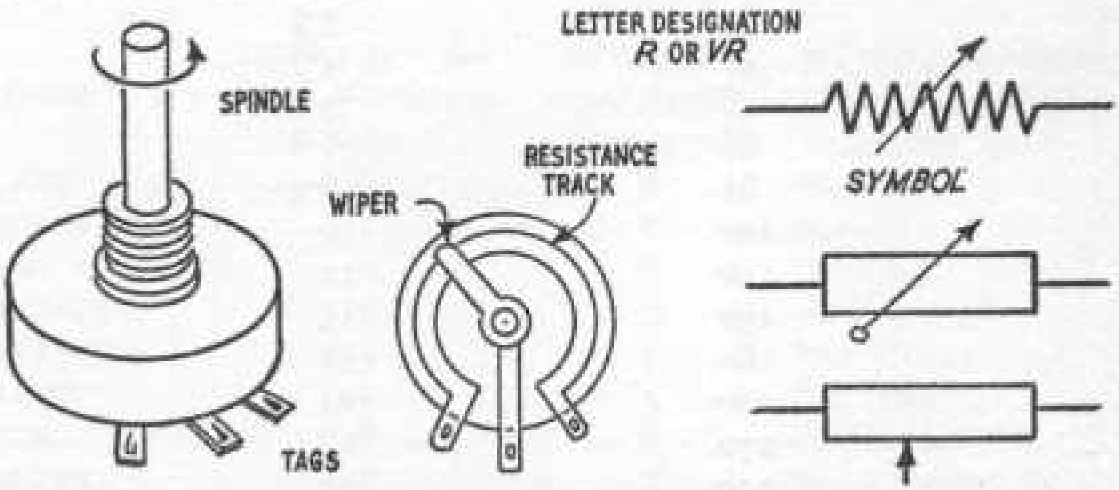

Fig. 10. *The variable resistor or potentiometer. Note the internal connections. All three tags, or just the centre tag and one end may be connected up, according to the type of circuit*

The other type of resistor met with is a *variable resistor*, which is more usually called a *potentiometer*. It usually has the appearance shown in Fig. 10, with a centre spindle which is turned to vary the resistance. There are some types in the shape of a slide, however. The symbol used is the same as for a (fixed) resistor with an arrow through it.

A potentiometer always has three connecting tags. The outer tags are connected to the ends of the resistance track (which may be carbon or a coil of resistance wire). The centre tag is connected to the wiper which moves over the track as the spindle is turned. To connect a potentiometer into a simple circuit as a variable resistance, therefore, connections are made to one of the end tags and the centre tag.

Potentiometers are mostly used for volume controls on radio receivers.

Capacitors (old name '*Condensers*')

Capacitors may be similar in appearance to resistors, but slightly larger, a more sausage-like shape with rounded ends, disc-shaped or wafer-shaped—*see* Fig. 11. Their value is almost always marked on the body in mF (millifarads, or one-thousandth farads); μF (microfarads or one-millionth farads); or pF (picofarads, or one million-millionth farads).

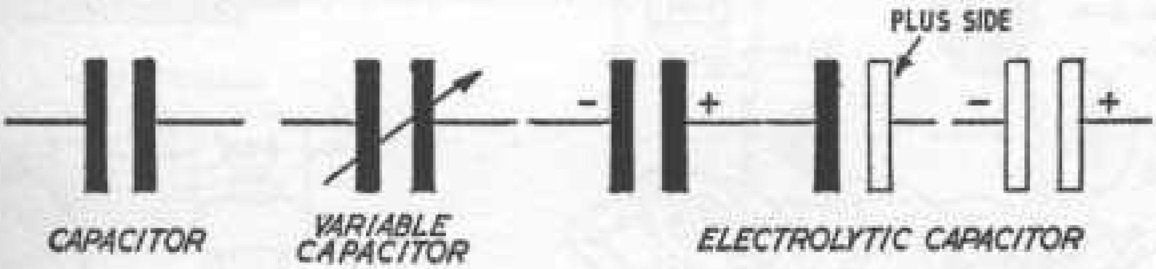

Fig. 11. *The symbols which may be used to designate capacitors on a circuit drawing. In practice, all capacitors from 0·1 microfarads up are electrolytic type*

There is also a special type known as an *electrolytic capacitor* which is almost always readily identified because it is enclosed in a metal case and one end is painted red or marked + or positive. Electrolytic capacitors are used for larger values than it is possible to make in simple mica, paper or ceramic types. It is very important that they be connected the right way round (positive to positive in the circuit), otherwise they will be ruined. This is because the dielectric material in them is formed during manufacture by passing a current through them in a certain direction, and if a reverse current is applied when they are used in a circuit the dielectric will be broken down.

The symbol for a capacitor is two thick parallel lines, as shown in Fig. 11. In the case of an electrolytic capacitor the + and − sides may also be marked to show which way round the capacitor is to be connected, but this is not invariably done on circuit drawings. An electrolytic capacitor may also be indicated by using one solid and one 'open' or outline bar for the symbol, in which case the solid side shows the −

side. Sometimes two outline bars are used to designate an electrolytic capacitor to distinguish it from an ordinary capacitor, in which case + and − sides would normally be marked. In American practice one bar is curved and one straight to designate a capacitor. The letter used to designate a capacitor is C, the different capacitors in a circuit being designated C1, C2, etc., as with resistors.

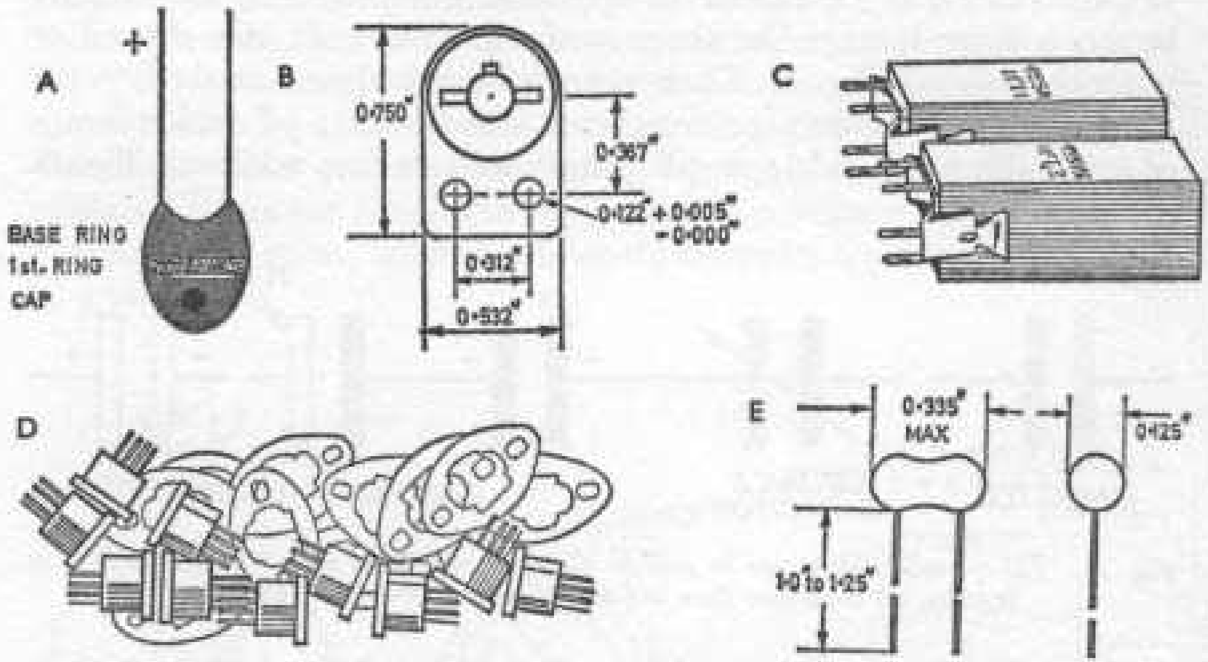

Fig. 12. *A. Miniature bead-type capacitors. B. Ceramic trimmer (capacities up to 50 pF) C. IF Transformer. D. Transistor holders (with mounting rings). E. Sub-miniature tunular capacitor. Where values are not marked on capacitors a colour code is used, viz:*

COLOUR CODING FOR CAPACITORS

Working Voltage (Base Ring)		*Capacitance Code*			
Colour	*Volts*	*Colour*	*1st Ring Tens*	*2nd Ring Units*	*Cap Multiplication Factor*
White	3V	Brown	1	1	× 10 μF
Yellow	6V	Red	2	2	
Black	10V	Orange	3	3	
Green	15V	Yellow	4	4	
Blue	20V	Green	5	5	
Grey	25V	Blue	6	6	
		Violet	7	7	
Orange	35V	Grey	8	8	× 0·01 μF
		White	9	9	× 0·1 μF
		Black	−	−	× 1·0 μF

Some other types of capacitors are shown in Fig. 12. For miniature receivers mica compression type or 'trimmer' capacitors are most widely used because of their compact size. A variable capacitor together with an aerial coil is employed for the tuned circuit in practically all radio receivers.

Diodes

A crystal diode is somewhat smaller than a sub-miniature resistor and comprises a germanium crystal enclosed in a tiny glass envelope with leads emerging from each end—*see* Fig. 13. Like an electrolytic capacitor it is marked with a positive end (usually painted red), thus identifying the proper way round to connect it (although in many circuits this polarity is not important).

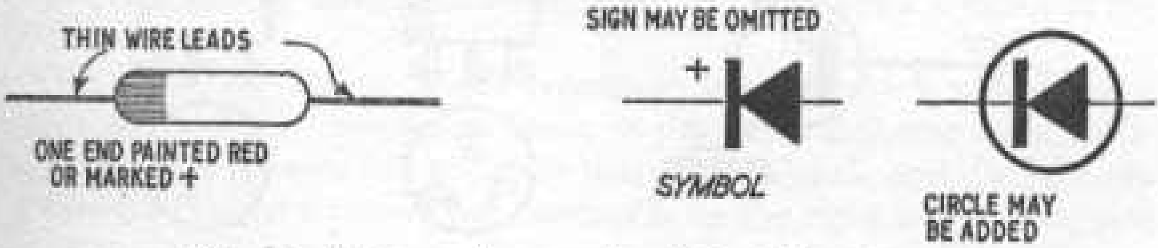

Fig. 13. *Appearance of a germanium diode, and symbols used*

The action of a diode is that of a 'one-way-only' conductor. Current flows readily through the diode in one direction, but the diode offers very high resistance to current flow in the opposite direction, equivalent to cutting off the flow entirely. It is this unique property which enables the diode to be used as a *detector* to chop off the 'bottom half' (reverse direction current) of a modulated RF signal applied to it. It passes only the 'top half' of the signal which then contains a DC component varying with the modulation, i.e. passes a DC current varying in an identical pattern to that of the AF modulation applied to the original carrier signal.

The standard symbol for a diode is also shown in Fig. 13. The standard letter for designating a diode is D. No value would be associated with such a component. Any figures of letters appearing alongside would refer to the type number or manufacturer's coding.

Transistors

Transistors take the place of valves in modern radio receiver circuits. They are somewhat similar in basis to diodes, but with an additional element and three leads, and electrically equivalent to a triode valve in many respects. They come in various shapes and sizes but the main types which are likely to be met are shown in Fig. 14.

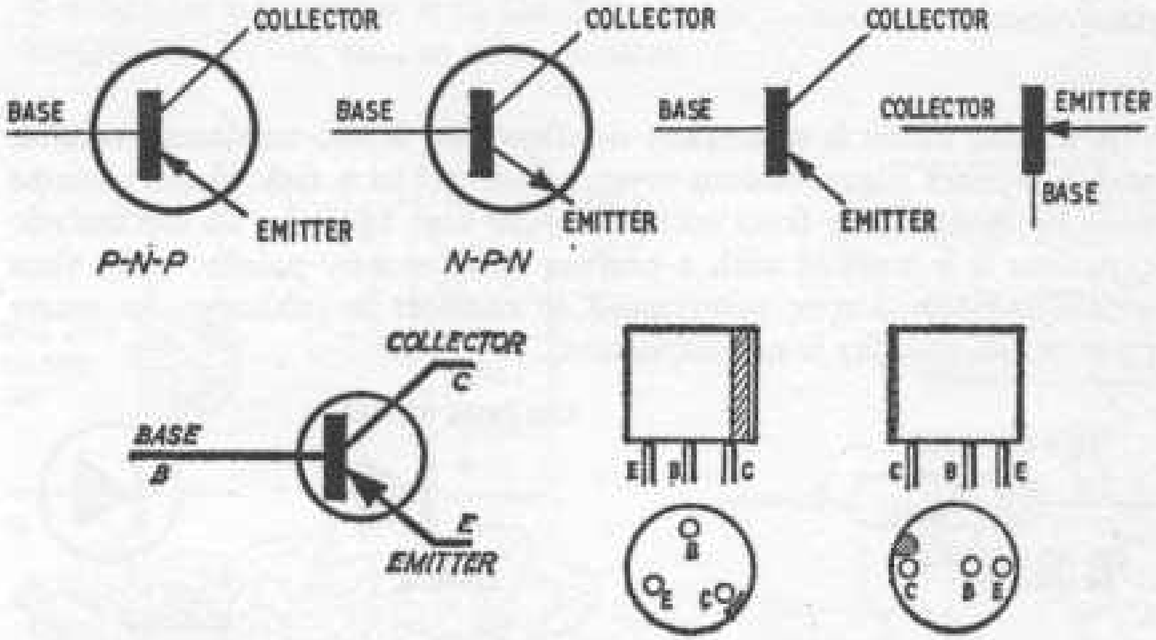

Fig. 14. *Various symbols used for transistors; also the two common forms of transistor lead configurations (the triangular configuration being characteristic of older types)*

The three elements in a transistor are known as the Base (B), Collector (C) and Emitter (E). These are connected to the three thin wires which emerge from the bottom of the transistor and it is important to be able to identify these properly. If a transistor is connected up the wrong way round, not only will it not work but it may well be ruined. This applies both to mixing up the leads and getting the polarity of the connections the wrong way round.

The collector lead (C) is invariably marked by a coloured blob or spot on the case nearby. Base (B) and emitter (E) leads are then identified by the positions shown in Fig. 14, looking at the bottom of the transistor from which the leads emerge. On older type transistors the three leads are in line. The collector is again marked with a white or coloured spot. The emitter is then the farthest lead away in the line and the base the one next to it. Base and emitter leads are always closer to each other than to the collector, whatever the arrangement of leads.

There is an exception in the case of a power transistor. This may have only two leads, in which case the collector is electrically connected internally to the case and connection is made to it by a tag held in contact with the top of the mounting base by one of the mounting nuts. The two leads are marked E for emitter and B for base on the bottom of the transistor.

Transistors can be of two types—P-N-P or N-P-N. P-N-P transistors are mostly used in this country (Japanese radio engineers prefer N-P-N types). With a P-N-P transistor the positive battery supply must always be connected to the emitter and the negative supply to the collector. These polarities are reversed with a N-P-N transistor. With either type, the basic rule applies that collector and base must always be connected to the same polarity (negative in the case of a P-N-P transistor), which will be opposite to the polarity applied to the emitter.

We need not bother about transistor theory (which would fill a large volume), how transistors work, or the many different types available. For our purpose it is sufficient that they do work, and if we specify a suitable type in a circuit and connect it up the right way round, that is all that really matters.

A transistor is a three-element device and these three elements are always shown on the symbol for a transistor. The base is represented by a thick black line; the collector by a thin line touching the base; and the emitter by another thin line with an arrowhead. If the arrowhead points to the base, this designates a P-N-P transistor. If it points away from the base, this is a N-P-N transistor.

The symbol most commonly used is to show the collector and emitter leads angled at 45 degrees on the same side of the base, the whole enclosed in a circle with a lead to the base emerging from the circle as well as the collector and emitter lines on the other side. Sometimes the circle is omitted from the symbol; and sometimes the collector and emitter are shown as horizontal lines, one on each side of a thick black vertical line representing the base (again with or without an enclosing circle).

Other components

Symbols for other components used in receiver circuit diagrams are shown in Fig. 15. These are easy to remember and identify, and are

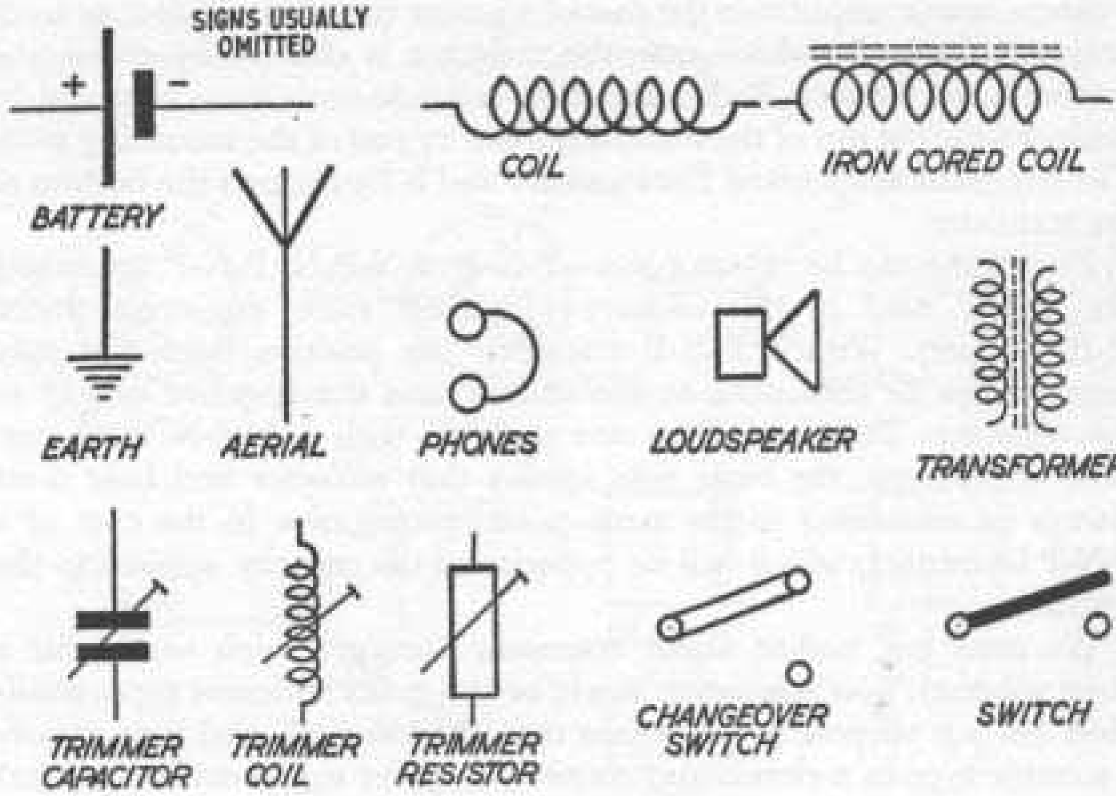

Fig. 15. *Symbols used for other circuit components*

also normally specified by value, where appropriate. If special constructions are involved, such as coils, these are described later in appropriate chapters.

Headphones

The type of 'headphone' normally used with transistor receivers is a deaf-aid earpiece, although ordinary headphones can also be used. Most simple circuits are designed to use a *high impedance* earpiece (or headphone) since this provides properly balanced conditions for the output stage without having to use a transformer.

It should be noted that the impedance of the earpiece (or headphone) is different from its D.C. resistance. Thus a suitable deaf-aid earpiece would be of 2,000 ohms D.C. resistance, giving a typical impedance figure of the order of 7,500 ohms. High impedance headphones would be expected to have an impedance of about 10,000 ohms for a D.C. resistance of 300 to 4,000 ohms.

Loudspeakers

All miniature loudspeakers have a low D.C. resistance of about 3 ohms, and thus a correspondingly low impedance. To couple to a circuit which requires a high impedance load for the output a step-down transformer has to be used. One side of the transformer then provides the necessary high impedance load, the speaker being connected to the other side and inductively coupled to the receiver circuit under properly balanced conditions.

The transformer ratio required for coupling a 3 ohm loudspeaker can be determined from the following:—

To provide a 10,000 ohm output impedance—30:1
To provide a 20,000 ohm output load impedance—41:1.

Transformers

Transformers may also be used in certain receiver designs to match the output impedance from one stage to the input impedance of the next stage; and at the same time this will provide 'gain' or amplification. The turns ratio of the transformer in this case is usually 4·5:1. The primary winding of such transformers can always be identified by the fact that this will have the higher resistance.

A variety of transformers are made in sub-miniature sizes suitable for transistor radio work.

Batteries

A particular advantage of transistor circuits is that they require only low voltages for operation and current drain is usually small. A more or less standard voltage for transistor receivers is 9 volts, although some simple circuits work on less.

Dry cells ('dry batteries') are perfectly adequate for most purposes, a PP3 (9 volts) size having a life of 35 to 50 hours against a current drain of 2 to 3 milliamps. Lower voltages can be provided by pen-cells (1·5 volts) single, or connected in series to give 3 volts (two cells), 4·5 volts (three cells), or 6 volts (four cells). The 'high energy' type are to be preferred when using pen-cells. Although more costly initially, they have a much longer and more consistent performance.

Sub-miniature circuits may use Mallory mercury cells since these are very much smaller than dry cells—scarcely larger than a shirt button in the case of the smallest size. Each cell has an output of 1·4 volts, normally requiring the use of at least two cells connected in series to power a sub-miniature receiver. Another advantage offered by Mallory mercury batteries is that their voltage remains constant throughout their useful life. With dry cells voltage tends to fall off continuously with use, at first slowly and then more rapidly. This can introduce problems of stability in transistor circuits, calling for 'D.C. stabilization' of the circuit (*see* Chapter 9). Mallory mercury cells are considerbaly more expensive than dry batteries, so they would not normally be employed except for miniaturized circuits built to go into a 'minimum size' case, with an external earpiece of headphones. For loudspeaker receivers a minimum size for the speaker is about three inches square, and the size of the case to accommodate this would normally leave enough free space to accommodate a PP3 battery or the required number of pen-cells.

CHAPTER 3

HOME CONSTRUCTION TECHNIQUES

RADIO designs are normally presented in the form of circuit drawings with the components represented by symbols and the intermediate connections represented by solid lines. Component values are marked by the individual components, or annotated separately, and thus a circuit drawing gives all, or nearly all, the information required to build the design.

However, there is quite a difference between a theoretical drawing of a circuit and its physical counterpart. The symbols representing the components, for example, do not represent the actual size and shape of the components, or physically indicate the manner in which they are to be connected. Nor does a circuit drawing necessarily represent the actual position of individual components in a finished, wired-up job. All these points can be confusing to a beginner, but 'translation' of a theoretical circuit drawing into its physical counterpart for building is not a difficult job with simple receiver circuits, provided a number of basic rules are followed. These are:

1. Decide on a suitable method of mounting the components (*see* later).

2. Allow plenty of room for positioning the individual components. The more clear space you have around components the easier it will be to wire them up, bearing in mind that all joints have to be soldered. You need experience, and considerable skill in soldering, to produce really compact assemblies where all the components are crowded into a minimum of space.

3. Try to follow the layout of the theoretical circuit diagram as far as possible in the physical layout of components. This will make it easier to plan the layout, and also to check through the connections.

There are a number of other points which will come out in later descriptions. Certain components may need mounting rigidly, like a tuning capacitor. Others, like resistors, capacitors and transistors can be 'free standing', simply supported by their leads.

Starting point in any case is to decide just how you are going to mount the components, and there are many ways in which this can be tackled. Look at Fig 16, for example. This shows a simple circuit drawing and its physical counterpart wired up in exactly the same pattern without using any form of mounting at all. This is called a 'Christmas tree' assembly and is often used for experimental testing of simple

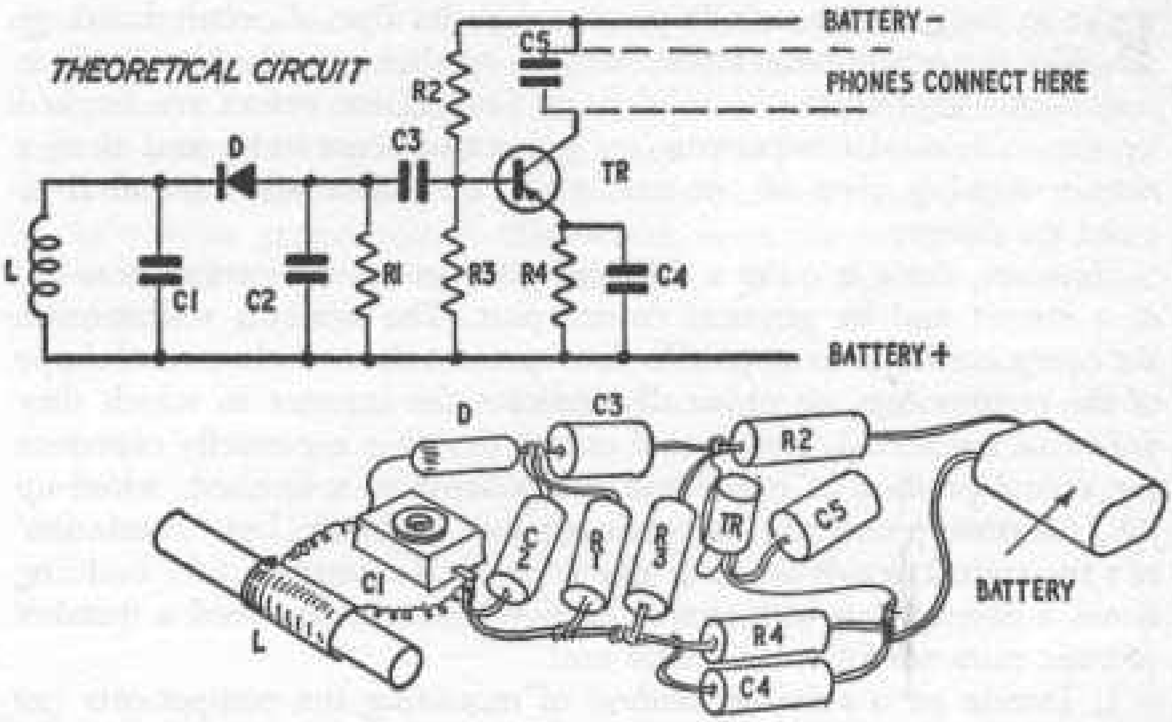

Fig. 16. *Theoretical circuit for a crystal reciever and* (below) *connection of components without using any base panel. This is known as 'Christmas tree' construction*

circuits intended for temporary use only. It produces a working circuit, but it cannot be handled or moved without the danger of 'shorting' some of the wires and possibly damaging components in the circuit if the battery is connected. Although it is probably the quickest way of building a circuit, therefore, it is not a practical method for general use.

For a practical assembly we do need some form of baseboard on which components can be mounted. This has to be of insulating material when 'Paxolin' is the preferred material. (Note: Older valve-type radio receivers are commonly built up on a metal chassis, but this type of construction is hardly ever used with transistor circuits).

Using a Paxolin panel as a base we can re-design the theoretical circuit in physical form to arrive at suitable positions for mounting points for the various components. For these mounting points we can use solder tags, as shown in Fig. 17. The position of each required mounting point is marked on the base panel, a hole drilled in the panel and the tag rigidly mounted in position either with an eyelet (which

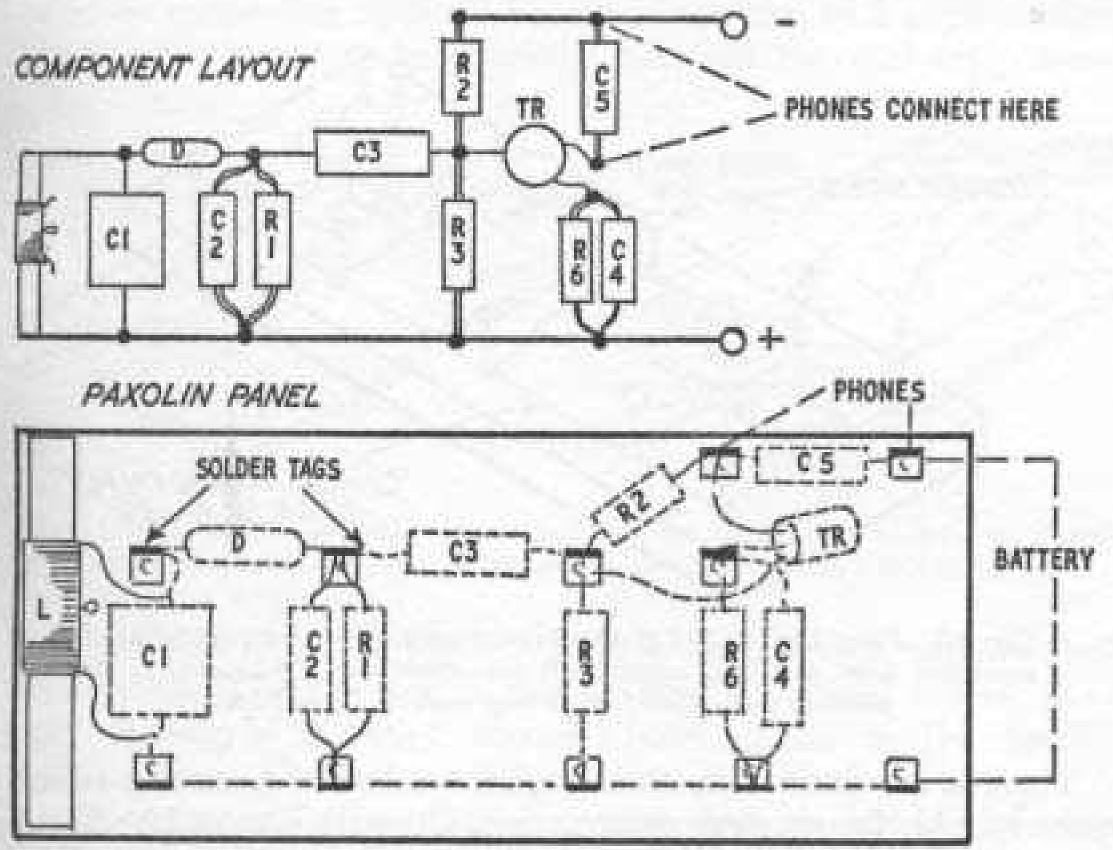

Fig. 17. The circuit of Fig. 16 translated as a physical layout of components; and (below) the same layout planned for assembly on a Paxolin panel using solder tags mounted on the panel for connection points

requires the use of a punch or special pliers to close the eyelet) or with a small brass bolt and nut (8BA size is usual). Components are then mounted by soldering their leads directly to appropriate eyelets, this at the same time completing the connections for the components in the circuit.

