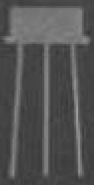
21 SIMPLE TRANSISTOR RADIOS YOU CAN BUILD

—From Crystal Sets to Superhets

By R. H. Warring



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WORKING CIRCUIT DESIGNS

PUBLISHER'S NOTE

Some of the circuits in this book have been adapted from H. Ness's *Handbook of Tested Transistor Circuits* (Babani Press), and the tables of transistor characteristics are based on data from Electrovalue Ltd., to which grateful acknowledgement is made.

1 RADIO MADE EASY!

Everyone knows what a radio is, but many people find it difficult to understand how a radio receiver works. Reading technical books on the subject is not always a help. The language of radio, and the understanding of technicalities, can prove difficult or even impossible without some previous background knowledge of the subject. So we will start right from scratch–in plain language!

The 'sending' of sound is easy to understand. When someone speaks he (or she) sends out a sort of pressure wave from the mouth. This travels through the air at approximately 335 metres per second, or 1,100 feet per second (the speed of sound). When a sound wave reaches the ear of a listener (anyone who happens to be in the way of it), the pressure wave will set parts in the ear vibrating, the 'signal' being transmitted to the brain and 'received' as an impression of sound–Fig. 1.1.

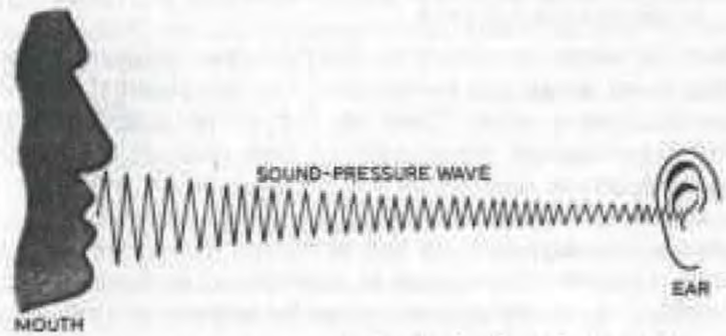


Fig. 1.1 Speech is transmitted directly through the air by sound-pressure waves.

Sound-pressure waves have another characteristic: their strength decreases quite rapidly with distance. Doubling the distance between 'sender' and 'receiver' would result in the level of sound received being reduced by one *quarter* (not one half).

The only effective way to increase 'distance of sending' or *range* is to increase the strength of the original sound, by shouting, for instance, although this will not greatly increase the range. (Remember that the strength of the sound-pressure waves decrease in proportion to distance *times* distance, or $(\text{distance})^2$.) The other method is to increase the strength of the original sound by using a megaphone or public-address system. Both are devices which boost sound, known as *amplifiers*. A simple megaphone is a mechanical amplifier, while a public-address system is an electronic sound amplifier, based on a *microphone*, an *amplifier circuit*, and a *loudspeaker*–Fig. 1.2.

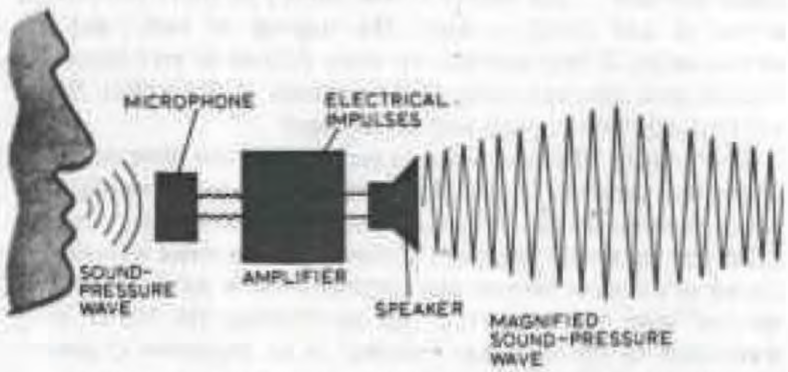


Fig. 1.2 To extend the range of sound transmitted, some form of amplifying device can be used.

Here the microphone acts rather like the human ear, being vibrated by the sound waves, but turning this effect into electrical impulses rather than nerve pulses. These are fed to the amplifier, which considerably magnifies the strength of these electrical signals. The stronger signals are then fed to a loudspeaker, which works like a microphone in reverse. It is fed with electrical impulses to set a diaphragm vibrating, which in turn generates a sound-wave 'output'. Because the incoming signal (into the microphone) has been magnified or amplified, the sound wave issuing from the loudspeaker is very much stronger than the original 'input' sound.

Such a system is still limited in range. Words spoken into a public-address system may be heard, under favourable conditions, as far

away as, perhaps, one mile–but certainly not much further. Also, wind blowing in opposition to the sound will considerably reduce the range. So to increase range still further, some other method of transmitting the sound must be used–Fig. 1.3.

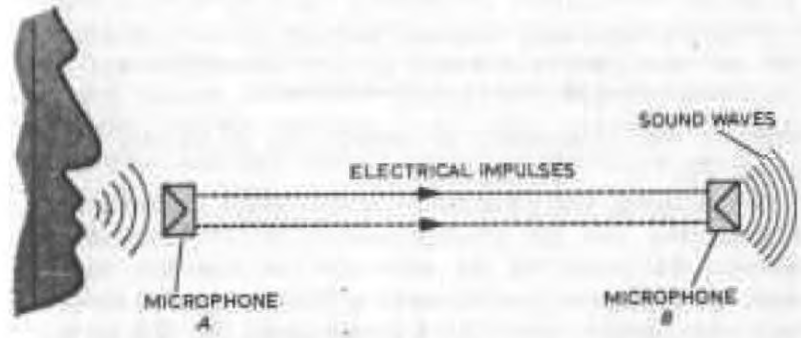


Fig. 1.3 To transmit sound over longer distance, wires are used to connect two microphones. In a simple system, the microphones can also work as speakers. In the usual telephone system, a separate microphone and speaker (earpiece) are used at each end.

Again the original sound is directed into a microphone, which is connected by two wires to another microphone. Each microphone can act either as a microphone *or* speaker. Microphone *A* turns sound into electrical impulses, which are transmitted along wires to microphone *B* which is vibrated to turn these impulses into the original sound; in other words, it is working as a speaker. If sound is now introduced into microphone *B*, electrical impulses will be transmitted along the wires back to *A*, which now acts as a speaker.

The particular advantage of a 'wire' system is that once the sound is turned into electrical impulses, these impulses can be transmitted over quite long distances without greatly diminishing in power. There will be a reduction in power with increasing length of wire, because all wires or conductors of electricity offer some *resistance* to the passage of electric currents. The greater the wire length, the greater the resistance, and thus the greater the loss of electrical energy. This will show up in the 'received' sound, being much weaker than the original.

There are ways of compensating for this; for example, the inclusion of a battery in the circuit, to produce a more 'responsive' microphone circuit (i.e. make the electrical impulses, generated by the microphone,

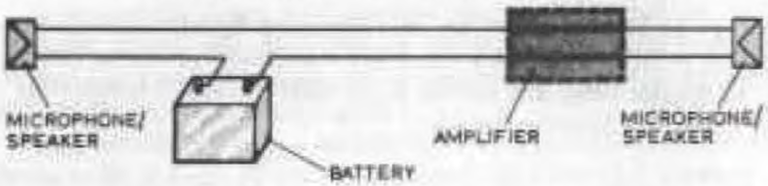


Fig. 1.4 Better sound transmission over wires is given by added power (via a battery). An amplifier can also be introduced into the circuit to boost the strength of the electrical impulses.

stronger). Also, if necessary, an amplifier can be included in the circuit–Fig. 1.4.

Before leaving this particular set-up it is worth explaining that, although two wires are shown connecting the two microphone/speakers, the system will also work with *one* wire. But, since a single-wire connection cannot complete a 'loop' for electrical currents, some other 'common' connection is needed at each end. This can be a connection to *earth*, and provides the 'return path' for the circuit–Fig. 1.5. There are disadvantages in such a system used for telephonic communication (which we have been describing), but the use of earth as a 'common' connection is very useful in radio work, as will be seen later. The earth may be 'real'–i.e. a connection to a physical earth; or 'virtual'–i.e. connection to a common line in the radio circuit with no external earth connection.

Telephonic transmission is possible over very long distances, but it does need interconnecting wires and one or more 'switching centres' in order to be able to connect one 'sender' to more than one 'receiver', or alternative 'receivers'.

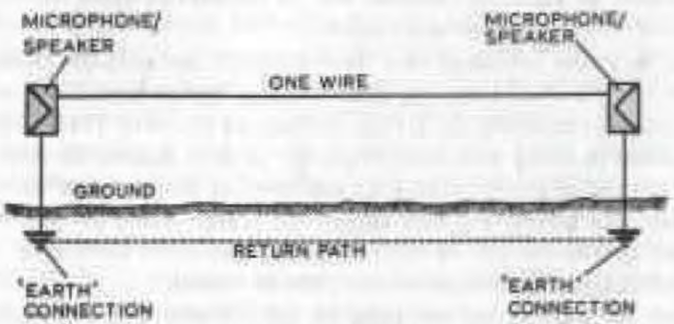


Fig. 1.5 Simple telephone systems can operate over a single wire with 'earth return'.

Radio is wire-less transmission (hence the original name, *wireless*): electrical impulses generated in a microphone are sent directly through the air–and *any number* of receivers can *tune in* to the same signal at the same time. The 'sender' becomes a *broadcast station*, each of the listeners using a radio receiver to hear the broadcast signals.

But electrical impulses, generated by sound waves reaching a microphone, cannot be sent directly. In the absence of connecting wires in the microphone, nothing will happen. The trick is to turn the electrical impulses generated in the microphone into a type of electrical signal which *will* travel through the atmosphere (and even into space); involving turning the electrical impulses into *radio-frequency waves*.

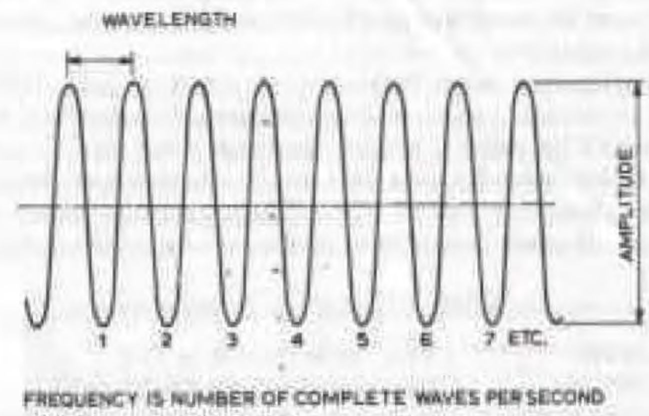


Fig. 1.6 A waveform is defined by its wavelength–or now, preferably frequency–and amplitude. Amplitude is a measure of the 'power' or strength of the wave.

A wave is simply a way of expressing, in physical form, a transmission involving energy. (A simple wave is shown in Fig. 1.6.) The characteristics of the wave are defined by its *wavelength*, or distance from crest to crest, and by its *amplitude* or 'swing' on either side of the centre-line along which the wave is moving.

Instead of wavelength, however, it is more convenient to speak of *frequency*, the number of complete waveforms produced per second. Wavelength, frequency and the *speed* of the wave are simply related as follows:

$$\text{wavelength} = \frac{\text{wave speed}}{\text{frequency}}$$

Wavelength (where used) is normally quoted in *metres*; frequency is now quoted in *Hertz* (abbreviated Hz).

All the sound and electrical waves we have considered so far have been at *audio* (or 'hearing') frequency (abbreviation AF). The original sound waves (which are an audio frequency) are converted directly into electrical waves, and back again into sound waves, all at the same frequency. The complete range of audio frequencies is from about 30 Hz (a very low, deep note) to around 16,000 Hz. The ear cannot respond to frequencies outside this range, so they are not heard. Neither, as we have noted, are any of these audio-frequency waves directly transmissible through the air over any distance, mainly because their *amplitude* decreases rapidly with increasing distance. *Amplitude* is a measure of the power or 'strength' of the wave (think of sea waves for a simple comparison).

Radio-frequency waves travel with the *speed of light*, 300,000 metres per second. Because of their high speed, their amplitude is far less modified by distance. Another distinction is that radio-frequency waves (abbreviation RF) are sent out in all directions from the source–a characteristic of all electro-magnetic radiation (unless constrained or 'beamed' in a position or direction by suitable reflecting devices).

The various radio waves are divided into categories, namely:

10–30 kHz	Very low frequencies, or VLF.
30–300 kHz	Low frequencies, or LF (long wave).
300–3,000 kHz	Medium frequencies, or MF (medium wave).
3–30 MHz	High frequencies, or HF (short wave).
30–300 MHz	Very high frequencies, or VHF.
300–3,000 MHz	Ultra-high frequencies, or UHF.
3,000–30,000 MHz	Super-high frequency, or SHF.

The LF range corresponds to the 'long wavelength' band; the MF range covers the 'medium wavelength'; and the HF covers the 'short waveband'.

An immediate problem arises. Radio waves (RF) cannot be heard, so how can they be made to transmit sound? The answer is surprisingly simple: the radio-broadcast station transmits an RF signal corresponding to the particular RF frequency allotted to it–Fig. 1.7. This is called the 'carrier', and since it will normally be well above 30,000 Hz it cannot be heard (except possibly some side-effects in the form of a little 'noise').

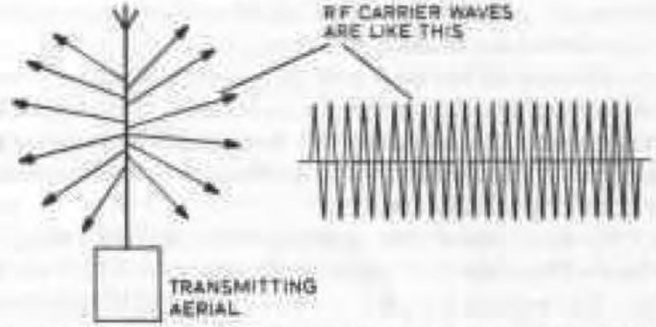


Fig. 1.7 Form of a steady RF carrier wave which is transmitted at a specific frequency.

To transmit sound–speech or music–a microphone is used to turn sound waves into audio-frequency (AF) electrical waves, just as in the previous systems described. Alternatively, these AF electrical waves can be obtained direct from a disc or tape recording, etc.

This 'sound' signal is superimposed on the carrier wave being transmitted. Instead of having a constant waveform (constant amplitude, as in Fig. 1.7), the combination of the AF ('sound' wave) with the carrier results in a wave something like that shown in Fig. 1.8. The 'top'

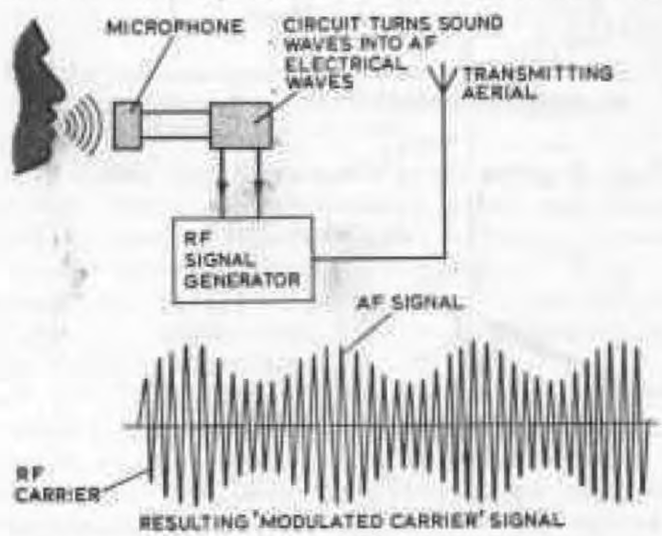


Fig. 1.8 The effect of superimposing an audio-frequency (AF) signal on the RF carrier is a modulated carrier-wave transmission.

and 'bottom' of the carrier wave now assume the form of the 'sound' wave, which is thus carried along with the carrier.

This combination is known as a *modulated wave*. The 'sound' or AF wave has modified the form of the RF carrier wave, or modulated it. It is also easy to see that what has actually been modified or modulated is the *amplitude* of the carrier wave; so this form of radio transmission is called *amplitude-modulation* or AM.

This is the only type of radio transmission we shall be dealing with in this book. There are others, notably *frequency modulation* or FM, used for VHF working (which is outside the scope of reception by simple radio receivers).

No problems, therefore, in getting AF signals 'on the air'. In fact, the air is literally full of such signals almost every hour of the day, radiated from different broadcast-transmitting stations.

The next step is to be able to pick them out of the air, so to speak; and, in particular, to pick out or *tune in* to the one particular station we are trying to listen to.

A single length of wire will 'pick up' virtually all AM signals present. This is because each signal represents varying amounts of electrical energy passing across the wire when, by a phenomenon known as

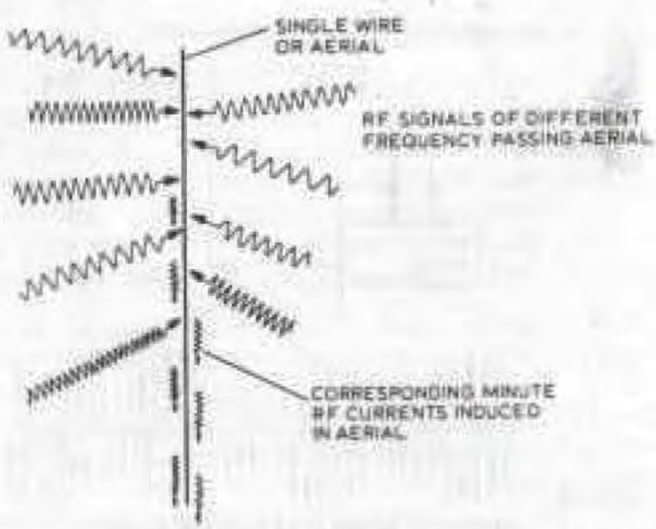


Fig. 1.9 A simple wire aerial is a very weak 'receiver' of radio signals (by a process known as induction).

induction, a part of that varying energy will appear in the wire as an *induced current*. This current will vary with the same *frequency*, and duplicate the same *modulation*, as the original signals–Fig. 1.9.