Planning such a layout is not at all difficult. Basically, on the circuit drawing, each point represented by a black dot • is a connecting point, or a solder tag position on the physical layout. You may have to position these slightly differently on the layout in order to accommodate the shape and size of adjacent components, so if you have any doubts about this, lay the components out in position roughly, following the theoretical circuit, and plan your connecting point positions from this. With a little practice you will soon be able to estimate suitable positions for the solder tags without this additional aid.

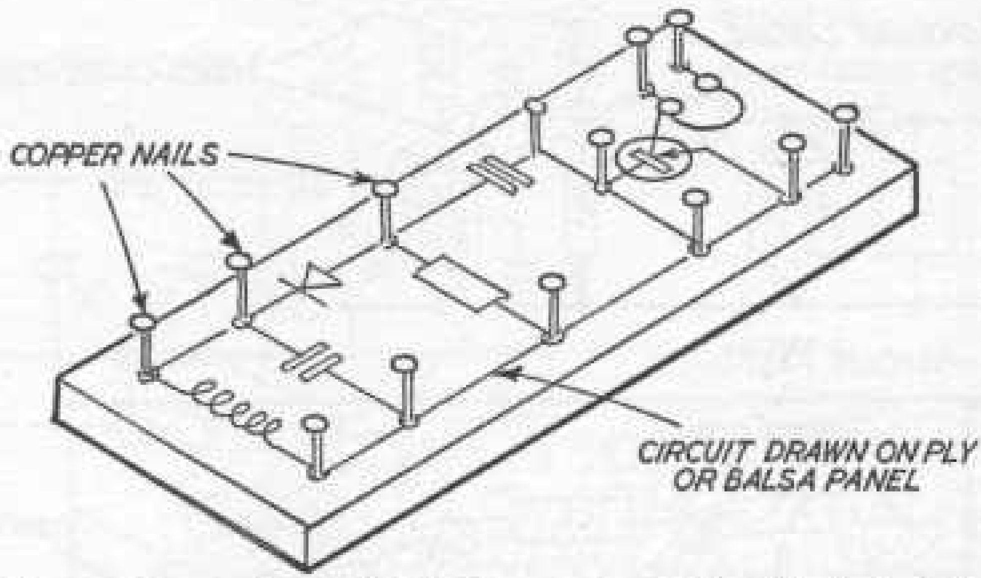

Fig. 18. *A very basic method of circuit construction. Having determined suitable connection point positions, copper nails are driven into a baseboard in these positions and soldered connections made to the nail heads*

There is an alternative, and simpler, method of mounting which is quite suitable for amateur construction, although it would be frowned upon by the professional! We shall describe this for it has a particular appeal to beginners who are not familiar with electronic assemblies but can quite happily work in other materials. The same principle as above is used, but instead of a Paxolin plate we use *plywood* (or even hard balsa sheet). And instead of the solder tags which have to be riveted (or bolted) in place, we use large headed ½-in. copper nails. The circuit can be drawn out on the ply, connecting points marked, and a nail driven into the ply at each connecting point—Fig. 18. Components are then connected to the heads of the nails to complete the circuit, each connection being soldered as when using solder tags.

Another type of construction which may be used with simple circuits is *bus-bar* assembly. It will be noticed that most theoretical circuits incorporate a long line at the top and bottom of the diagram to which the majority of the connections are made (i.e. these lines contain the majority of black dots or connecting points in the circuit). Instead of a series of tags at each connection point along these two lines we could equally well use a solid conductor, e.g. a length of 16-gauge tinned copper wire mounted on a Paxolin panel as shown in Fig. 19. Such common connecting lines are known as bus-bars in a physical circuit. Shorter bus-bars can be mounted between the two main ones to

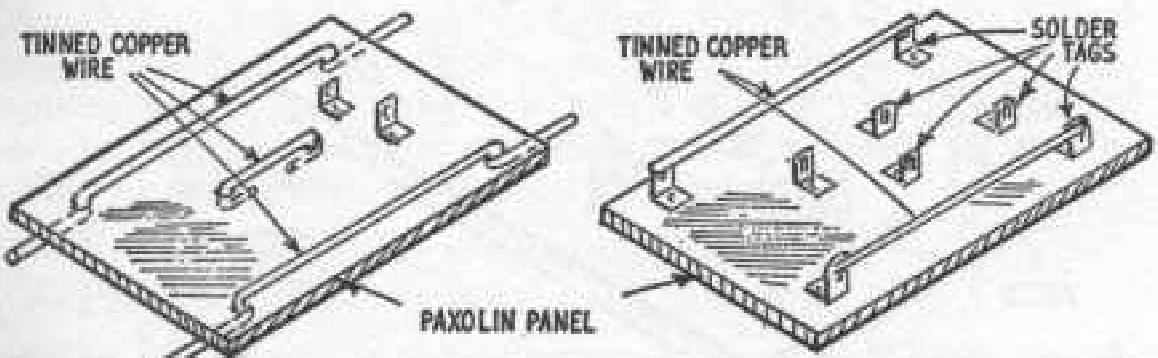

Fig. 19. *Two methods of laying out a circuit on a Paxolin panel using bus-bars. Individual or separate connection points are determined by mounting solder tags on the panel*

accommodate other common connections, or individual tags mounted at these points. The main bus-bars could also be soldered to a tag at each end, instead of doubling through holes drilled in the panel, as shown.

Pegboard assembly is another alternative particularly suited to amateur construction. This is shown in Fig. 20. The base in this case is standard pegboard (or drilled hardboard) with holes spaced at $\frac{3}{4}$-in. intervals. Connecting points comprise little brass pillars or pegs, usually cut from $\frac{3}{16}$in. diameter brass rod, drilled and tapped to take a 6BA screw. These pegs can be mounted either by pushing into the holes, or bolted in place using two washers and a screw, as shown in the detail diagrams of Fig. 20. The latter method is preferred for a permanent assembly. Connection is then made to screws in the top of each peg, or the individual leads and wires can be soldered to the pillars. Suitable pegs are produced commercially for use with standard pegboard, and one advantage of the system is that circuits can be completed with screwed connections only, with no soldering—although soldering is normally always to be preferred for radio receiver connections. The main disadvantage of pegboard is that it does produce a rather large assembly, particularly for the size of components normally employed with transistor circuits. It is also somewhat unwieldy to use when dealing with more complicated circuits. For the absolute beginner, however, it has definite attractions.

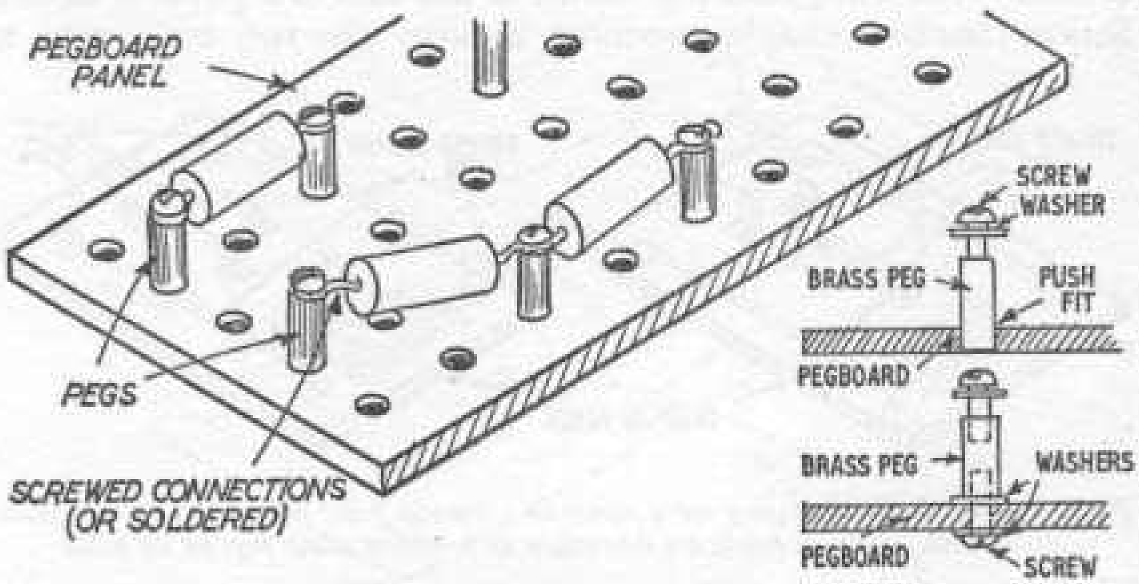

Fig. 20. *Pegboard assembly offers a simple method of construction, although the size of the layout is often unduly large. The brass 'pegs' are available commercially, to fit standard drilled hardboard (pegboard)*

The favoured method of construction for professional-built transistor radio receivers is printed circuit assembly. Here all the wiring connections are formed in copper foil on one side of a sheet of Paxolin, which is then drilled with holes to take the component leads. These leads are simply passed through their respective holes and soldered in place. The only real disadvantage involved for one-off jobs is the skill, and time, necessary to produce the printed circuit panel, involving designing a suitable wiring circuit, drawing it on the foil and then etching away surplus copper. Nevertheless, any serious amateur radio constructor will want to tackle printed circuits once he has become reasonably proficient and their construction is dealt with in a later chapter.

Kits of parts for making a transistor radio receiver offer particular advantages for the beginner since they are nearly always based on a printed circuit panel which is ready-finished, and pre-drilled. This eliminates the necessity of planning out the component layout and then constructing the base unit (by whichever of the above methods is chosen). It does, however, restrict the choice of designs to those which are produced in kit form.

Soldering has already been mentioned as an *essential* requirement for making off all connections (with the possible exception of pegboard assembly). This is a technique which is readily acquired with practice, provided you go about it the right way. Always use an electric soldering iron of the right size, and only resin-cored solder (never use solder and a separate flux). Iron size should be 60 watts with a $\frac{3}{16}$ in. bit for general work. For compact circuits, and particularly printed circuit assemblies, a smaller iron will be better—say with a $\frac{3}{32}$ in. or even $\frac{1}{16}$ in. bit for crowded circuits—and never more than 50 watt rating.

The two main secrets of successful soldering are:

1. The joint (and the tip of the iron) must be clean.
2. The iron must be hot enough.

Wires on components and solder tags are normally already tinned, but not necessarily clean. Even handling the wires will fingerprint them and make them greasy. It only takes a moment to ensure that such parts are clean. Wrap a piece of fine emery paper around the lead or tag, grasp it between finger and thumb and pull it along the wire without using too much pressure (which could strain the internal connection of the lead). But do not do this with transistor leads.

The tip of the iron can be cleaned by wiping it with an old rag when it is hot. The tip should also be tinned, i.e. covered with a layer of solder. If solder does not stick to the end of the iron, clean the tip thoroughly with a file, or emery paper, until it does.

An electric iron takes a minute or so to warm up to full heat after being switched on. It is hot enough to use when solder applied to the tip melts immediately (and on a clean iron will remain on the tip in the form of a molten blob).

The correct way to complete a soldered joint is shown in Fig. 21. As soon as the iron is hot enough it is laid under (or on one side of) the wires to be joined. Solder is then applied to the *opposite* side, and should melt almost at once and spread evenly over the joint. Only hold the iron in contact with the joint long enough to melt and spread the

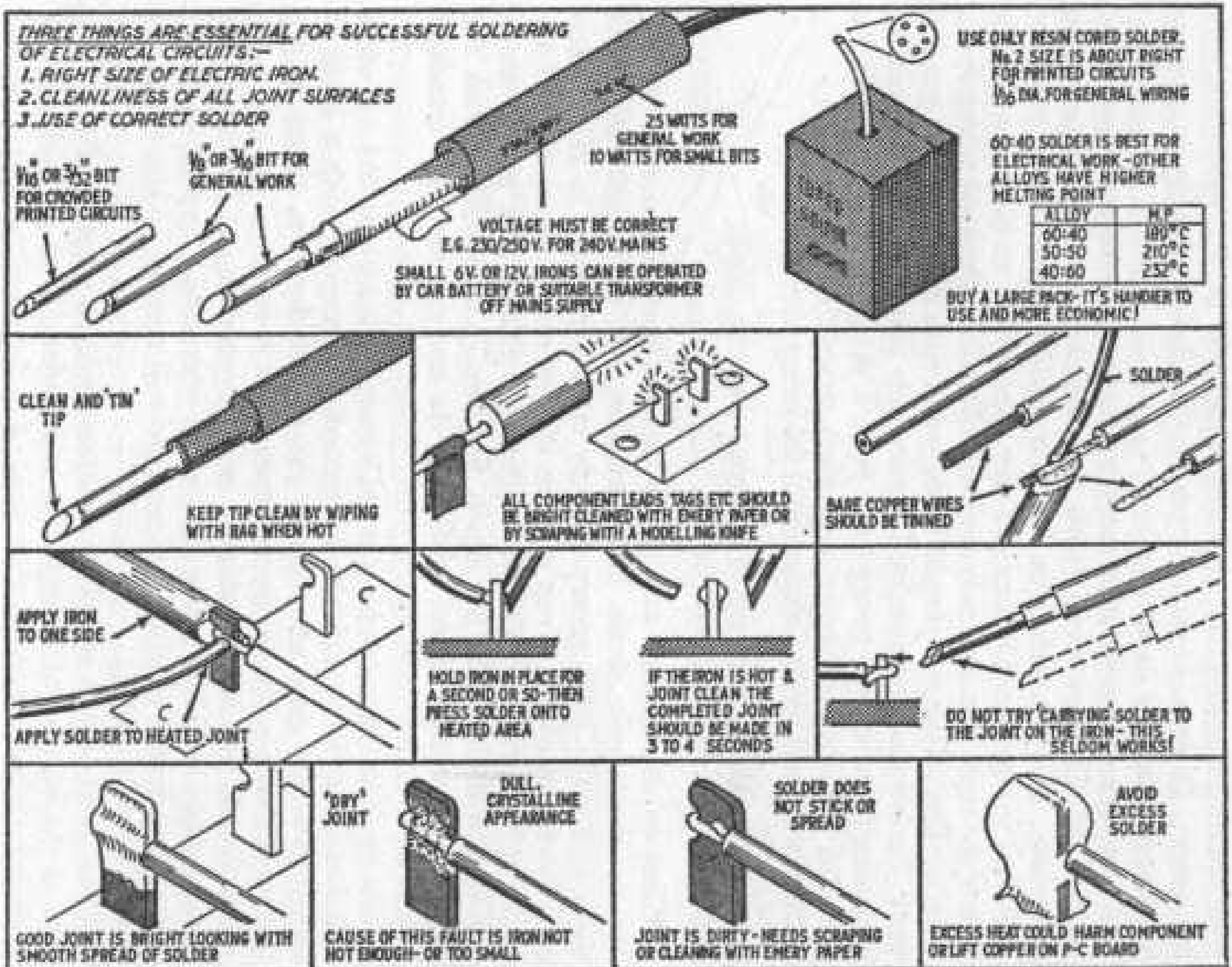

Fig. 21. *Correct procedure for successful soldering*

solder, then remove and allow the joint to cool down. Blowing on the joint will speed cooling.

If the solder does not melt readily, then the iron is not hot enough. If this happens on a second joint, after successfully completing the first, possibly you are using too small an iron, It is losing too much heat on each joint. You will then have to allow time for it to heat up between each joint. If it happens on the first joint, the cause may again be that the iron is too small—the joint is conducting away more heat than the iron is supplying. In that case you will need to use a larger (higher wattage) iron, otherwise you are in danger of producing a 'dry joint'. This is characterized by a crystalline appearance of the soldered joint. The resulting connection is very poor, and can readily break away. Dry joints are one of the most common sources of trouble in electrical wiring.

If the solder does not spread out over the joint as it melts, then almost certainly the joint surfaces are dirty. The only cure for this is to clean the joint and try again. You will not overcome a dirty surface by applying more solder in an attempt to make it spread. Joints, in fact, should be completed with a minimum of solder—enough for the job and no more.

The application of a soldering iron to a lead conducts heat quite rapidly up through the lead into the component, so to prevent components getting overheated never hold the iron in place for long periods. With clean surfaces and an iron which is hot enough, a joint should be completed in a matter of two or three seconds at the most. No component will suffer heat damage in this time. You are not likely to damage resistors by overheating, but you can cause capacitors to start melting—and transistors are *particularly* susceptible to overheating. The following additional precautions therefore apply:

1. Make the joint as quickly as possible—never hold the iron in contact with a transistor lead for more than 2 or 3 seconds.
2. Never cut transistor leads short. Use a minimum length of lead of ½-in., and preferably 1 in.
3. If you are not confident about being able to complete the joint in a second or so, grip the lead with a pair of pliers to act as a 'heat shunt', conducting some of the heat of the soldering iron away.

An alternative method of mounting transistors, which avoids soldering completely, is to use transistor holders (transistor sockets). These are easy to mount and connect to the circuit. The transistor is then simply plugged into the holder. One advantage of using transistor holders in a circuit is that it enables transistors to be changed readily, without resoldering, e.g. if the performance of a transistor is not up to the standard required.

CHAPTER 4

MAKING CRYSTAL SETS

THE so-called crystal set is the simplest possible type of radio receiver, comprising simply a tuned circuit and a detector. It gets its name from the fact that a simple crystal diode (in the old days a crystal and a 'cat's whisker' combination) is used as the detector. It has many limitations, but since such a simple and inexpensive circuit is involved it is an excellent start for absolute beginners, especially in areas where radio signal strength is high, e.g. fairly near to a powerful local broadcast station.

Basically the success of a simple crystal set depends very largely on the efficiency of the tuned circuit, since the complete set has no source of power other than that of the radio transmission which it receives. The tuned circuit must therefore be capable of tuning in to a broadcast station (or stations) of suitable power and passing as much as possible of that power on to the detector.

We need not concern ourselves unduly at this stage with the theoretical aspects of the tuned circuit, except to understand that this consists essentially of a capacitor and an inductance or coil connected in a closed loop—*see* Fig. 22. This electrical loop will have a specific *resonant frequency*, depending on the values of the capacitor and inductance; which is the same as saying that the circuit is tuned to maximum response to radio transmissions at that resonant frequency.

To make the tuned circuit tunable over a range of frequencies it is only necessary to vary one, or other of the two component values. This can be done by using a variable capacitor used with a fixed coil; or a variable inductance, used in conjunction with a fixed capacitor. The former method is the more usual since it is simpler to adjust a variable capacitor than a variable inductance; but both are really equally suitable methods. We can try both in the experimental circuits which follow.

Of the two components required, the inductance is made and the capacitor is bought. An inductance is merely a coil and to improve

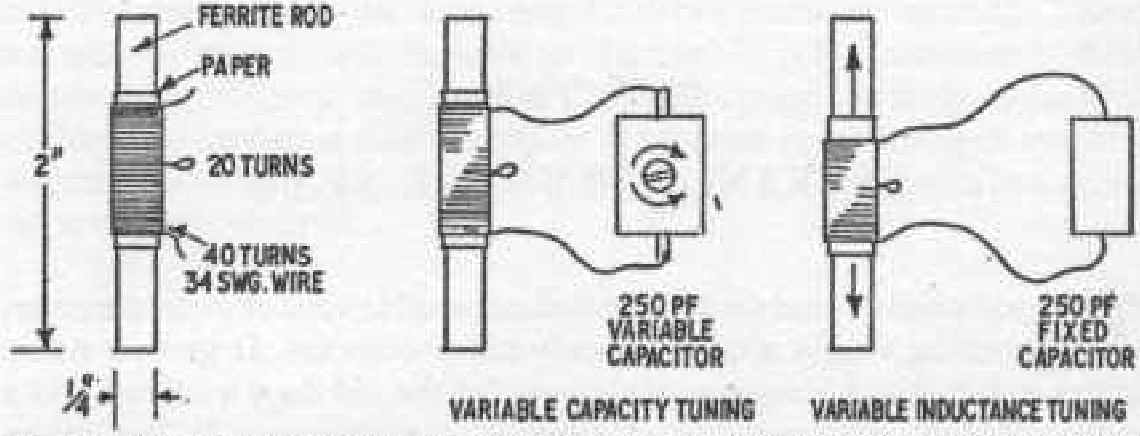

Fig. 22. *Construction of a simple aerial coil. This is associated with a 250 pF variable capacitor connected in parallel (i.e. to each end of the coil). The circuit can then either be tuned by adjusting the capacitor, or sliding the coil up and down the ferrite rod to vary the coil inductance. In practice variable capacitor tuning is normally employed, but coil position can also be adjusted for fine tuning*

its efficiency we will wind it on a ferrite rod (a special material made from iron dust with high electromagnetic properties). Ferrite rods are made in various diameters and lengths (and in the form of slabs). For the coil specified, ¼-in. diameter rod is required, cut to a length of 2 in. if it cannot be bought in this length. A ferrite rod is quite brittle, so to cut it, it should be notched around the circumference with a small triangular file. It can then be broken off neatly.

A wrapping of paper should then be made around the rod (any type of paper will do), and a winding of 34 s.w.g. enamelled or silk-covered-enamelled wire made over it, as shown in Fig. 22. Note that the complete coil comprises 40 full turns, but after 20 turns have been made a smaller loop is made off the core and twisted together and the remaining 20 turns taken around the core. This smaller loop forms a tapping point for connection at the centre of the coil, the insulation being scraped off the wire at this point to make a soldered connection possible.

Although a simple coil we have already ensured relatively high efficiency in two ways:

1. By winding the coil on a ferrite rod.

2. By introducing a tapping point for connecting the detector so that the load is applied only across half rather than the whole coil. This reduces the damping effect of the load and makes the selectivity of the tuned circuit that much better.

Normally, however, it will be necessary to use an external aerial as well connected to one end of the tuned circuit 'loop', with the other end connected to a good earth. Up to 50 ft. or more of thin copper wire makes a good aerial; and a water pipe makes a good earth. Only in areas of strong radio signal strength can a crystal set be expected to work on a ferrite rod aerial alone.

The aerial coil just made can be mounted on a base panel, as shown in Fig. 23, and associated with either a variable capacitor or fixed

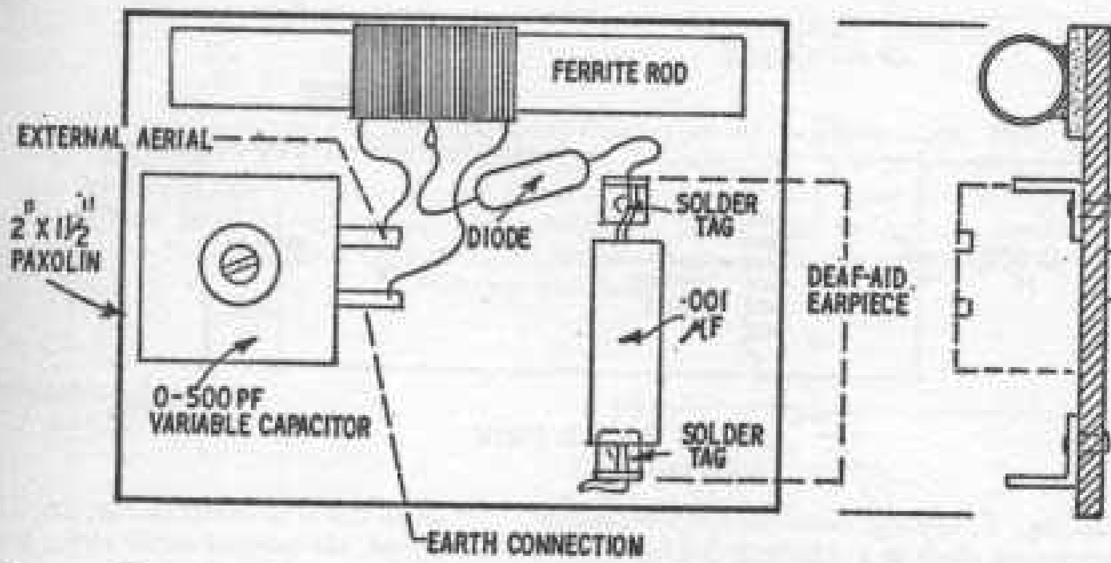

Fig. 23. *The prepared aerial coil mounted on a Paxolin panel, with provision to mount all the other components to complete a crystal set. The ferrite rod can be mounted on special clips (usually plastic), or glued to scrap material stuck to the Paxolin.*

capacitor, of the values shown in Fig 22, depending on whether we want to operate the circuit as 'capacity tuned' or 'inductance tuned'. In the latter case several turns of paper should be wrapped around the ferrite rod before winding the coil and then overlaid with gumstrip or gummed paper to form a rigid sleeve which can slide up and down the rod. The coil is then wound in place over this sleeve. Since the rod must be moved by the fingers a plastic washer or similar shape of insulating material must also be glued to the end of the rod in order to avoid 'hand capacity' effects. Rod position is then adjusted by grasping the plastic and not the rod itself.

Fig. 24 shows the complete circuit for the receiver. The additional components required are a point contact germanium diode (Mullard

OA81, OA91, or equivalent); a 1,000 pF (0·001 μF) fixed capacitor; and a high impedance deaf-aid earpiece (or high impedance headphones with a D.C. resistance of 1 kilohm or more).

That is all there is to it. The set is permanently 'switched on' and it is merely a case of tuning in via adjustment of the variable capacitor (or sliding the ferrite rod in and out of the coil) until a station is picked up and heard. Signals will normally be heard only very weakly, and some too weakly to be intelligible; but it should be possible to tune in

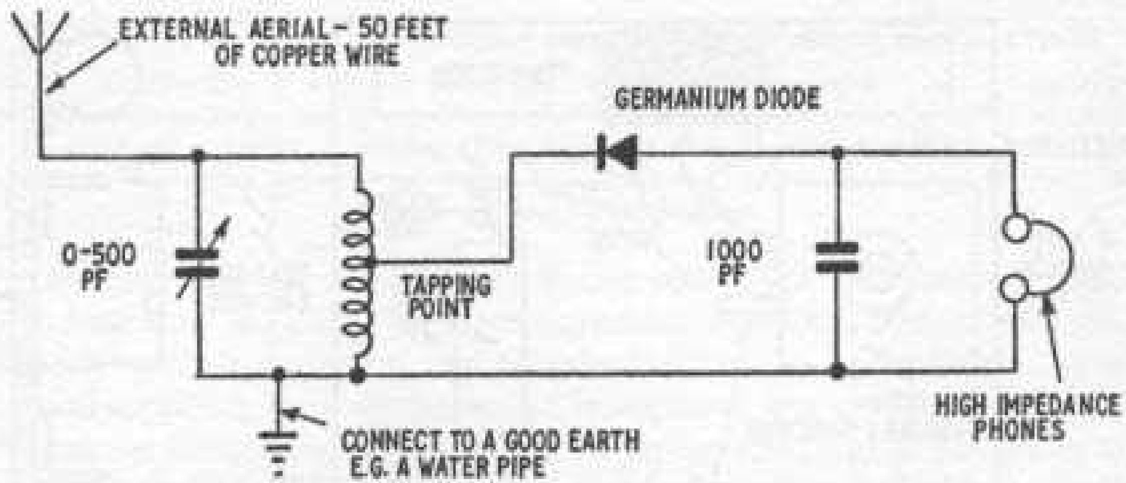

Fig. 24. *Theoretical circuit for a crystal receiver. The aerial coil is as shown in Fig. 22. The germanium diode is a Mullard OA81, OA91, or equivalent. An external aerial and a good earth connection is necessary with such a simple set*

to any strong signal at intelligible hearing strength. If not, try lengthening and/or repositioning the external aerial wire; or try to find a better earth connection. There are also other little tricks you can try to improve reception. Connecting the aerial wire to the springs of a bed sometimes works wonders. In a particular area the set may also work better with the external aerial connected to the earth end of the tuned circuit (and no external earth connection). In some localities where radio reception in general is poor a crystal set may be difficult to get to work at all (although you should pick up *some* station, even if very, very weakly). In others you can get surprisingly good signal reception on one or more stations and pick up others very weakly.

If you *can* get crystal set reception in your area with this simple circuit, then it is worth experimenting with further circuits, as follows:

Fig. 25 shows how you can improve the volume of the reception by

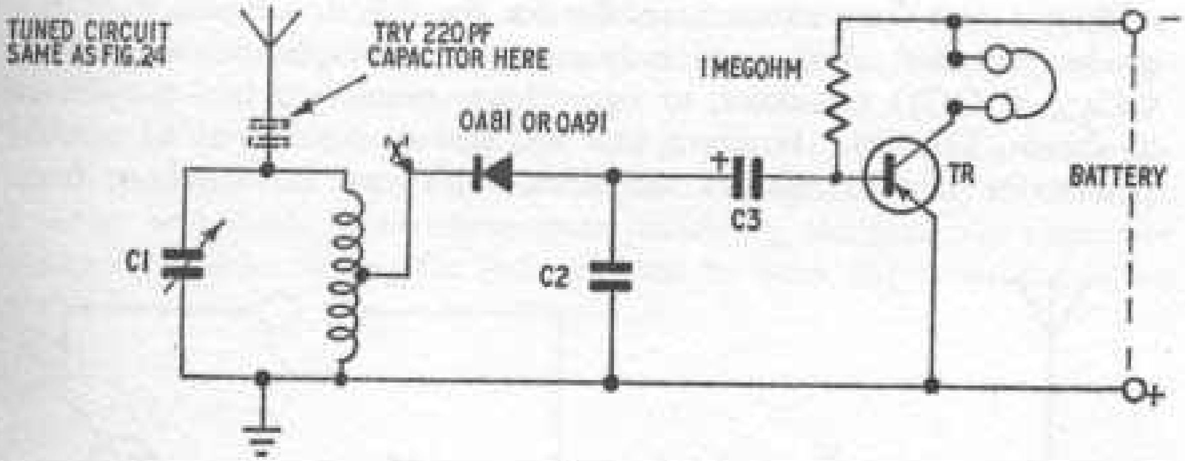

Fig. 25. *The same circuit as Fig. 24 with the addition of an AF amplifier stage. This requires the use of a transistor (Mullard type OC45, OC71, or equivalent), and an additional resistor and capacitor. C2 should be 1,000 pF and C3 8 microfarads (which being an electrolytic type must be connected the right way round). Performance may be improved by 'capacity coupling' the external aerial to the tuned circuit. Connecting the aerial at point 'X' instead of directly to the tuned circuit may also be better*

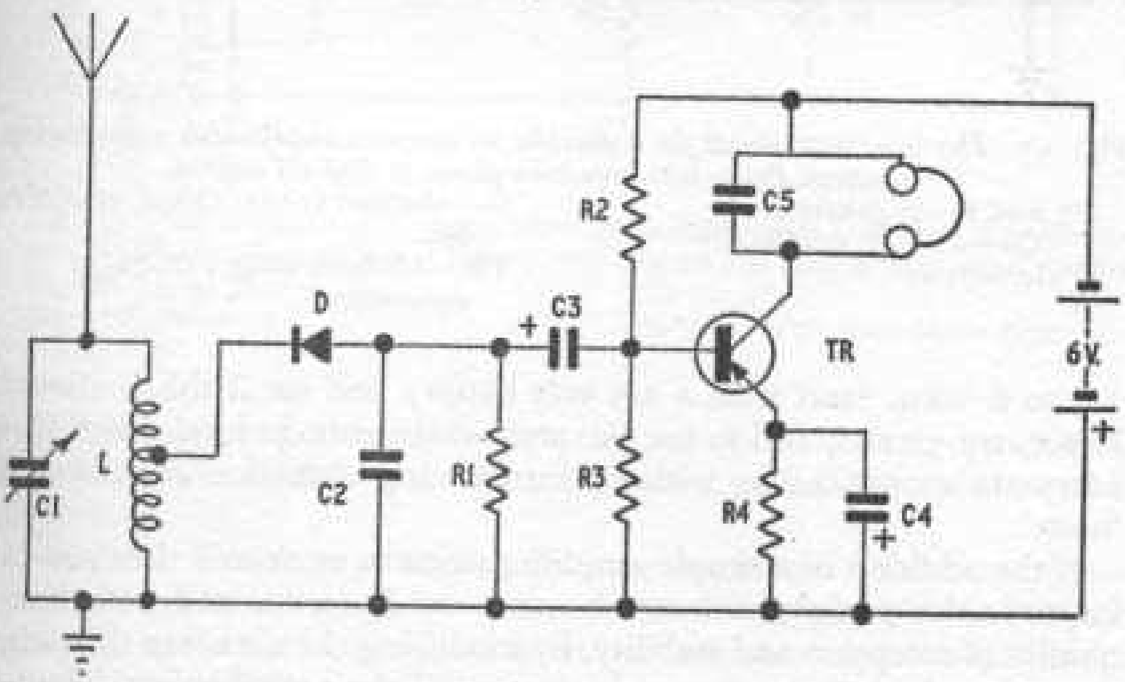

Fig. 26. *A further improvement in the basic crystal set with a stabilized AF amplifier circuit*

C1 and L—as Fig. 24
C2—1,000 pF
C3—4 to 8μF (6 volt D.C.) electrolytic
C4—90 to 150μF (6 volts D.C.) electrolytic
C5—1,000 pF
R1—470 kilohms
R2—22 kilohms
R3—10 kilohms
R4—1 kilohm
D Mullard OA81, OA91, or equivalent
TR Mullard OC45, OC71, or equivalent

adding a transistor as an amplifier for the AF signal passed by the diode (detector). You need only one extra component—a Mullard OC45, or OC71 transistor, or equivalent—connected into the circuit as shown. This time, however, you will also need a battery to provide power for the (transistor) amplifier. This can be anything from

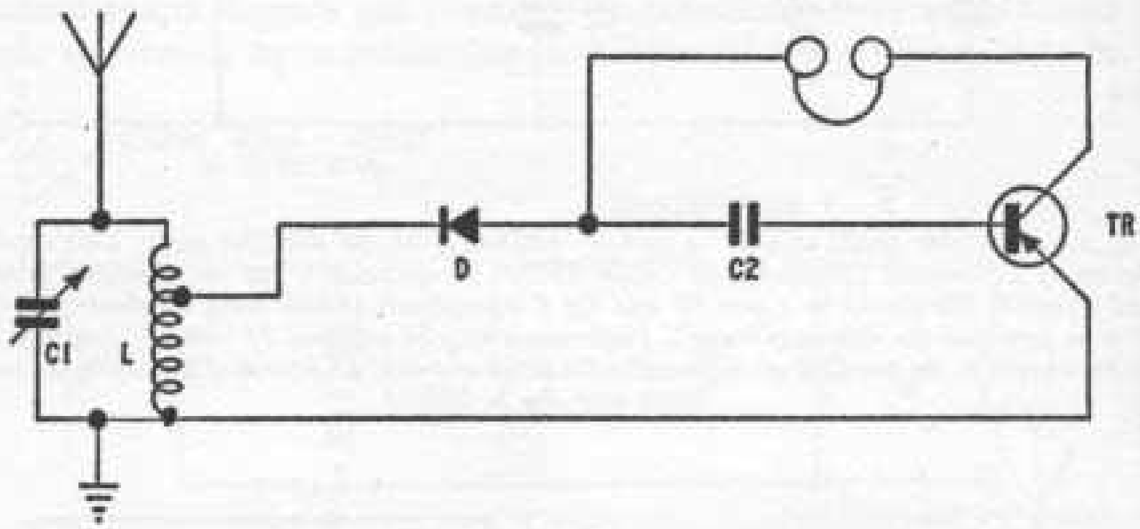

Fig. 27. *This is a 'trick' circuit for it provides for transistor amplification without using a battery. Drives high impedance phones or deaf-aid earpiece*

C1 and L—as previous
C2—2 μF (6 volts D.C.) electrolytic
D—Mullard OA81, OA91, or equivalent
TR—Mullard OC45, OC71, or equivalent

1·5 to 6 volts. Start with a 1·5 volt battery and see if this is enough. If not, try 3 volts, and so on, but stop at the voltage level which gives adequate amplification without introducing distortion of unwanted 'noise'.

If the addition of a simple amplifier seems to work well then you can improve the performance much more satisfactorily, and with better quality of reception and stability, by modifying the circuit to the rather more complicated one shown in Fig. 26. This introduces stabilization of the transistor.

Fig. 27 shows a trick circuit which is worth trying as an experiment. It uses a diode detector and a transistor amplifier, but eliminates the battery, so we are back to a circuit which is powered entirely by the incoming RF signal. The diode, in fact, supplies both the AF signal and the power to drive the transistor, the collector of the transistor being connected to the output side of the diode through the earphones.

Fig. 28 is another trick circuit which also eliminates the battery—and the diode detector as well. In this case part of the transistor is acting as a diode (the emitter-base junction), charging the capacitor which provides energy for the collector to work the transistor as an amplifier as well.

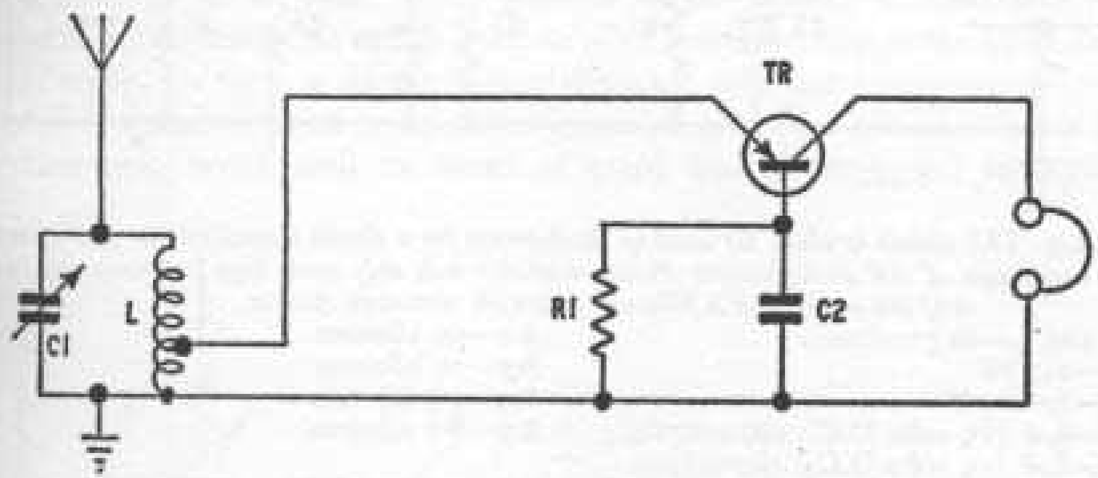

Fig. 28. *This is another trick circuit where the transistor acts both as a diode detector and an amplifier, again without a battery. Will only work in areas of good signal strength*
C1 and L—as previous
R1—10 kilohms
C2—1 μF
phones—high impedance type

These latter two are purely experimental circuits which demonstrate how the power of RF waves already present in the atmosphere can be utilized.

As far as simple crystal receivers are concerned the circuit shown in Fig. 29 is about as far as one can reasonably go. This is basically the same circuit as Fig. 26, with an additional stage of amplification—still not enough, incidentally, to operate a loudspeaker satisfactorily. Further attempt to boost the AF signal only exposes the limitations of the simple crystal circuit, particularly its selectivity. It is not worthwhile pursuing possible further developments, therefore. To improve the performance of our transistor radio receiver we have got to utilize rather more elaborate circuitry.

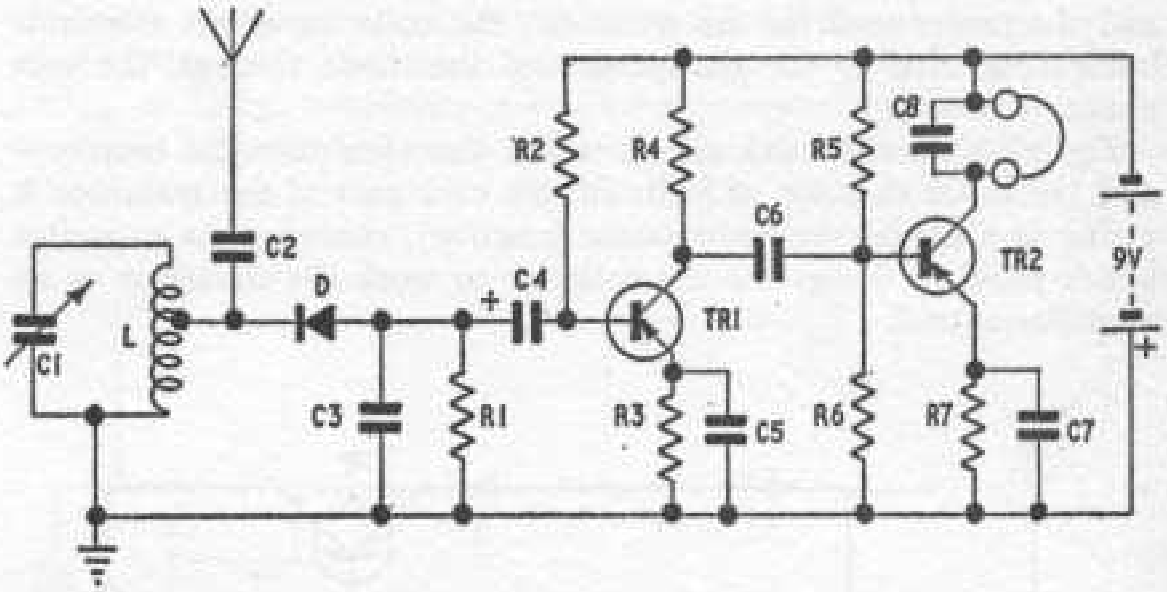

Fig. 29. *This circuit is about the limit of development for a simple crystal receiver and incorporates two stages of AF amplification. Power available will only work high impedance phones or deaf-aid earpiece or a balanced armature miniature speaker*

C1 and L—as previous
C2—220 pF
C3—1,000 pF
C4—8μF (15 volts D.C.) electrolytic
C5—8μF (15 volts D.C.) electrolytic
C5—8μF (15 volts D.C.) electrolytic
C6—8μF (15 volts D.C.) electrolytic
C7—8μF (15 volts D.C.) electrolytic
C8—0·005 to 0·01 μF
R1—47 kilohms
R2—22 kilohms
R3—10 kilohms
R4—4·7 kilohms
R5—8·2 kilohms
R6—3·3 kilohms
R7—470 ohms
D—Mullard OA81, OA91, or equivalent
TR1—Mullard OC71, or equivalent
TR2—Mullard OC71, or equivalent

Battery—start with 3 volts and increase up to 9 volts, maximum if necessary

CHAPTER 5

TRF RECEIVERS

ONE distinct limitation with all simple receiver circuits is that the performance achieved is very much dependent on the strength of the original RF (broadcast) signal present in the aerial. If this signal is weak, no amount of AF amplification after detection can make good this deficiency. In fact, a simple diode detector will not work properly if the RF signal applied to it is very weak. Thus the simpler types of circuit only work well in areas of good broadcast signal strength.

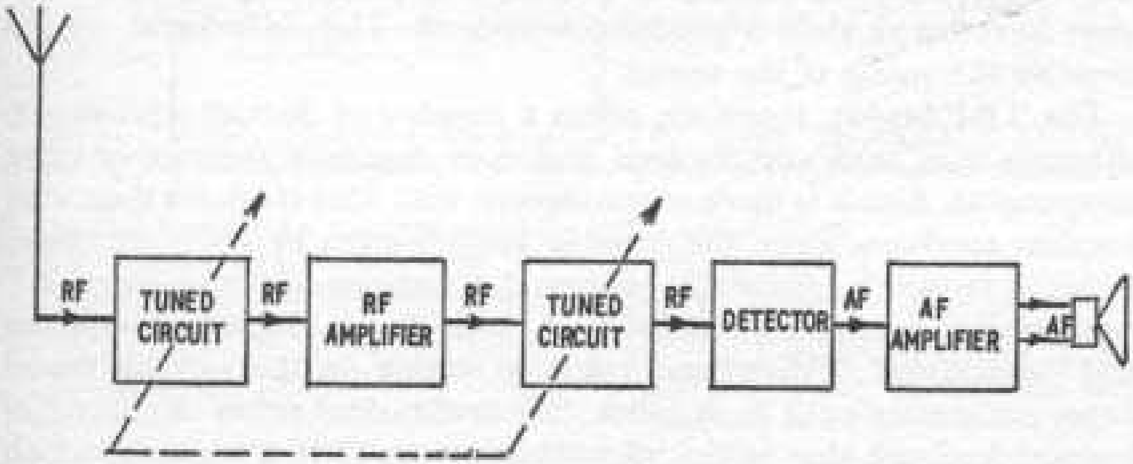

Fig. 30. *Block diagram of a Tuned Radio Frequency (TRF) receiver*

They will not pick up weak signals from distant stations at a sufficient level for good reception, no matter how many stages of AF amplification are applied. Improving the efficiency helps in passing as high a percentage of the original RF signal as possible to the detector stage—but it cannot in any way boost the original signal.

The Tuned Radio Frequency (TRF) receiver, however, does just that—amplifies the incoming RF signal before it is passed on to the detector. A block diagram of such a circuit is shown in Fig. 30 where it will be noticed two tuned circuits are involved (usually mechanically coupled or 'ganged' together). The first of these accepts the required signal (i.e. tunes to the required frequency), which is then boosted by the RF amplifier and passed through the second tuned circuit and on to the detector. This is then followed by one or more stages of AF amplification, as required. Basically, in fact, we have a conventional tuned circuit/detector/amplifier set-up with the addition of a 'front end', comprising a tuned circuit and an amplifier. The *sensitivity* of the receiver is improved by the fact that weaker incoming signals can now be handled successfully (because they are boosted or amplified). Sharper tuning can also be employed (and indeed is necessary to eliminate interference from broadcast stations operating on adjacent frequencies). This calls for greater attention to the tuned circuit design (and is also the main reason why two tuned circuits are used), but considerably improves the *selectivity* of the receiver. Because of the boost the RF signal receives before it reaches the detector, considerably less amplification of the AF signal passed is required after the detector stage in order to yield a good listening level. This, in general, should improve the *quality* of the sound.

The TRF layout, therefore, offers a number of distinct advantages, although it is more complicated and does require a number of extra components. Also it is more advantageous with *valve* receivers than with *transistor* receivers, since the possible amplification or gain, per stage, with the former is inherently greater. Nevertheless the transistor TRF receiver is a perfectly practical type, provided it is properly aligned and 'neutralized'. 'Alignment' refers to setting up the variable tuned stages accurately with each other. 'Neutralization' refers to control of internal feedback due to the internal capacitance of transistors, which if not controlled could lead to the RF amplifier stage becoming unstable and oscillating continuously (producing a howl or whistle in the loudspeaker or phones).

Fig. 31 shows a straightforward three transistor TRF circuit which should be simple enough to lay out on a suitable chassis plate (or pegboard) with a similar positioning of components. The only thing not obvious from the circuit drawing is that C1 and C4 are physically combined in one actual component, a ganged tuning capacitor, and thus C4 does not appear as a physical entity on the component layout. This is indicated by the dashed line connecting the two components on the theoretical circuit drawing. In practice, this merely means remembering that C4 is the 'second half' of the ganged tuning capacitor, and

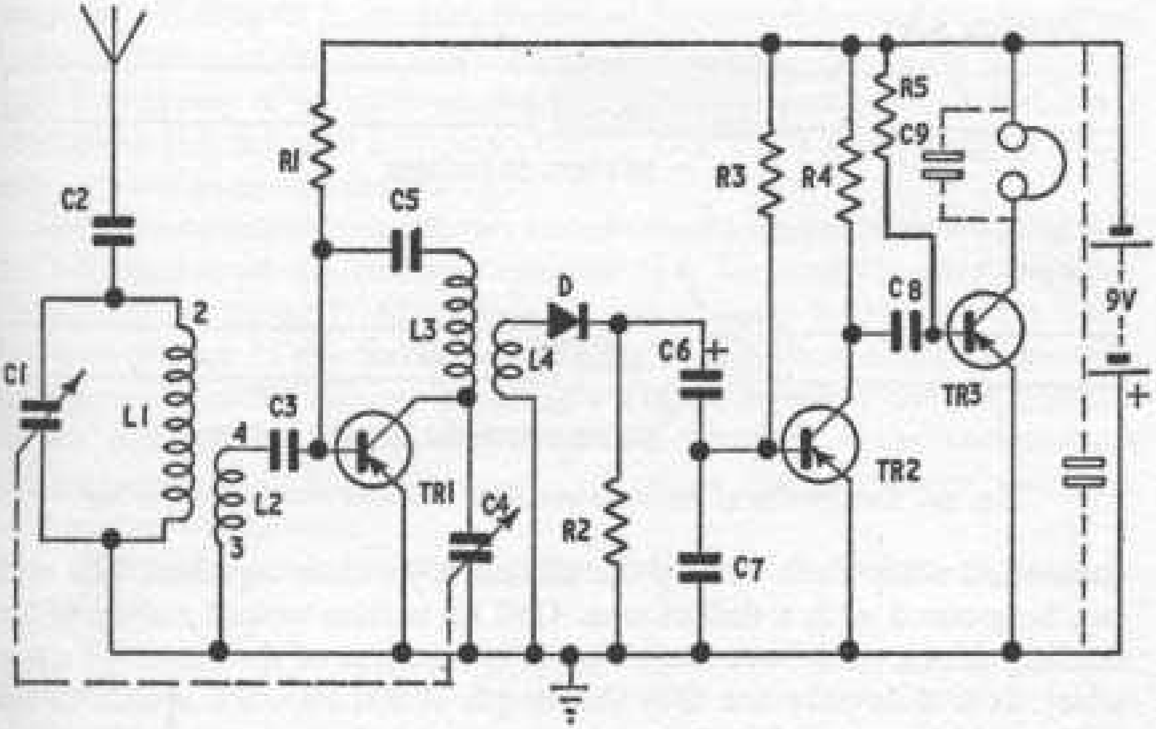

Fig. 31. *Complete circuit for a three-transistor TRF receiver. The addition of C9 (100μF) will improve quality of reception. Try also the effect of a 100μF capacitor connected across the battery*

L1, L2—transformer coupled aerial coil, made as shown in Fig. 31
C1, C4—O—500 pF gauged tuning capacitor (Jackson or similar)
C2—220 pF
C3—100 to 500 pF
C5—15 pF
C6—8μF (15 volts D.C.) electrolytic
C7—0·01μF
C8—8μF (15 volts D.C.) electrolytic
R1—1 megohm
R2—10 kilohms
R3—1 megohm
R4—4·7 kilohms
R5—1 megohm
L3, L4—50-turn coil wound on ferrite rod (L3), with 10-turn coil wound over one end (L4)—*see* text
TR1—Mullard OC45, or equivalent
TR2—Mullard OC71, or equivalent
TR3—Mullard OC71, or equivalent

the collector lead of transistor TRI has to be connected to the appropriate tag on the tuning capacitor.

The two coils L1/L2 and L3/L4 also need further explanation, otherwise all the other components involved are perfectly standard. The two coil pairs are 'transformer wound' or inductively coupled and different from the single winding we used previously for an aerial coil. Coil L1/L2 is wound on a 6-in. long ¼-in. diameter ferrite rod, as shown in Fig. 32. First a paper sleeve is formed around the rod and on to this is wound L1, comprising 50 turns of 38 s.w.g. enamelled or double silk

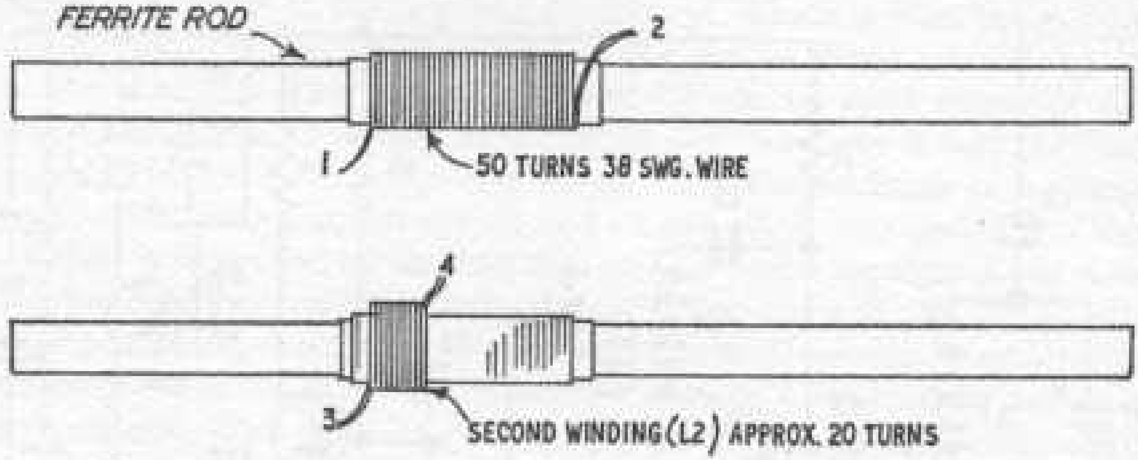

Fig. 32. *Construction of medium wave aerial coil with transformer coupling*

enamelled wire. Each turn of the coil must be close together. The ends can be secured with a dab of wax. Coil L2 is then wound on top of L1, starting at one end, but comprising only 10 turns of the same (38 s.w.g. wire). It is thus only one fifth the length of L1. Again the ends of this coil should be secured with wax.

This particular aerial coil can be used on a variety of the receiver designs which follow. The range of frequencies covered will depend on the position of the coil on the ferrite rod. Thus whilst adjustment of the tuning capacitor associated with the aerial coil will 'tune in' to a particular frequency, the position of the tuning capacitor corresponding to this tuned frequency may not be entirely satisfactory, i.e. other stations of different frequency may be 'off the end' of the tuning condenser movement.

The practical way to set up a tuned circuit is this. With the receiver circuit switched on, adjust the tuning capacitor to about its mid-position (i.e. in the case of postage stamp trimmer capacitors, screw right down and then back off about half a turn). Then *slide* the aerial coil along the ferrite rod until a station is picked up with a frequency in about the middle of the band, e.g. the Third Programme in the medium wave-band. Fix the aerial coil to the ferrite rod in this position with a dab of wax. The tuned circuit will then be capable of tuning over a maximum sweep up and down from the mid-frequency via movement of the variable capacitor alone.

Coil L3/L4 is made in very much the same way except that the length of ferrite rod need only be about 1 in. Also the paper sleeve must be a sliding fit to enable the rod to be moved in and out to adjust the inductance of the coil if necessary. There is also one other difference Coil L3 consists of 50 turns of 38 s.w.g. wire (the same as L1), but has a centre tap (i.e. a bared loop at 25 turns). Coil L4 is 10 turns of 38 s.w.g. wire wound over one end of L3.

In the complete circuit the two tuned circuits are tuned simultaneously by adjustment of the tuning capacitor (i.e. C1 and C4 vary together since they are ganged). Capacitor C3 controls the feedback from TR1, but adjustment of the ferrite rod core of L3/L4 may also be necessary to eliminate oscillation or 'howling'. This is affected by the position of the components in the RF amplifier circuit (i.e. the components centred around TR1), and two important considerations apply to this part of the circuit:

1. Keep the leads connecting the various components as short as practicable.

2. The coil L3/L4 *must* be screened from coil L1/L2 and adjacent components. The best way to do this is to cut a piece of thin aluminium sheet which can be bent to fit around L2/L3 just like a physical screen

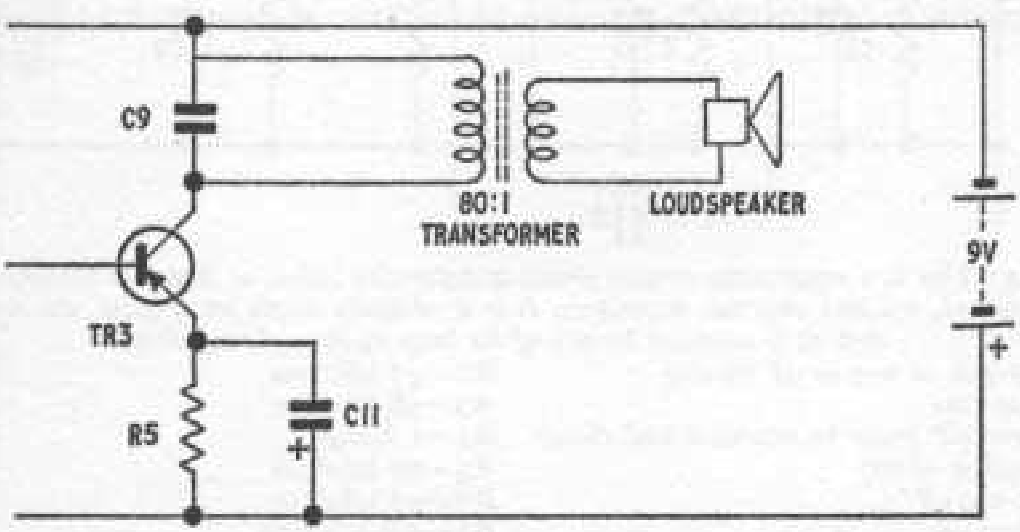

Fig. 33. *Additional circuitry for providing loudspeaker output on TRF receiver. 80:1 coupling transformer provides matched output for a 3 ohm miniature loudspeaker. Try first without R5 and C11. Then try effect of adding these stabilizing components*

R5—470 ohms
C11—100 μF (15 volts) electrolytic
C9—100 μF

—remembering that you must be able to reach the ferrite rod centre to adjust its position, if necessary.

The rest of the circuit is straightforward to assemble and needs no special attention other than suitable mounting of the individual com-

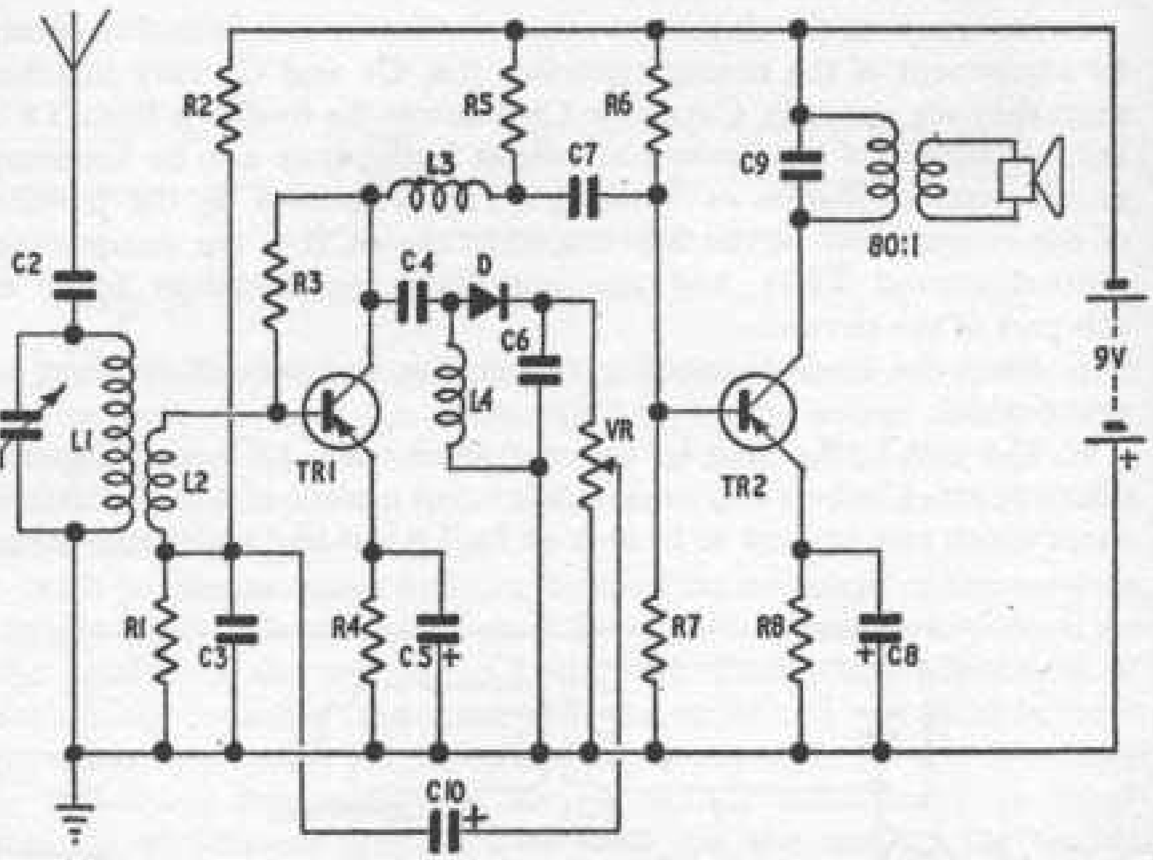

Fig. 34. *This is a regenerative receiver circuit incorporating reflex, so that it is actually a four-stage receiver, but uses only two transistors. It is a relatively simple set to align, although more difficult to construct because of the large number of components*

C1—0–400 or 0–500 pF tuning capacitor
C2—220 pF (may be omitted and direct coupling tried)
C3—0·001 μF
C4—100 pF
C5—100 μF electrolytic
C6—0·005 μF
C7—5 μF electrolytic
C8—100 μF electrolytic
C9—0·01 μF
C10—5 μF electrolytic
R1—10 kilohms
R2—47 kilohms
R3—56 kilohms
R4—1 kilohm
R5—22 kilohms
R6—47 kilohms
R7—5·6 kilohms
R8—150 ohms
L1—, L2— as Fig. 32
L3—millihenry RF choke—*see* Fig. 36 for home-made component
D—Mullard OA 71, or equivalent
TR1—Mullard OC45, or equivalent
TR2—Mullard OC71, or equivalent

ponents and correct connection. You may find, however, that the performance can be improved by the addition of capacitor C8 across the phones, as shown dotted.