The single length of wire, or *aerial* as it can now be called, is thus probably being affected by dozens of different RF signals, each inducing its own 'current image' in the wire; all these currents will be extremely minute–far too small to measure. So the aerial is only the starting point for a practical receiver; another example of 'electronic trickery' is required, namely a *tuned circuit* connected to the bottom of the aerial–Fig. 1.10.

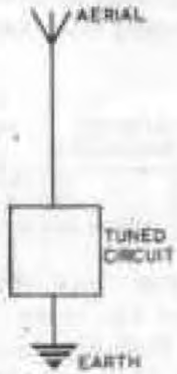


Fig. 1.10 The addition of a tuned circuit to an aerial produces amplification of signals induced in the aerial at one frequency only (the resonant frequency of the tuned circuit).

A tuned circuit normally comprises a *coil* (which is far more efficient than a straight wire for picking up induced currents), and a *capacitor* (which acts as a stop or a break in a circuit for direct current, d.c., but passes alternating current a.c.).

A capacitor also has the important property, when combined with a coil, of generating a greatly magnified induced current at the particular frequency known as *resonant frequency*.

This is a very important factor in the behaviour of a *tuned circuit*. Radio signals at that frequency, present in the aerial, will be greatly magnified or amplified, while other signals at different radio frequencies will not. Thus, apart from picking up and magnifying a particular broadcast frequency, the tuned circuit virtually rejects all the other signal currents present in the aerial because they are so minute.

Since the resonant frequency of the tuned circuit depends on the value of the capacitor and coil *inductance*, a suitable combination of values can be calculated to give maximum response (i.e. 'resonate') at any particular broadcast frequency. However, this would largely restrict the scope of the receiver; therefore, one of the tuned-circuit components is made *variable* in value, which means that the tuned circuit can now be adjusted to *tune in* to a whole range of separate broadcast frequencies.

One more step is needed to complete a basic receiver. The tuned circuit, when adjusted for resonance, is picking up the original carrier plus sound signals, or modulated RF signals. As this signal cannot be fed directly to a speaker (not being at audio frequency) it is fed through a *detector*, which need be nothing more than a simple component called a *diode*–Fig. 1.11.

Fig. 1.11 A diode acts as a detector.

A *diode* is another stop-go device, which passes a.c. or d.c. in one direction, but stops current flow in the other. The effect of passing modulated RF through a diode is to 'chop off' the 'bottom' of the signal, leaving two separate components; one being the 'top half' of the original carrier, the other a varying d.c. component, following exactly the variations of the original AF signal used to modulate the carrier–Fig. 1.12.

The output from a diode detector can, in fact, be fed direct to a suitable speaker, which will respond to the varying d.c. signal, turning this into audible sound in a similar way as telephonic transmission–Fig. 1.13. The RF signal 'top half' present will not affect the speaker,

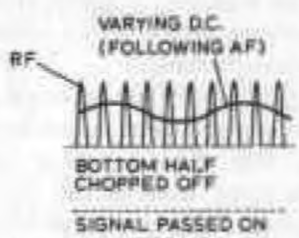


Fig. 1.12 The form of the signal passed by a diode detector–a mixture of 'chopped' RF and a d.c. component varying in AF

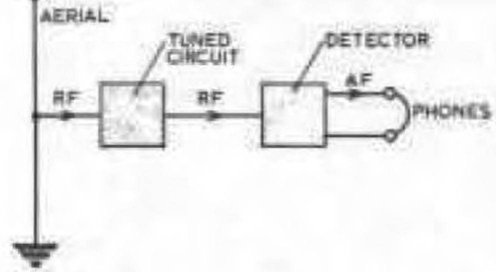


Fig. 1.13 The basic stages which make up a simple receiver.

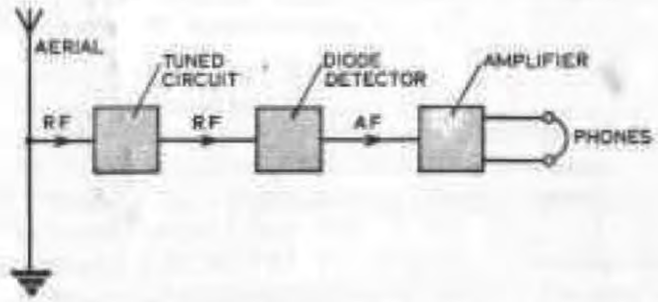


Fig. 1.14 More output power can be obtained from a receiver by interposing one (or more) stage(s) of amplification after detection.

although it may be desirable to introduce some further components to smooth out possible interference with the sound signal required.

Such a basic circuit relies only on the *tuned circuit* for the amount of amplification produced–and thus the volume of sound heard in the speaker. Surprisingly, this can be all that is necessary to hear a limited number of stations quite clearly on a simple crystal set, using an earpiece as a speaker. To produce better volume, however, it is a relatively straightforward matter to introduce one or more stages of *amplification* after the detector–Fig. 1.14.

2 THE LANGUAGE OF RADIO

The following abbreviations are normally used to designate *components*, particularly on circuit drawings.

A Aerial; or current value in amps.
E Earth; or potential (e.m.f.).
R Resistor (the different resistors in a circuit being numbered R1, R2, R3 etc., for individual identification); or resistance.
VR Variable resistor or potentiometer (although sometimes the 'V' is dropped and just R used).
C Capacitor (numbered C1, C2, C3 etc., in a circuit). Variable capacitors are normally designated C, *not* VC. Also symbol for capacitance.
CT Trimmer capacitor.
D Diode.
L Coil (or inductance).
RFC Radio-frequency choke.
T Transformer.
TR Transistor, although there are alternatives used, e.g. Tr, VT and T; also sometimes Q. If T is used for transistors, then TR is used for transformers.
FET Field-effect transistor.
I Current.
IC Integrated circuit (module).
PC Printed circuit or printed-circuit board (PC board).
S or SW Switch.
J Jack.
V Voltage or e.m.f.
Z Impedance.

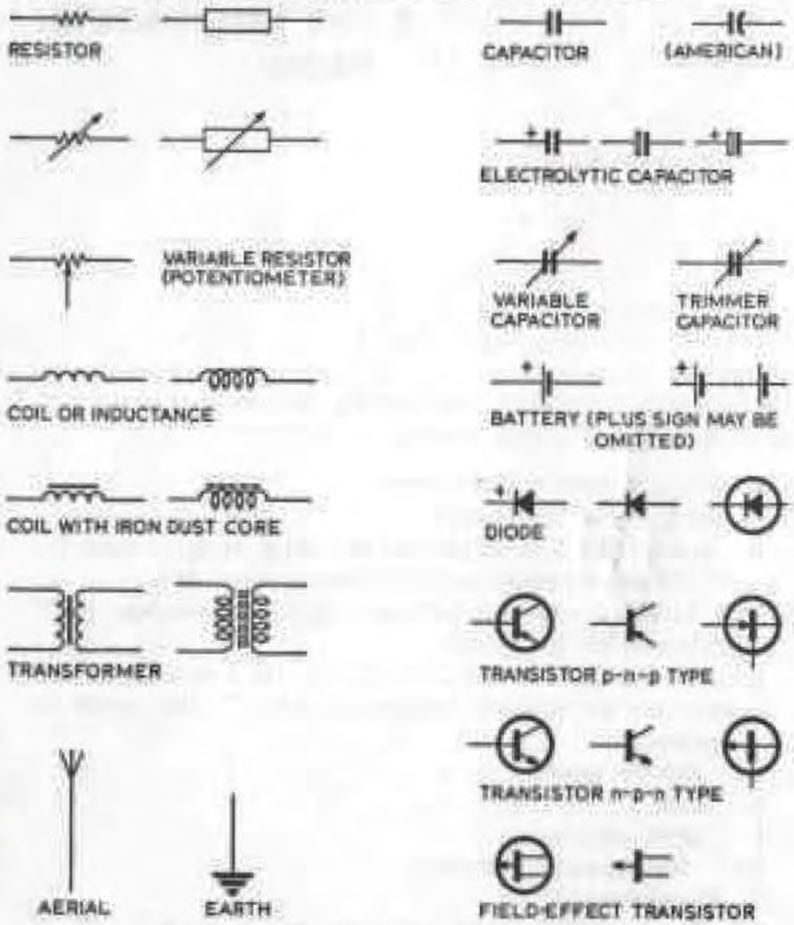


Fig. 2.1 Standard symbols used in circuit diagrams with alternatives in most cases. These cover the symbols most likely to be found on British, European and American circuit diagrams.

Components on circuit diagrams are also designated, and easily identified, by symbols, and here again there are some variations to be found – see Fig. 2.1.

Basic quantities are measured in units as follows.

Resistance	in ohms (Ω).
Capacitance	in farads (F).
Inductance	in henrys (H).
Impedance	in ohms.
Potential difference or e.m.f.	in volts (V).
Current	in amperes (amps).
Power	in watts (W).

Numerical values of these units are often too large or too small to be expressed conveniently, when the following *prefixes* are used (representing multiples or sub-multiples).

Prefix	Symbol	Factor by which unit is multiplied	Example
mega	M	1,000,000	10 MHz (10 megahertz) = 10,000,000 Hz
kilo	k	1,000	10 kΩ = 10,000 ohms
milli	m	1/1000 or 0.001	2 mA (2 milliamps) = 0.002 amps
micro	µ	1/1,000,000 or 0.000001	6 µV (6 microvolts) = 0.000006 volts
nano	n	0.000000001	not widely used as a prefix in basic electronics
pico	p	0.000000000001	220 pF (220 picofarads) = 0.000000000220 farads

**Note:* the unit name is often omitted when the inference is obvious. Thus for a 10-kΩ resistor, the value would be quoted as 10 k.

As a simple guide, mega (M) and kilo (k) are most usually found describing high values of *radio frequency* and *resistors*.

Milli (m), and to a lesser extent micro (µ), are most commonly associated with very low values of *current* or *voltage*, and practical values of *inductances*.

Practical values of *capacitors* are invariably quoted in microfarads (µF) or picofarads (pF).

Note: components are described in detail in Chapter 11.

3 CRYSTAL SETS

The simplest type of radio receiver consists of an aerial, a tuned circuit and a detector–plus headphones to listen to the signals received by the tuned circuit. It is generally called a *crystal set* because it works on the same principle as the very earliest radio sets, using a lead-galena crystal and a 'cat's whisker' as a detector. The only real difference is that the crystal and cat's whisker have been replaced by the much more efficient point-contact *diode*.

A simple *tuned circuit* can be made by winding a coil of wire of specific diameter and length (number of turns) to match the capacitance range of a variable capacitor. The combination of coil (inductance) and capacitance can then be adjusted by turning the variable capacitor spindle to be resonant, or tune in to various broadcast frequencies. The signal which is tuned in is then passed to the diode which blocks the RF content, and rectifies and passes on the AF content to the headphones, which transform these signals into audible sounds.

The tuned circuit can be combined with the aerial by winding the coil on a *ferrite rod*. This increases the inductance of the coil (reducing the length of wire required), whilst the rod itself also acts as an aerial to pick up the radio signals. This is the type of aerial employed in most domestic radio receivers. However, with very simple sets working with very weak signals, an external aerial may also be required.

The performance of all simple, low-powered receivers is, in fact, very much dependent on the efficiency of the aerial and tuned circuit, which can be regarded as the critical part of the system. Performance can perhaps be improved by experimenting with different aerial/tuned-circuit systems, and by the addition of further circuitry, as explained in later chapters.

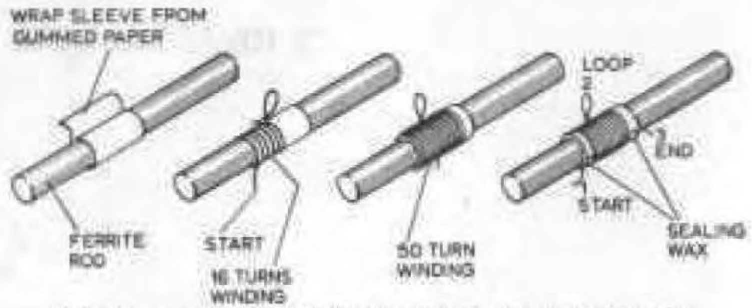


Fig. 3.1 Aerial tuning coil wound from 38-s.w.g. wire on a 5/16-in. diameter ferrite rod.

Fig. 3.1 details the construction of a suitable coil for a tuned circuit, matched to a ferrite rod of 5/16 in. diameter and about 4 in. long (see Chapter 4 for alternative coil windings on different rod sizes). If a rod is purchased longer than 4 in., it can be used as it is, or cut down by marking around with a file and then breaking off the surplus length.

Cut seven 1-in. lengths of gumstrip. Moisten one and wrap around the rod gummed side up. Now add about another half a dozen wrappings of similar length over the first, this time with gummed side *down* to form a reasonably rigid tube. Make sure that the paper tube is a *sliding* fit on the ferrite rod and leave to dry thoroughly (preferably removed from the rod so that it cannot become stuck to it).

When the paper tube is quite dry it should be rigid, when the coil windings can be applied. The wire to be used is 38-s.w.g. enamelled copper wire, the number 38 referring to the actual diameter of the wire according to the standard wire gauge (s.w.g.).*

Starting about 1/4 in. in from one end of the paper tube, wind the wire carefully round the tube, with each turn tight against the one before it, until sixteen full turns have been completed. Then make a loop in the wire, as shown, and carry on winding, with succeeding turns touching, until fifty turns in all have been completed. The two loose ends of the coil (the start and finish) can be secured with a dab of sealing wax whilst the projecting loop can be twisted together (e.g. by putting a pencil through the loop and twisting up). Cut off the loop, leaving about 1/2 in. protruding from the main coil, bare the wire ends and solder together. This forms point 2 on the coil; the start is point 1, and the end point 3–see Fig. 3.1. It will be easy to remember these

* American wire gauge (AWG) is about two sizes smaller than the British standard wire gauge (s.w.g.). For example, 38 s.w.g. is approximately the same as 36 AWG.

without marking since the loop or tapping point (2) comes much closer one end (1) than the other (3).

Cut a panel of *Paxolin sheet* to about the size shown in Fig. 3.2, using a hacksaw.* On this secure a *tag strip*, as shown, and drill a hole to mount a miniature or small-size 500 pF *variable capacitor.*

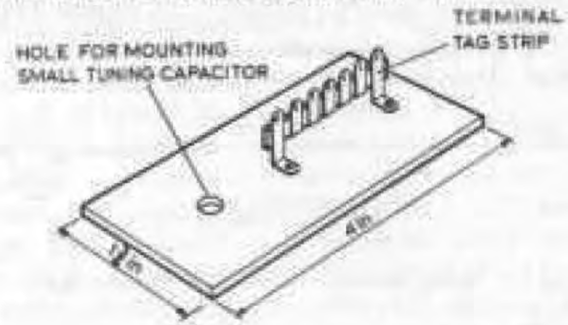


Fig. 3.2 Paxolin panel and tag strip for crystal set circuits.

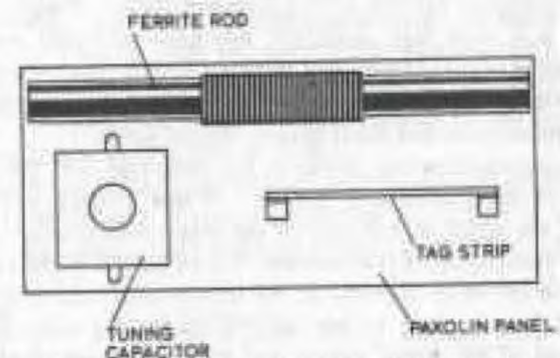


Fig. 3.3 Layout of components on Paxolin panel.

The aerial coil is then mounted on the panel as shown in Fig. 3.3, gluing the coil on to the Paxolin with two or three dabs of sealing wax, or some other suitable adhesive. *Note:* the ferrite rod must be free to slide in the paper tube for 'tuning' adjustments.

Virtually any miniature germanium or silicon diode will be suitable for the detector. Recommended types, which are readily available, are 1N34 and 1N914.

Earphones must be of *high-impedance* type, which need not be expensive to buy, and the higher the impedance the better the reception.

* A phenolic or fiberglass sheet may also be used.

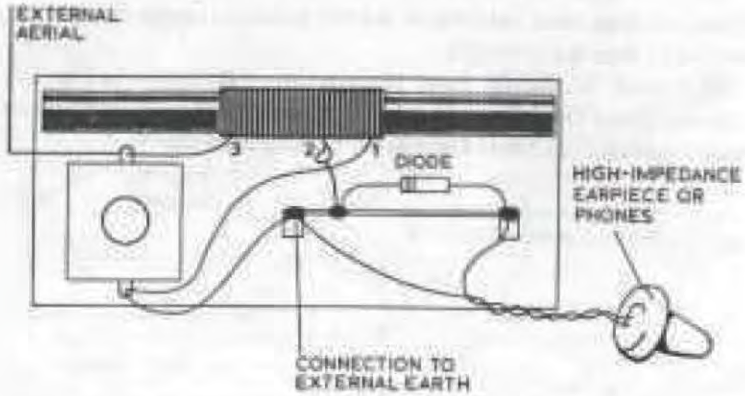


Fig. 3.4 Wiring connections to complete the crystal set.

Alternatively a deaf-aid type earpiece can be used; this will not give the same volume or quality of reproduction as headphones, but is a less expensive component. This should preferably be of the *high-impedance magnetic* type, with high sensitivity. Any high-impedance earpiece will suffice, but if of crystal type will require a resistor, connected across it, to complete the circuit. This will reduce the amount of current flowing through the earpiece and lower the strength of signal.

Wiring connections are shown in Fig. 3.4. End 3 of the aerial coil (the end of the 50-turn coil) connects to one terminal of the tuning capacitor, the aerial or 'hot' end of the tuned circuit, and the point to which an external aerial is connected. The other end of the coil (end 1) connects to the other terminal of the tuning capacitor, from which an additional wire is taken to the first tag on the tag strip. This is the 'earthy' end of the tuned circuit, and the point to which an external earth is connected. Leave plenty of slack wire between the coil and tuning capacitor.

The other connections are then as follows:

(i) Tapping point of the coil wire bared and connected to the second tag.
(ii) The diode also soldered to this same tag, and to any other free tag.
(iii) Headphone (or earpiece) leads to the 'earthing' tag, and to the 'free' tag to which the above diode has been connected. All connections should be made with *soldered* joints.

The wiring-up can be checked against the *circuit diagram* shown in Fig. 3.5 (ignoring the components shown with broken lines). The set should now be 'working'.

In areas of strong signal strength, no external aerial or earth connections should be necessary. Performance will, however, be improved in any area by attaching an aerial wire (which can be any thin wire, e.g. using the same wire as for the coil winding), of up to 160 feet. The longer the aerial the better the reception, provided it is led away from the receiver to as *high* a point as possible.

An earth connection may further improve aerial performance; by this we mean a connection to some conductor positively in contact with the ground (preferably buried), an excellent example being a metal water-pipe. Thus, if an earth connection is found to be necessary (or you want to try one to see how performance is affected), connect a wire from the 'earthing' tag on the receiver to a convenient water-pipe.

This question of obtaining a *good* aerial and earth is a most important one in areas of poor signal strength. Linking up to a television aerial is often a good plan, since TV aerials are also usually mounted as high as possible. If bare wire is used, it is also important that the upper (free) end of the aerial is not made fast to something which could produce an earth connection (e.g. a damp tree), or at least is suitably insulated from such a support. String is not an efficient insulator; that, too, can conduct when wet.

Quite good results are often obtained by using the springs of a bed as an aerial, in which case an earth connection is usually not necessary. Sometimes, too, when other attempts to yield a good signal strength in

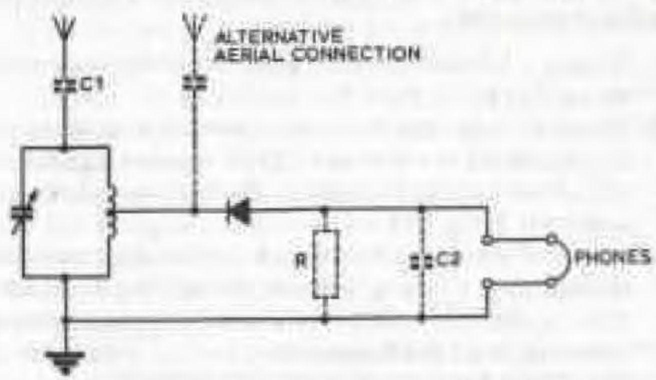


Fig. 3.5 *Circuit I.* Circuit diagram of basic crystal set.

the aerial have failed, connecting the *aerial* side of the tuning coil to a *good earth* (a water-pipe) can produce better results, the normal earth connection being left off.

Tuning

The receiver is adjusted as follows. Turn the tuning capacitor to fully close the vanes, then open about half a turn on the spindle or knob. (If you are using a trimmer as a tuning capacitor, screw right down and then open half a turn.)

The tuning coil should now be slid up and down the ferrite rod (the coil leads were left a fairly long time to give the necessary freedom of movement) until BBC Radio 3 is heard.*

It may be necessary to slightly alter the adjustment of the variable condenser to tune in to this programme. Also, because of the ferrite-rod aerial the set will be directional, that is, the signal strength received will depend to some extent on the direction in which the aerial rod is pointing, so position the set to pick up the maximum volume.

Having established the best position of the tuning coil on the rod to receive BBC Radio 3, fix permanently with a dab of sealing wax. You should then find it possible to tune in to further stations by altering the setting of the variable capacitor—e.g. typically Radio 4 in about the middle of the capacitor travel and Radio 1 towards the other end.

Any reception you get will almost certainly be very weak and (unless you live close to a broadcast station) you can really feel satisfied if you get any station at all at audible strength. But it is surprising how, sometimes, even quite distant stations can be heard. Also you can often improve the reception and listening strength by quite simple modifications. Try these in order:

(i) Connect a 1,000-pF capacitor across the headphone (earpiece) connections (C2 in Fig. 3.5).

(ii) Instead of connecting the external aerial directly to the tuned circuit, connect one lead to a 220-pF capacitor, and the other end of the capacitor circuit to the 'hot' end of the tuned circuit (C1 in Fig. 3.5).

(iii) Instead of connecting the external aerial to the tuned circuit, connect to the tapping point of the coil (tag to which the diode is also connected). Try a direct connection, and also connecting in a 220-pF capacitor.

* Tune to an AM broadcast station near the lower end of the dial—close to 550 kHz.

(iv) Try connecting a 1.2-k resistor (or higher value) across the phone connection (R in Fig. 3.5). You may be using the wrong type of phones or earpiece, which do not provide a proper load or complete the circuit.

If there is a complete lack of response, check for faulty wiring-up. A more likely cause, however, is lack of an external aerial or earth connection in an area where these are strictly necessary for adequate reception; or an inefficient aerial (too short) or poor earth connection (bad electrical contact to a good earth point, or connection to a bad earth point).

Another possible cause of apparent failure may be too much outside noise entering the ear so that it is impossible to detect the very weak radio signal as it is being tuned in. Headphones are better than a single deaf-aid type of earpiece in this respect but, in any case, a really quiet room is virtually essential for initial setting up and tuning adjustments. Also, if your adjustment of the tuning control is too coarse, you may completely miss the setting for the station you are looking for, without realizing it.

Reception will also tend to vary with weather conditions. Some days it may be so poor that what was normally a strong station is hardly heard at all. The simple basic receiver has many limitations but, since it costs very little to construct and nothing at all to operate, this must be regarded as inevitable.

Providing you can hear something—even if too weak a signal to distinguish properly—you can certainly improve the performance of your basic set by further experimentation with tuned circuits (see Chapter 4) and/or the addition of amplification to the circuit. You can also try other types of basic crystal set, as described in the following projects.

Circuit 2 (Fig. 3.6) is identical to *Circuit 1* except that, instead of a diode, a transistor is used as a detector. Only two of the transistor leads are connected—the emitter (*e*) connection to the tapping part of the coil, and the base (*b*) to the 'earthy' end of the circuit. The collector lead of the transistor is ignored (bend it out of the way so that it cannot accidentally short out the other leads).

You can try almost any type of low-cost AF transistor; recommended types are OC42 2N370, 2N2925, 2N5088.

With the addition of two more components, Circuit 2 can be modified to work the transistor both as a detector and an amplifier, to give stronger signals through the headphones. Using the same transistor type

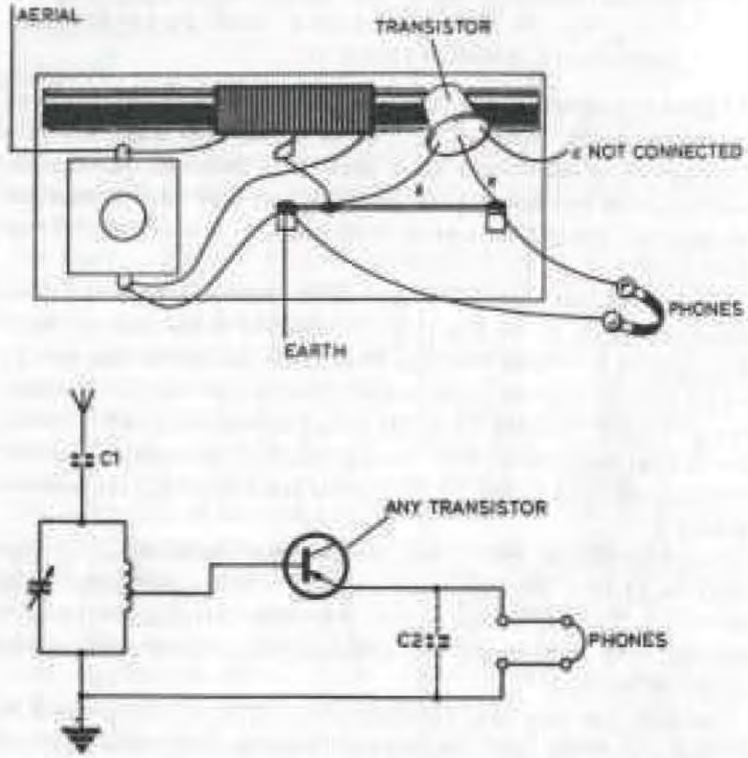


Fig. 3.6 *Circuit 2.* Crystal set using transistor instead of a diode.

as above (or near-equivalent) resistor R should be 15 k and capacitor C3 1 μF or higher.

This time a battery is also required to supply power for the transistor to work as an amplifier. This can be from 1.5 V up to 9 V. Remember the rules for polarity of connection: those shown in Fig. 3.7 are for a p-n-p transistor; an n-p-n transistor would need the battery connected the opposite way round. Battery polarity also affects the connections of capacitor C3 (if an electrolytic or polarized type).

Experiment further by trying the effect of using additional capacitors in the circuit, e.g. C1, 220 pF; C2, 0.001 μF (try other values as well); C4, 0.001 μF (try other values as well).

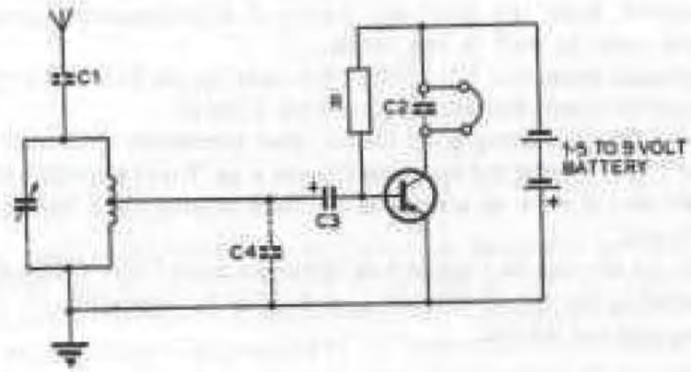


Fig. 3.7 *Circuit 3.* Crystal set with amplification.

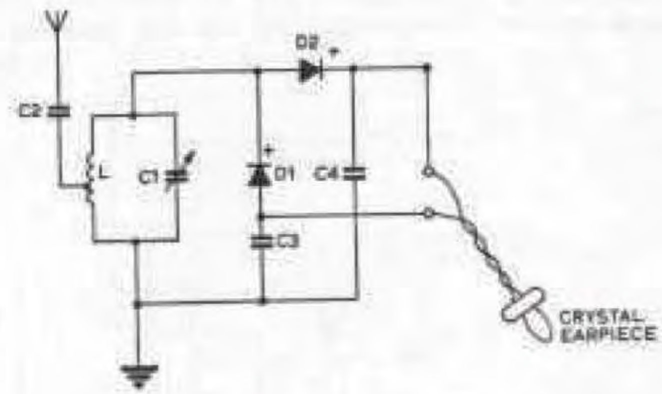


Fig. 3.8 *Circuit 4.* Double diode crystal set.

This circuit incorporates 'voltage doubling' to improve the signal volume and should give better performance than a single diode circuit. L and C1 are the usual tuned circuit, but an unusual feature is that the *aerial* is connected to the coil tapping point. Any type of germanium diodes can be used (they should preferably be the same), making sure to connect them the right way round. A high-impedance *crystal* earpiece must be used in this circuit.

Capacitor values are: C2, 220 pF (this capacitor can be omitted--try with and without in the circuit); C3 and C4, 1,000 pF.

The optimum tapping point for the aerial connection to the coil L is best found by trial and error (see Chapter 4 on 'Tuned Circuits'), but the set should work at a nominal one-third tapping point from the 'earthy' end.

This set can also be tried with conventional tuned-circuit coupling--i.e. aerial to the top of the coil L, and diode D2 connection to the tapping point on the coil.

4 MORE ABOUT TUNED CIRCUITS

The basic combination of a coil of certain *inductance* connected in parallel with a *variable capacitor* is the form of tuned circuit used in most radio receivers, from simple crystal sets upwards. The *tuning range* of such a circuit is determined by the respective values of inductance and capacitance used. At the same time, the *resistance* of the coil can have a significant effect on the *selectivity* of the circuit, so that a particular broadcast frequency is tuned into sharply, with other nearby frequencies rejected.

In the simple tuned circuit used for the crystal set of Chapter 3, the aerial is connected to the upper or 'hot' end of the coil, the other end of the coil being earthed; the diode is connected to a tapping point on the coil. Performance may well be improved by adjusting both the aerial-connecting point and the diode-connecting point, as shown in Fig. 4.1.

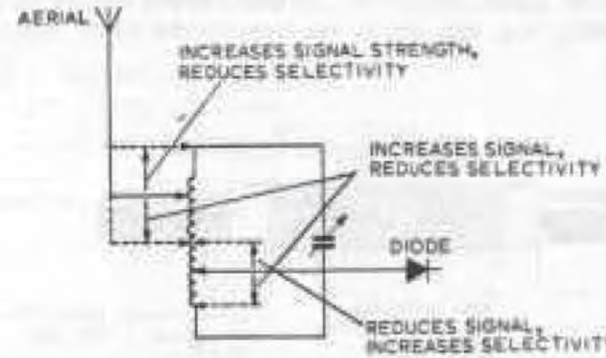


Fig. 4.1 The effect of varying the tapping points on the aerial coil.

Connecting the aerial to the 'hot' end should give the loudest signal, but the *selectivity* of the circuit may be poor because of the coil *resistance* involved in the actual circuit to earth. Connecting the aerial to a tapping point lower down the coil (towards the 'earthy' end) should improve selectivity, but reduce signal strength. Experimentation will produce the optimum aerial-connecting point. There will also be an optimum tapping point for the diode.

Finding optimum tapping points for the aerial and diode connections is a bit tricky on a close-wound coil since each tapping point tried has to be bared by scraping off the enamel insulation, with the risk of producing shorted turns. The same *effect* can be provided by removing, or adding, turns at each end of the coil, using the original tapping point for the diode connection–e.g. see Fig. 4.2. Unless the *total* number of turns on the coil remain the same, however, the inductance of the complete coil will be altered, and thus the tuning range of the tuned circuit (see later). Then the *diode* tapping point will be shifted.

For this type of experiment an air-cored coil of relatively large diameter is easier to use, wound on a card or paper tube to which two $\frac{1}{4}$ in.[2] lengths of hardwood or balsa strip have been cemented. The windings can be bared by scraping or sandpapering over this raised section, and individual wires carefully separated to avoid shorting–Fig. 4.3. Optimum tapping points can be established by pushing bared ends on the aerial- and diode-connecting wires into the raised section of the coil, soldering in place very carefully once they have been found. This should not result in shorting out more than a few turns at these points; which will not greatly modify the coil inductance if allowed for in the initial winding (e.g. add five or six turns to the design number of windings).

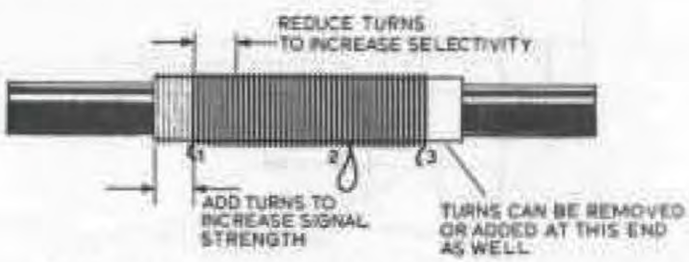


Fig. 4.2 The effective tapping point on a simple coil can also be varied by adding or removing turns on each end of the winding.

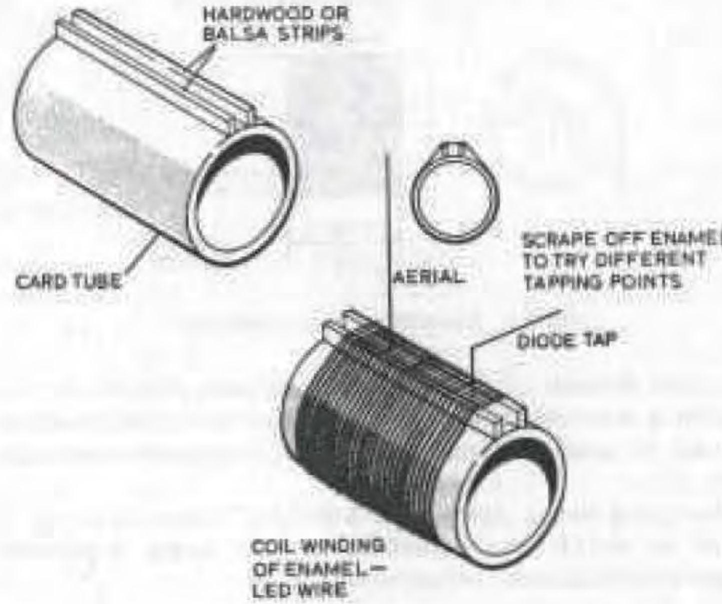


Fig. 4.3 Construction of an air-cored aerial coil.

In air-cored coils, the inductance can be calculated with reasonable accuracy from the diameter and number of turns (see also Fig. 4.4):

$$L, \text{ inductance, microhenries} = \frac{R^2 \times N^2}{9R + 10l}$$

where R = coil radius in inches,
l = coil length in inches,
N = number of turns.

The more usual form of this formula is:

$$N = \sqrt{\left(\frac{(9R + 10l) \times L}{R^2}\right)}$$

(A worked-out example using this formula is given later.) This is based on the turns of the coil being close-wound, in enamelled copper wire,

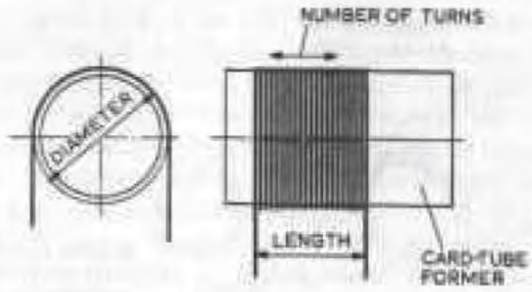


Fig. 4.4 Air-cored coil design parameters.

The actual diameter of the wire is not significant, provided the coil diameter is reasonably large (e.g. greater than 1 inch). The formula is not valid for smaller-diameter air-cored coils, or for coils wound on a ferrite rod.

The typical tuning capacitor has a rating of (about) 50 pF up to 350 pF or 500 pF. The relationship between tuning or *resonant frequency* and inductance and capacitance is:

$$\text{resonant frequency } (f) = \frac{1}{6.28\sqrt{(LC)}} \times 10^6 = \frac{0.16}{\sqrt{(LC)}} \times 10^6$$

where L = inductance in microhenries (μH),
C = capacitance in picofarads (pF).