Although the volume to be expected from this three transistor TRF circuit is appreciably higher than that obtainable by a simple crystal set with two stages of amplification (i.e. as given by TR2 and TR3), the design as shown still only specifies headphones (or a deaf-aid ear-piece). Sufficient power should be available in areas of good radio signal strength for loudspeaker reproduction, when the modification as shown in Fig. 33 can be tried, replacing the earphones in the circuit with an 80:1 (miniature) output transformer connected to a 3 ohm loudspeaker. Capacitor C8 is strictly necessary in this case.

An interesting variation on a transistor TRF circuit is shown in Fig. 34 where only a *single* tuned circuit is used, and only two transistors. There is some loss of selectivity in this design, so that the tuning is somewhat broader and thus reception is more liable to interference from neighbouring broadcast stations. No alignment or adjustment of neutralization is necessary, however, so the circuit is much simpler to get working. It also has sufficient power to drive a loudspeaker (through an output transformer) and has the additional refinement of a volume control.

CHAPTER 6

REFLEX RECEIVERS

THE last TRF receiver described in the previous chapter saved on the number of stages (if not actual number of components) by incorporating what is known as reflex action. This, in simple terms, means that part of the AF output from the detector stage is fed back or reflexed into the input. At the same time the incoming signal from the tuned circuit is also amplified as an RF signal before being fed to the detector stage. Thus all the basic features of a true TRF circuit are accomplished,

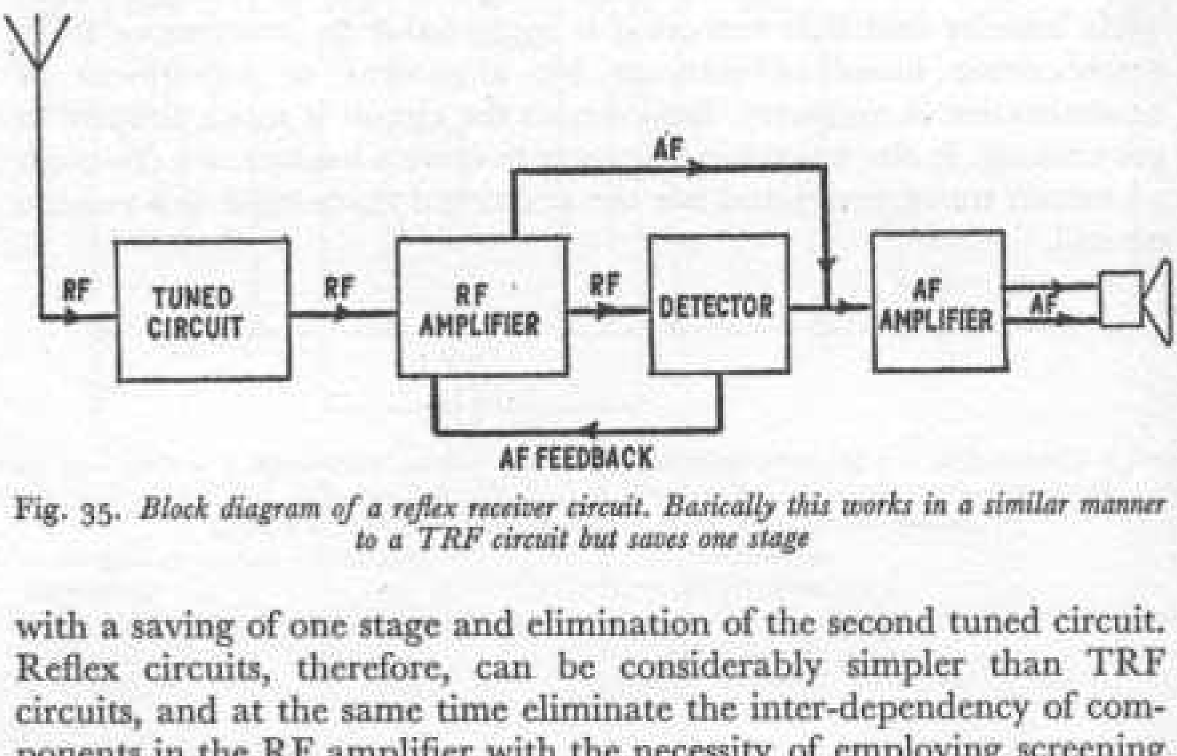

Fig. 35. *Block diagram of a reflex receiver circuit. Basically this works in a similar manner to a TRF circuit but saves one stage*

with a saving of one stage and elimination of the second tuned circuit. Reflex circuits, therefore, can be considerably simpler than TRF circuits, and at the same time eliminate the inter-dependency of components in the RF amplifier with the necessity of employing screening and neutralization adjustment.

The block diagram of a reflex circuit, on the other hand, looks quite complicated—Fig. 35. This should not bother us unduly as it is the final working circuit that matters, but we may as well understand the basic principle of operation, and the practical limitations.

As the diagram shows, the tuned circuit is followed by an RF amplifier, supplying boosted (RF) signal to the detector—the value of which has been discussed in the previous chapter. All of the AF output from the detector is fed back to the RF amplifier stage input for amplification at AF. Thus the (single) RF amplifier stage is made to do a double duty—amplify both RF and AF. The amplified AF output can be taken directly to headphones (three-stage reflex circuit); or through a further stage providing AF amplication (four-stage reflex circuit), followed by as many *additional* AF amplifier stages as necessary. Thus a four-stage reflex circuit (i.e. incorporating one AF amplifier stage) would normally still only be expected to operate headphones direct (or a speaker via an output transformer). A five-stage reflex circuit would provide adequate loudspeaker power (but would require output matching); and a six-stage reflex circuit still more output power. In practice there is a limit to the number of additional (AF amplifier) stages which can usefully be added, since reflex circuits are normally limited to simple designs of compact layout. We shall, therefore, describe only two of these circuits, both of which are intended for use with a deaf-aid earpiece (or headphones) for listening.

The first—Fig. 36—is a three-stage receiver although it employs only one transistor, which acts as both an RF and AF amplifier. The aerial coil L1/L2 is identical with that of Fig. 32. The only other components with which we are not already familiar are the RF chokes L3 and L4. These can be bought ready made (1 millihenry chokes); or wound as shown in Fig. 37.

Each coil is wound on a standard $\frac{1}{4}$-in. diameter polystyrene coil former (a standard radio component) which is fitted with two $\frac{5}{8}$ in. diameter cheeks or 'washers' cut from any thin insulating material and cemented in place $\frac{3}{16}$ in. apart as shown. Some 38 s.w.g. insulated wire is then wound on the former, layer upon layer between the cheeks, until the whole of the space is filled. Wrap the winding with a turn or two of cellulose tape to hold it in place and secure the start and finish ends of the wire with wax. This will give a coil of approximately 1 millihenry inductance, when the dust core is screwed into the centre of the coil former. The actual value can be adjusted by screwing the dust core in or out, if necessary, to align the completed receiver.

The four-stage reflex receiver is shown in Fig. 38 is identical with the one just described, except for the addition of another stage of AF

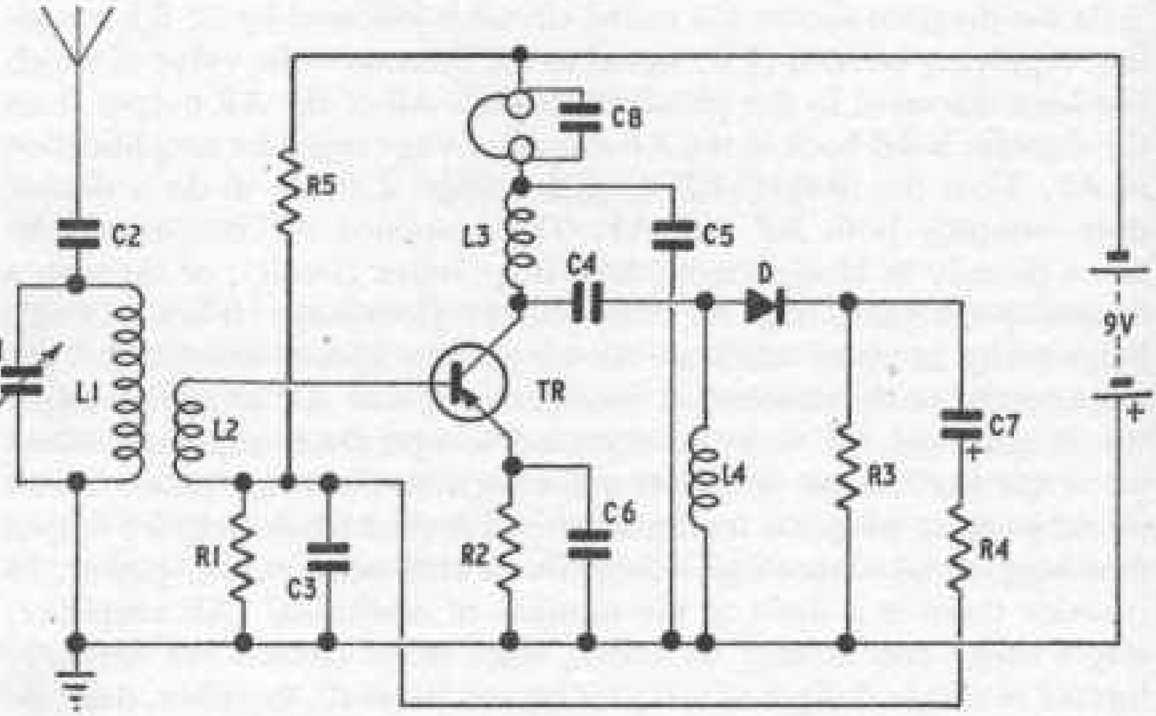

Fig. 36. *A three-stage reflex circuit which uses only one transistor—a simple and easy to construct receiver capable of excellent performance in areas of moderate to high signal strength*

L1, L2—transformer coupled aerial coil, as Fig. 32
C1—0–250 pF tuning capacitor
C2—220 pF (may be omitted and direct coupling of aerial tried)
C3—0·01 μF
C4—47 pF
C5—0·005 μF
C6—32 μF (15 volts D.C.) electrolytic
C7—10 μF (6 volts D.C.) electrolytic
C8—0·009 to ·01 μF
R1—4·7 kilohms
R2—3·3 kilohms
R3—22 kilohms
R4—1 kilohm
R5—22 kilohms
L3—RF choke (*see* Fig. 37)
TR—Mullard OC44, OC45 or equivalent
D—Mullard OA81, OA91, or equivalent

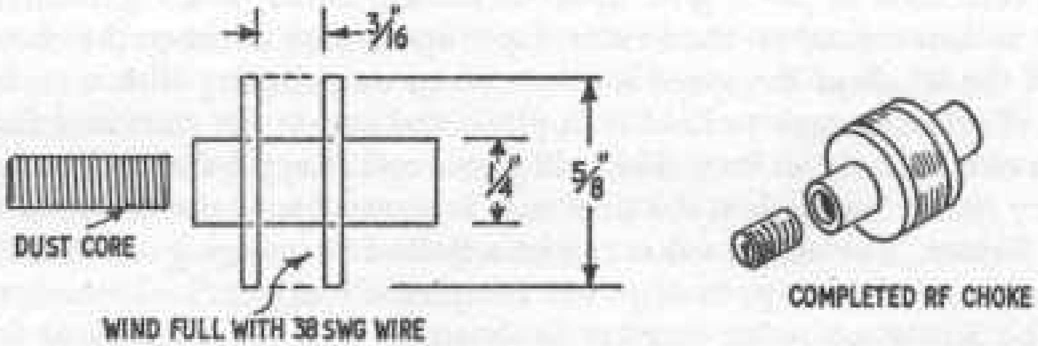

Fig. 37. *Construction of an RF choke (L3 in the circuit of Fig. 35)*

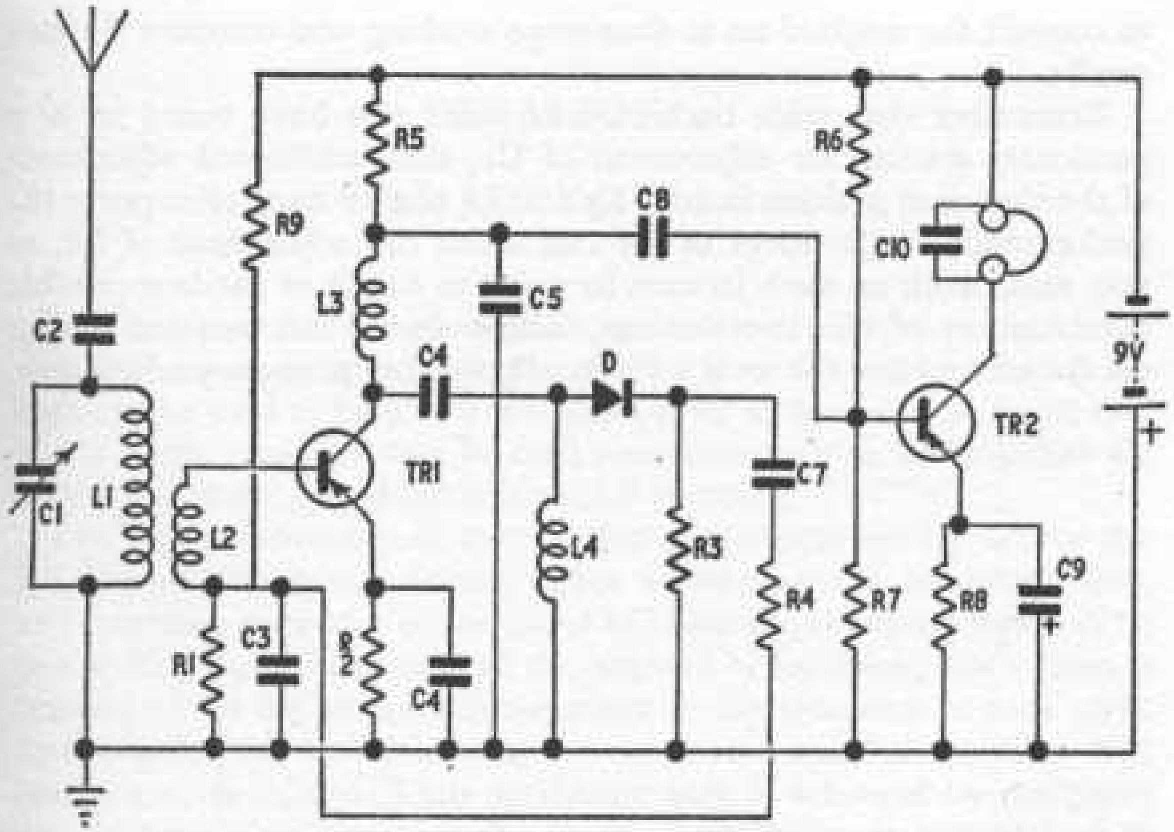

Fig. 38. *A four-stage reflex circuit. This should have enough output to operate a loudspeaker via a step-down transformer (replacing the phones); or an additional stage of amplification could be added for loudspeaker reproduction*

L1, L2—as Fig. 32
L3—as Fig. 37
L4—as Fig. 37
C1—0–250 pF tuning capacitor
C2—220 pF (may be omitted)
C3—0·01μF
C4—47 pF
C5—0·005μF
C6—32μF (15 volts D.C.) electrolytic
C7—10μF (6 volts D.C.) electrolytic
C8—8μF (15 volts D.C.) electrolytic
C9—8μF (19 volts D.C.) electrolytic
C10—0·005 to 0·01μF

R1—4·7 kilohms
R2—3·3 kilohms
R3—22 kilohms
R4—1 kilohm
R5—4·7 kilohms
R6—22 kilohms
R7—10 kilohms
R8—4·7 kilohms
R9—22 kilohms
D—Mullard OA81, OA91, or equivalent
TR1—Mullard OC44, OC45, or equivalent
TR2—Mullard OC71, or equivalent

amplification (transistor TR2 and its attendant components). It is recommended that if you want to try reflex circuits you lay out a base panel to accommodate all the components necessary for the four-stage circuit. You can build the three-stage circuit on this and try it out first. It is then a simple matter to add on the additional components to convert the original set to four-stage working and compare the two results.

Remember that with both circuits, once you have tuned in to a particular station via adjustment of C1, then additional adjustment of the dust core position in coils L3 and L4 can be tried to improve the performance. Adjustment of L3 can affect the adjustment of L4, so you must work on each in turn in order to arrive at the best possible combination of the two settings, These should not require further readjustment once the set is initially aligned for optimum performance.

CHAPTER 7

REGENERATIVE RECEIVERS

We now come to one of the most important types of simple receiver layouts—the regenerative circuit. We have already seen how feedback can be used to boost the RF signal prior to the detector stage, and how a single transistor can be used simultaneously as an amplifier for both RF and AF (provided it is an RF type).

The regenerative circuit carries this to the extreme by taking the RF output of a *transistor detector*, which would normally be disregarded, and returning part of it to the input to boost the incoming signal. The gain is directly proportional to the amount of feedback, but a limit is reached where the feedback is too great for the transistor to cope with. At this point the transistor ceases to work as a rectifier/amplifier and breaks into oscillation. Thus maximum gain is achieved by designing the feedback circuit so that the point of oscillation is approached as nearly as possible without the transistor actually going into oscillation. The actual gain which may be achieved can be as great as 100:1, thus vastly improving the sensitivity of the detector. The only real disadvantage—apart from having a more sensitive circuit—is that this gain is not achieved without some penalty, in this case some loss of the *quality* or reproduction.

A block diagram of a regenerative receiver is shown in Fig. 39. The new element added is a phase changer which is necessary to ensure that the feedback from collector to base of the detector transistor is applied to the input in the same manner, so that the feedback is positive. An alternating current is involved (RF) and the corresponding voltage appearing at the collector of the transistor will be 180 degrees 'out of phase' with the input to the base, tending to cancel rather than boost the RF input which is applied directly to the base. Thus the phase changer is necessary to reverse the phase of the feedback, so that it is applied to the input in the same phase.

This all sounds very complicated, but that is the fault of standard terminology. In practice the phase changer is simply an additional coil incorporated with the aerial coil, and connected to it inductively. If the coil is connected to the collector of the transistor one way round it will provide negative feedback; and connected the other way round it will provide positive feedback. Thus if the circuit does not work, all that is usually wrong is that the coil has been connected the wrong

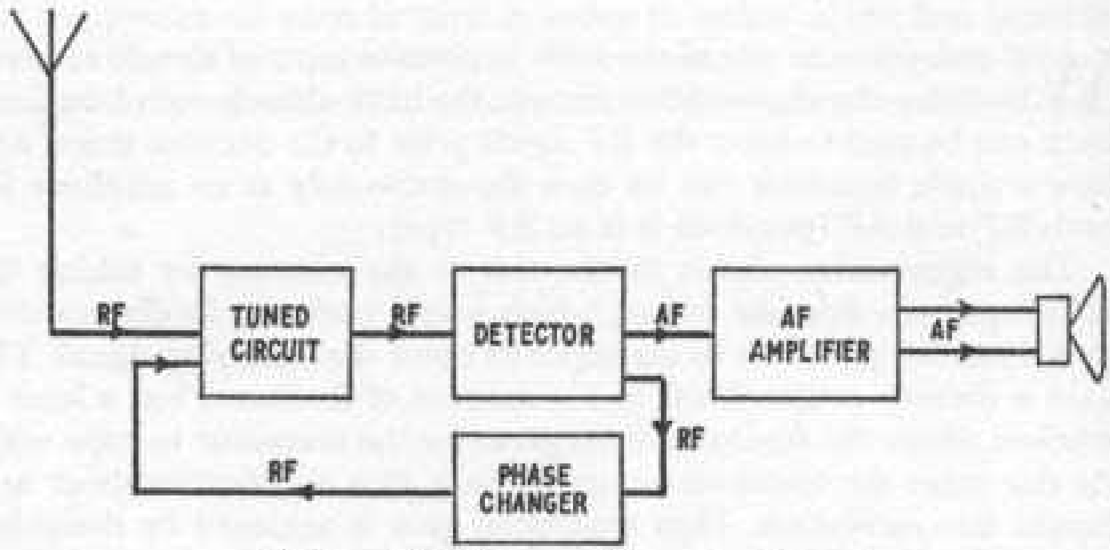

Fig. 39. *Block diagram of the regenerative receiver*

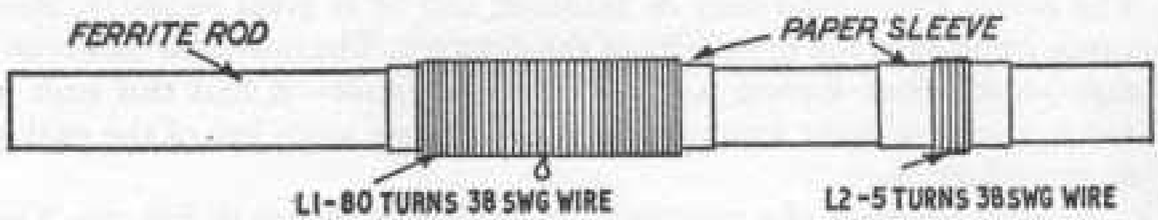

Fig. 40. *Winding of an aerial coil and coupling coil for regenerative receivers*

way round. Reversing the connections will then produce the required phase change.

Such a coil is shown in Fig. 40, associated with a similar aerial coil to that previously described. The feedback coil comprises 8 turns of 38 s.w.g. insulated wire wound on a paper sleeve. Sliding the coil up and down the ferrite rod, adjust the degree of coupling between the feedback coil and the aerial coil.

A simple single transistor regenerative circuit is shown in Fig. 41. The transistor used must be of RF type and high quality, such as a selected Mullard OC44, OC45, or equivalent. The circuit is otherwise quite straightforward, with the exception of the addition of the variable capacitor C4. This is provided as a means of controlling the amount of reaction or feedback. It is connected across the collector of the transistor and either end of the tuned circuit (the diagram shows it connected to

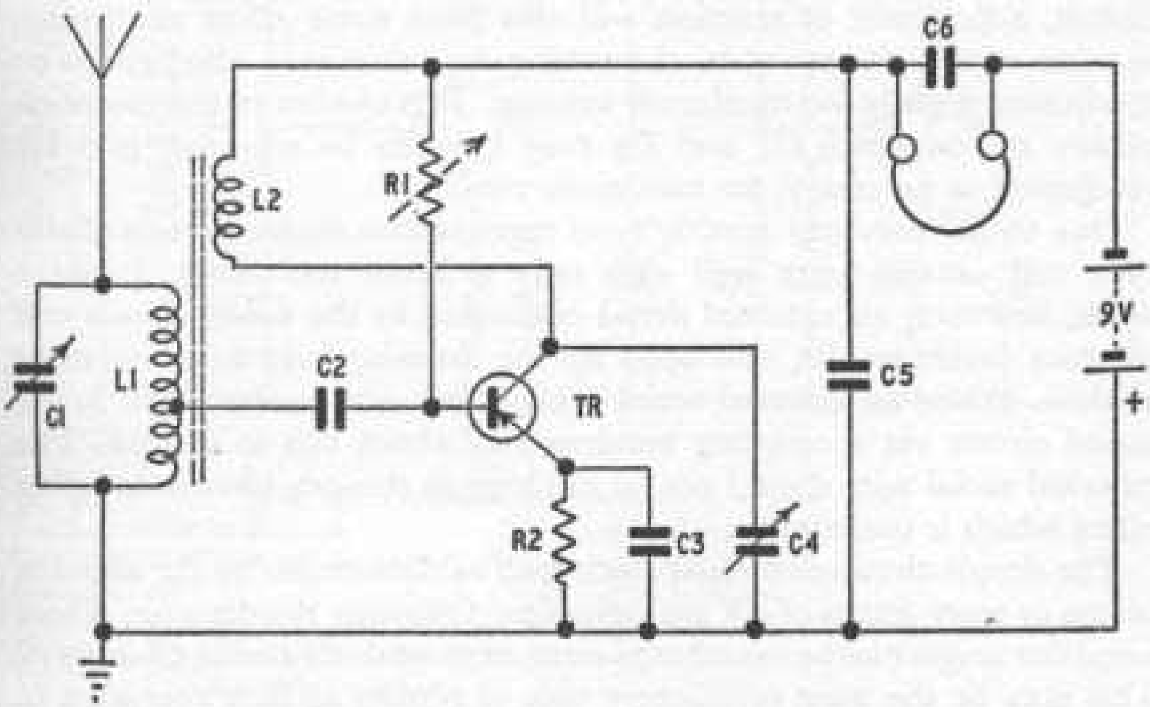

Fig. 41. *Simple circuit for a regenerative receiver using a single transistor*

L1, L2—Coils as Fig. 40
C1—100–500 pF tuning capacitor
C2—220 pF to 0·1 μF (or trimmer capacitor with this range)
C3—2 μF (15 volts D.C.) electrolytic
C4—100–500 pF variable capacitor
C5—0·005 μF
C6—0·005 to ·01 μF
R1—4·7 kilohms to 1 megohm (or 1 megohm variable resistor for adjustment
R2—3·3 kilohms
TR—Mullard OC44, OC45, or equivalent
High impedance planes

Note: The use of a trimmer capacitor for C2, and a variable resistor for R1 will help in adjusting the set for smoothest regeneration.

the 'earth' end, but it could equally well be connected to the other end).

The receiver is set up by adjusting the position of the feedback coil on the ferrite rod to arrive at the strongest signal tuned in via C1 (the tuning capacitor) with the reaction control (C4) set in about its mid-position. The reaction can then be adjusted for maximum results by turning C4 one way or the other until the transistor breaks into oscillation and a howl is heard in the earpiece, then turning back until the howl disappears. The set is then adjusted for maximum reaction and should be at its most sensitive. If oscillation cannot be produced by adjustment of C4 to its limit, reverse the connections of the reaction coil and try again. Since the reaction control is coupled to the tuned circuit, adjustment of reaction will also have some effect on tuning, so after setting the reaction, the tuning capacitor may also have to be readjusted slightly for maximum volume. This applies to the reception of any station. Both C1 and C4 may have to be adjusted, and C1 readjusted as necessary, for maximum results.

Due to the excellent sensitivity of regenerative receivers, sets of this type will usually work well with only a ferrite rod aerial. In some areas, however, an external aerial connected to the tuned circuit will produce better results, and open up the listening field to many more stations. When an external aerial is used it should be connected to the tuned circuit via a coupling condenser of about 100 to 200 pF. The external aerial wire should not be too long as this can have a damping effect which is undesirable.

The simple circuit described lends itself to elaboration by the addition of one or more stages of AF amplification, following the detector. These amplifier stages can be exactly the same as those described in Chapter 9. This may be the most satisfactory way of getting audible reception in areas of low signal strength still only using the ferrite rod aerial (i.e. with no external aerial).

A similar circuit with two stages of AF amplification is shown in Fig. 42. No particular difficulties should be experienced in setting up this receiver, which should work well with just the ferrite rod aerial in all but very poor areas of reception. Instead of earphones, sufficient output power should be available to drive a miniature loudspeaker via a suitable coupling transformer (this replacing the headphones in the circuit).

A rather more superior type of three-transistor receiver is shown in Fig. 43. This is a design by Mullard. The first transistor (which is of AF type, Mullard AF117 or OC45) acts as a regenerative RF amplifier and audio preamplifier simultaneously; and is followed by a diode detector and two stages of AF amplification. Sufficient power is available to drive an 80 ohm (high impedance) loudspeaker direct without the need for an output transformer.