This is more conveniently written as a solution for the *product* of inductance and capacitance required, i.e.

$$LC = \frac{0.025}{f^2} \times 10^{12}$$

For the medium waveband the range of frequencies to be covered is 500 to 1,500 kHz.* Thus, to encompass this range, the products of LC required are:

at 500 kHz

$$LC = \frac{0.025}{(500)^2} \times 10^{12}$$

$$= 0.001 \times 10^8 \text{ (approx.)}$$

* In the U.S.A. the AM broadcast band is from 530 to 1600 kHz.

at 1,500 kHz

$$LC = \frac{0.025}{(1{,}500)^2} \times 10^{12}$$

$$= 0.0001 \times 10^8 \text{ (approx.)}$$

At one end of the capacitor tuning range where $C = 50$ pF, inductance L required is:

$$\frac{0.001 \times 10^8}{\cancel{50}\ 500}$$

$$= 200\ \mu\text{H}$$

At the other end of the capacitor tuning range where $C = 500$ pF, inductance L required is:

$$\frac{0.0001 \times 10^8}{\cancel{500}\ 50}$$

$$= 200\ \mu\text{H}$$

Using a 1-in. coil diameter (0.5-in. radius) and a coil length of 1.5 in.

$$N = \sqrt{\left(\frac{(4.5 + 15) \times 200}{0.5^2}\right)}$$

$$= \sqrt{15{,}600}$$

$$= 125$$

In other words, a 125-turn air-cored coil of this size should be about right for covering the medium waveband, matching a 50–500 pF variable capacitor. Tapping point (or diode connection) would nominally be one-third of the coil length from the 'earthy' end.

Air-cored coils can also be designed in this way for long-wave coverage (more turns); or short-wave reception (less turns), which is not likely to be so good because of the low efficiency of the coils. Also, at higher frequencies the resistance of the *capacitor* is also significant, and so simple calculation of coil size is no longer valid.

The efficiency of a tuning coil can be expressed in terms of the magnification of the original signal received, when tuned to resonance, and decreases with increasing coil resistance. The magnification produced in a resonant circuit is referred to as the 'Q'; a high-Q coil is thus desirable for maximum performance and selectivity, and is essentially a low-resistance one. For this reason larger diameter air-cored coils, using thicker wire, are more effective than smaller diameter coils wound from thinner wire (since wire resistance increases with decreasing diameter).

Equally, the inductance of a wound coil can be increased by winding it over a magnetic-iron core, such as a ferrite rod. Much smaller diameter coils can be used, requiring less turns, to produce the inductance required—both reducing the length of wire and its resistance.

Because the actual inductance produced is dependent on the size and characteristics of the core material, windings for ferrite-rod aerials cannot be calculated, and are based on empirical results, or optimum windings established by trial and error.

Common sizes of ferrite rod available are:

¼-in. diameter	length 3¼ in.
5/16-in. diameter	lengths 4, 5, 6 and 8 in.
⅜-in. diameter	lengths 4, 5, 6, 8 and 10 in.

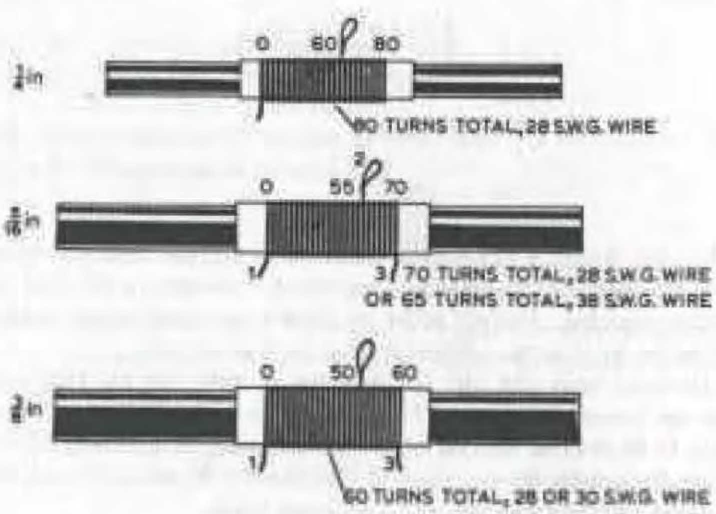


Fig. 4.5 Medium-wave aerial coil windings on three sizes of ferrite rod.

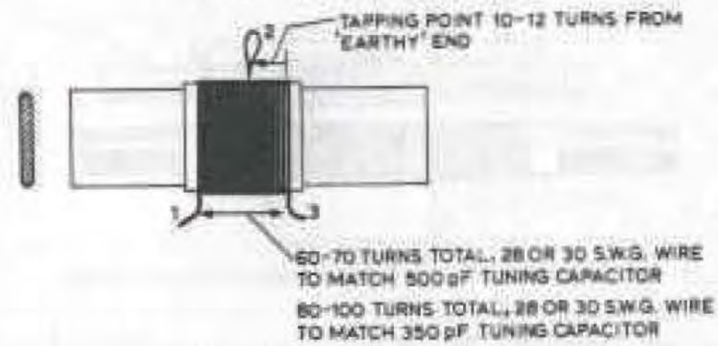


Fig. 4.6 Medium-wave winding for a ferrite slab.

A long length enables maximum adjustment of coil position (a way of 'trimming' the aerial) and, also, additional coils to be incorporated on the same rod, if the circuit needs them (e.g. for multi-waveband coils). But it is the diameter which really determines the winding specification.

Recommendations for medium-wave coil windings for these three standard ferrite-rod diameters are given in Fig. 4.5, all windings being enamelled copper wire. Normal tapping points are one-third from the 'earthy' end. It is a simple matter to experiment with different windings—e.g. adding more turns to extend the *wavelength* upwards (i.e. lower frequencies), or reducing the number of turns to extend the *wavelength* coverage downwards (i.e. for higher-frequency transmissions).

Ferrite-core material is also available in slab form, which is often easier to accommodate in a small receiver case. A typical ferrite-slab size is 2½ in. long by ¾ in. wide, with a thickness of ⅛ in. or less. A typical winding specification is shown in Fig. 4.6.

Generally, the long waveband should be covered by *doubling* the number of turns used for the medium waveband. *Reducing* the number of turns shifts the coverage out of the medium waveband down into the trawler band (80 m) and 'top-band' (160 m). For short-wave coverage very few turns indeed will be needed—perhaps less than half a dozen—and the optimum number can only be determined by careful experiment.

Separate coils for the various wavebands to be covered can be accommodated on the same ferrite rod and connected to a common tuning capacitor via a waveband switch—Fig. 4.7. This is the usual

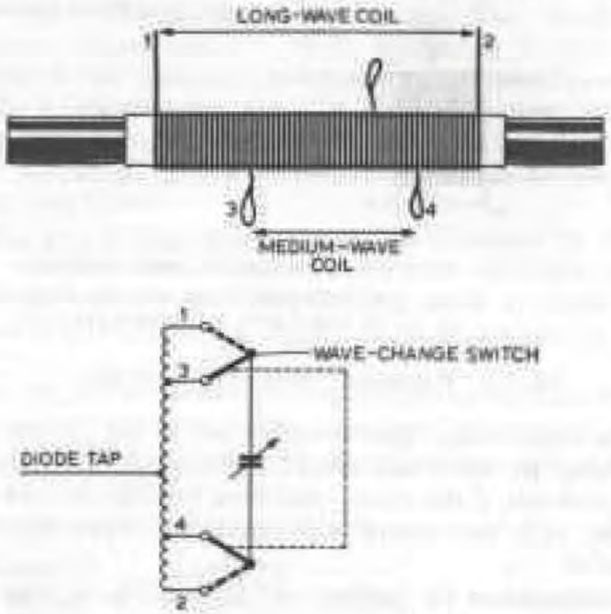


Fig. 4.7 Long- and medium-wave aerial coil connected to wave-change switch.

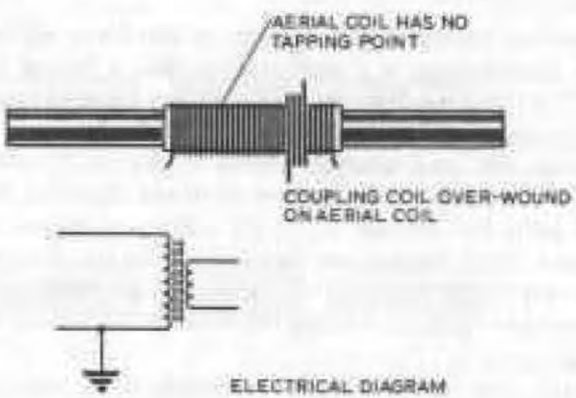


Fig. 4.8 Inductively-coupled aerial coil.

Fig. 4.9 'Loose' inductive coupling with separate coupling coil.

procedure with an elaborate receiver circuit and domestic radios, but is seldom satisfactory with the simpler circuits because of the tuned-circuit characteristics (i.e. the need for meticulous adjustment to get optimum results for any single waveband coverage).

All the coil constructions so far described are based on single windings (covering a specific waveband) with a tapping point for the output (diode connection in the case of simple receivers). The alternative form is to provide *inductive coupling* for the output in the form of an overwinding, which can comprise five or more turns of the same gauge wire used for the main winding–Fig. 4.8. The optimum number of turns for the overwinding depends on the degree of coupling required, which in turn is influenced by the characteristics of the following circuit. The position of the coupling coil can also affect the performance, although usually it is best positioned over the 'earthy' end

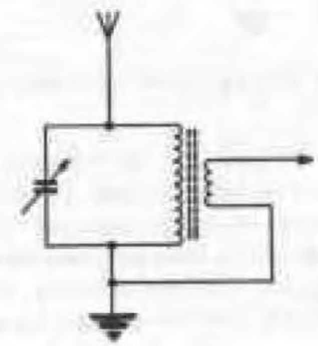


Fig. 4.10 Transformer coupling between tuned circuit and next stage of receiver.

of the main coil. Both number of turns and coupling-coil position are subjects for experimental adjustment to obtain optimum results.

Sometimes a coupling coil is wound on the ferrite rod, separate from the aerial coil, providing a 'loose' coupling–Fig. 4.9. Regenerative receivers often make use of this form of coupling for introducing 'feedback' into the front of the circuit (see Chapter 9).

Inductive coupling is also called *transformer* coupling, since the principle of passing current generated in one coil into another coil is the same. With transformer coupling (Fig. 4.10) the aerial coil has no tapping point, and is an alternative to direct coupling, where the next stage of the circuit is connected directly to a tapping point on the coil.

There is a third method of coupling which may be used between stages in a radio circuit–*capacity coupling*. Here, connection between the stages (e.g. to the tapping point on the aerial coil) is made through a capacitor, which isolates the two stages as far as d.c. flow is concerned (only a.c. will pass through the capacitor)–Fig. 4.11.

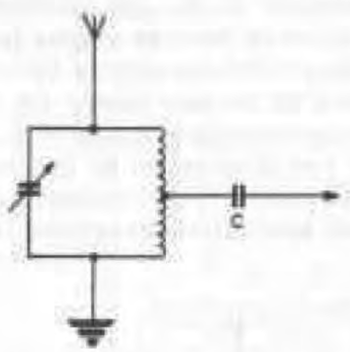


Fig. 4.11 Capacity coupling between tuned circuit and next stage of receiver.

Again the optimum value for the capacitor depends on the characteristics of the circuits being coupled. To couple an aerial coil to the next stage in a receiver, optimum values can vary from 200 pF to 10 μF. In general, though, a high value gives best results.

Direct, transformer, and capacity coupling are alternatives for connecting any two stages in receivers–not just the tuned circuit to the next stage.

5 AMPLIFIERS

It is a characteristic of a transistor that it works as an *amplifier* of signals. In the most widely used mode of connection of transistors for such duties with input and output circuits both connected to the emitter (common-emitter mode), the degree of amplification or current gain is called the 'beta' (β) of the transistor. This is given as h_{FE} (or static forward current ratio) in transistor characteristics data (see also Chapter 7).

A basic transistor amplifier circuit is very simple–and is identical for a p-n-p or n-p-n transistor, except for the battery polarity–see Fig. 5.1. Virtually any low-power AF transistor can be used in this circuit. The *bias resistor* (R) must have a value providing a collector current not exceeding the maximum specified rating for the transistor used, the actual current flowing in the collector circuit also being influenced by the voltage of the battery.

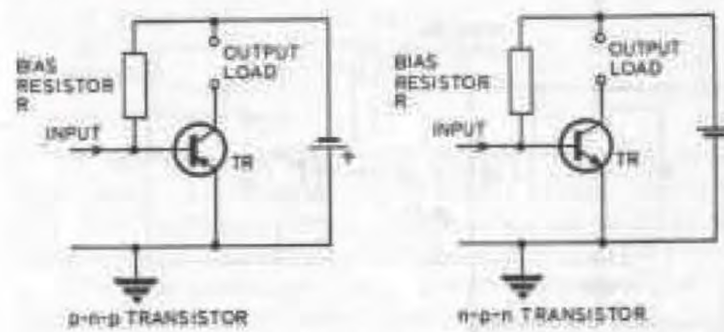


Fig. 5.1 Basic amplifier circuits with simple current biasing via a single resistor.

Knowing the transistor characteristics, a suitable value for R can be calculated as follows:

$$R = \text{gain} \times \frac{\text{battery voltage}}{\text{collector current}}$$

$$= h_{FE} \times \frac{\text{battery voltage}}{I_c}$$

where I_c is equal to, or preferably less than, the specification figure for I_c max.

Assuming that an OC72 transistor is being used, and the battery voltage is 9 V, specified figures are:

$$I_c \text{ max} = 250 \text{ mA}$$
$$h_{FE} = 30 \text{ to } 90$$

Taking the maximum gain, and 2.5 mA as a 'safe' working figure for the collector current:

$$R = 90 \times \frac{9}{0.0025}$$
$$= 324 \text{k}\Omega$$

A suitable (preferred-value) resistor would thus be 330k.

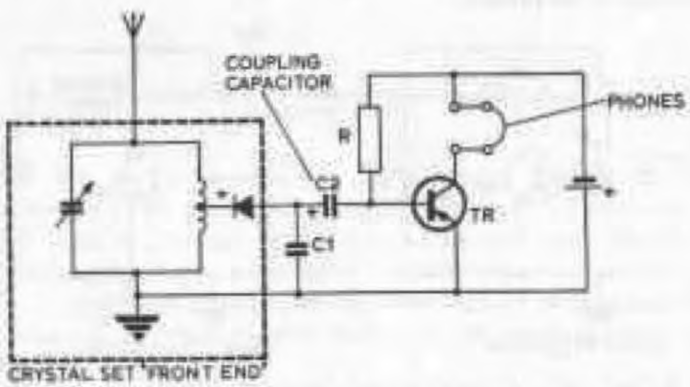


Fig. 5.2 *Circuit 5.* Crystal set with single stage of amplification. Any RF transistor can be used for TR.
AF

Fig. 5.2 shows the complete circuit for a simple AF amplifier of this type, coupled to the 'front end' of a basic crystal set. The detector (output) is coupled to the amplifier via capacitor C2, a suitable value for which would be 10 μF or higher (e.g. 20, 25, 30, 40 or 50 μF); capacitor C1 (0.001 μF) may not be necessary. The output load in the collector circuit is formed by high-impedance phones.

Note that the *polarity* of the battery used to power this circuit is important (as far as the transistor connection is concerned); also the connections to the *diode* and C2 (which will normally need to be an electrolytic type to provide the high-capacity value required). With an n-p-n transistor the battery polarity would be reversed; and also the diode and electrolytic capacitor connections.

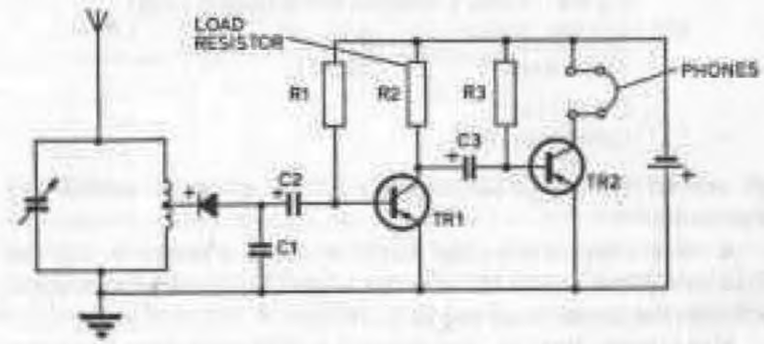


Fig. 5.3 *Circuit 6.* Crystal set with two stages of amplification. Component values matching OC71, OC72 or near equivalent for TR1 and TR2:

R1, 470 k — C1, 0.001 μF
R2, 4.7 k — C2, 8 or 10 μF
R3, 470 k — C3, 8 or 10 μF

Battery voltage 6 to 9 V.

The same type of circuit can be used to provide additional amplification, if required, simply by adding another amplifier stage (Fig. 5.3). The second amplifier stage can be identical to the first or based on a higher-power transistor taking the higher output present and providing even greater gain. The load in the output (collector) of the first amplifier stage is provided by a resistor (R2) (which should be about the same value as the phone resistance, 3.3 to 4.7 k), and the two stages coupled by a capacitor (C3). Value of R3 depends on the second transistor used, and may be anything from 47 Ω to 470 kΩ; capacitors

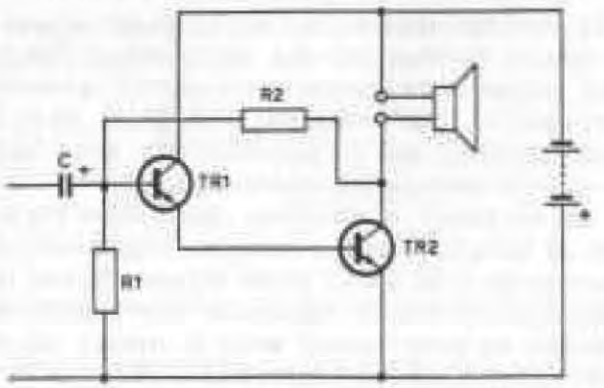


Fig. 5.4 *Circuit 7.* Amplifier for loudspeaker output

TR1, OC72 R1, 6.8 k
TR2, AD140 R2, 33 k

C, 8 or 10 μF
Loudspeaker, 80 Ω

C2 and C3 can be 10 μF or larger (20 μF up to 50 or 100 μF), electrolytic.