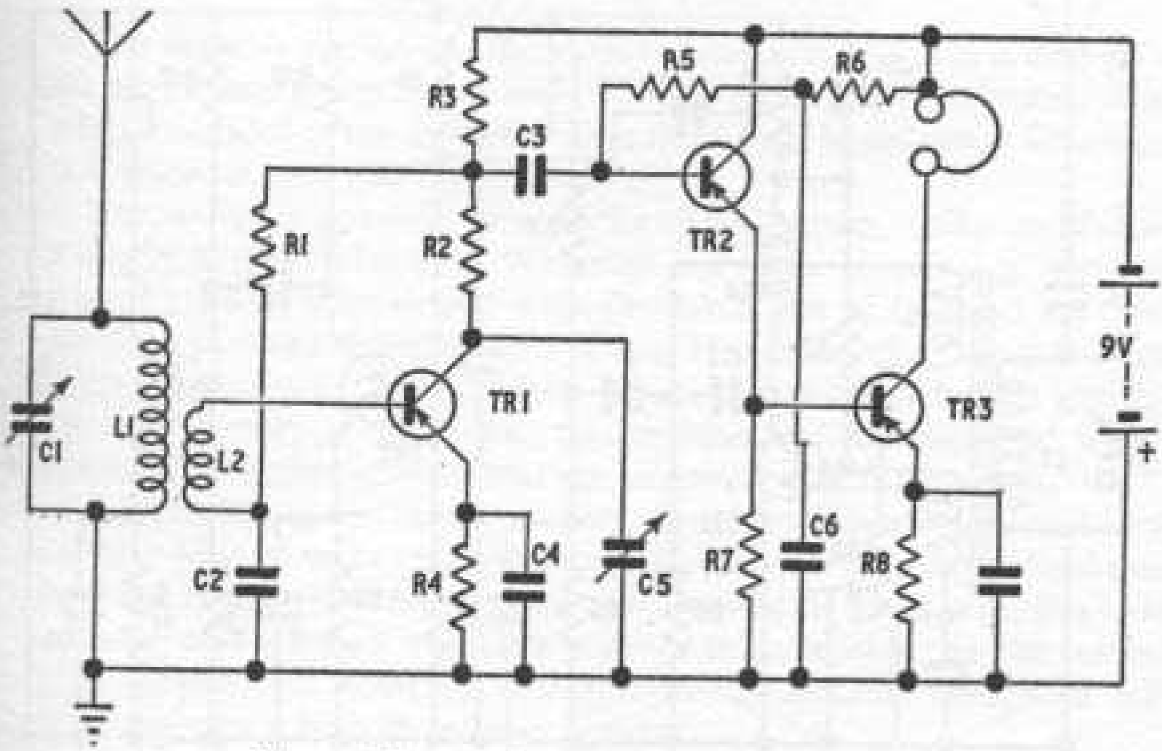

Fig. 42 *Three-transistor regenerative receiver circuit*

L1, L2—coils as Fig. 40
C1—0-250 pF tuning capacitor
C2—0·01 μF
C3—2 μF (3 volts D.C.) electrolytic
C4—2 μF (15 volts D.C.) electrolytic
C5—30 pF trimmable capacitor
C6—6 μF (15 volts D.C.) electrolytic
C7—8 μF (15 volts D.C.) electrolytic
R1—1 megohm
R2—22 kilohms
R3—22 kilohms
R4—3·3 kilohms
R5—470 kilohms
R6—470 kilohms
R7—4·7 kilohms
R8—4·7 kilohms
TR1—Mullard OC44, OC45, or equivalent
TR2—Mullard OC71, or equivalent
TR3—Mullard OC71, or equivalent

The receiver works as follows. The output from the aerial winding L1 is amplified by the transistor and developed across the choke L4. Part of the amplified signal is returned to the aerial circuit via C6 and L3, producing regeneration. The RF signal output is applied to the diode detector D1, which is slightly forward biased to improve its working efficiency; and the resulting AF signal is fed back to the first transistor via C7 and L2 for amplification. Amplified AF is finally fed via C5 to the second and third transistor stages for further amplification. This output is also controlled by R3 (which is the load in the collector circuit of TR1), and by using a variable resistor for R3 this can also work as a volume control.

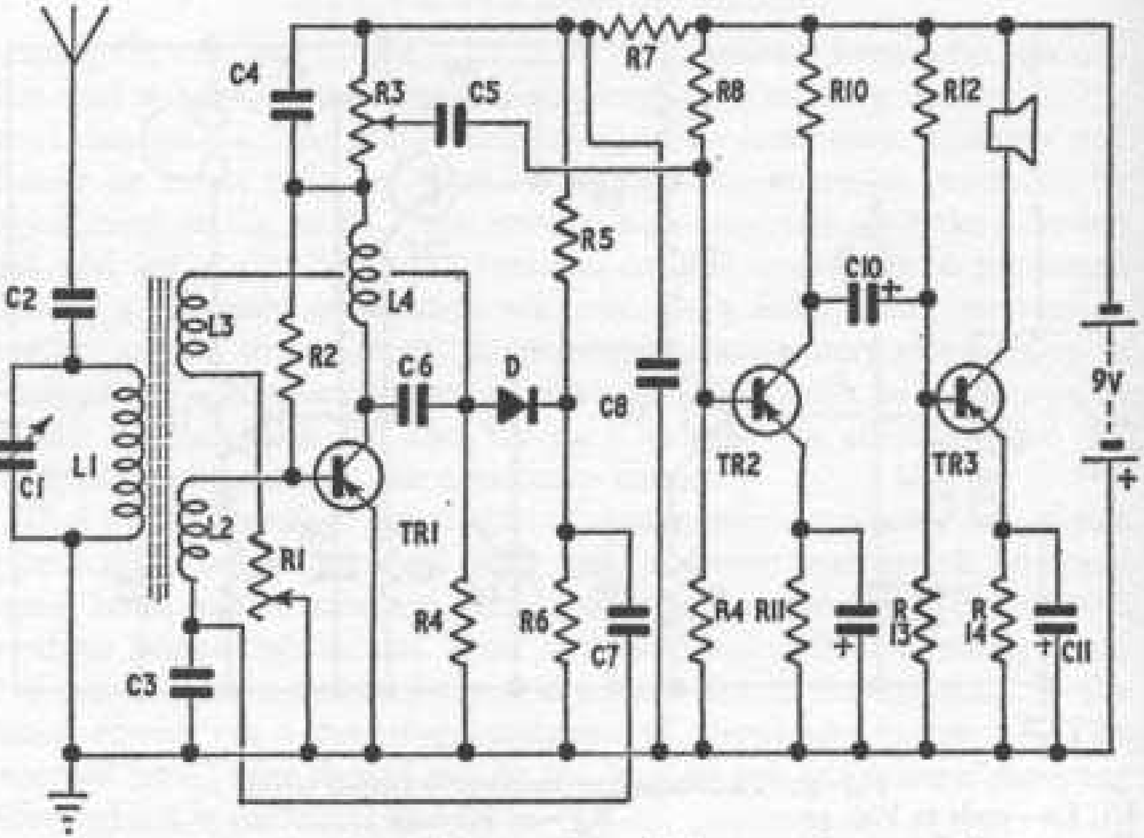

Fig. 43. *Mullard design for a three-transistor radio incorporating regeneration*

L1—60 turns 46 s.w.g. wire on Mullard FX2367 ferrite slab
L2—3 turns of 46 s.w.g. wire } *see* text
L3—4 turns of 46 s.w.g. wire }
L4—100 turns of 46 s.w.g. wire on coil former with dust core (*see* text)

C1—12 pF
C2—365 pF Jackson type 01
C3—0·02μF Mullard C296AA/A22K
C4—100 pF
C5—10μF (16 volts D.C.) Mullard C426AM/E10
C6—330 pF
C7—10μF (16 volts D.C.) Mullard C426AM/E10
C8—40μF (16 volts D.C.) Mullard C426AM/E40
C9—100μF (4 volts D.C.) Mullard C426AM/B100
C10—40μF (16 volts D.C.) Mullard C426AM/E40
C11—320μF (2·5 volts D.C.) Mullard C426AM/A320

R1—50 kΩ linear potentiometer
R2—560 kΩ
R3—5 kΩ logarithmic potentiometer
R4—4·7 kΩ
R5—150 kΩ
R6—10 kΩ
R7—2·2 kΩ
R8—33 kΩ
R9—4·7 kΩ
R10—1·5 kΩ
R11—470 Ω
R12—680 Ω
R13—100 Ω
R14—10 Ω

D—Mullard OA70
TR1—Mullard AF117, OC45 or equivalent
TR2—Mullard OC71, or equivalent
TR3—Mullard OC81, or equivalent

The variable resistor R1 provides reaction control and is thus set to the maximum possible feedback without oscillation developing. Since it is not coupled to the tuned circuit it should not be necessary to readjust this, once set, nor will it affect tuning.

The aerial is specially wound for this receiver, using a Mullard FX2367 ferrite aerial slab. Windings are made in 46 s.w.g. insulated wire, L2 being inter-wound with the earth end of L1; and L3 inter-wound $\frac{3}{4}$ in. from the earth end of L1. The choke (L4) consists of 100 turns of 46 s.w.g. wire wound on a tuning slug taken from a 470 kc/s IF transformer; or on a $\frac{1}{4}$-in. polystyrene coil former fitted with a tuning slug. Other components are as specified in the caption.

It is possible to use the same circuit to drive a lower impedance loud-speaker (e.g. 10 to 15 ohms speaker). In this case the output load must be balanced by connecting a 40 ohm resistor in series with the loud-speaker, and a 100μF capacitor coupled in parallel across the resistor. The output will, however, be substantially reduced compared with that given by a high impedance speaker.

A further development of the regenerative circuit is the *super regenerative receiver*, which is recognized as a distinct type since it operates on a somewhat different principle. Whereas in the regenerative receiver the sensitivity is limited by the degree of adjustment possible before the circuit breaks into oscillation, the super regenerative receiver is adjusted to near the point of oscillation and the detector switched in and out of oscillation by another oscillator, known as the quench oscillator.

How this is utilized is a little difficult to follow at first, but the following explains the principle involved in simple terms. Oscillation is really an amplified burst of energy. In the case of a receiver circuit, RF oscillations can build up to a peak determined by the limit that the transistor involved can handle. The time that such oscillations take to build up to their peak will depend on the amplitude of the modulated signal received, so we can say that oscillation time is a measure of the original modulation of AF component. Such a super regen oscillator is thus capable of acting as a detector.

To employ such oscillations in this manner requires that they must be stopped, or quenched. Time growth to the peak of an oscillation is not uniform, however, so it is better to apply quenching some time before the peak is reached. Also the oscillations produced by one quench cycle must die away before the next cycle starts, so that each cycle is initiated entirely by the RF signal, and independent of the previous cycle. The resulting output will then be a pattern of the RF modulation, with a possible gain of many million times from a single stage.

There is, however, one basic snag. For satisfactory performance the circuit requires a quench frequency of 100 to 1,000 times less than the signal frequency, which in the case of medium wave broadcast frequencies means that the most suitable quench frequency is liable to lie in the audible frequency range, which complicates the design. There is also the fact that the receiver is being switched in and out of oscillation at the quench frequency and will tend to act as a weak transmitter of signals at this frequency. This could affect nearby radio receivers, although this is not so important a point as it can be overcome.

The design of a satisfactory super regen receiver, therefore, is somewhat tricky; and it can also be a tricky circuit to set up for satisfactory working. If slightly out, it may have a tendency to oscillate uncontrollably and simply howl. Nevertheless super regen receivers can be made to perform well—as well as a superhet, in fact, with far less components—provided it is appreciated that the circuit is a tricky one and needs very careful attention to detail.

Basically there are two types of layout. The most straightforward one uses a separate transistor for the quench oscillator, varying either the base or collector bias of the super regen oscillator. The other type is known as a self-quenching circuit where the quench oscillations are derived by feedback. In this case the bursts of oscillation are maintained at the same amplitude, but the *time* between each is varied as the input signal varies. The action of the oscillations is then blocking or 'squegging'.

Two quite simple circuits for super regen receivers are shown in Figs. 36 and 37. Whilst capable of satisfactory working these should be regarded largely as experimental, and should not be tackled until some previous experience has been gained in building and setting up simpler types of receivers. Once reasonably familiar with the behaviour of such circuits, however, there is no reason why these super regen circuits should not be tackled successfully.

The circuit of Fig. 44 uses a minimum of components and comprises just four stages—a tuned circuit, super-regenerative oscillator (which

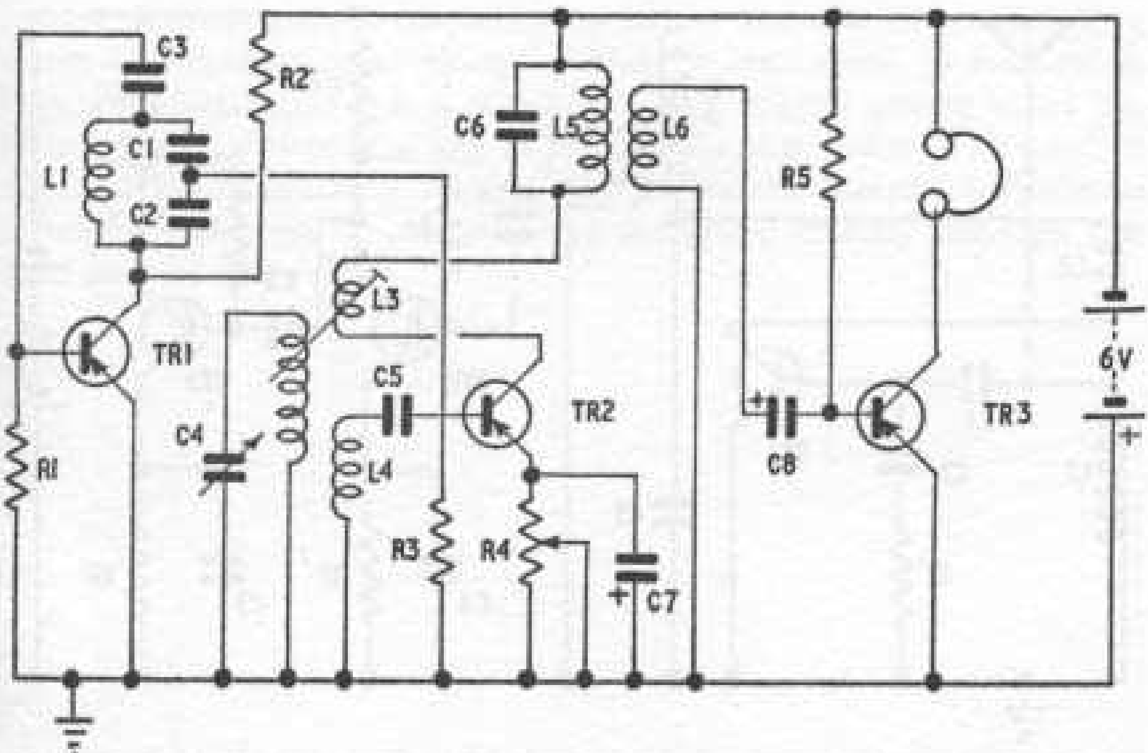

Fig. 44. *Simple super-regenerative receiver with quench oscillator. The phones may be replaced with a 2:1 step-down transformer to work a 3 ohm miniature loudspeaker in areas of good signal reception*

L1—80 turns 38 s.w.g. wire on ferrite rod
L2—15 turns (separate adjustable winding)
L3—20 turns (separate adjustable winding)
L4—RF choke as Fig. 37
L5, L6—5:1 transformer
C1—0·005μF (trimmable)
C2—0·005μF (trimmable)
C3—0·005μF
C4—0–300 pF variable
C5—0.01μF
C6—0·001 μF
C7—6μF (15 volts D.C.) electrolytic
C8—6μF (15 volts D.C.) electrolytic
R1—10 kilohms
R2—47 kilohms
R3—4·7 kilohms
R4—0–5 kilohms (variable)
R5—50 kilohms
TR1—Mullard OC71, or equivalent
TR2—Mullard OC44, or equivalent
TR3—Mullard OC71, OC72, or equivalent

acts as a detector), a separate quench oscillator, and one stage of audio amplification. There is no reason why the phones should not be replaced with a 20:1 step-down transformer with the output side connected to a 3 ohm loudspeaker, as there should be adequate power at this stage to drive a speaker.

Coils L1, L2 and L3 are all wound on the same ferrite rod. Adjustment of the position of L3 relative to L2 is critical since this controls

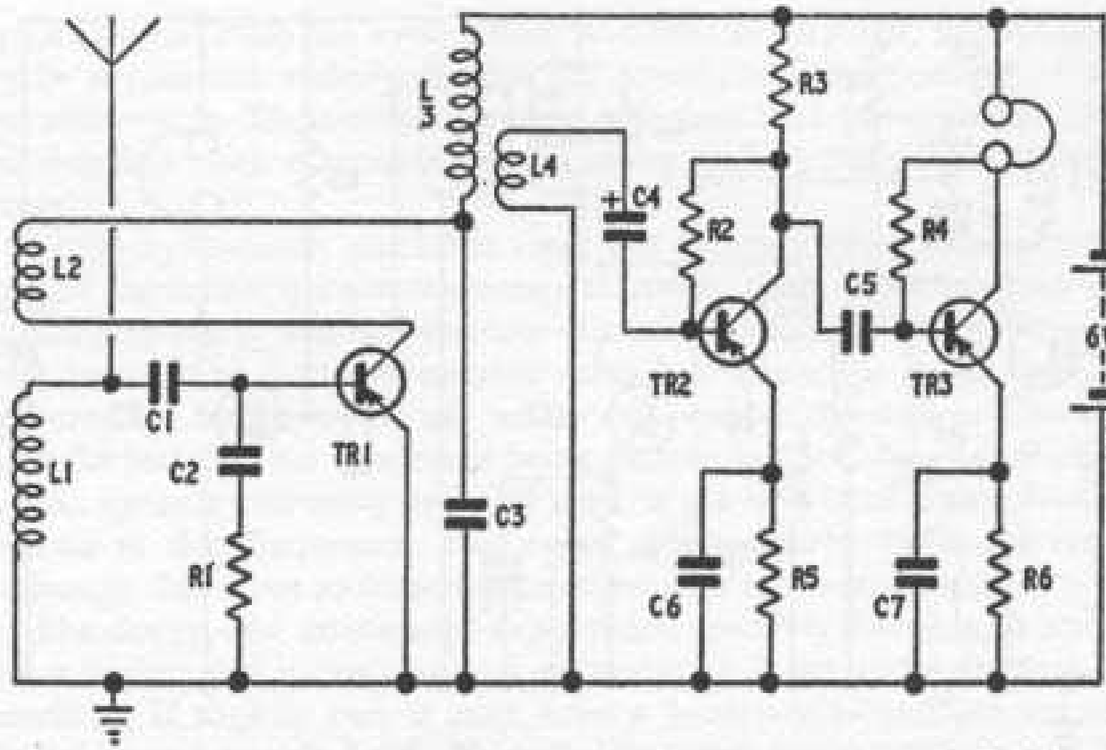

Fig. 45. *Self-quenching super-regenerative circuit. The phones can be replaced with a 2:1 step-down transformer to drive a 3 ohm miniature loudspeaker*

L1—50 turns of 38 s.w.g. wire wound on ferrite rod
L2—50 turns of 38 s.w.g. wire wound on top of L1
L3, L4—4·5:1 miniature coupling transformer
C1—500 pF
C2—0·002 μF
C3—400 or 500 pF
C4—6μF (6 volts D.C.) electrolytic
C5—6μF (6 volts D.C.) electrolytic
C6 8μF (6 volts D.C.) electrolytic
C7—8μF (6 volts D.C.) electrolytic
R1—170 ohms
R2—220 kilohms
R3—4·7 kilohms
R4—50 kilohms
R5—4·7 kilohms
R6—4·7 kilohms
TR1—Mullard OC44, OC45, or equivalent
TR2—Mullard OC71, or equivalent
TR3—Mullard OC71, or equivalent

Note: R5 and C6 and R6 and C7 may be omitted to save four components and the emitters of TR2 and TR3 connected directly to the positive line.

the coupling and thus the oscillation of the OC44 transistor. The receiver must be set up until it is just on the point of oscillation, when slight variations in the base bias of the transistor will bring it in and out of oscillation. All the coils, and transformers, should be shielded from other components, and component spacing throughout should be generous to avoid interaction, which can lead to instability or distortion.

The other circuit (Fig. 45) is of the self-quenching type, so does not have a separate quench frequency oscillator, and also dispenses with a choke in the quenching circuit. Although less prone to interaction between components it is a somewhat more critical circuit to set up. In particular, different values of R1 and C1 may have to be tried in order to get satisfactory results. Also an external aerial will almost certainly be necessary, connected to the tuned circuit, although this need only be quite short.

CHAPTER 8

THE SUPERHET

THE superheterodyne, or 'superhet' is the *élite* of receiver circuits, and the type generally employed for most of the more expensive commercial sets. The principle advantage it offers is that both the selectivity and gain are independent of the signal frequency, and the performance generally superior to any other type. Unfortunately, the circuit becomes considerably more complicated—although surprisingly

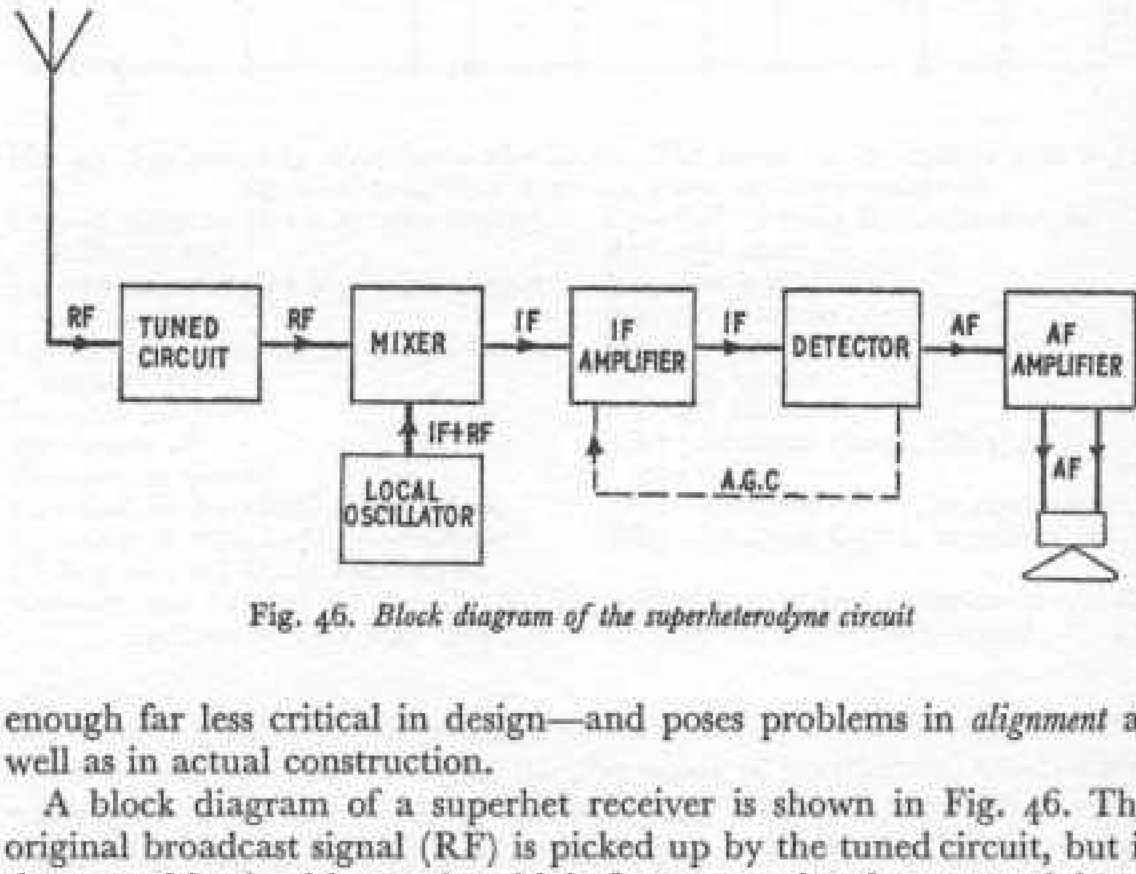

Fig. 46. *Block diagram of the superheterodyne circuit*

enough far less critical in design—and poses problems in *alignment* as well as in actual construction.

A block diagram of a superhet receiver is shown in Fig. 46. The original broadcast signal (RF) is picked up by the tuned circuit, but is then combined with another high frequency signal generated by a separate part of the circuit known as the local oscillator. The mixer stage then extracts the 'difference frequency', which it passes on to an amplifier and then to a detector. The detector extracts the AF signal, which is then passed on through one or more stages of amplification, as necessary.

This mixing of signals and the extraction of a 'difference frequency' for amplification and detection may seem unnecessarily complicated, but it has several advantages. In the first place it makes the receiver very much more selective, so that it readily rejects unwanted RF signals. The fact that the 'difference frequency' passed on by the mixer is lower than RF means that it can be amplified more readily, with less distortion than amplification applied directly to RF, and problems associated with feedback are minimized since the amplifier is dealing with a constant frequency.

We will now consider the basic circuit in a little more detail. The *tuned circuit* is conventional and designed to cover, say, a range of from 800 to 1,800 kHz. The tuned circuit can thus be adjusted (tuned) to pass on any RF signal with a frequency within this band.

The *local oscillator* does purely what the name suggests, i.e. it generates a signal of a specific frequency which is related to the RF frequency by a common difference, the difference frequency being known as the IF (or intermediate frequency). Since this difference has to be constant over the tuning range, it follows that the local oscillator has to 'tune' in step with the tuned circuit and shift this tuned frequency up, or down, by a value exactly equal to the IF.

The value chosen for the IF is almost invariably 470 kHz. Standard practice is also to apply an upward rather than a downward shift of frequency, as this has certain technical advantages. For the tuning range given above, therefore, the local oscillator would be designed to provide a range of frequencies from $800 + 470 = 1{,}270$ kHz to $1{,}800 + 470 = 2{,}270$ kHz, in step with the tuned circuit, sweeping the range 800 to 1,800 kHz.

The *mixer* thus receives two RF signals—one at the true RF, direct from the tuned circuit, and one at RF plus IF, direct from the local oscillator. The result of mixing the two is to extract the difference or beat frequency, i.e. the IF frequency which now contains the AF components of the original RF signal. This is then amplified and finally detected to extract the AF component, with all the advantages of working with a relatively low RF frequency (i.e. the intermediate frequency of 470 kHz) which is *constant* as far as the RF signal.

There is, in fact, one basic limitation in that 'image' signals which yield the same difference (but with opposite value of the IF) can also appear and be passed on. The ratio of the strength of the true signal to the false (or image) signal is known as the image ratio, and in order to achieve a satisfactory image ratio it is necessary to have good selectivity in the design. The choice of a fairly high IF is also helpful, as this shifts the separation of the true and image frequencies (by a value equal to twice the intermediate frequency). These are technicalities which need not bother the circuit constructor so much as the circuit *designer*.

One other feature of the basic superhet circuit shown is 'feedback' from the detector to the IF amplifier, denoted as AGC or 'automatic gain control'. This provides automatic regulation of the gain of the receiver in inverse proportion to the signal strength and thus tends to keep the output level of the receiver constant regardless of input signal strength. It is not necessarily incorporated in all superhet receiver designs, but since it is so simple to arrange—and has obvious advantages—it is commonly employed, as it eliminates much of the need to readjust the volume control when tuning in to different stations.

Because the selectivity of a superhet receiver is extremely important it is invariably best to employ commercially wound, rather than home-made, aerial coils for the tuned circuit. These are available in a wide variety of types and sizes and normally incorporate separate windings for the medium and long wave-bands. Each specific type is related to a given size (value) of variable capacitor for tuning over the frequency range(s) for which the coil is designed. An advantage offered by most commercial coils is that they are machine wound in the most efficient way, rather than limited to relatively straightforward and somewhat inefficient coils achieved by hand winding.

Further to improve the selectivity of the receiver, RF amplification is commonly applied immediately following the tuned circuit, prior to the RF signal being passed on to the mixer. This can be done using a RF transistor in the simple circuit shown in Fig. 47, capable of giving a power gain of up to 20 dB, but there are some important considerations. Thus the very fact that an amplifier is used after the tuned circuit implies a loading on the tuned circuit which could reduce its selectivity. To avoid this it is necessary to couple the RF amplifier to the mixer via a RF transformer with a step-down ratio of about 5:1.

There is also the chance that the amplifier may tend to become unstable and oscillate, calling for additional components to maintain stability. One such method is to employ a capacitor and resistor in series connected directly between the transistor base and output, providing feedback characteristics matched to the characteristics of the

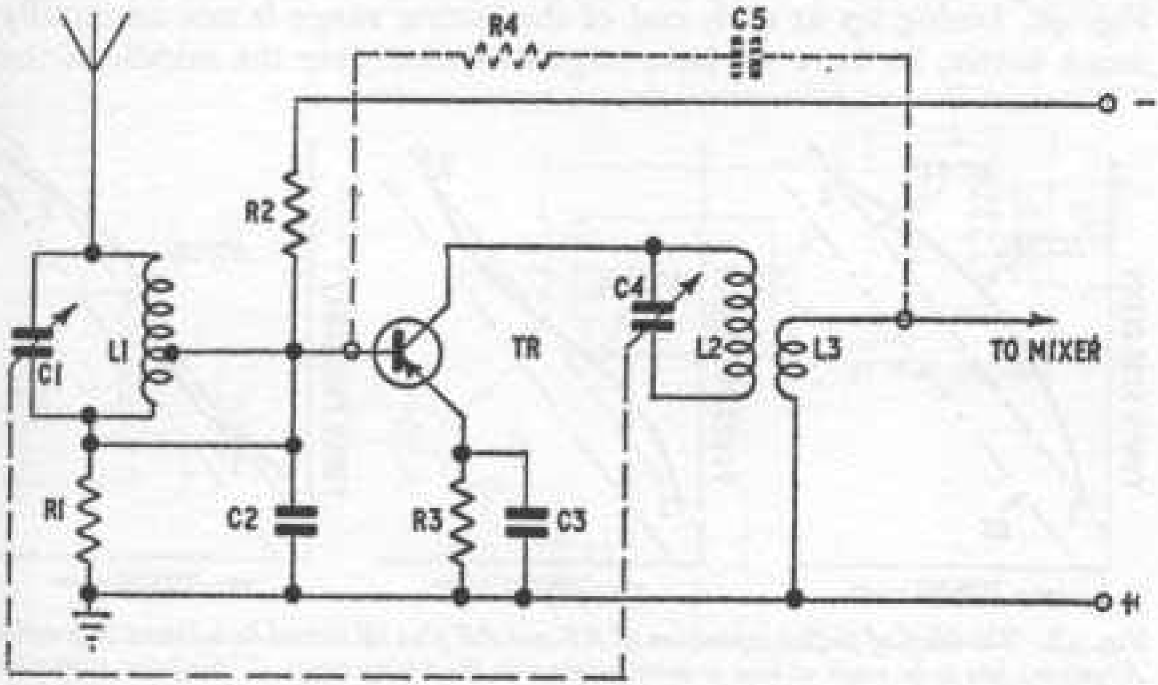

Fig. 47. *Front end of simple superhet circuit, which also provides RF amplification. Bias base for the transistor is supplied by R1 and R2. R3 provides DC stabilization and C3 is a bypass to prevent negative feedback. The addition of C5 and R4 in series between the output and transistor base is advisable to eliminate any tendency towards self-oscillation, i.e. to provide neutralization*

particular transistor in the circuit. Thus what started out as a simple RF amplifier circuit has demanded several modifications of detail, and some quite skilled knowledge of radio circuit design, in order to become a fully acceptable circuit. What is more, we are still only at the very front end of the receiver.