A more compact two-stage amplifier circuit is shown in Fig. 5.4. This may prove capable of operating a small 80 Ω loudspeaker direct, although the current drain will be quite high.

Alternatively, three or four stages of amplification using low-power transistors, following a basic 'front end' crystal set, should provide enough power to drive a small loudspeaker at the final output, through a suitable step-down transformer, to provide an impedance match (see Chapter 6).

Simple amplifier circuits of this type have the important limitation that performance of the transistor(s) will tend to vary with temperature. There is also the possibility of 'thermal runaway' developing, which can destroy the transistor(s), because as the external temperature increases the collector current also tends to increase, which in turn causes a further increase in junction temperature, so the effect is cumulative and goes from bad to worse, even to the point of ruining the transistor completely. It is possible to overcome this trouble by arranging for the circuit to be self-biasing or d.c. stabilized so that a constant operating collector current is provided, regardless of transistor type or temperature variations. In other words, the working point of the collector circuit is stabilized.

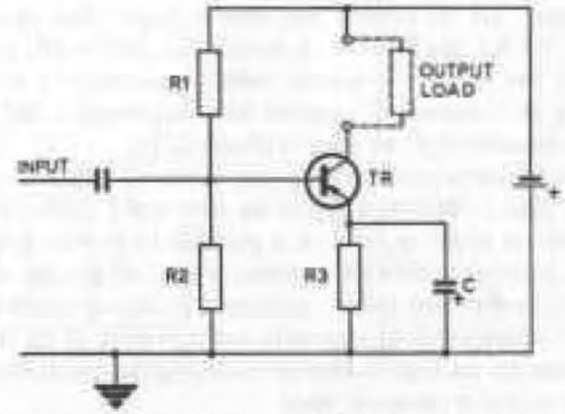


Fig. 5.5 Stabilized bias circuit for transistor amplifier stage. Typical values for low/medium-power transistors

R1, 22 k C, 8 or 10 μF
R2, 10 k
R3, 1 k

A further advantage of a stabilized circuit is that it makes the performance of the amplifier less dependent on the characteristics of individual transistors, which can differ appreciably even for the same type. Capacity coupling between stages should be used since this makes each stage independent as regards working, rather than inter-dependent.

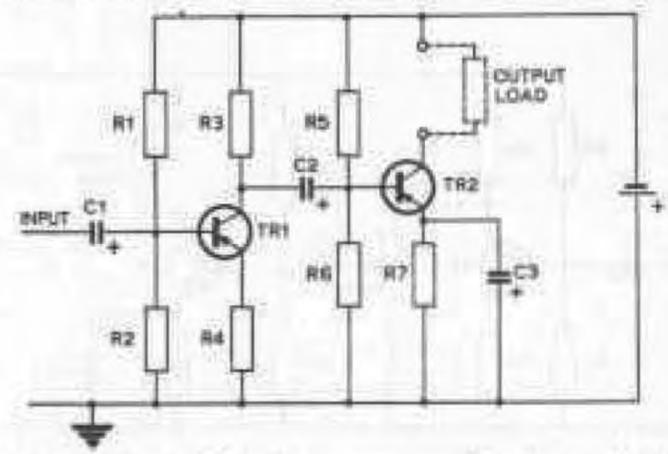


Fig. 5.6 *Circuit 8.* Practical two-stage amplifier using two low/medium-power AF transistors. (See Chapter 7 for determination of matching component values.)

To achieve this the original bias resistor is split into two separate values R1 and R2 (see Fig. 5.5). A further bias resistor (R3) is applied directly to the emitter, in parallel with a capacitor (C) to act as a by-pass for AF currents. (Transistor bias requirements, and data on transistor characteristics, are given in Chapter 7.)

A receiver design incorporating two stages of amplification with stabilized circuits following a crystal set front end is shown in Fig. 5.6. This, in fact, is about as far as it is practical to go with such a basic circuit as, although additional complete stages will provide more gain and greater final output power, deficiency in the circuit will also be aggravated–notably lack of sensitivity and selectivity in the front end. Such deficiencies are best tackled by modifying the circuit design from the simple 'crystal set detector' basis.

The amplifier stage(s) also provides a convenient point to insert a *volume control* into the receiver circuit. This takes the form of a potentiometer which can replace one of the bias resistors, or be placed in series with the flow of the current after the first stage of amplification–Fig. 5.7. This will introduce minimum distortion over the volume control range.

On low-power receivers which give satisfactory reception without an external aerial, a volume control can be an unnecessary refinement. Since the ferrite aerial has directional characteristics, merely turning the set one way and the other will produce changes in signal strength.

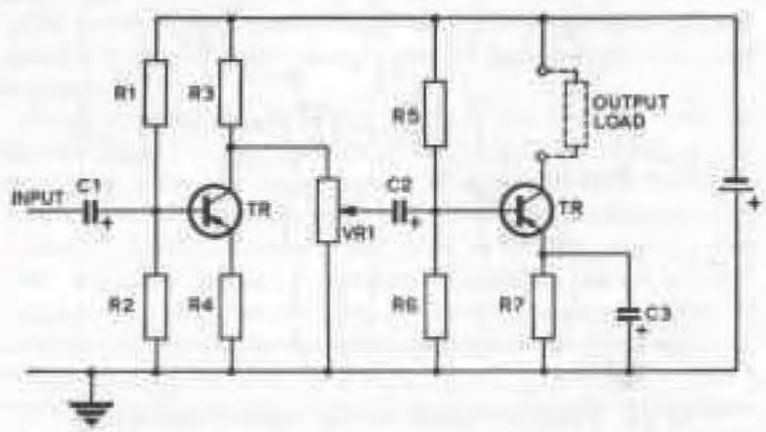


Fig. 5.7 *Circuit 9.* Two-stage amplifier with volume control.

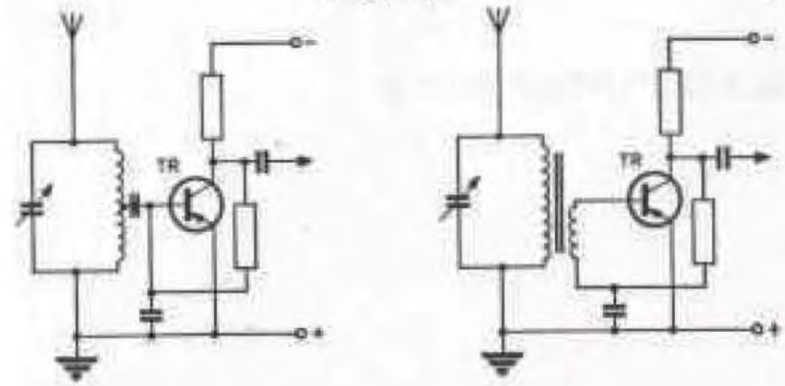


Fig. 5.8 Basic pre-amplifier circuits. The transistor (TR) must be an RF type; p-n-p transistors shown in these diagrams. If n-p-n transistors are used, the battery polarity must be reversed.

Pre-amplifiers

A pre-amplifier is designed to amplify signals between the tuned circuit and detector stages. The main difference is that the transistor(s) selected must be an RF type since it is handling RF signals at this stage. Otherwise the basic circuit is similar to that of an AF amplifier–see Fig. 5.8.

6 THE OUTPUT STAGE

By a suitable choice of transistors, the amplifier stages can be used to power a loudspeaker direct, using a minimum of components. A typical circuit of this type was shown in Fig. 5.4, using a high-gain AF transistor for TR1, and a power transistor for TR2. The main disadvantage of such a set-up is the relatively high current drawn by the circuit.

Single transistor outputs work with 'Class A' operation, which means that the values of bias and signal voltage applied to the transistor ensure that collector current always flows. Fig. 6.1 shows a basic Class A output circuit incorporating transformer coupling to a loudspeaker.

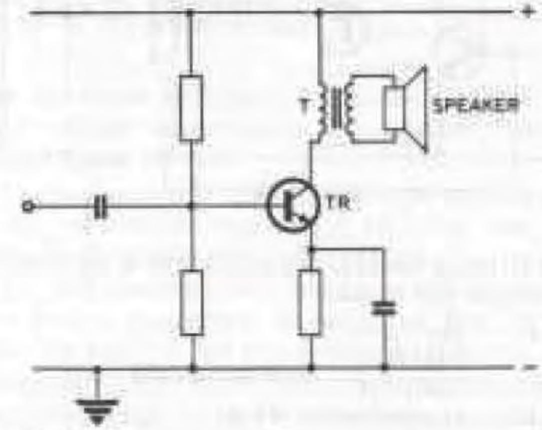


Fig. 6.1 Basic Class A output. TR is output transistor working as an amplifier. Loudspeaker impedance is matched to output load requirements via the step-down transformer T.

A more economic way of producing satisfactory output power is to employ a single transistor *driver* working a complementary pair of transistors (an n-p-n and a p-n-p selected with matched characteristics) in push–pull configuration. The output power obtained from a pair of transistors in push–pull is considerably more than double the power obtained from a single transistor of the same type. With 'Class B' operation the transistors are biased to nearly cut-off, so that only a marginal current flows under 'quiet' conditions. Push–pull outputs may, however, also be designed for 'Class AB' operation, with rather higher current drains.

Basically, distortion is lowest with Class A operation, whilst Class B operation provides the lowest current drain but introduces the

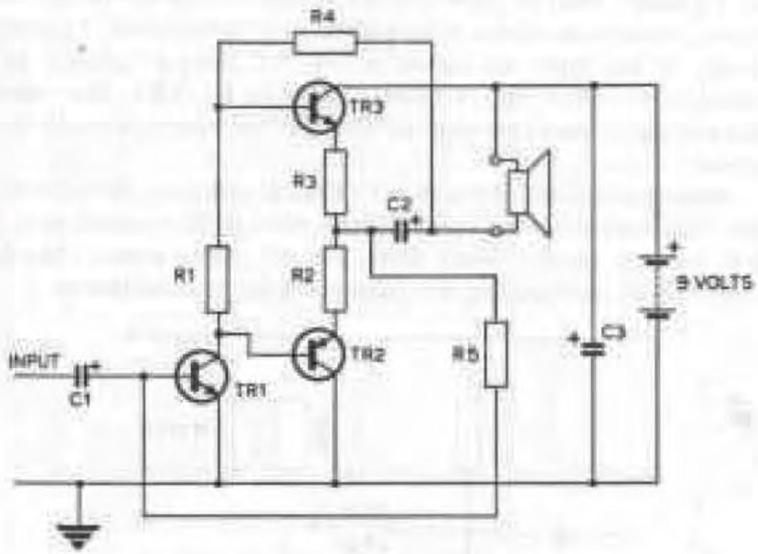


Fig. 6.2 *Circuit 10.* Push–pull output. TR1 is the driver, TR2, TR3 the push–pull amplifier.

R1, 68 TR1, OC72
R2, 1 TR2, OC81 } complementary pair
R3, 1 TR3, AC127 }
R4, 1 k Loudspeaker, 3 Ω or 8 Ω
R5, 56 k
C1, 5 μF
C2, 250 μF
C3, 50 μF

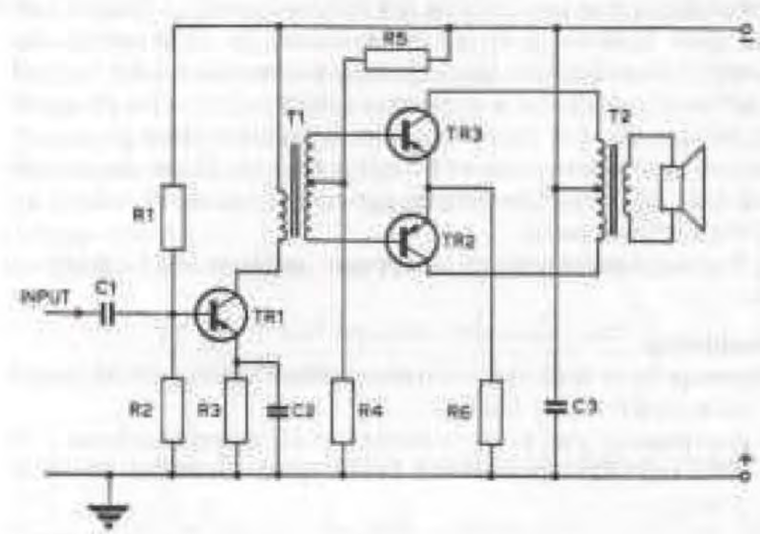


Fig. 6.3 *Circuit 11.* Push–pull output with transformer coupling. TR1 is the driver; TR2, TR3, AD140 or AD149. Typical component values:

R1, R2 to match TR1 (depending on type used)
R3, 1 k C1, C2, 50 μF
R4, 100 C3, 50 μF or 80 μF
R5, 4.7 k T1, coupling transformer
R6, 10 T2, output transformer

possibility of crossover distortion being present, which can be overcome by applying a slight forward bias to each transistor. Class AB offers a compromise between the two.

Two types of basic push–pull output circuits are shown in Figs. 6.2 and 6.3, one with direct coupling and the other using transformer coupling, both interstage (between driver and push–pull input) and to the loudspeaker. The coupling transformer can provide additional amplification; an output transformer, on the other hand, is invariably a step-down type to adjust the loudspeaker impedance to the required output impedance. Both types of circuits have their advantages and disadvantages, although for simpler receivers all-transistor circuits are usually preferred.

Much also depends on the requirements of the receiver. Thus to operate a small loudspeaker successfully an *audio power output* of 5 mW or better is required (higher still for larger speakers, of course). At the other extreme, about 10 μW represents, for most people, the threshold of audibility in high-impedance phones; and 0.1 mW a normal minimum for comfortable listening and ready identification of sounds in headphones. For easy listening with high-impedance phones, an audio output power of up to 0.5 mW is desirable. Higher signal levels will tend to 'swamp' headphones but can, of course, be reduced by fitting a volume control.

Typical characteristics of headphones, earpieces and loudspeakers are:

Headphones

High-impedance type, d.c. resistance 2,000–4,000 Ω; typical impedance 10,000 Ω (at 1 kHz).

Low-impedance type, (i) d.c. resistance 15 Ω, typical impedance 80 Ω (at 1 kHz); (ii) d.c. resistance 80 Ω, typical impedance 120 Ω (at 1 kHz).

Earpieces

High-impedance type, d.c. resistance 2,000 Ω; typical impedance 7,500 Ω (at 1 kHz).

Low-impedance type, (i) d.c. resistance 4 Ω, typical impedance 15 Ω (at 1 kHz); (ii) d.c. resistance 14 Ω, typical impedance 60 Ω (at 1 kHz); (iii) d.c. resistance 60 Ω, typical impedance 250 Ω (at 1 kHz).

Loudspeakers

Typical d.c. resistance 3 Ω; typical impedance 8–16 Ω.

It will be obvious from a study of these figures that low-impedance phones, a low-impedance earpiece, or a loudspeaker will be a mis-match

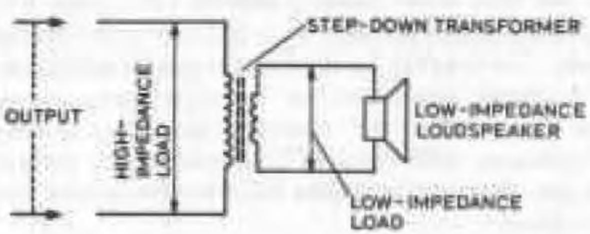


Fig. 6.4 Load balancing via output transformer.

for coupling to an output requiring a *high-impedance load* (as in the case of most of the simple all-transistor output circuits).

To employ low-impedance phones, earpiece or a loudspeaker with an output requiring a high-impedance load, a matching step-down transformer (output transformer) must be used. The primary of the transformer then provides the required output load, indirectly coupled to the secondary to which is connected the low-impedance phones or speaker–Fig. 6.4.

The turns ratio required from the transformer is easily calculated as:

$$\sqrt{\left(\frac{\text{output load impedance required in ohms}}{\text{phone or speaker impedance in ohms}}\right)}$$

Some typical transformer ratios and their suitability for matching are:

Ratio	Listening device	Equivalent output load impedance (Ω)
41:1	8-Ω Speaker	15,000
35:1	4-Ω earpiece	5,000
30:1	8-Ω Speaker	7,000
18:1	14-Ω earpiece	5,000
14:1	15-Ω earpiece	2,000
9:1	60-Ω earpiece	5,000
5:1	80-Ω headphones	2,000

For other required output load impedances, the turns ratio can be calculated from the formula.

Tone controls

The output voltage after amplification will only be a faithful reproduction of the original input if the amplifier produces the same gain for all signals, whatever their frequency and complexity. This is seldom the case with simple circuitry, so that the balance of the original sound or speech is upset and distortion results. If the gain is inadequate at low frequencies, the sound reproduced will tend to be tinny or harsh; conversely, if the gain is inadequate at the higher frequencies the sound is subject to booming.

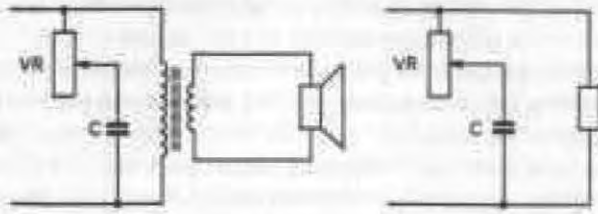


Fig. 6.5 Simple tone controls.

An adequate measure of tone control can be realized by connecting a variable resistance (potentiometer) and fixed capacitor in series across the primary terminals of the output transformer; or directly across the speaker, as shown in Fig. 6.5.

This, in effect, forms another tuned circuit, the resonant frequency of which can be altered by adjusting the setting of the potentiometer to favour or raise the treble or bass in the output signal by, effectively, additional amplification. The tone control on a domestic receiver is usually of this form–the knob controlling a potentiometer connected in series with a fixed capacitor across the output transformer. Typical values used are: potentiometer, 0–5 k; fixed capacitor, 0.1 μF.