Still further problems arise when we come to consider the local oscillator. On the face of it, it seems a relatively simple matter to use one half of a ganged tuning capacitor to ensure exact variation with the tuned circuit as the variable part of an oscillator circuit having a fixed difference equal to the IF. In practice this concept of perfect separation is impossible to achieve, and the deviation of a realistic circuit may be quite wide. The best we can hope for is to be able to correct this by *alignment*, using trimming controls.

Assuming that we align the two circuits up somewhere near the middle of the tuning range we have a fairly localized range of constant IF, but considerable discrepancy as we depart from this tuning point—Fig. 48. Lining up at each end of the tuning range is not necessarily much better, for here we have large deviation over the middle of the

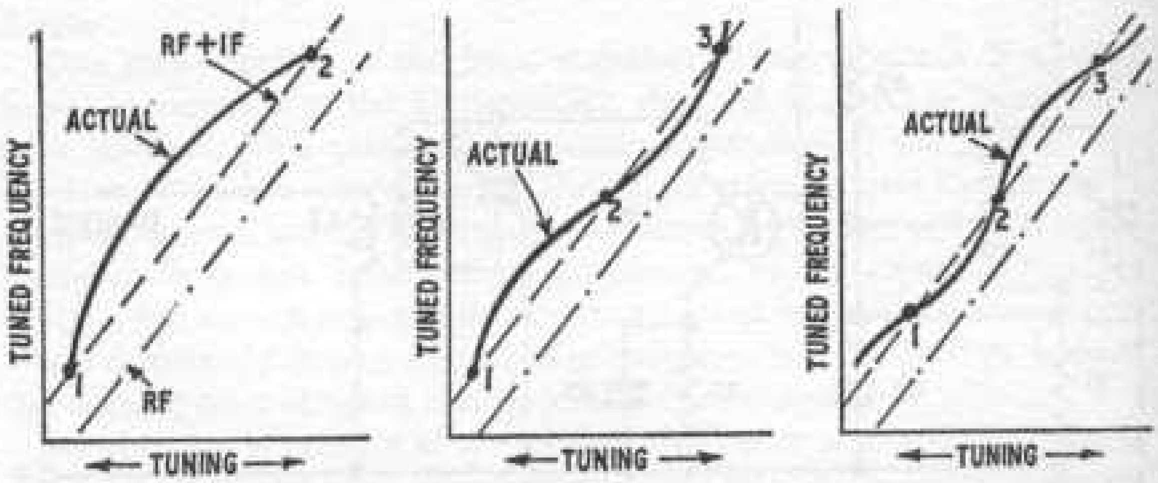

Fig. 48. *The ideal of perfect separation of RF and RF plus IF cannot be achieved in practice Alignment has to be made at two or more points over the tuning range. Three-point alignment is usually satisfactory, with minimum deviation if points 1 and 3 are in from the ends of the band*

tuning range. Lining up at three points is much better, as shown—and better still if the two end points are taken in from the extremes of the tuning range.

Theoretically, at least, close alignment is more important for the lower frequency end than the higher frequency end of the tuning range. However, if alignment is concentrated on the lower frequency end, the *selectivity* of the circuit at the upper frequencies may suffer. Thus there is no simple, or complete, answer to alignment. It is a matter of arriving at the best possible compromise when initially setting up the receiver.

In modern superhet circuits, the local oscillator and mixer are commonly combined, the two functions being performed by a self-oscillating mixer or *autodyne* circuit. This has the advantage of saving on components and, generally, the frequency stability of the autodyne circuit is better, which simplifies alignment. The basic circuit involved is not complex—*see* Fig. 49—but the practical circuit would also introduce padders and trimmers to provide a final means of adjustment and alignment; also screening where necessary to eliminate unwanted feedback between the tuned circuit and oscillator coils. The elimination of stray capacitance effects is particularly important—so components

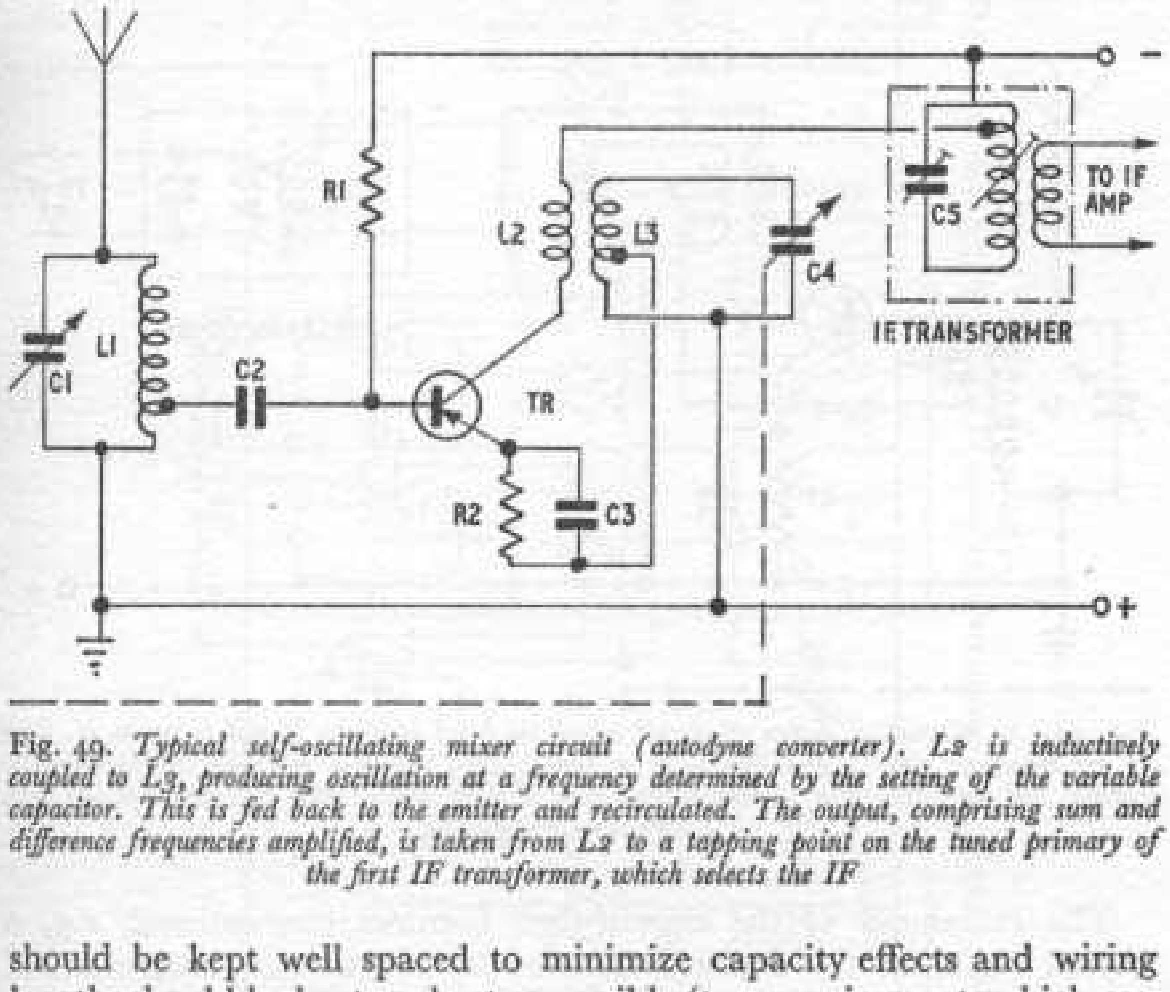

Fig. 49. *Typical self-oscillating mixer circuit (autodyne converter). L2 is inductively coupled to L3, producing oscillation at a frequency determined by the setting of the variable capacitor. This is fed back to the emitter and recirculated. The output, comprising sum and difference frequencies amplified, is taken from L2 to a tapping point on the tuned primary of the first IF transformer, which selects the IF*

should be kept well spaced to minimize capacity effects and wiring lengths should be kept as short as possible (two requirements which can be in direct opposition at times!).

Output from the mixer is invariably fed to an IF transformer, which receives a mixture of local oscillator frequency, signal frequency and sum and difference frequencies of the two. To 'tune' the circuit to resonate at the required (IF) frequency, the IF transformer must be associated with a capacitor—Fig. 50. This is usually of fixed value, when alignment of the tuned circuit to the IF is done by varying the inductance of the coil—in practice by adjustment of the iron dust coil in the core of the transformer.

If a single-stage IF amplifier circuit is used then the IF transformer must usually be double tuned (i.e. both coils of the transformer associated with a capacitor, and tuned). Where two or three stages of IF amplification are used then single tuned IF transformers are usually satisfactory.

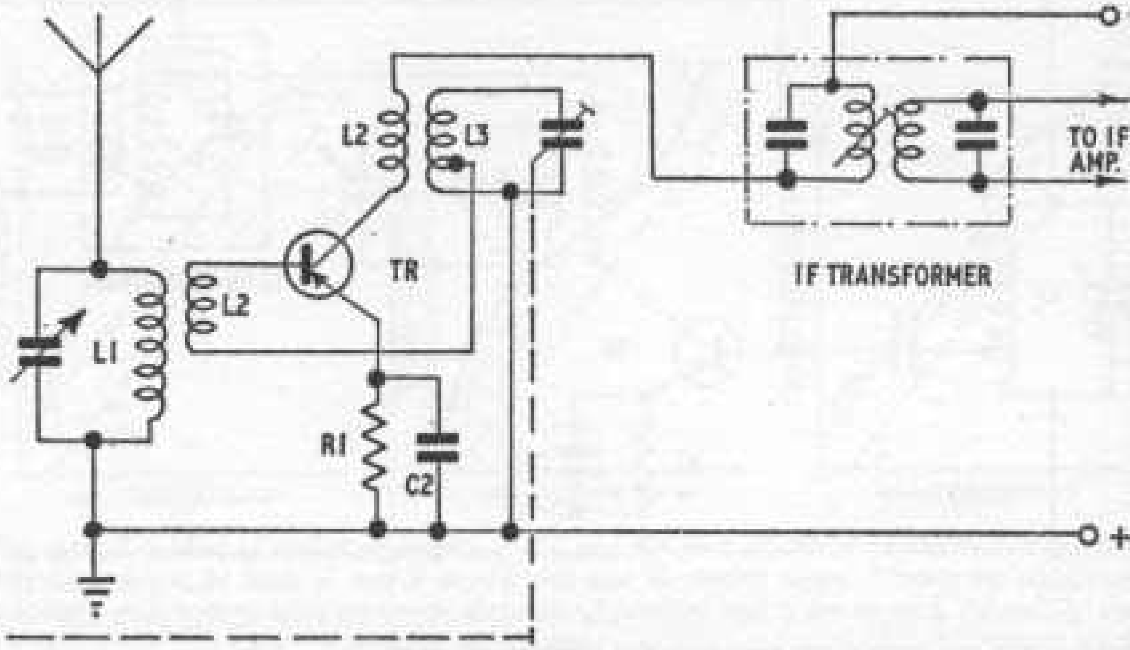

Fig. 50. *An alternative design of circuit where the local oscillator signal is fed to the base of the transistor and is thus known as a base-injected autodyne converter. Performance is similar, but the selection of a suitable transistor is more critical since this must operate with a high cut-off frequency*

The remainder of the circuit then becomes conventional, e.g. a crystal diode for the detector followed by one or more stages of AF amplification. In practice, the latter normally incorporates a driver stage and an output stage, with the output designed to provide the power required; which may range from as little as 1 milliwatt for driving earphones, to 500 milliwatts for driving a small speaker, and up to 5 watts for driving a large speaker.

A complete circuit for a six-transistor superhet receiver is shown in Fig. 51, with a performance capability equal to that of most commercial receivers. One Mullard OC44 and two Mullard OC45 transistors are

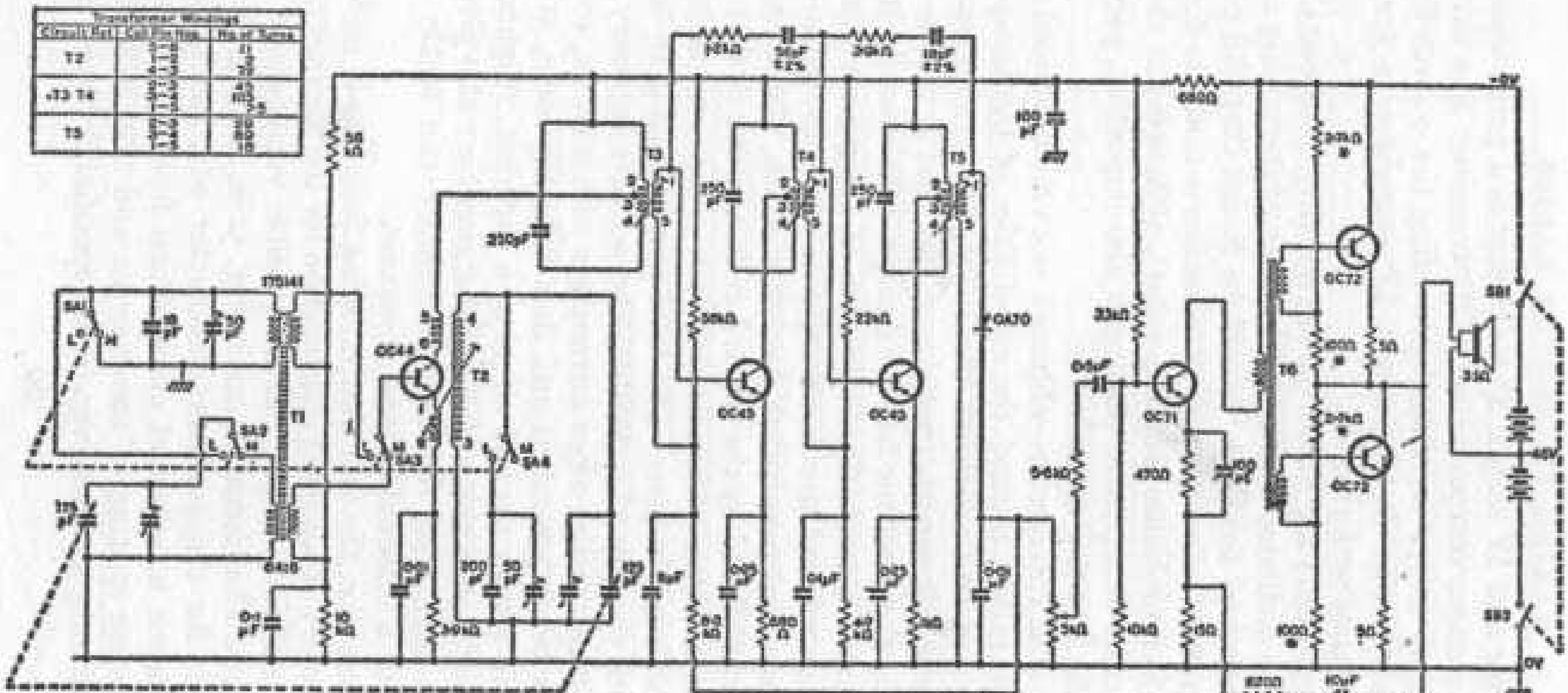

Fig. 51. *Mullard design for a six-transistor superhet receiver. Tolerance of resistors marked with an asterisk should be 5 per cent; others 10 per cent*

used in the mixer and IF stages. The detector is a germanium diode, whilst the audio stages comprise one OC71 transistor as a driver with a matched pair of OC72 transistors providing the output for a low impedance loudspeaker. Double-tuned IF transformers are recommended for optimum performance.

All component values are shown on the drawing. A screen should be used between the oscillator and aerial sections of the tuning capacitor to eliminate undesired feedback. It will be found that the possibility of feedback is greatest when the tuning capacitor is tuned to the highest frequency (i.e. has minimum working value), although this should not be a critical factor. Component placing is also important, particularly in the case of the first two stages.

It is obvious that this circuit—although not very advanced as far as superhets go—is rather beyond the capabilities of the inexperienced amateur to lay out and construct efficiently. The same comment, in general, applies to all superhet receivers; but that is not to say that they are beyond the amateur builder's scope. The answer, in fact, is quite a simple one. A considerable number of designs are available in kit form, based on printed circuit assembly in which the printed circuit panel is complete and pre-drilled. In other words, the layout of the components is established by the printed circuit panel, so that building the set becomes a matter of assembling each component in its correct position and soldering in place. The total cost of such a kit is directly comparable with the cost of individual components necessary to build a similar set. There are also other advantages with a kit set, such as the IF transformers being pre-tuned and thus reducing some, at least, of the difficulties in setting up and aligning a superhet. Alignment constructions *specifically applicable to that particular circuit* are also given in the instructions, so that even the virtual beginner can tackle superhet construction with a reasonable hope of success.

For this reason—i.e. the fact that building from kits is undoubtedly the most satisfactory of superhet construction for the average enthusiast—we shall not elaborate further on the possible variations in superhet layout and design. The circuit shown in Fig. 51 is, however, a perfectly practical project for the amateur constructor who has gained some previous experience in superhet construction from kits, provided he allows for generous spacing of components and does not attempt to produce a minimum size receiver. If he specifically wants a smaller

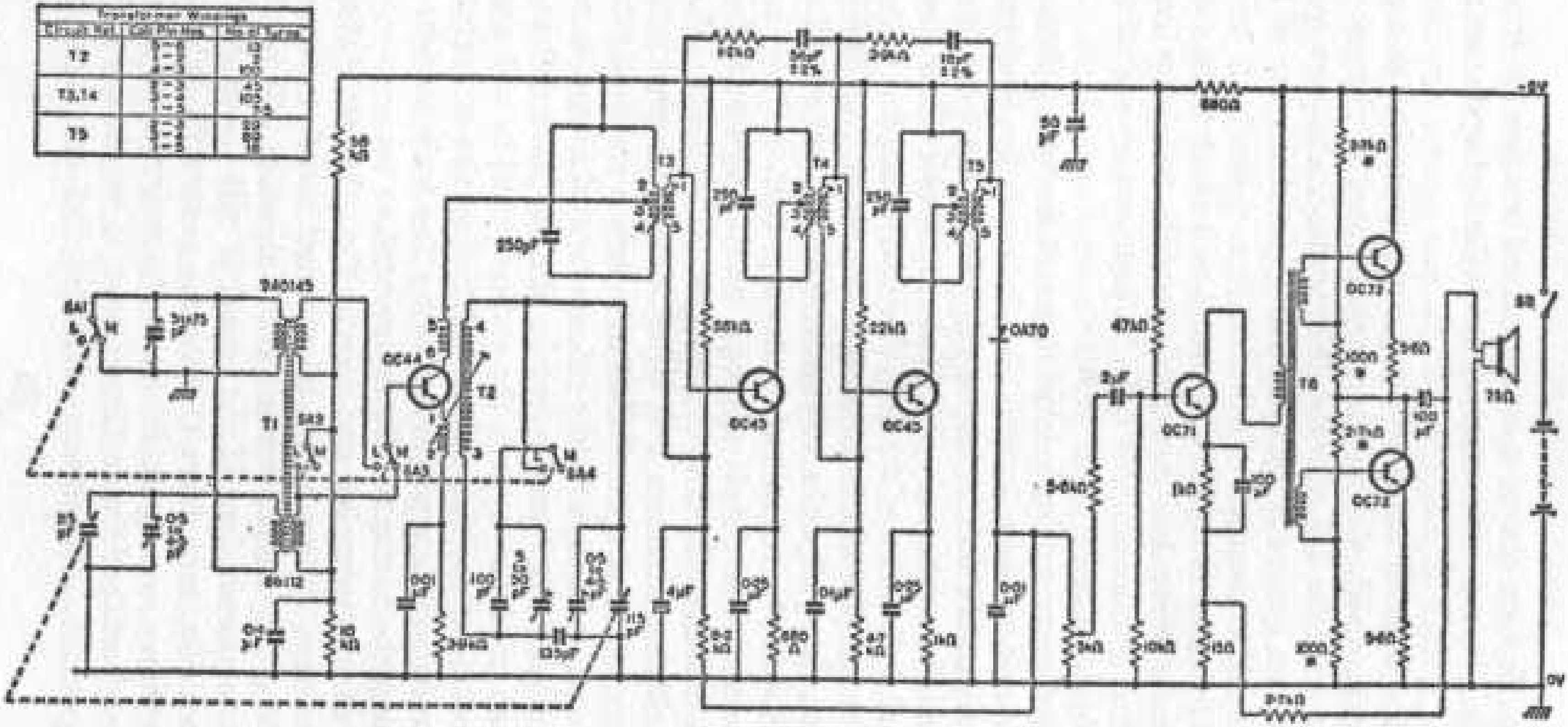

Fig. 52. *Miniaturized revision of the Mullard superhet receiver design of Fig. 51. Tolerance of resistors marked with an asterisk should be 5 per cent ; others 10 per cent*

receiver, then Fig. 52 shows a miniaturized version of the original Mullard design. This is particularly suitable for laying out on a printed circuit panel.

The following specific notes are, however, appended as a guide for the alignment of superhets. The more experienced worker would carry out alignment with the aid of a signal generator, although quite satisfactory results can generally be achieved without the use of this relatively expensive instrument.

Alignment (without a signal generator) will have to be carried out using broadcast stations, but the use of one of the following instruments is advised as being more suitable than 'adjustment by ear' of the signal heard in the loudspeaker:

1. An output meter with an impedance of about 25 ohms which is connected to the receiver output in place of the loudspeaker; or
2. A high resistance voltmeter capable of reading 0–12 or 0–5 volts A.C. which can be connected across the speech coil of the loudspeaker to give a visual indication of the output signal strength.

Neither of these instruments is *essential*, however. Provided you have a keen ear you can judge the strength of the output signal almost as well by listening to the volume of the loudspeaker.

Having checked the circuit through completely—and this is very important as mistakes in connection are easily made—identify the aerial and oscillator trimmers and adjust them to approximately mid-position. Adjust the tuning control to tune into a station in the middle of the medium wave-band, with the volume control turned to maximum. If a tuning indicator is incorporated in the set (as it will be with kit sets, other than miniature types), the station tuned in will probably be way off the indicated position on the dial. Adjust the oscillator trimmer to bring the station to its proper point on the scale, and/or slide the aerial coil along the ferrite rod for adjustment.

Now turn the complete set one way or the other until the received signal is a *minimum*. If the set has an external aerial, uncouple this so that it is working only on the ferrite rod aerial, which will be directional and respond to orientation. If the signal is still quite strong in the 'minimum' position, turn down the volume control (if judging volume by ear rather than a meter), as it will then be easier to judge any further change. Now adjust the IF transformer cores to maximum signal in this 'minimum' position. Adjustment of the second core may affect the setting of the first, and so on—so repeat adjustment in all cores, as necessary, in order to obtain the best possible result.

Readjust the tuning control to tune into a station near the high frequency end of the broadcast band. Adjust the aerial trimmer to align with the proper point on the tuning scale (if applicable). If this does not prove practical, adjust both aerial trimmer and oscillator trimmer.

Readjust the tuning control to tune into a station near the high frequency end of the broadcast band. Adjust the aerial trimmer and/or oscillator trimmer to align with the proper point on the tuning scale (if applicable).

Now check all three stations again, in turn—middle, high frequency end, low frequency end—and re-adjust as necessary. Repeat until all three stations are as near correctly aligned as possible, and adjustment of one end has no effect on the other end. If this proves impossible using the trimmers alone, try altering the position of the aerial coil on the ferrite rod and start over again.

Alignment on the long wave-band will usually be quite straightforward. All that is usually necessary is to set the tuning control to the calibrated position and then slide the long wave coil backwards or forwards along the ferrite rod until the scale position lines up.

Finally, check again the adjustment of the IF transformers for maximum signal with the receiver in the 'minimum strength' receiving position. These may, or may not, need readjustment.

Note: in the case of a miniature superhet where there is no tuning scale and the station positions are 'nominal' or merely marked on the case, the procedure can be simplified.

First tune into a strong station in the middle of the wave band, turn the set to 'minimum strength' receiving position and adjust the IF transformer cores for maximum volume. Repeat the process for typical stations at opposite ends of the band, remembering to orient the receiver for 'minimum strength' signal before adjustment in each case.

Using a signal generator, alignment is more exact and is carried out in two stages. The IF stages are tackled first, setting the signal generator to the IF frequency (usually 470 kHz). The signal can be applied directly to the base of the IF transistors, working backwards through the circuit, via a 0·5 F. capacitor and 820 ohm resistor in series with the generator output lead (never apply the signal generator output lead directly to a component in the circuit). The IF cores are adjusted for maximum output.

For alignment of the tuned circuit the signal generator is connected to a 6 in. loop wound from a 6 ft. length of insulated wire (making four complete turns), with a 390 ohm resistor in one lead. Place this loop about two feet from the aerial of the receiver. Adjust trimmers, and/or aerial coil position on the ferrite rod, to conform to calibration settings for frequencies at the middle and near each end of the band concerned.

In case of real difficulty, then, probably the best answer is to call in the services of an expert, or the local radio service shop. The latter will have a signal generator and test equipment and can carry out alignment without much trouble *provided the set as constructed has no faults or wrong connections*. It is one thing to align a superhet—which does not take an expert long—but quite another matter to find and diagnose a fault. The latter can be quite an expensive job, if professional assistance is called in and the faults are due to bad workmanship or are particularly obscure.

CHAPTER 9

CIRCUIT DESIGN

ONCE having constructed and studied a number of receivers to different circuit designs a fairly obvious pattern emerges. Definite configurations of components emerge, and the receiver is inevitably made up of a number of stages coupled together. Furthermore, some of these stages, like the tuned circuit, detector and audio amplifier, are basically the same for any type of receiver, different in detail only. Such stages, therefore, have specific design requirements.

The Tuned Circuit

This comprises a coil and a capacitor connected in parallel. (Although series connection can also be used, with similar results, we can ignore this alternative since it is seldom employed in practical receiver designs.) The coil is primarily a resistance, but with a fluctuation current passing through it (i.e. the RF signal) its effective resistance is modified, so that it is the inductance which is of primary importance as far as tuning is concerned. The resistance of the coil is also significant, however, as this will affect the selectivity of the tuned circuit. The lower the resistance of the coil the sharper or more peaky will be the tuning and the better the magnification of the signal at resonance or 'Q' of the coil—*see* Fig. 53.

This favours the use of coils wound from thicker wire and of relatively large diameter, i.e. relatively bulky components which do not fit into the compact size normally associated with a transistor receiver. Thus aerial coils are, in fact, usually wound from thinner wire, and made relatively small in diameter. Any loss of 'Q' or magnification, as a consequence, is more than compensated by winding the coil around a highly inductive coil, e.g. a ferrite rod. This greatly increases the actual inductance of the coil, enabling a shorter length of wire to be used (decreasing coil resistance) and increases the efficiency of the coil. Some loss of selectivity may still be present, however—i.e. the coil has what is known as broad tuning—but this again can be offset by using special forms of winding (which also increase the coil efficiency again). This is not *essential*, however. A simple winding on a ferrite rod core can be quite adequate, although proprietary machine-wound coils may be preferred as having an assured high efficiency and performance.

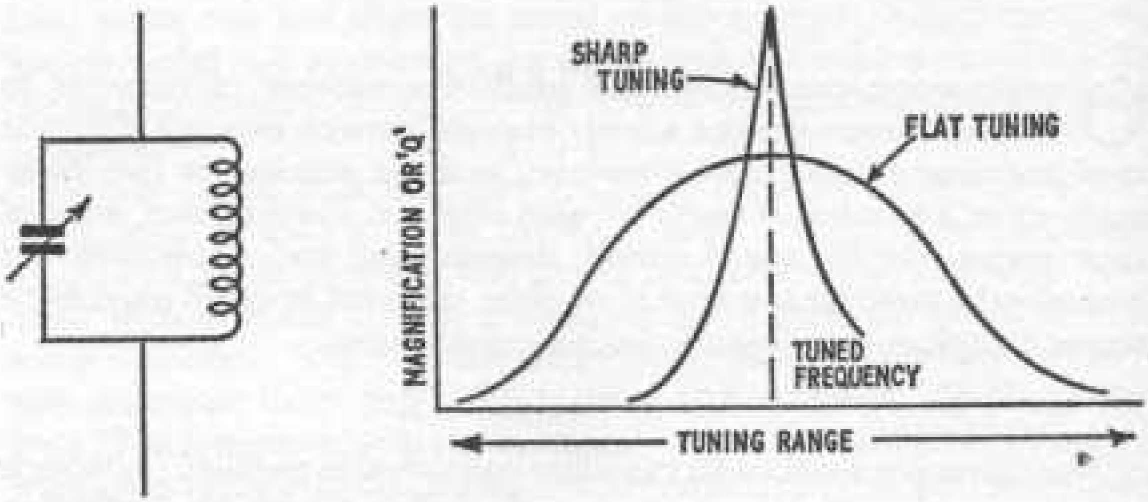

Fig. 53. *Tuning of a tuned circuit may be sharply peaked, or relatively flat (with lower magnification), depending primarily on the resistance of the tuning coil. 'High Q' coils are necessary for good performance.*

The resonant frequency of the tuned circuit is given by the following equation:

$$\text{resonant frequency} = \frac{1}{2\pi\sqrt{LC}} = \frac{0{\cdot}1593}{\sqrt{LC}}\ \text{(Hz)},$$

where L is the inductance of the coil in henries and C is the capacity of the capacitor in farads.

To tune over a range of frequencies, either L or C must obviously be made variable—usually C by using a variable capacitor (tuning capacitor). The coil inductance required is then worked out to match the range or 'swing' of a suitable variable capacitor to give tuning capabilities over a specific broadcast band.

The 'swing' of common tuning capacitors is from 0 to 250 or 50 to 500 picofarads. Thus to cover the medium wave broadcast band from 500 to 1,500 kHz the coil inductance required would need to be of the order of 200 μ henries and 100 μ henries respectively. Actually it is quite difficult to *calculate* coil inductance, except for coils wound on an open former, and so suitable specifications for the coil are normally determined experimentally for a specific diameter of ferrite rod (or cross section of ferrite slab). Also the coil does not necessarily have to be an *exact* match. Its inductance can be varied by sliding it along the ferrite rod, i.e. altering its position on the rod. If the coil is a 'near match', this practical form of adjustment enables correction to be made to bring a mid-frequency broadcast station into the middle of the 'swing' of the variable capacitor.

With simple coil windings adjustment of inductance can also be made by removing or adding turns. Coils comprising a single winding with a tapping point are known as *auto-transformers*. In this case the inductance of the coil can be increased by adding coils to each end; or reduced by removing coils from each end *in the same ratio to the tapping point*. Thus if the tapping point comes at, say, 16 turns on a 50 turn coil, the coil ratio is 16:34 or approximately 1:2. Turns should thus be added (or removed) in the ratio of 1 from the 16-turn end to 2 from the 34-turn end. This is necessary to retain the auto transformer balance. The tapping point, it should be noted, is always nearest the earth end with such coils.

An aerial coil of the auto transformer type is *directly* coupled to the next stage in simple circuits, i.e. a connection is taken directly from the tapping point as in Fig 54. Some 'follow up' circuits, however, will not accept direct coupling in this manner, when the form of the aerial coil can be modified to comprise a main coil with a smaller 'coupling' coil wound over one end. This provides transformer coupling—Fig. 54. A typical main coil in such cases would comprise about 50 turns on a ferrite rod and 20 turns on the coupling coil. The degree of coupling can be varied by adding or removing turns on the coupling coil. (In practice the coupling coil would be wound with about 30 turns and turns then removed until optimum performance was achieved).

The inductance of coils required to cover the long wave band (600 to 2,000 metres) is not readily achieved with simple windings on a ferrite rod (although easy enough with an air cored coil of 1-in. diameter by extending the number of turns from 100 to about 225, using 38 s.w.g. wire). On a proprietary aerial coil, therefore, the long wave coil is a separate special winding with transformer coupling. The tuned circuit then comprises, in effect, two separate pairs of coils switched in and

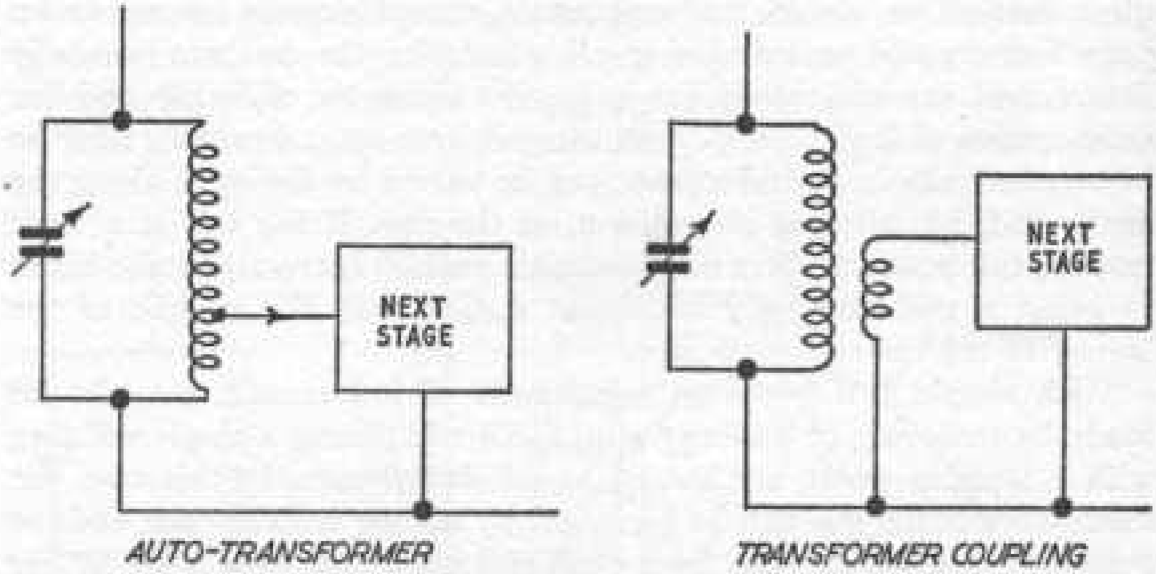

Fig. 54. *Two methods of coupling—from a tapping point on a coil (autotransformer coupling); and by the use of a separate coil inductively coupled to the first (transformer coupling)*

out of series connection by a wavechange switch, as in Fig. 55. This is a far more satisfactory method than trying to tune over the whole range of a single coil, which would crowd all the medium wave frequencies into a relatively small proportion of the variable capacitor movement. Similarly, on more advanced receivers, separate aerial coils and switching facilities are provided for short wave and VHF coverage, although

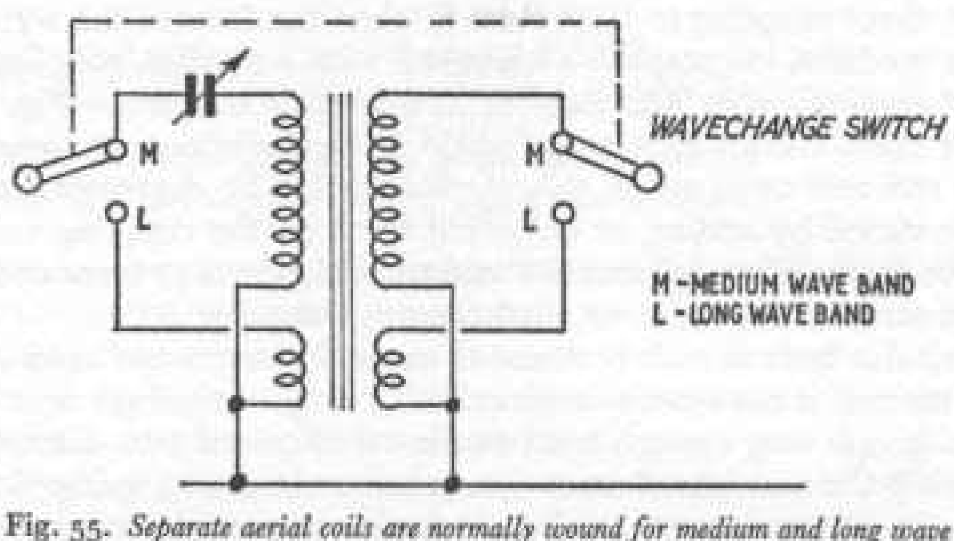

Fig. 55. *Separate aerial coils are normally wound for medium and long wave reception (the latter comprising additional turns to be connected in series). The additional coils are switched into the circuit in series, or switched out, by the wavechange switch*

the principle of operation of the tuned circuit remains the same in each case.

Detector Stage

The detector of a transistor receiver is usually a diode which, to work as a rectifier, must be associated with a suitable load. This load is provided by a resistor—*see* Fig. 56. If this resistor is made variable, then this will form a *volume control* feeding the detected AF signal to the AF amplifier stage(*s*) of the receiver. In practice the variable resistor or potentiometer nearly always has a capacitor connected in parallel

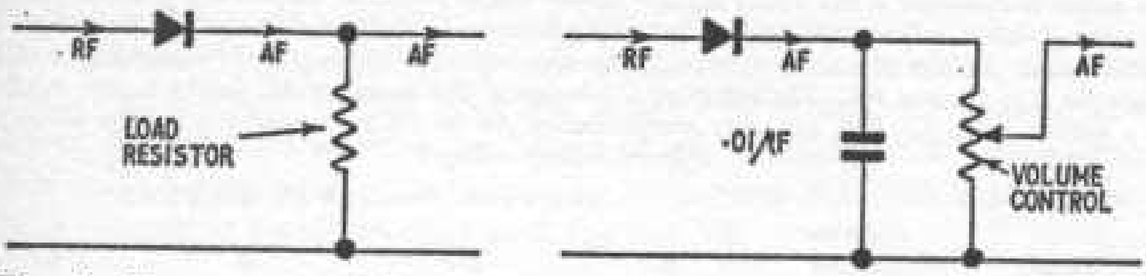

Fig. 56. *The output can only be developed across a load—a simple resistor in this case. If the resistor is of variable type, this component can also act as a volume control by determining the exact amount of potential difference, and thus current, developed across the load*

with it, as this will improve the performance of the detector circuit (the same applies when the resistor is of fixed value in simpler circuits).

The main limitation of the diode detector is that its performance is very poor if the incoming RF signal is very weak. Thus to receive weak signals satisfactorily it may be necessary to improve the efficiency of the tuned circuit by the addition of an external aerial; or interpose a preamplifier stage for the RF between the tuned circuit and the detector, as described in previous designs (Chapter 5). Otherwise the detector stage is usually the least worry in the design of the complete circuit.

Transistor Bias and Stabilization

In a majority of applications the transistor is connected in what is termed common emitter configuration (implying that the emitter lead is connected to both the collector and base circuits). The transistor then has to be supplied with direct currents in the base-emitter and collector-emitter circuits. This can be done by connections as shown in

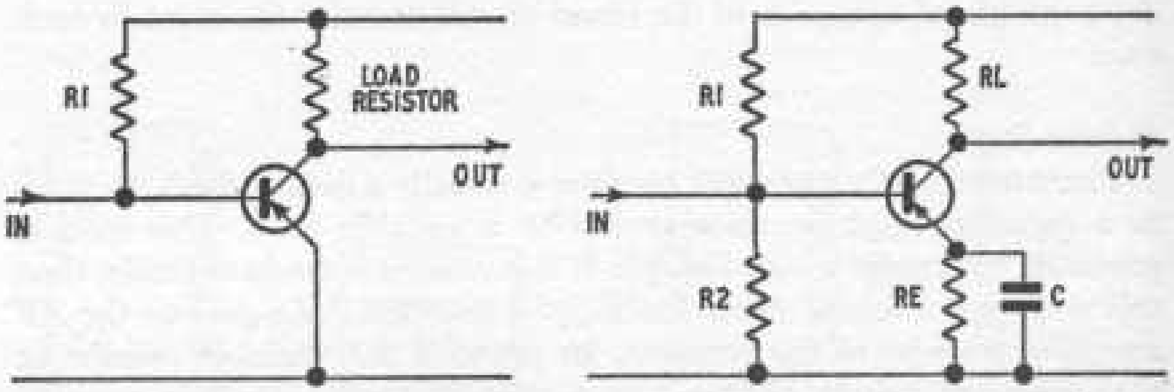

Fig. 57. *Basic transistor amplifier stage* (left). *Resistor R1 provides bias for the transistor and the output is developed across a load resistor (which can be phones or the primary of a transformer, for a single-stage output amplifier). A better performance is realized, however, by providing DC stabilization for the transistor* (right). *The required stability is given by choosing suitable alues for R1, R2 and RE. The capacitor C 'decouples' RE to reduce AC feedback. One kilohms is a typical value for RE, but more specific values for an OC71 transistor are given below for different battery voltages*

Battery Volts	*Collector Current (milliamps)*	RESISTOR VALUES IN KILOHMS *R1*	*R2*	*RE*	*RL*
		R-C Coupling			
4½	0·5	18	2·7	1	3·3
6	0·5	33	3·9	1	3·3
	1·0	39	10	1	2·2
	1·5	22	10	1	1·5
9	1·0	62	10	1	3·9
	1·5	39	10	1	2·7
12	1·0	82	10	1	5·6
	1·5	56	10	1	4·7

Fig. 57, R1 being a bias resistor for the transistor. The bias is necessary in order to supply a definite amount of current to the base side rather than a controlled voltage.

The current flowing through the collector-emitter circuit will be equal to the current gain of the transistor (the 'beta' of the transistor, times the sum of the base-emitter current and the leakage current from collector to base). Unfortunately, however, the leakage current is not necessarily constant. It will rise rapidly with an increase in temperature of the transistor, for example. A rise in leakage current will thus cause a rise in collector current causing more heating. At best, the set-up is unstable. At worst, the final rise in current can be sufficient to burn out the transistor.

It is thus necessary to provide both *bias* and *stabilization* to arrive at a satisfactory circuit, such as shown in the second diagram. Here the bias of the transistor is provided by the voltage drops across resistors R1 and R2. The value of these resistors is chosen so that the current flowing through the potential divider formed by R1 and R2 is much larger than the base current of the tansistor. This holds the base potential reasonably constant regardless of any variations in base current.

At the same time resistor RE controls the voltage on the emitter. If the collector current rises the voltage dropped across RE will rise and the potential difference between the base and emitter will be reduced. This will reduce the base-emitter current, which consequently will reduce the collector current. Conversely, if the collector current falls, compensation will be provided to increase it again. Thus RE provides D.C. stabilization, but its presence in the circuit has one undesirable effect. It will tend to produce distortion or blocking of AF. However, this can be overcome quite simply by by-passing RE with a capacitor, thus providing an alternative path for the AF.

Coupling Methods

Direct and transformer coupling has already been described in connection with the tuned circuit. Transistor stages need rather more consideration as it is imperative that output from the preceding stage and input to the next stage be suitably matched. Thus whilst direct coupling is possible, this could upset the current values in the two stages and alter the D.C. operating conditions. This, in turn, would affect the stabilization and the performance of both stages. Alternative methods of coupling are therefore almost invariably used.

The simplest and most widely used is resistance-capacitor (R-C) coupling which, in effect, merely needs a capacitor as the coupling element as resistance is already present in the stage—*see* Fig. 58. A typical value for a coupling capacitor is from 1 to 10 μF, although lower values may be used to reduce the physical size of the component in miniature receivers. This value implies the use of an electrolytic capacitor.

Transformer coupling is an alternative method, with the advantage that it can also provide amplification. One transformer coupled stage, in fact, can achieve the same gain as two R-C coupled stages. The main requirement is that the primary of the transformer must match the output impedance of the transistor, whilst having as low a D.C. resistance as possible; and the turns ratio must match this output impedance to the input impedance of the next stage. This normally calls for a turns ratio of about 4·5:1, which is more or less a standard value for coupling transformers. There is one inherent disadvantage with transformer

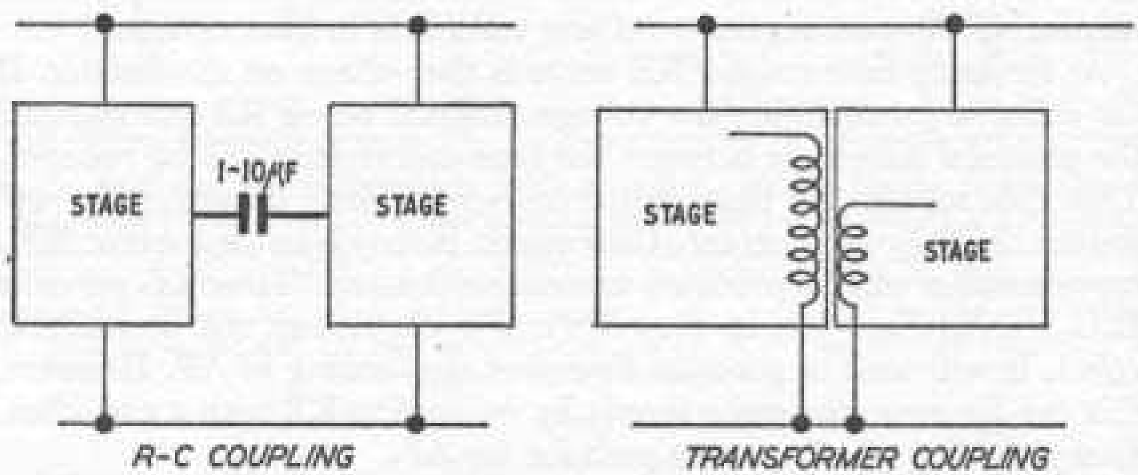

Fig. 58. *Two common forms of inter-stage coupling shown in diagrammatic form. R-C coupling involves the use of a capacitor only as the resistance (R) component is provided by the input resistance of the next stage*

coupling, however. It does tend to introduce distortion of the signal, although this might not be a serious problem.

Audio Amplifier Stages

The stabilized circuit of Fig. 57 is a basic transistor amplifier stage (known as a class A amplifier) widely used in simple receiver circuits. A typical choice is the OC71 transistor, when suitable values for R1, R2 and RE can be found by reference to the table, when using R-C coupling. The by-pass capacitor would be of the order of 8μF. Note that this table also gives a suitable value for the matching collector load resistance.

Two (or more) such stages can be coupled together with R-C coupling. The output load can be high impedance headphones (to match the collector load requirements of the circuit as shown in the table); or can be used to drive low impedance headphones or a low impedance loudspeaker (if sufficient power is available) via a step-down transformer, as shown in Fig. 59.

We can also add a further refinement to this circuit—a tone control, as shown in Fig. 59. This consists of a potentiometer and a fixed capacitor connected in parallel with the primary of the output transformer, which thus really becomes another tuned circuit. Thus adjustment of the potentiometer will vary the resonant frequency of this circuit, 'favouring' treble or base (high or low frequencies) by providing additional amplification at the tuned frequency. Typical component

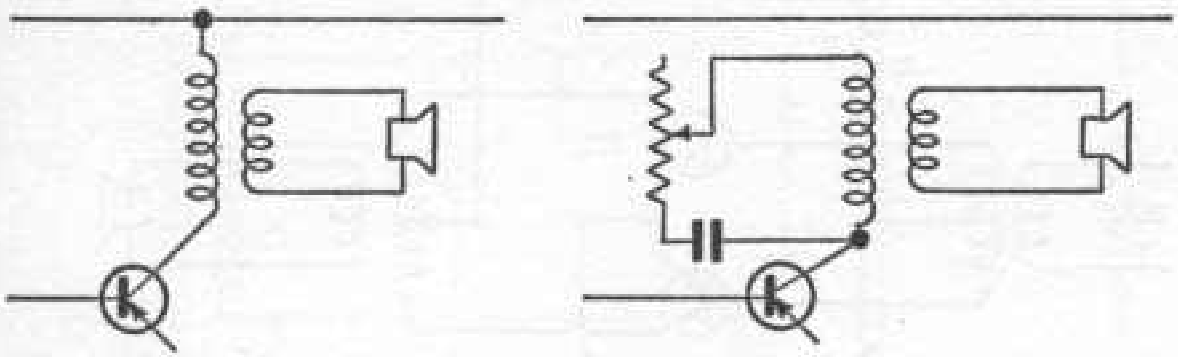

Fig. 59. *Straightforward transformer coupled output to permit use of a low impedance loudspeaker* (left). *On right is the same circuit with tone control added. Suitable values for the potentiometer and capacitor are 0–10 kilohms and 1·0μF, respectively*

values used are: 0–10 kilohms for the potentiometer and 0·1 μF for the fixed capacitor.

Fig. 60 shows quite a different type of AF amplifier output stage, known as class B or 'push-pull'. It is so called because one transistor conducts whilst the other cuts off, and vice versa, giving a 'push-pull' effect. It is considerably more efficient than a Class A output and also has a low current drain. It can thus be regarded as a superior circuit, although it is a little more tricky to get working satisfactorily.

In the first place the transistors employed must be a matched pair, i.e. matched for identical characteristics. Also the values of resistors R1 and R2 are somewhat critical. If both transistors are biased exactly to cut-off 'crossover' distortion can occur. The simplest way to avoid this is to use a variable resistor for R1 and adjust as necessary to eliminate this form of distortion. Alternatively, different values of R1 can be tried, if fixed resistors are to be employed.

Class B or push-pull output stages are invariably used with transformer coupling to the preceding stage, this being the most satisfactory method of providing the 'split' input.

Other types of Transistors

The type of transistor used in the circuits so far described are alloy-junction transistors, referring specifically to their construction. They

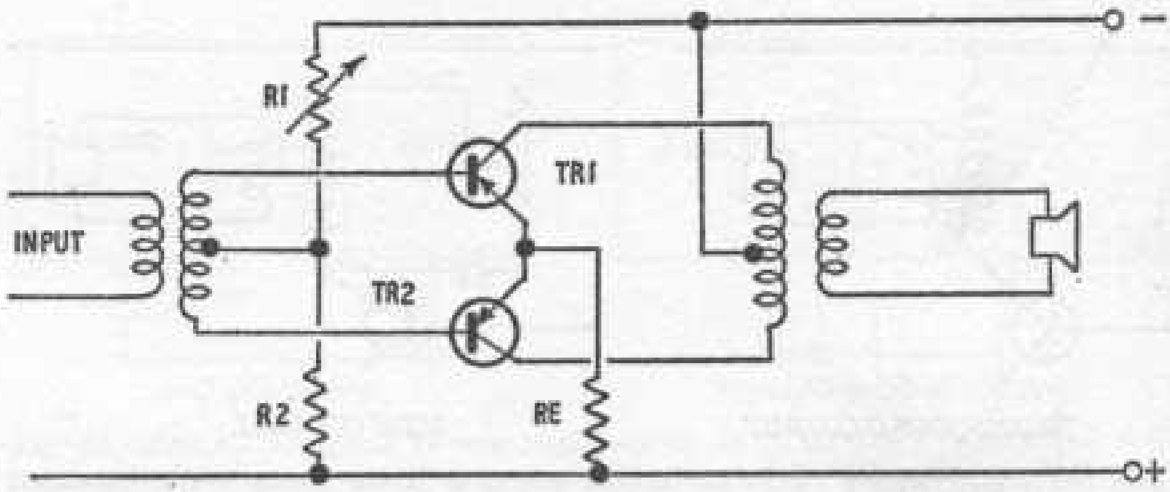

Fig. 60. *Class B push-pull audio amplifier output stage, favoured for low current drain and higher efficiency than a single transistor output. It is important that the transistors used be a matched pair. It is also advantageous to use a variable resistor for R1, or try different values, in order to eliminate 'crossover' distortion*

OC72 or OC81 transistors are mostly used for Class B amplifiers, when typical values for a 6-volt battery circuit would be:

R1—about 8 kilohms (say 6·8, 8·2 or 10 kilohms for three possible sizes of fixed resistors)
R2—180 ohms
RE 470 ohms (or even omitted and emitters directly connected to positive line).

are by far the most common type, and freely available. For specific circuits other types may be preferred because of their more favourable characteristics. The two main types in this category are the surface barrier transistor, and the silicon planar transistor.

Surface barrier transistors are of high frequency type—i.e. they can operate at frequencies up to 30 mHz or better, and have excellent performance even when operating with very low currents. They are thus particularly suited for miniature receivers using very small batteries. Also they are efficient as detectors, making their use in regenerative circuits attractive.

Thus Fig. 61, for example, shows a simple regenerative receiver circuit using a single surface barrier transistor and a very low battery voltage. The transistor in this circuit actually performs three functions —RF amplifier, AF amplifier and detector.

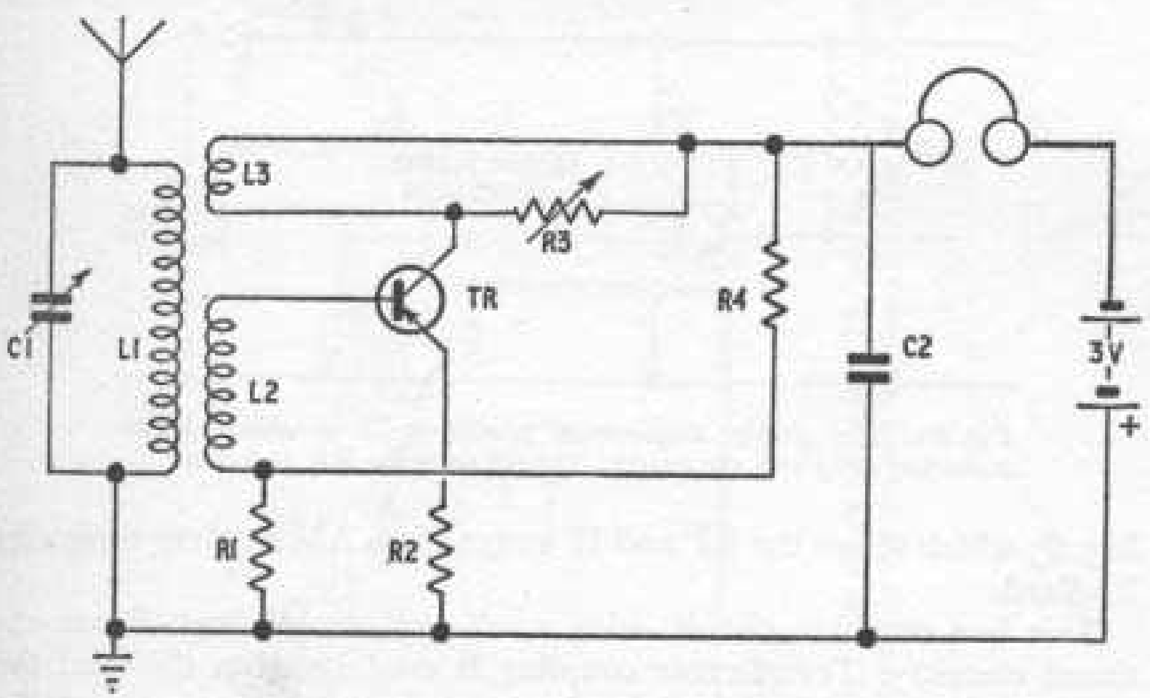

Fig. 61. *Regenerative receiver circuit using surface barrier transistors and capable of operating on a very low voltage—ideal for a miniaturized set using Mallory mercury batteries*

L1, L2—coils as Fig. 32.
L3—2 turn coil on separate sleeve, to be adjusted up and down ferrite rod
C1—250 pF variable capacitor
C2—0·01 μF
R1—10 ohms
R2—100 ohms
R3—0–5 or 0–10 kilohms potentiometer
R4—3·3 kilohms
TR—Any type of surface barrier transistor
High impedance phones or deaf-aid earpiece

Silicon planar epitaxial transistors are a more recent type, particularly developed for use in RF and IF stages of modern transistor radios. They are of N-P-N type (not P-N-P, which is the common type used in this country), and differ also in shape from ordinary transistors. The leads are brought out from the base in the form of three rigid self-locking strips, specially designed for inserting in printed circuit boards.

Besides having superior performance characteristics to other types of transistors, particularly at higher frequencies, their stability is much better and only simple current biasing may be required in most circuits. This involves the use of only one resistor connected in the base-collector circuit, as shown in Fig. 62. This can result in a considerable saving in components in the whole receiver circuit, as evident from

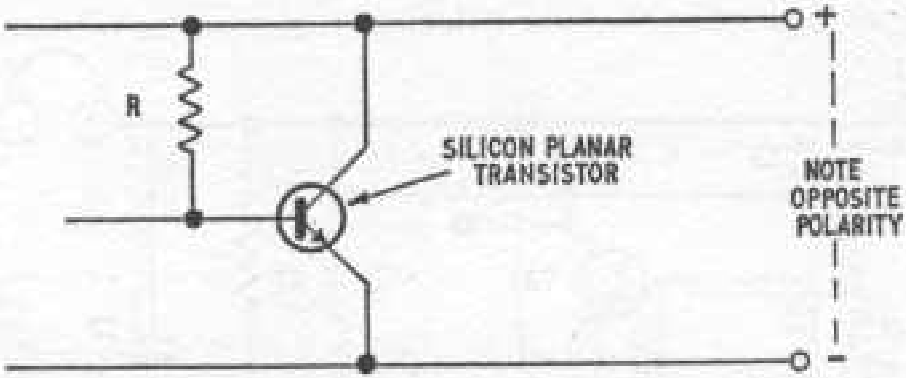

Fig. 62. *The simple stabilization possible with a silicon planar transistor, using only one resistor. Typical value for R is 100 ohms*

Fig. 63 which shows the RF and IF stages of an AM receiver design by Mullard.

This is a superhet circuit, with a self-oscillating mixer of conventional circuitry. Transformer coupling is used between this and the first IF stage; and between the first and second IF stages, and the second IF stage and the detector. The complete radio circuit would then, of course, have a suitable audio amplifier added on.