7 TRANSISTORS, BIAS AND STABILIZATION

The two conventional bias arrangements for transistors are shown in Figs. 7.1 and 7.2, both having advantages and disadvantages. Current bias is the simpler of the two, since it requires only one resistor which determines the values of the base current I_B and the operating or emitter current I_E, viz:

$$I_B = \frac{V_S - V_{BE}}{R}$$

$$I_E = \frac{V_S - V_{BE}}{R}(1 + h_{FE})$$

V_{BE}, the base-emitter voltage, is of the order of 0.1 to 0.2 V for germanium transistors, 0.6 to 0.7 V for silicon transistors. In normal practice there will be negligible change in current with variations of V_{BE}, but will be dependent on the spreads of h_{FE} (the small signal

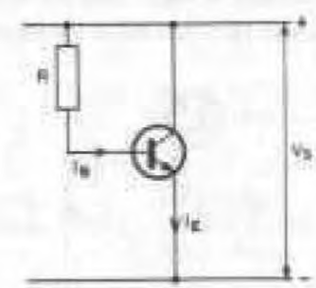


Fig. 7.1 Simple current bias circuit.

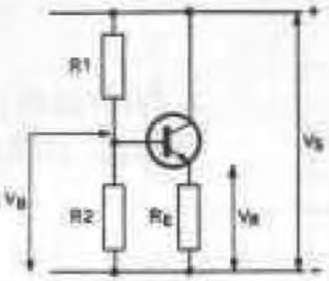


Fig. 7.2 Conventional voltage bias circuit.

forward current ratio of the transistor). Thus simple current biasing is most suitable for transistors which have only narrow h_{FE} spreads.

Voltage biasing with emitter feedback yields the following voltage relationships (see also Fig. 7.2):

$$V_B = \frac{R2 \, . \, V_S}{R1 + R2}$$

$$V_E = \frac{R2 \, . \, V_S}{R1 + R2} - V_{BE}$$

The emitter current is therefore:

$$I_E = \frac{R2 \, . \, V_S}{R_E(R1 + R2)} - \frac{V_{BE}}{R_E}$$

For the effect of spreads to be negligible the voltage V_E must be large compared with changes in V_{BE}. Also, R_E must be large if changes in emitter current I_E, due to variations in the supply voltage V_S, are to

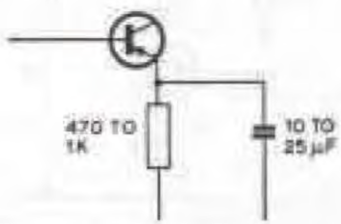


Fig. 7.3 Stabilization, with common component values used.

be kept small. In practical circuits a voltage drop (V_E) of 1 V with germanium transistors and 3 V with silicon transistors is aimed at.

The collector-to-base leakage current is a major factor contributing to the shift in operating point of a transistor, since this is highly sensitive to temperature. Thus bias stabilization is normally desirable with germanium transistors, the usual arrangement being as shown in Fig. 7.3. Silicon transistors have negligible leakage current, even over their full working temperature range, and stabilization is not necessary, except in some cases where other characteristics developed in the particular circuit may make it a prudent addition.

Working characteristics of a number of readily available transistors are summarized in the following tables. Data on other types are available from the manufacturers; also in many suppliers' catalogues.

Germanium Transistors

p-n-p low power

	OC41	OC42	OC70	OC72	OC75	OC81	OC81D
V_{cbo} max.	16	16	30	32	30	32	32
V_{ceo} max.	15	15	30	32	30	32	16
V_{eb} max.	12	12	10	10	10	10	10
I_c max. mA	150	125	50	250	100	500	250
P_t max. mW	84	83	125	125	150	240	200
h_{FE} (h_{fe})	20–80	40 min.	20–40	30–90	60–120	50–250	20 min.
@I_c mA	50	50	0.5	80	1	50	2
I_{cbo} max. μA	30	30	5	15	10	10	10
@V_{cb}	15	15	15	10	4.5	10	10
V_{ce} sat. max.	0.2	0.2	0.21	0.25	0.21		
@I_c/I_b mA	50/3	50/1.5	9/0.5	125/12.5	9/0.5		
f_T min. MHz	3	5.5	1 typ (fhfb)	1 typ	1 typ (fhfb)	1 typ (fhfb)	1 typ (fhfb)

Small, medium current switching, AF amplifiers n-p-n

	2N1302	2N1304	2N1306	2N1308	ASY28	ASY29	NKT713
V_{cbe} max.	25	25	25	25	30	25	30
V_{ceo} max.	25	20	15	15	15	15	30
V_{eb} max.	25	25	25	25	20	20	15
I_c max. mA	200	200	200	200	200	200	500
I_c peak mA	300	300	300	300	300	300	
P_t max. mW	150	150	150	150	150	150	150
h_{FE}	20 min.	40–200	60–300	80 min.	30–80	50–150	50–150
@ I_c mA	10	10	10	10	20	20	50
I_{cbo} max. µA	6	6	6	6	35	35	15
@ V_{cb}	25	25	25	25	30	25	10
V_{ce} sat. max.	0.2	0.2	0.2	0.2	0.25	0.25	0.15
@ I_c/I_b mA	10/0.5	10/0.25	10/0.17	50/2	50/2	50/1.25	50/5
f_T typ. MHz	10	15	20	30	14	20	1 (fhfb)

Audio frequency amplifiers, low power output, n-p-n

	NKT773	AC127	AC176	AC176K	AC187K
V_{cbo} max.	15	32	32	32	25
V_{ce} max.	15	32	20	20	15
V_{eb} max.	5	10	5	5	10
I_c max. mA	300	500	300	300	1000
P_t max.	150	200	700	1000	1000
h_{FE}	50–250	25–143	52–180	52–180	100–500
@ I_c mA	50	500	500	500	500
I_{cbo} max. µA	15	10	100	100	15
@ V_{cb}	10	0.5	25	25	10
V_{ce} sat. max.		1.0	0.6	0.6	
@ I_c/I_b mA		500/50	500/10	500/10	
f_T min. MHz		1.5	1.0	10	1.0

High power output, p-n-p

	NKT403	NKT404	NKT405	AD140	AD142	AD149	AD150
V_{cbo} max.	80	60	60	55	80	50	32
V_{ceo} max.	32	32	32		50	30	30
V_{eb} max.	40	20	20	10	10	20	10
I_C max. A	10	10	5	3	10	3.5	3.5
P_t (θ°C) W	50(25)	50(25)	50(25)	36(37)	30(55)	22(50)	22(50)
h_{FE}	50–150	50–150	100–200	30–100	30–170	30–100	30–100
@ I_c A	1	1	1	1	1	1	1
I_{cbo} max. µA	150	150	150	100	5000	350	1000
@ V_{cb}	30	30	30	14	80	14	30
V_{ce} sat. max.	0.42	0.42	0.42		0.3		
@ I_c/I_b A	1/0.1	1/0.1	1/0.1		5/0.25		
f_T typ. MHz	0.35	0.35	0.35		0.45	0.5	0.45

Silicon transistors

Audio frequency amplifiers, small signal, general purpose, n-p-n

	2N3708	2N3709	2N3710	2N3711	2N3904	2N4124
V_{cbo} max.	30	30	30	30	60	30
V_{ceo} max.	30	30	30	30	40	25
V_{eb} max.	6	6	6	6	5	5
I_c max. mA	30	30	30	30	100	200
P_t max. mW	250	250	250	250	310	310
h_{FE}	45–660	45–165	90–330	180–660	100–300	120–360
@ I_c mA	1	1	1	1	10	2
I_{cbo} max. µA	0.1	0.1	0.1	0.1	0.1	0.05
V_{ce} sat. max.	1	1	1	1	0.2	0.3
@ I_c/I_b mA	10/0.5	10/0.5	10/0.5	10/0.5	10/1	50/5
f_T typ. MHz					200	300 min.

Audio frequency amplifiers, low level, low noise, n-p-n

	2N2484	2N2924	2N2925	2N2926	2N4286	2N5088
V_{cbo} max.	60	25	25	18	30	35
V_{ceo} max.	60	25	25	18	25	30
V_{eb} max.	6	5	5	5	6	3
I_c max. mA	50	100	100	100	100	50
P_t max. mW	360	200	200	200	250	310
h_{FE}	100–500	150–300	235–470	35–470	100 min.	300–900
@I_c mA	0.01	2	2	2	0.01	0.1
I_{cbo} max. µA	0.01	0.5	0.5	0.5	0.05	0.05
Noise factor dB	3 max.	2.5 typ.	2.5 typ.	2.5 typ.		3 max.
f_T typ. MHz	60 min.	120	120	120	280	50 min.

8 TRF RECEIVERS

The tuned radio frequency (TRF) receiver is based on 'double tuning'–one before and one immediately after the pre-amplifier or RF amplifier, as shown in the block diagram of Fig. 8.1. The two tuned circuits are literally identical and, in fact, are usually 'ganged' together, using twin variable condensers and adjusted by a single control knob (although the respective circuits are wired to the separate electrical parts of the two-part condenser–see Fig. 8.2).

To provide *complete* matching of these two tuned circuits, the two separate variable condensers are individually adjusted with the aid of smaller 'trimming' capacitors mounted in parallel with them. Similarly, the inductances of the two tuning coils completing the respective tuned circuits can be matched for identical performance by winding on coil formers with iron-dust cores. In this manner small differences in the actual wiring up of the two tuned circuits, and in effective component values, can be balanced out for optimum performance. This, in fact, is a necessary process in setting up or *aligning* the complete receiver for best performance, and can be done quite satisfactorily on a trial-and-error basis.

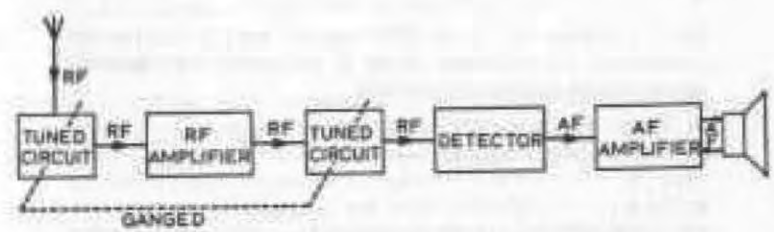


Fig. 8.1 Block diagram of a tuned radio frequency (TRF) receiver.

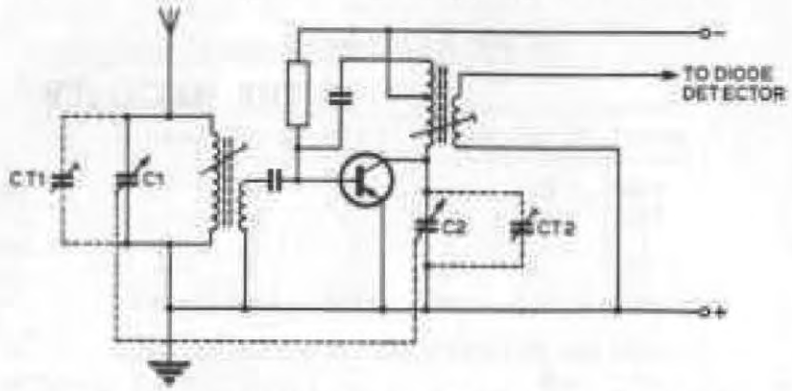


Fig. 8.2 Double-tuned circuit with RF amplifier–the 'front end' of a TRF receiver.

A simple one-transistor TRF receiver circuit is shown in Fig. 8.3. Alignment difficulties are minimized by employing a proprietary coil L1, L2, L3 for TRF working, eliminating the need for ganged tuning

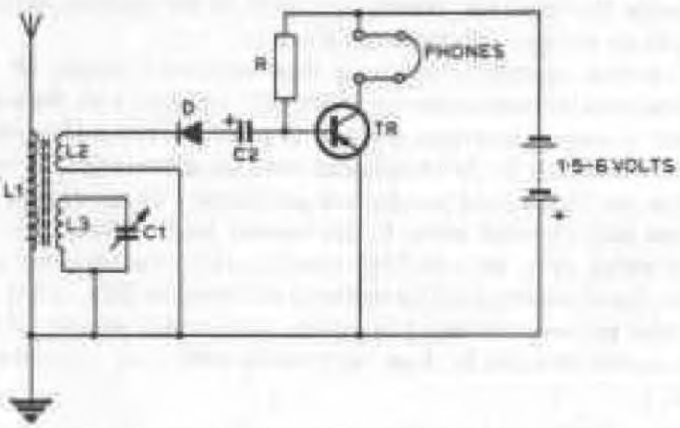


Fig. 8.3 *Circuit 12.* Basic TRF receiver using a minimum of components. An interesting circuit to experiment with against a crystal set with transistor amplifier(s).

L1, L2, L3, proprietary TRF coil (Teletron type HAX)
C1, 500 pF variable capacitor (Jackson)
C2, 2 µF
R, 220 k
TR, OC70, OC71, or any AF transistor (value of R to be adjusted to match higher power transistors)

capacitors with separate trimmers. It is an interesting circuit to experiment with and compare the performance against that obtained from a basic crystal set with one stage of amplification added. It should be superior, but like the crystal set will require an efficient external aerial and good earth connections before satisfactory listening volume is obtained in most areas.

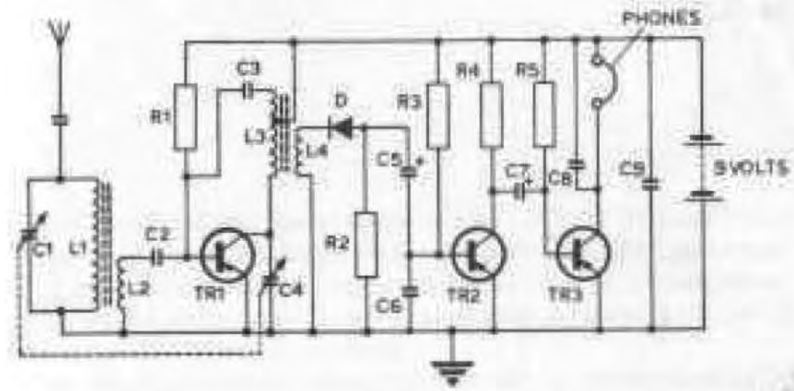


Fig. 8.4 *Circuit 13.* Three-transistor TRF receiver. Using higher power AF transistors (TR2 and TR3), this design could operate a loudspeaker instead of phones.

C1, C4, ganged tuning condenser (Jackson, 500 pF)

C1, 0.01 µF	R1, 1 MΩ
C3, 15 pF	R2, 10 kΩ
C5, 8 µF electrolytic	R3, 1 MΩ
C6, 0.01 µF	R4, 4.7 kΩ
C7, 8 µF electrolytic	R5, 1 MΩ
C8, 0.005 µF	TR1, OC45
C9, 100 µF, 12 volt working	TR2, OC71
	TR3, OC71

L1, L2, standard ferrite aerial windings (see Chapter 4)
L3, 50 turn coil on ferrite rod with centre tapping
L4, 10 turns
D, any crystal diode

L3, L4 can be wound exactly as L1, L2, except that the 50-turn winding has a centre tap. A short length of ferrite rod should be used for the core, L3, L4 being wound on a paper sleeve so that the rod can be slid in and out for adjustment purposes.

Important. Coil L3, L4 will need screening from L1, L2 and associated components. This can be done with thin aluminium sheet, suitably fitted around L3, L4.

Performance can be improved by using a higher power transistor for amplification, and/or adding a further stage or two of amplification. This follows along the same lines as for other receivers–see Chapter 5.

A rather more elaborate TRF circuit, but again using low-power transistors, is shown in Fig. 8.4. This uses a standard ferrite rod aerial with inductive coupling (see Chapter 4), and a ganged tuning capacitor for C1, C4.

9 REGENERATIVE AND REFLEX RECEIVERS

In the crystal set, and similar simple receivers, a weak RF signal in the aerial is fed directly to the detector, and the extracted AF signal amplified to the required level to operate headphones or a loudspeaker. However, no amount of AF amplification *after* detection is effective if the original RF strength is too small.

An obvious method of improving this state of affairs would be to amplify the RF signal picked up by the aerial and tuned circuit *before* passing to the detector. This is quite a practical arrangement, the immediate advantages being an improvement in both *sensitivity* and *selectivity*, and also *quality* of reproduction. Improved sensitivity means that weaker (more distant) stations can now be received at greater volume; better selectivity means that sharper tuning can be obtained, a necessity to eliminate interference from adjacent stations now more readily picked up.

Quality is improved because there is less demand for AF amplification, while the output power can readily be boosted to operate a loudspeaker without putting any particularly high demands on either the efficiency of the aerial system or the AF amplifier stages.

An elementary circuit of this type is shown in Fig. 9.1, using a single transistor as a pre-amplifier, followed by a diode detector. This is easy to build and should work quite well in most areas, although still almost certainly requiring a good external aerial and earth connections for the best results, and must be used with an *inductively coupled* tuned circuit.

There is, however, a method of considerably improving the performance of this set by incorporating *regeneration*. This is done by taking part of the amplified signal and feeding it back into the tuned

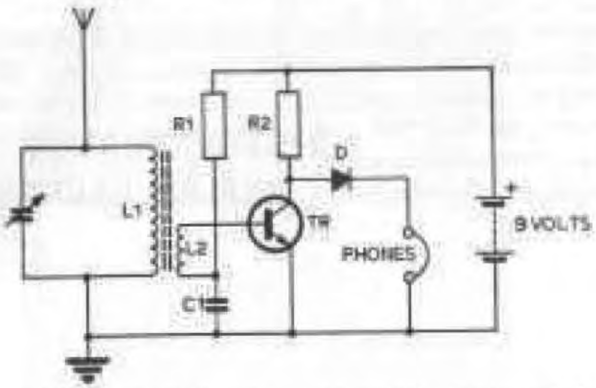


Fig. 9.1 *Circuit 14.* Single-transistor receiver with pre-amplifier. TR, 2N2926 (or equivalent). Matching component values:

C1, 0.01 μF
R1, 1 MΩ
R2, 2.2 k
L1, L2, inductively coupled aerial coils
D, any crystal diode

circuit, where it will be amplified again, resulting in a further improvement in selectivity and sensitivity. Care should be taken that not too much signal is fed back, causing the circuit to become unstable and oscillate or 'squeal'.

This modification is shown in Fig. 9.2. One length of insulated wire

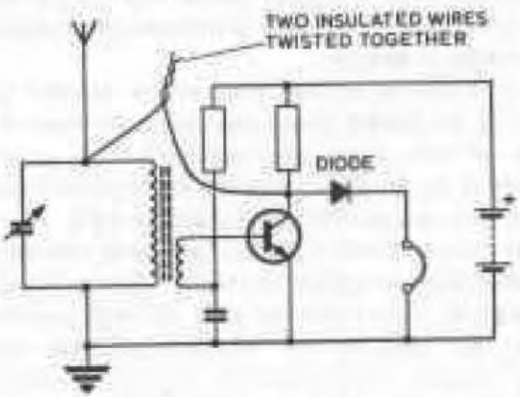


Fig. 9.2 *Circuit 15.* The design of Fig. 9.1 converted to regenerative working. The twisted wires can be replaced by a 10-pF or 20-pF trimmer capacitor.

is connected to the front end of the diode, another to the top end of the tuned circuit. The free ends of these two wires are then twisted together over a length of about half an inch.

This, in effect, provides a capacitive coupling for the feedback signal where the actual amount of feedback can be varied by twisting the wires more tightly together, or untwisting part of their length. The optimum amount of 'twist' can be determined by experiment, when the final performance should be considerably better than that of the original circuit. However, the *position* of the twisted wire coupling relative to other components is critical; any slight disturbance can considerably modify the performance or cause the receiver to oscillate.

For a more stable arrangement, a 10-pF or 20-pF trimmer capacitor can be used instead of twisted wires to provide the feedback coupling, adjusted for optimum results.

If the set does not work with 'regeneration', or the results are poorer than the original circuit, then the feedback is probably 'negative' rather

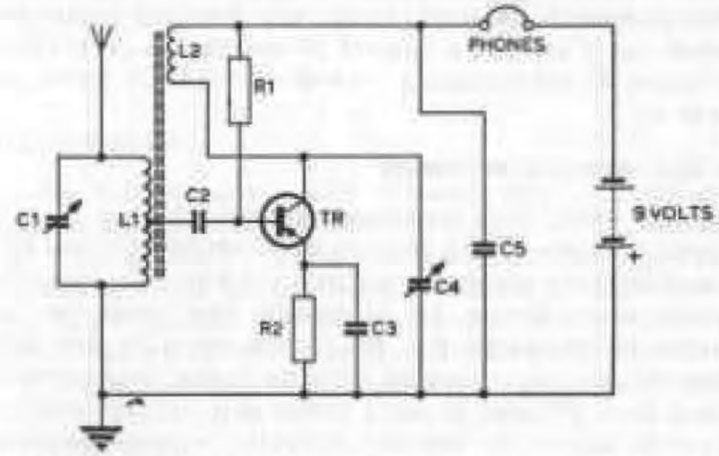


Fig. 9.3 *Circuit 16.* Simple regenerative receiver with inductively coupled feedback

TR, OC42 (or equivalent)
C1, 500-pF tuning capacitor
C2, 220 pF to 0.1 μF (find best value by experiment)
C3, 2 μF to 8 μF
C4, 500-pF variable capacitor
C5, 10 μF
R1, 1 M to 4.7 M (find best value by experiment)
R2, 3.3 k

than 'positive'. Reversal of the coupling-coil connections should correct this.

An even better arrangement is to use *inductive* rather than capacitive coupling for the feedback, which can be done by winding a feedback coil on the same ferrite rod as the aerial coil. A suitable feedback coil is made by winding 8 turns of 38-s.w.g. wire on a similar paper sleeve to the tuning coil, so that the finished coil can be slid up and down the ferrite rod. The degree of coupling can then be adjusted by sliding this feedback coil up and down the rod to arrive at a position which gives optimum results.

The circuit is also modified somewhat, as shown in Fig. 9.3, to include a variable capacitor connected to the transistor collector to control the amount of reaction or regenerative feedback. If the set does not oscillate with this variable capacitor adjusted to *minimum* capacity (i.e. vanes fully closed) then the feedback coil must be reversed on the ferrite rod (alternatively reverse the coil connections to the rest of the circuit).

This particular circuit can also be used as the 'front end' of a receiver to which one or two further stages of AF amplification can be added (see Chapter 5); and terminating in a push–pull output if desired (see Chapter 6).

The super-regenerative receiver

The limit to which ordinary regenerative amplification can be carried is the point at which oscillation starts, so the RF amplification (and thus the sensitivity) of a regenerative receiver is limited by this factor. The super-regenerative receiver is a development which overcomes this limitation by introducing into the detector circuit an alternating voltage, of a frequency somewhat above the audible range (typically between 20 to 100 kHz), in such a manner as to vary the operating point of the detector. In effect, this interruption or *quench* frequency switches the detector (originally adjusted to be near the point of oscillation) in and out of operation. The time taken for the RF oscillations to build up to their peak will be proportional to the original modulated signal (i.e. the RF signal picked up by the aerial), and by arranging for these to be quenched before they can reach their peak, extremely high amplification is possible–equivalent to a gain of over one million in a single stage in certain cases.

On this basis, the circuit is ideal for increasing the sensitivity of a receiver in a relatively simple manner. However, both the design

requirements and adjustment are somewhat critical, but more advanced and detailed treatment of these is beyond the scope of this book. The super-regenerative receiver, too, is not particularly suited for the reception of normal broadcast frequencies. The circuit requires a ratio of signal frequency to quench frequency of the order of 1,000:1 or greater, which means that for a broadcast signal of 500 kHz the quench frequency must be of the order of 500–1,500 Hz, or in the audio band. A further limitation is that, as they are continually oscillating, they will cause interference on other receivers in the neighbourhood–although this effect can be minimized by suitable circuit design.

A further variation, which is even less suitable for lower radio frequencies but again is capable of giving excellent results with very high frequencies, is the self-quenching super-regenerative receiver. In this case, as the name implies, the super-regenerative detector supplies its own quench frequency. The frequency of these quench oscillations depends on the feedback and the 'time constant' of the circuit, the time between each burst of oscillation varying as the input signal varies. The action of the oscillations is said to be a blocking or 'squegging' effect.

Reflex receivers

A reflex circuit works on a rather different principle. Here the *audio frequency* signal following the detector is fed back into a pre-amplifier stage, the complete circuit shown in block diagram form in Fig. 9.4 also providing RF and AF amplification. It looks a more complicated circuit involving a considerable number of components but, in fact, a *single* transistor can be made to perform the work of RF and AF amplifier.

Fig. 9.5 shows a basic single-transistor reflex circuit which is fairly non-critical and should be easy to operate satisfactorily; this is actually a three-stage circuit.

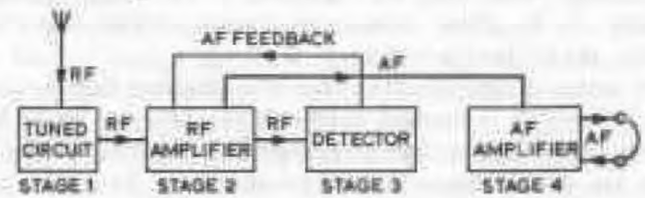


Fig. 9.4 Block diagram of a four-stage reflex receiver.

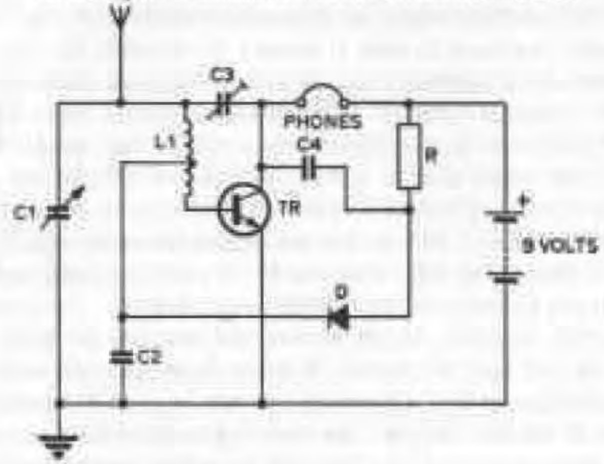


Fig. 9.5 *Circuit 17.* Single-transistor three-stage reflex receiver.

L1, standard aerial coil with tapping point
C1, 500-pF variable capacitor
C2, 0.05 μF
C3, 10 pF or 20 pF
C4, 1,000 pF
R, 1 M
TR, 2N2926

A rather more conventional design is shown in Fig. 9.6; the 'front end' of this circuit comprises the tuned circuit feeding an RF amplifier stage. In this type of circuit the tuning coil must be inductively coupled. The output from the RF amplifier employs what is known as *choke capacitance* coupling, a radio-frequency choke coil (RFC) being used to ensure an adequate load impedance for RF currents without having a d.c. voltage drop (i.e. offering high resistance to RF but low resistance to d.c.). The use of this choke coil also means that the gain of the amplifier varies with the frequency of the input, because the reactance of the choke varies with frequency. This effect is not desirable, but is tolerable in this type of circuit.

The output of amplified RF is fed from this stage into the detector stage. A feedback is arranged as follows: the AF signal passed by the detector, plus a little residual RF appearing at this point, is passed back to the base of the transistor in the previous stage, the AF being little affected by the capacitor C7. However, any RF is heavily attenuated or reduced, thus the transistor is made to perform the additional function

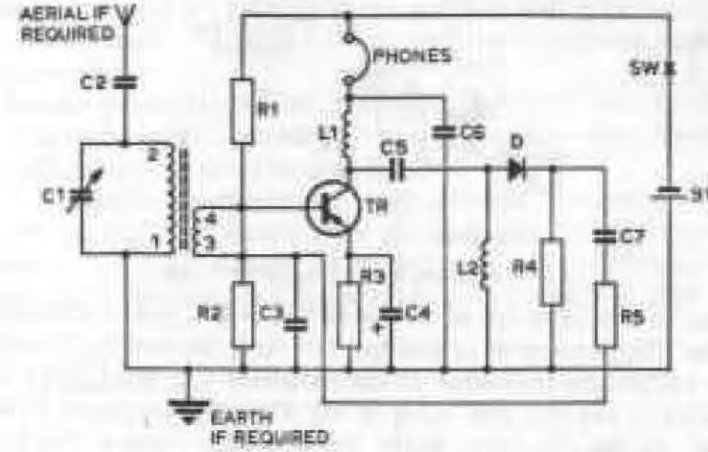


Fig. 9.6 *Circuit 18.* Single transistor three-stage reflex receiver with choke capacitance coupling.

C1, 100-500 pF	R1, 22 kΩ
C2, 220 pF	R2, 4.7 kΩ
C3, 0.01 μF	R3, 3.3 kΩ
C4, 32 μF/1.5 V	R4, 22 kΩ
C5, 47 pF	R5, 1 kΩ
C6, 0.005 μF	D, diode
C7, 10 μF/3 V	TR, OC42

L1 and L2, RFC (choke coils) (see text)

of an AF amplifier. By choosing a suitable value for C7 a low reactance to RF is assured, but a high reactance to AF. For example, a 0.01 μF capacitor has a reactance of 30 Ω at 500 kHz, increasing to 3,000 Ω at 5 kHz. If 5 kHz represents the *upper* limit of AF signals likely to be encountered, reactance will become proportionately higher at lower audio frequencies. Conversely, for radio frequencies above 500 kHz the reactance will decrease proportionately.

Specification for the RFC is 1 or 1.5 millihenries (mH). A suitable coil can be made by winding on a standard ¼-in. diameter coil former, using 38-s.w.g. enamelled wire. Cut two ¾-in. diameter cheeks from thin Paxolin or similar insulating material to fit together on the coil former, spacing them ⅛ in. apart–Fig. 9.7. The space between the cheeks is then completely filled with a winding of 38-s.w.g. insulated wire, winding on one layer with turns adjacent, then a second layer over the top, and so on until the coil has built up to the same diameter as the cheeks. The coil windings can be held with a wrapping of cellulose tape and the ends

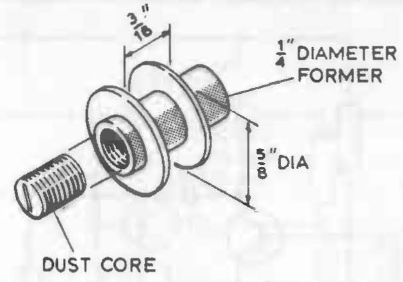


Fig. 9.7 Coil former for winding the RFC coils.

should be secured to one of the cheeks with sealing wax or something similar. The provision of an iron-dust core to fit the centre of the coil core enables the inductance of the completed coil to be varied by screwing in and out, thus taking up any differences introduced in the actual winding; in other words, the dust core forms a trimming adjustment.

All the other components used are familiar, standard types. High-impedance headphones, or a high-impedance magnetic type earpiece must be used with this circuit.

The same circuit can be modified for regenerative working as well (regenerative-reflex receiver), simply by connecting a 10-pF trimmer

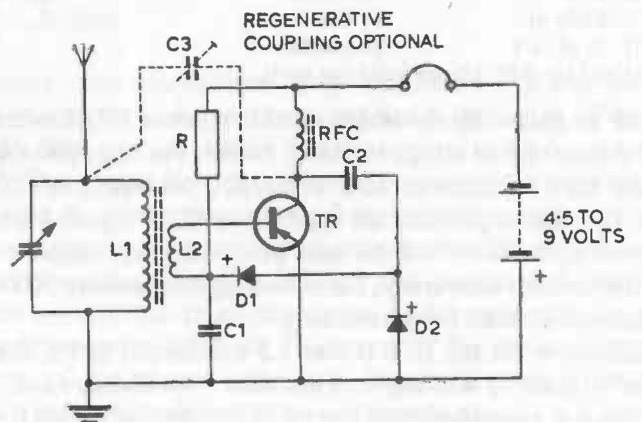


Fig. 9.8 *Circuit 19.* Single-transistor reflex receiver using two diodes.

C1, 0.01 μF	TR, OC44 (or equivalent)
C2, 220 pF	
C3, 20 pF	
R, 100 k	

capacitor between the collector of the transistor and the 'hot' end of the tuned circuit. This capacitor is adjusted to give optimum regenerative coupling.

In areas where radio reception is generally good, either circuit (reflex or regenerative-reflex) if assembled correctly should give good listening strength without the use of an external aerial.

It is possible to simplify the single-transistor three-stage reflex receiver by using two diodes in the circuit instead of one. A typical circuit of this type is shown in Fig. 9.8. Again the circuit may be converted to regenerative-reflex working by connecting a 10-pF or

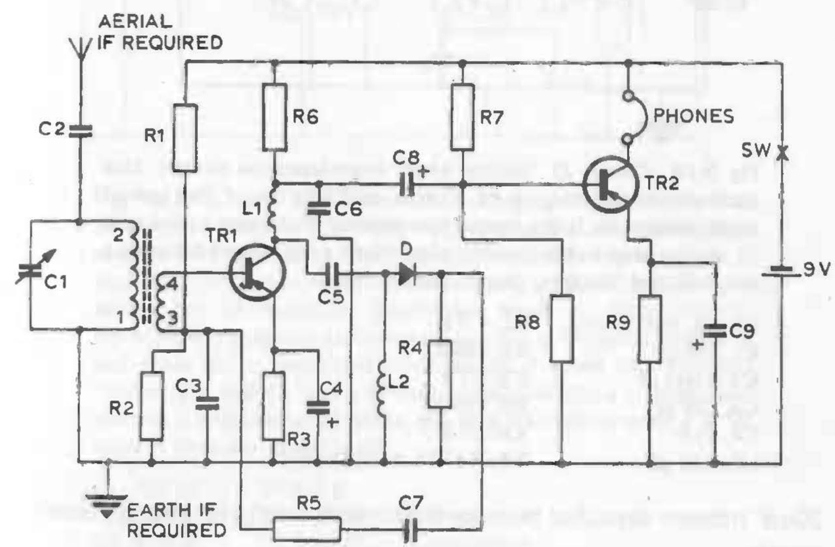


Fig. 9.9 *Circuit 20.* Four-stage reflex receiver. This is an extended version of the design given in Fig. 9.6–the same basic circuit with the addition of an AF amplifier stage. Using low-power transistors, output power is matched to high-impedance phones.

C1, 500 pF	D, any crystal diode	R1, 22 k
C2, 220 pF	L1, L2, choke coils	R2, 4.7 k
C3, 0.01 μF	(see text)	R3, 3.3 k
C4, 32 μF	TR1, OC44, OC45, XA102,	R4, 22 k
C5, 47 pF	or near equivalent	R5, 1 k
C6, 0.005 μF	TR2, OC71	R6, 4.7 k
C7, 10 μF		R7, 22 k
C8, 8 μF		R8, 10 k
C9, 8 μF		R9, 4.7 k

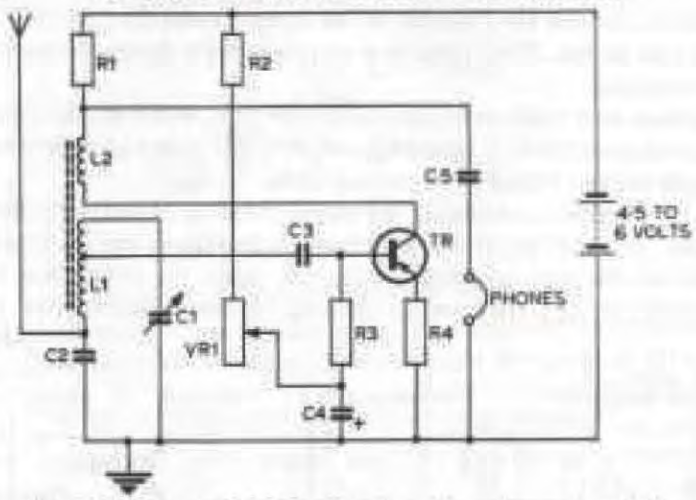


Fig. 9.10 *Circuit 21.* 'Mighty Atom' single-transistor receiver. This particular circuit design is by Weyrad, matching one of their special regen aerial coils. It is a regenerative receiver which uses a minimum of components and is capable of excellent performance for such a simple circuit. Matching phones are 50–100 Ω.

L1, L2, Weyrad coil	R1, 4.7 k
C1, 350 pF	R2, 100 k
C2, 0.001 μF	R3, 4.7 k
C3, 220 pF	R4, 100 k
C4, 8 μF	VR1, 5 k
C5, 0.01 μF	TR, XA103, or equivalent

20-pF trimmer capacitor between the transistor collector and the tuned circuit.

The output from the reflex stage may be fed directly into headphones (three-stage circuit); or may be followed by a stage of normal AF amplification (four-stage circuit—see Fig. 9.9); or further stages of amplification (five-stage circuit), etc, all the additional stages being AF amplifier stages.