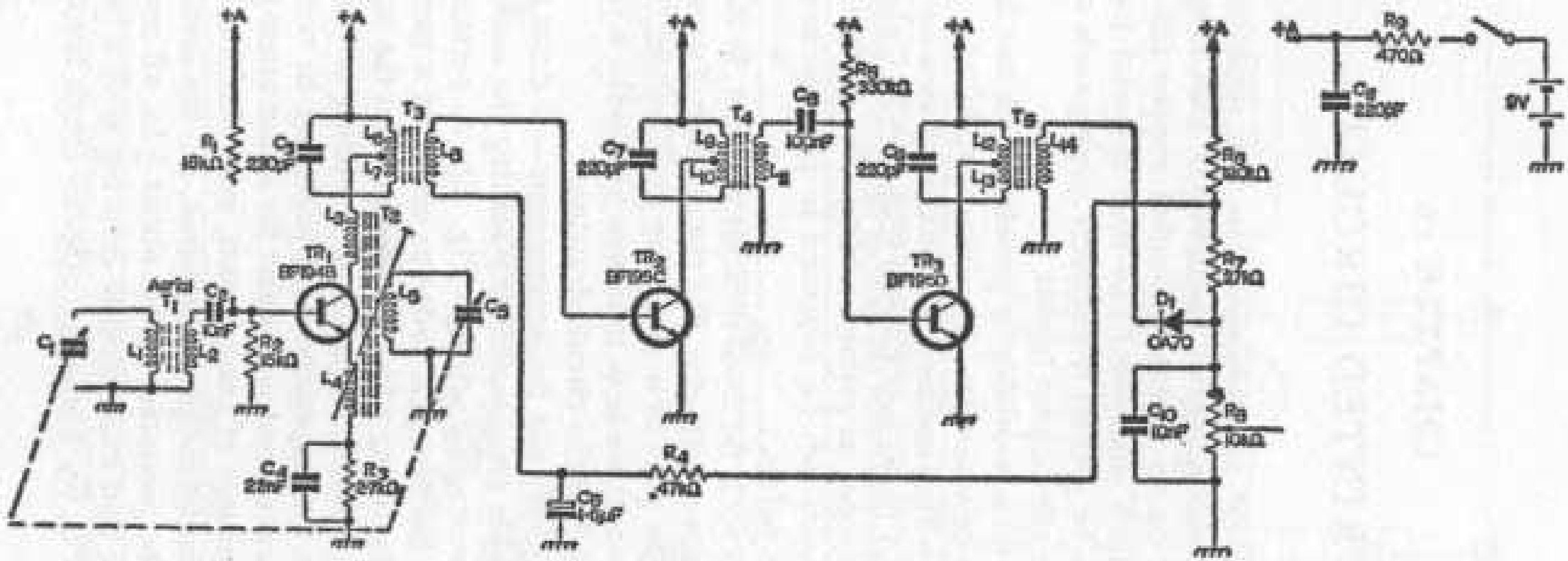

Fig. 63. *RF and IF stages of a transistor superhet receiver using silicon planar transistors. The addition of AF amplifier stage(s) would complete the receiver. All component values are marked on this drawing which is a Mullard circuit design*

CHAPTER 10

PRINTED CIRCUITS

PRINTED circuits—or printed wiring, as it is sometimes called—is based on a laminate material consisting of thin sheet Paxolin or equivalent material on to which is bonded copper foil of 2, 3 or 5 thousandths of an inch thickness. The base material itself is usually $\frac{1}{16}$ in. thick, but can be greater if relatively large panels are to be used to accommodate the component layout.

The 'stock' material is available in panels, which can be cut to final size with a hacksaw or razor saw (the latter produces a much cleaner cut). The necessary wiring connections are then drawn on to the copper face in 'resist ink' and unwanted copper then etched away leaving just the connections in copper as printed wiring. The panel is then drilled so that the components can be mounted in position and soldered in place at appropriate points.

The complete process is far from difficult and can, in fact, readily be tackled by the amateur constructor. For the purpose of detailed explanation we will take just part of a complete circuit—the Class A audio amplifier of Fig 57—and see how to design and make a printed circuit for this, starting with just the circuit drawing.

The first thing is to lay out the components—or draw them full size on paper—in a suitable arrangement for making the necessary connections by lines, representing wiring—Fig. 64. A certain amount of adjustment may be necessary in order to arrive at a neat and logical arrangement so that crossing wires are avoided, but the actual arrangement is not all that critical. Avoid close crowding of individual components, unless you are experienced in soldering in confined spaces. It is best to have them spaced well apart for a first attempt.

The basic arrangement of components, once decided, will more or less fix the overall size of the panel required, i.e. the area in which the components are to be mounted. Allow about $\frac{1}{4}$ in. all round this for a minimum panel size and start another drawing with a box of this size on tracing paper—Fig. 65. Using the original rough layout as a guide,

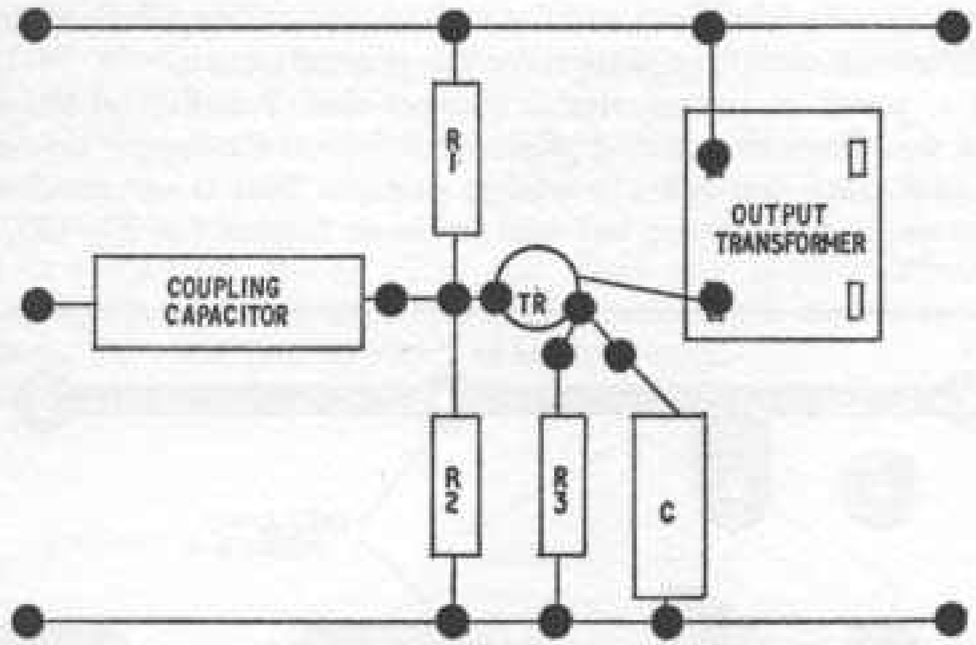

Fig. 64. *First stage in planning a printed circuit is to lay or draw out the components in suitable positions and mark connecting points required*

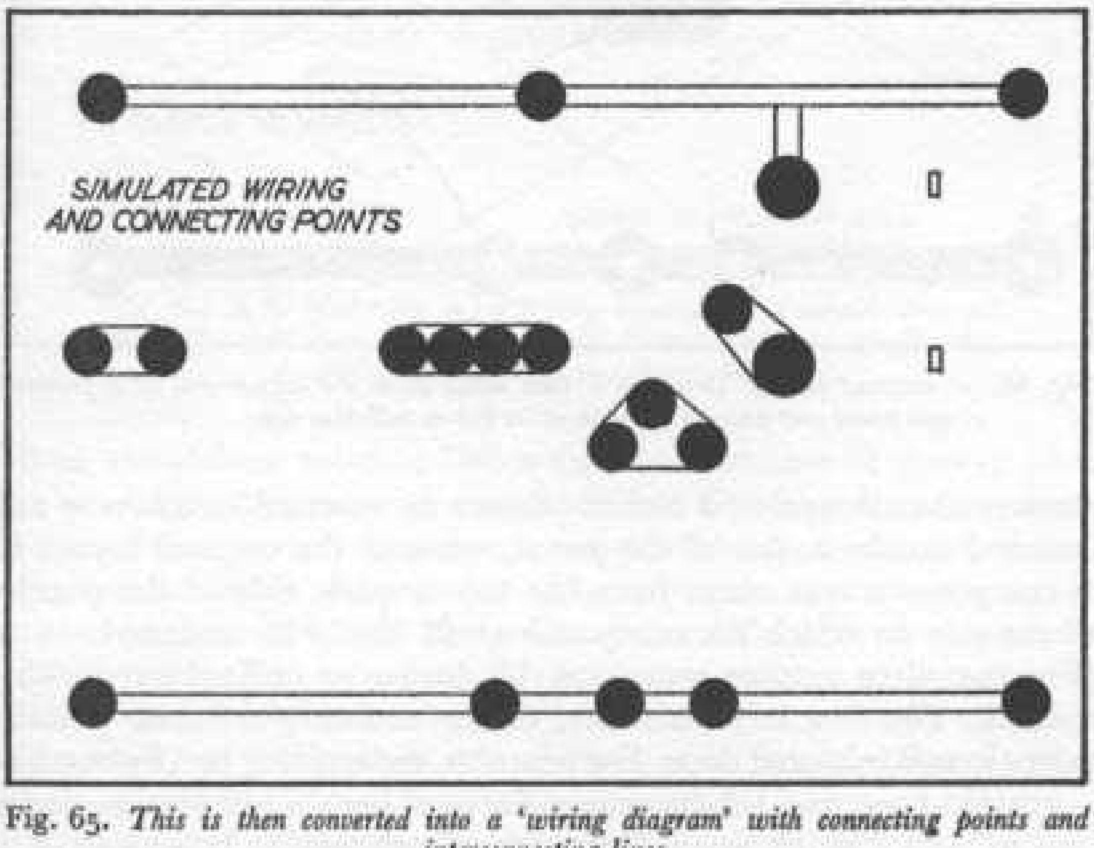

Fig. 65. *This is then converted into a 'wiring diagram' with connecting points and interconnecting lines*

mark on all the wiring lines and the various connecting points, as shown. This forms the complete pattern for the printed circuit.

Cut a panel of base material (copper-clad Paxolin) to the same outline size. Turn the tracing paper over, lay on the copper side of the panel and trace through the wiring pattern. This then transfers the pattern on to the copper, but mirror-image fashion (*see* Fig 66). It is

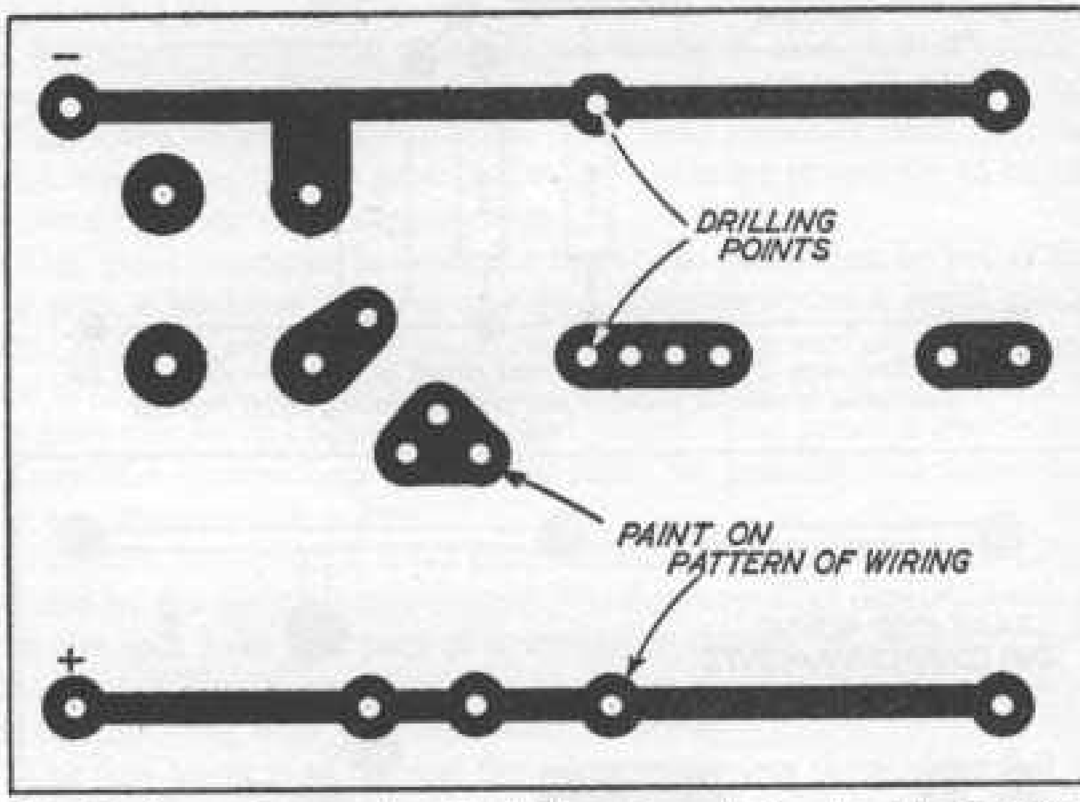

Fig. 66. *A reversed pattern (tracing) is then made on to the copper side of a printed circuit panel and painted on with resist ink or cellulose dope*

necessary that the printed circuit pattern be reversed in this way as it is printed on the *bottom* of the panel, whereas the original layout for the components was made from the top or plain side of the panel—and the side on which the components will finally be mounted.

The complete pattern must now be drawn or painted over with a resist ink. You can buy resist ink, or use ordinary cellulose paint or model aircraft coloured dope. For neatness, use a ruling pen for marking the straight lines, and ink compasses for marking the connecting circles, filling in with a paint brush. Connecting lines need to be at least $\frac{1}{16}$ in.

thick—twice that thickness if you have plenty of room to spare. Then leave the painted pattern to dry thoroughly. When quite dry, the panel can be etched.

This involves the use of an etching solution, which can be bought by that name. Alternatively you can make your own by making up a solution of ferric chloride to which is added a little dilute hydrochloric acid; or simply use dilute nitric acid. Both are equally effective as etching agents, although the ferric chloride solution is usually preferred because it does not 'gas' so much as straight acid.

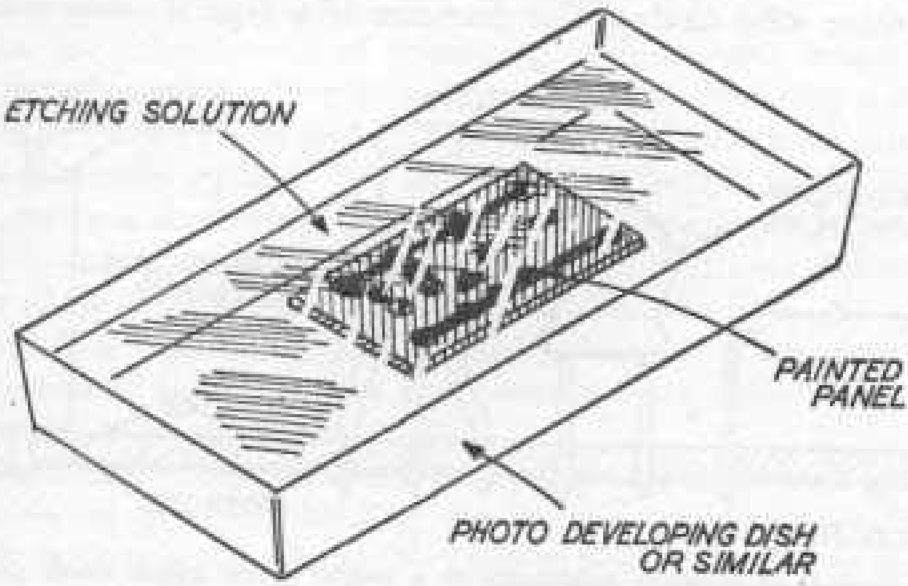

Fig. 67. *After immersion in an etching solution for a suitable time all the copper will have been eaten off the Paxolin panel except for that covered by the resist ink or cellulose dope*

Pour the etching solution into a shallow container of glass or plastic (the lid of a plastic sandwich case is ideal or a photographic developing dish). Lay the panel in the solution, copper side up, and gently rock the container to agitate the solution. The exposed copper will gradually be eaten away until only plain Paxolin is left, with the painted-on printed circuit. You can speed this process of etching by using a warm solution. Thus if heated to 100 degrees F., etching can be completed in a quarter of an hour or so, whereas with the solution at normal room temperature it may take an hour or more.

When all the copper has been etched away (*see* Fig. 67) the board can be removed from the solution and washed thoroughly by holding under a cold water tap. This will remove any traces of acid.

The next stage is to remove the resist ink or paint, using a resist remover or cellulose thinners, respectively. Simply rub on with a cloth and keep rubbing until all the ink or paint has been dissolved away, leaving the copper pattern which it has been protecting completely exposed.

The final stage is to drill the holes for mounting the various components. The solid circles represent the connecting points for the individual component leads, so a hole must be drilled in the centre of each of these solid circles. The diameter of a typical component lead

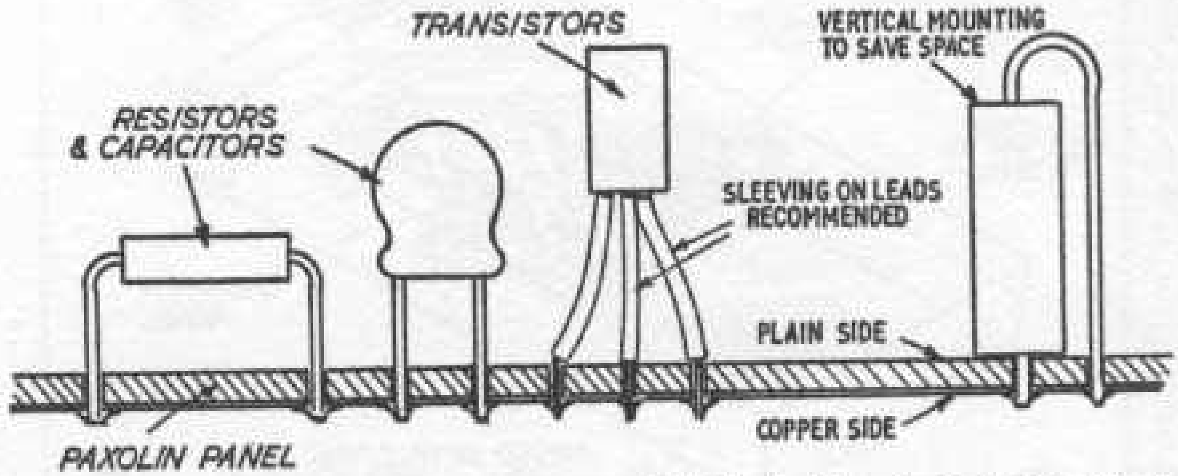

Fig. 68. *Methods of mounting components on a printed circuit board. Leads are soldered to the copper side and excess length of lead trimmed off.*

(except transistors) is 22 s.w.g. or 0·028 in., so a $\frac{1}{32}$ in. or No. 67 drill is about right. Make sure that you use a sharp drill (preferably a new one) and always drill from the copper side. This will not only enable you to centre the drill properly in the solid circle but also prevent possible damage to the copper you are drilling through. Also use a backing of fairly hard material under the board so that the plain face of the laminate is not damaged when the drill point breaks through (*see* Fig. 68).

The complete printed circuit panel is now ready to have the components mounted in position and soldered in place—with one proviso. It has been handled quite a bit, and so has probably become fingerprinted and greasy in parts. To ensure good soldered joints, clean the copper areas thoroughly by rubbing over with a scouring powder until really bright. Then rinse and dry thoroughly on a clean cloth.

Components are mounted by bending their leads so that these will pass through the appropriate holes in the board, then soldering the leads in place to the copper on the underside. Components should not fit tight against the board as this reduces the length of lead to a minimum with risk of overheating the component when soldering in place. There are exceptions, however, such as components with short tags in place or wire leads (e.g. transformers), which are mounted flush with the board. Transistors and diodes, on the other hand, should always be mounted on fairly long leads.

There are several ways of dealing with the surplus length of leads projecting through the board on the copper side. Probably the simplest is to solder in place first and then cut off the surplus lead with a small pair of side-cutting pliers. The neatest way is usually to cut the lead to length first and then solder in place. Some people prefer to cut the lead to length, turn over to hold the component in position and then solder. This is all right on a widely-spaced layout, but liable to lead to trouble when dealing with a crowded circuit, so it is not to be encouraged as good practice. It also makes components more difficult to unsolder and remove from the board, if necessary.

As with other circuit assemblies, soldering should always be completed as rapidly as possible—holding the iron in position only for a few seconds to complete the joint. If excessive heat is applied to the copper it may become delaminated and tend to peel off the Paxolin, although it is unlikely that the copper itself will be broken. If a part of the copper does become unstuck it can often be refixed by heating with a soldering iron and pressing back in place. If this fails, stick it down with a suitable adhesive. A summary of printed circuit soldering techniques is shown in Fig. 69.

Having once made a printed circuit panel and completed a printed circuit assembly, the advantages over ordinary wiring up will be appreciated. Starting with simple circuits first, like an amplifier stage which can be allied to different receiver front ends, the amateur will soon become quite proficient at the technique and almost invariably prefer it for future receiver construction. (A summary of printed circuit techniques is shown in Fig. 70.) The only real difficulty with laying out more complex circuits is planning the original layout successfully, and

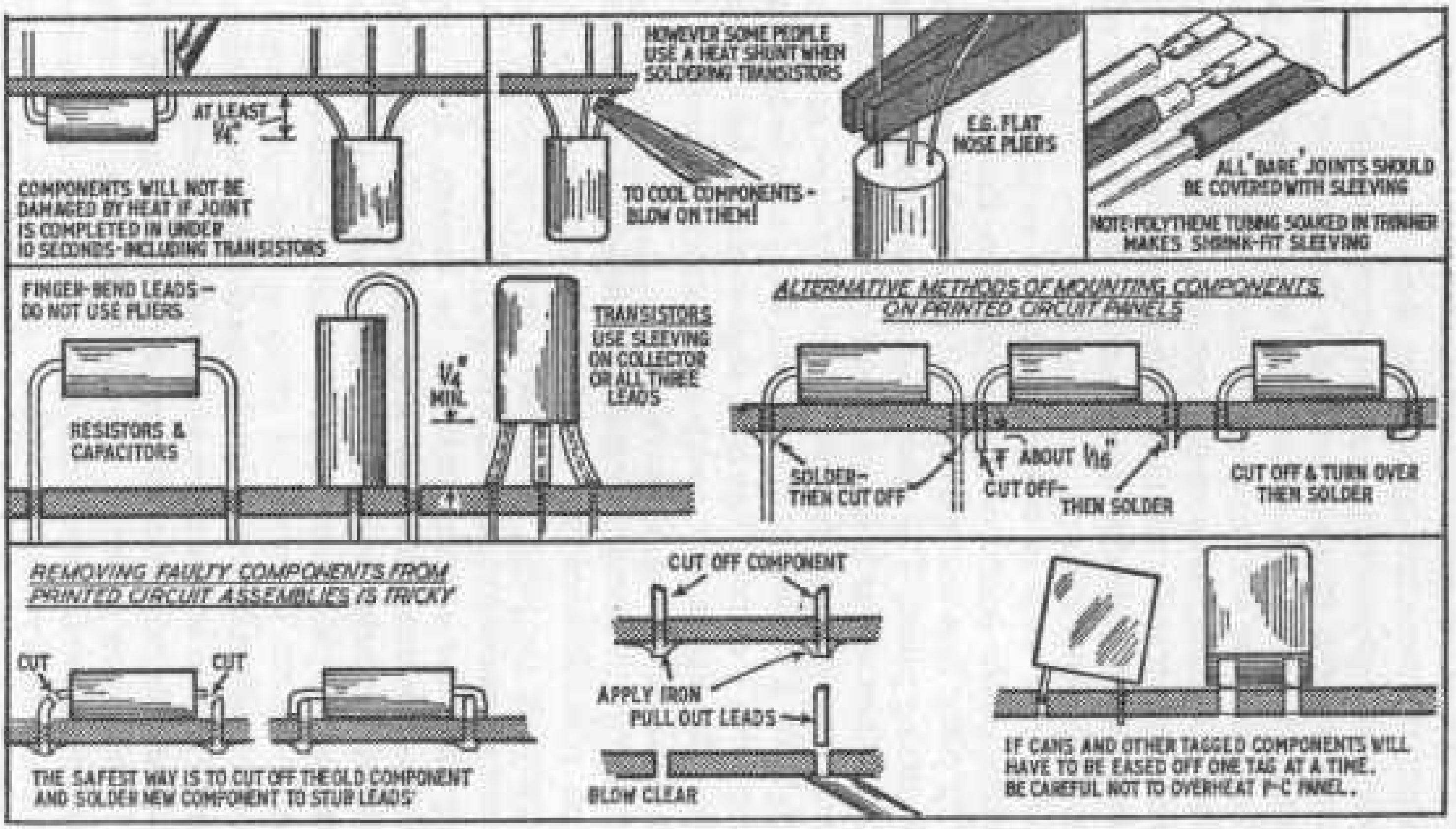

Fig. 69. *Printed circuit soldering techniques summarized*

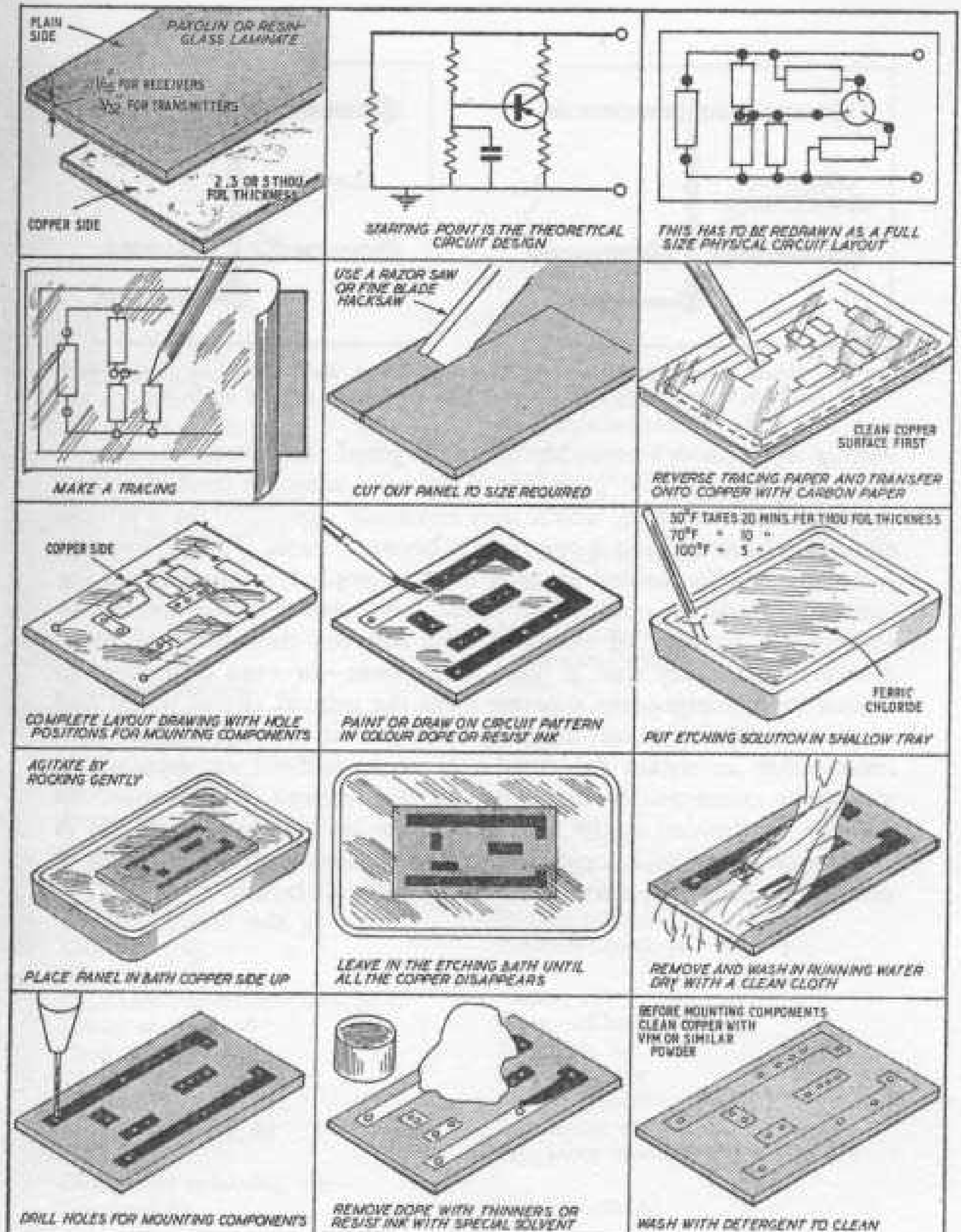

Fig. 70. *Printed circuit technique summarized*

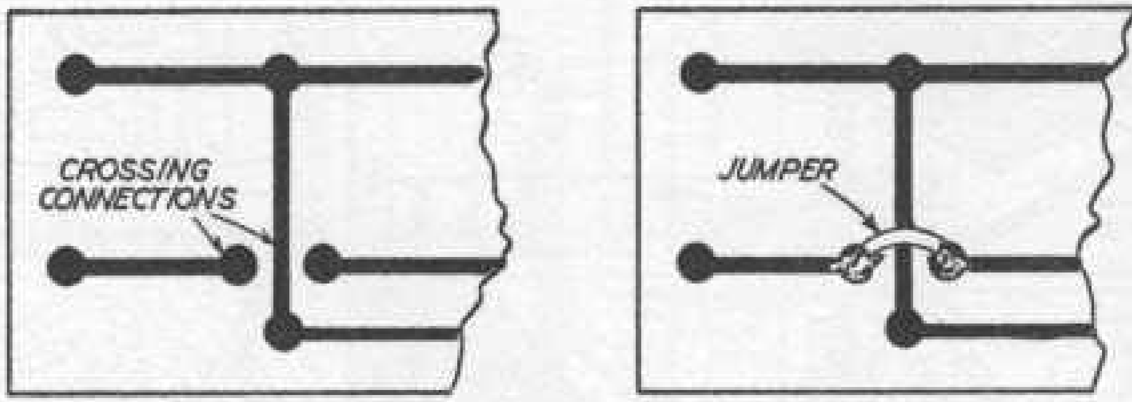

Fig. 71. *Where crossing conductor lines cannot be avoided, the break on the printed circuit panel can be bridged by a short length of insulated wire soldered in place*

ending up with a reasonably compact panel. But there are certain tricks you can employ. Thus one of the most common troubles is how to avoid leads crossing, which they obviously cannot do on a printed circuit without making a connection between them. Thus, if crossing points cannot be avoided on your layout, simply terminate one of the 'crossing' leads in connecting points and complete the circuit by soldering a 'jumper' of insulated wire between them, as in Fig 71. Similarly, you may find it more convenient—or even necessary—to mount some components separate from the printed circuit board and connect to suitable points on the printed circuit with external leads. A loudspeaker or socket for earphones or a deaf-aid earpiece would always be connected to the circuit in this manner, for example. All this can be decided at the first stage when laying components out in what appears to be a logical position and then rearranging them as necessary in order to arrive at a practical circuit layout.

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