As with the simpler circuits, however, there is a practical limit to the number of amplification stages which can usefully be added. The basic three-stage circuit (with no AF amplifier) should give audible headphone reception on a number of different stations; the four-stage circuit should give good headphone reception with local stations very loud; or equally be capable of giving good volume with a loudspeaker, depending on choice of transistors for the amplifier stages.

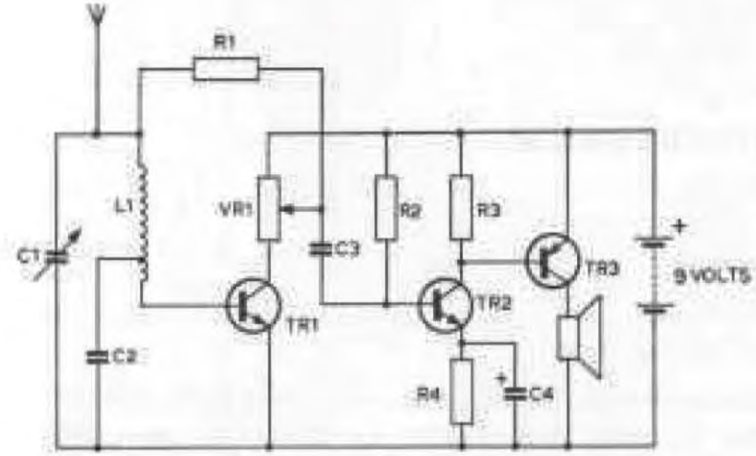


Fig. 9.11 *Circuit 22.* Three-transistor regenerative receiver with loudspeaker output. This design of regenerative receiver employs resistive feedback rather than capacity feedback. The advantage is that the regeneration, once adjusted, should remain at an optimum setting for all broadcast frequencies tuned in. With capacity regeneration, optimum adjustment is usually to a specific frequency and needs to be readjusted when the set is tuned to a different station. The coil (L1) is a 90-turn winding of 32-s.w.g. enamelled wire on a $\frac{3}{8}$-in. diameter ferrite rod with the tapping point 8 to 10 turns in from the 'earthy' end.

C1, 350 pF	VR1, 5 k
C2, 0.05 μF	TR1, 2N2926, or equivalent
C3, 0.05 μF	TR2, 2N2926, or equivalent
C4, 25 μF	TR3, AC128, or equivalent
R1, 390 k	Loudspeaker, 3 to 8 Ω
R2, 2.2 M	
R3, 100	
R4, 330	

10 SUPERHETS

The superheterodyne or *superhet* receiver works on a more complicated principle than other types and involves more stages and more components. The RF signal from the tuned circuit is combined with another HF signal generated by a *local oscillator* in the receiver itself in a *mixer* or *convertor* stage. This stage then has an output which is a 'beat' frequency, equal to the *difference* between the two signals, this 'difference' frequency being called the *intermediate frequency* (IF).

The IF output from the mixer is then amplified (in one or more stages) before being passed to the second detector stage, where the modulated IF is converted to AF and subjected to further stages of amplification. The second HF signal is generated within the receiver itself by the HF or local oscillator, applied to the mixer. A block

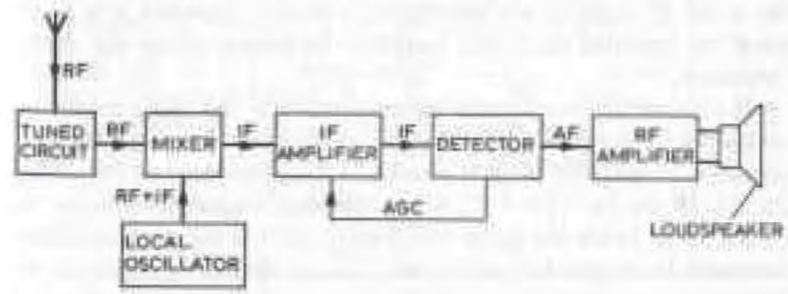


Fig. 10.1 Block diagram of a superhet circuit. Feedback of a proportion of the signal after detection is usually necessary to reduce gain on strong signals and prevent distortion through overloading. This is known as automatic gain control (AGC).

diagram is shown in Fig. 10.1, where it will be noticed that RF amplification can again be applied after the tuned circuit, if required.

The principal advantages offered by the superhet are that the gain and selectivity obtained from the IF amplifier do not depend on the frequency of the signal as they do with 'straight' receivers. Also the IF can be made lower than the signal frequency, resulting in higher stage gain and a narrower response curve. Again, too, since the IF amplifier is dealing with a constant frequency it can dispense with variable capacitors, reducing the risk of unwanted feedback and generally making the receiver less critical in design. The main disadvantages are the higher cost of such a circuit and the necessity of achieving proper alignment.

Most commercial domestic receivers are of the superhet type because of the superior performance offered and, although rather more complex, the type is equally suited to amateur construction.

The usual IF employed is between 450 and 475 kHz (455 kHz is more or less standard in this country) and the IF amplifier is tuned to the specific IF employed; this IF amplifier thus employs one or more stages of RF amplification with fixed tuning. A little thought will show that to 'feed' the IF amplifier correctly it will be necessary to vary the local oscillator in step with the tuned circuit. Thus if the receiver is designed to tune over a range of from, say, 800 kHz to 1,800 kHz and the IF is 470 kHz, then the oscillator frequency must range from 800 + 470 = 1,270 kHz to 1,800 + 470 = 2,270 kHz. Equally, to produce the same IF response the local oscillator could be set to 800 – 470 = 330 kHz to 1,800 – 470 = 1,330 kHz. The result would be the same as far as the IF amplifier was concerned; in practice, however, it is more usual to establish the local oscillator frequency above the signal frequency.

The converter thus actually receives two RFs: the signal frequency which can be designated Fs and the local oscillator frequency Fo. The following IF amplifier stage is tuned to a fixed frequency of Fo – Fs = Fi, the IF (or Fs – Fo = Fi, where the local oscillator frequency is chosen to be below the signal frequency); and it is the purpose of the converter to supply this particular IF as its output by a process of frequency conversion.

In fact, any oscillator HF will cause IF response at two signal frequencies, one equal to Fo – Fs and the other equal to Fo + Fs. One will be the real signal required, e.g. the correct value of Fs for the station selected, whilst the other is an undesirable *image* signal.

To clarify this by a numerical example, suppose the desired signal frequency is 800 kHz and the IF 450 kHz with the local oscillator set above the input signal frequency. To produce the necessary IF output at 800 kHz signal input the local oscillator will have to be set for 800 + 450 = 1,250 kHz. Exactly the same IF output will be produced, however, if a 1,250 + 450 = 1,700 kHz input signal is received, since the result of mixing will again be a frequency of 1,700 – 450 = 1,250 kHz. An essential feature of satisfactory working, therefore, is good *selectivity* in order to reduce the response to image signals to negligible effects.

The signal-to-image ratio, or image ratio as it is usually called, depends on the selectivity of the RF tuned circuits preceding the mixer or converter. At the same time the higher the IF the higher the image ratio, since raising the IF increases the frequency separation between signal and image and places the latter farther away from the peak of the resonance curves of the signal-frequency circuits.

The less experienced amateur–and certainly the beginner–is usually reluctant to tackle superhet construction because of the many complexities and large number of components involved, particularly in alignment, to get the circuit working satisfactorily. Probably the best approach, until experience is gained with superhet behaviour, is to build from kits, which include pre-aligned IF transformers. However, it is

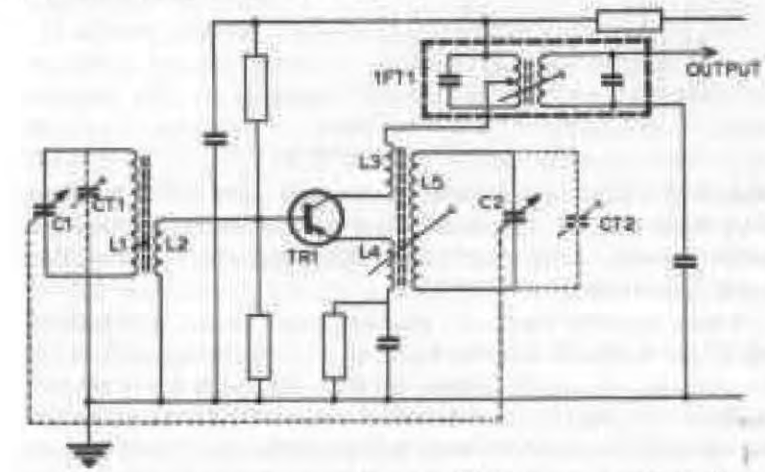


Fig. 10.2 Typical superhet 'front end', featuring conventional tuned circuit, local oscillator and mixer, and also one stage of IF amplification.

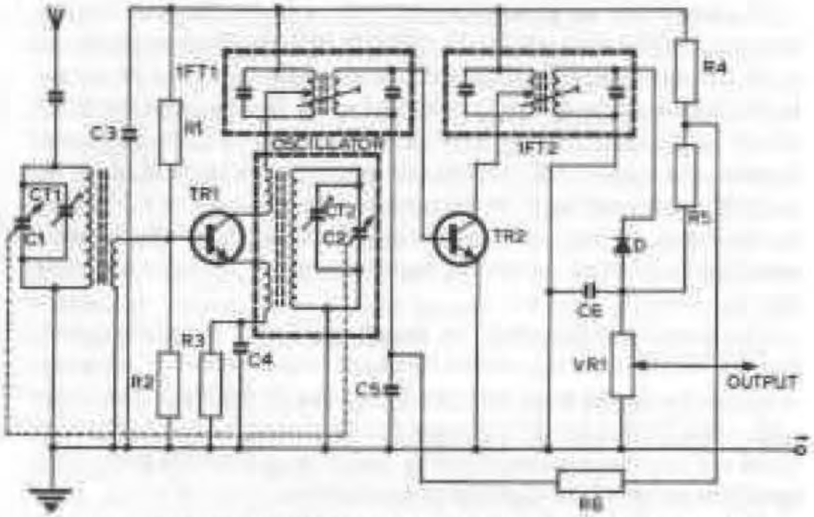


Fig. 10.3 *Circuit 23.* Complete superhet circuit up to output stage–*i.e.* to be followed by any suitable output circuit. This design uses n-p-n transistors.

TR1, 2N2924	VR1, 5-k potentiometer (volume control)
TR2, 2N2924	C1, C2, ganged tuning capacitor
R1, 330 k	C3, 5 or 8 μF
R2, 2.7 k or higher	C4, 0.01 μF
R3, 2.2 k	C5, 5 μF
R4, 100 k	C6, 0.01 μF
R5, 39 k	1FT1 and 1FT2, miniature IF transformers
R6, 33 k	0A70 or equivalent diode

possible to produce a working superhet circuit based on two transistors and a diode detector, with suitably selected components for the critical circuit elements–notably the ganged tuning capacitors, local oscillator and IF transformers.

A basic superhet 'front end' including tuned circuit, local oscillator and IF transformer is shown in Fig. 10.2. L1 is the tuning coil and L2 is the coupling coil (each wound on a ferrite rod); L5 is the local oscillator coil, inductively coupled to transistor TR1 via L3 and L4. The resonant frequencies of these two circuits are tuned simultaneously by the twin-ganged variable capacitors C1 and C2. In a practical circuit each variable capacitor would have its own trimmer capacitor, CT1 and CT2 respectively, for fine trimming.

Transistor TR1 is the mixer or *autodyne frequency changer*, the IF signal being selected by the IF transformer 1FT1.

The following sections, fed from 1FT1, use TR1 as an IF amplifier, and also provide the AF stage to feed the diode detector via a second IF transformer 1FT2. The whole of this circuit is shown in Fig. 10.3. An additional stage of IF amplification could be included, and also a more sophisticated output stage. Common practice is to follow a single stage of AF amplification by a push–pull output, with the driver transistor selected for high gain, and the output load formed by the primary of a phase-splitting transformer. However, keeping the number of components involved to a minimum and using only two IF transformers, considerably simplifies both construction and alignment.

Correct tracking of the aerial- and oscillator-tuned circuits to maintain the constant IF difference can be obtained by using a tuning capacitor with specially shaped vanes for the oscillator circuit; or by a conventional padded capacitor. Stray capacitance between the aerial and oscillator sections of the tuning capacitor can form a path for unwanted feedback between the two sections, so a screen is usually placed between them to prevent this. These effects can also arise between the wires connecting to the wavechange switch, so these must be kept as short as possible (or if completely incorporated on a printed circuit, the circuit elements kept short and well spaced to eliminate capacity effects).

In all cases, regardless of the type of oscillator and mixer, the first IF transformer receives a mixture of local oscillator frequency, signal frequency and the sum and difference of the two. It is therefore necessary to use a capacitor across the primary to produce an LC circuit to resonate at the IF. This capacitor is of fixed value (matched to the inductance of the coil), when any adjustment required for alignment is provided by an iron-dust core in the coil enabling the inductance to be varied over the necessary range. Once the overall LC value has been adjusted to a resonant frequency corresponding to the IF the tuning remains fixed.

Output from this stage is an AF modulated HF signal at the IF, which has also been subject to amplification.

Alignment with simple circuits should be quite straightforward and can be done without the aid of a signal generator. Particular care, however, must be taken not to overtighten the tuning slugs in miniature coils as these are easily jammed, resulting in permanent damage to the coil since it will be virtually impossible to remove the core without first removing the coil from the printed circuit; and equally almost impossible to remove the coil without damage.

To align without a signal generator, the set is tuned to the mid-way point on the long waveband and the core of L4 adjusted to receive BBC Radio 2. The tuning control should then be adjusted to the higher wavelength end of the medium waveband and the cores of IFT1 and IFT2 adjusted for maximum output. Further adjustment of volume can then be made by sliding the aerial coil along the ferrite slab, and once the best position is found the sleeve should be fixed with wax or cellulose tape. The receiver should then be tuned to 300 m approximately and capacitor C1 or its trimmer CT1 adjusted until an identifiable station is received and then brought up to maximum volume by adjustment of capacitor C2 or its trimmer CT2. If necessary, the alignment stages should be repeated for the medium waveband until all stations are received at good signal strength.

Using a signal generator, alignment is even simpler and more positive. The basic procedure should be:

(i) Injected signal, 600 kHz, adjust tuning to correspond to the end of the (medium) waveband.
(ii) Injected signal, 470 kHz, adjust IFT1 and IFT2 cores for maximum output.
(iii) Injected signal, 600 kHz, adjust coil position on ferrite rod for best results.
(iv) Injected signal, 1,450 kHz, adjust trimmers CT1 and CT2 for maximum output.

Mullard 6-transistor receiver

This design is for a simple portable receiver using alloy-junction transistors and a single 9-V battery with transformerless push–pull output. The circuit is suitable for making as a medium-size portable receiver with a Ferroxcube rod aerial, or in miniature size if preferred. The standard IF of 470 kHz is used with the local oscillator frequency above the signal frequency. One OC44 and two OC45 transistors are used in the mixer and IF stages. The detector is a germanium diode type OA70. The audio stages comprise one OC71 transistor driving a matched pair of OC72 transistors.

The OC44 operates as a self-oscillating mixer, with RF signals from the aerial coupling coil fed into the base of the OC44, leading to the

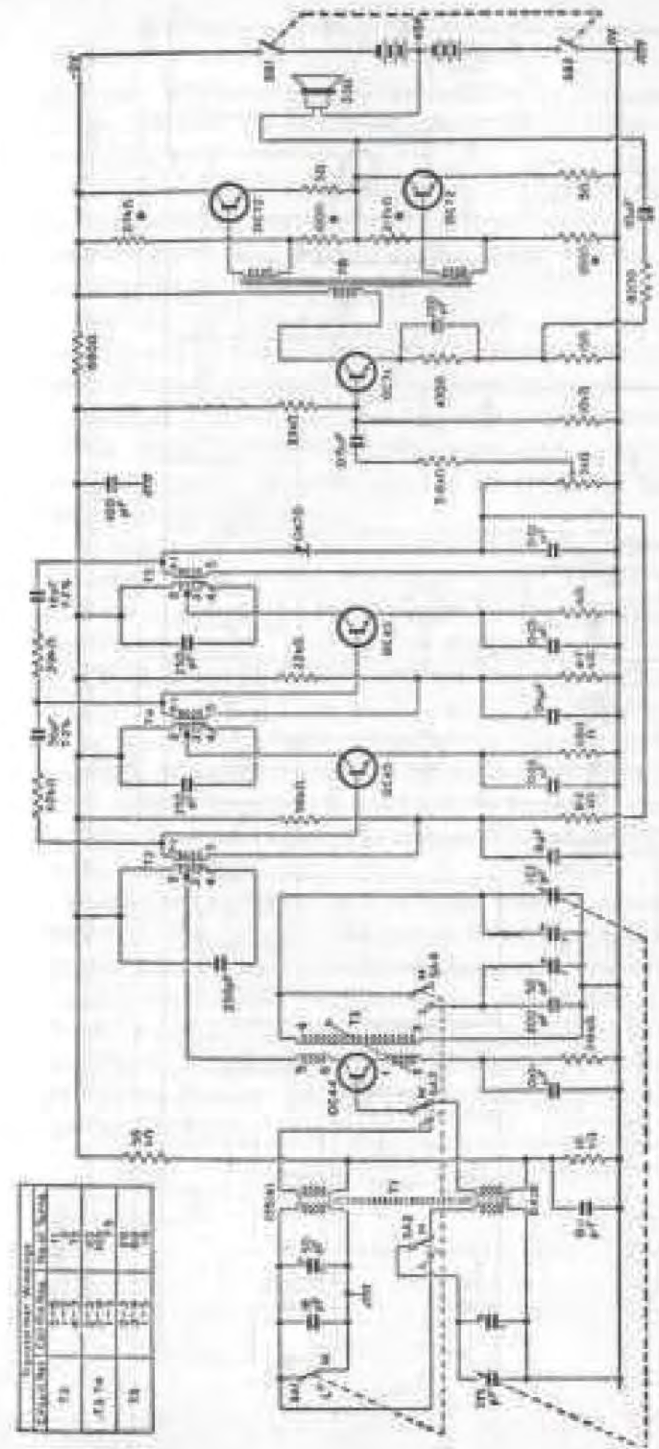


Fig. 10.4 Circuit 24. Mullard design for six-transistor superhet. Tolerance of resistors marked with an asterisk should be 5 per cent; others 10 per cent.

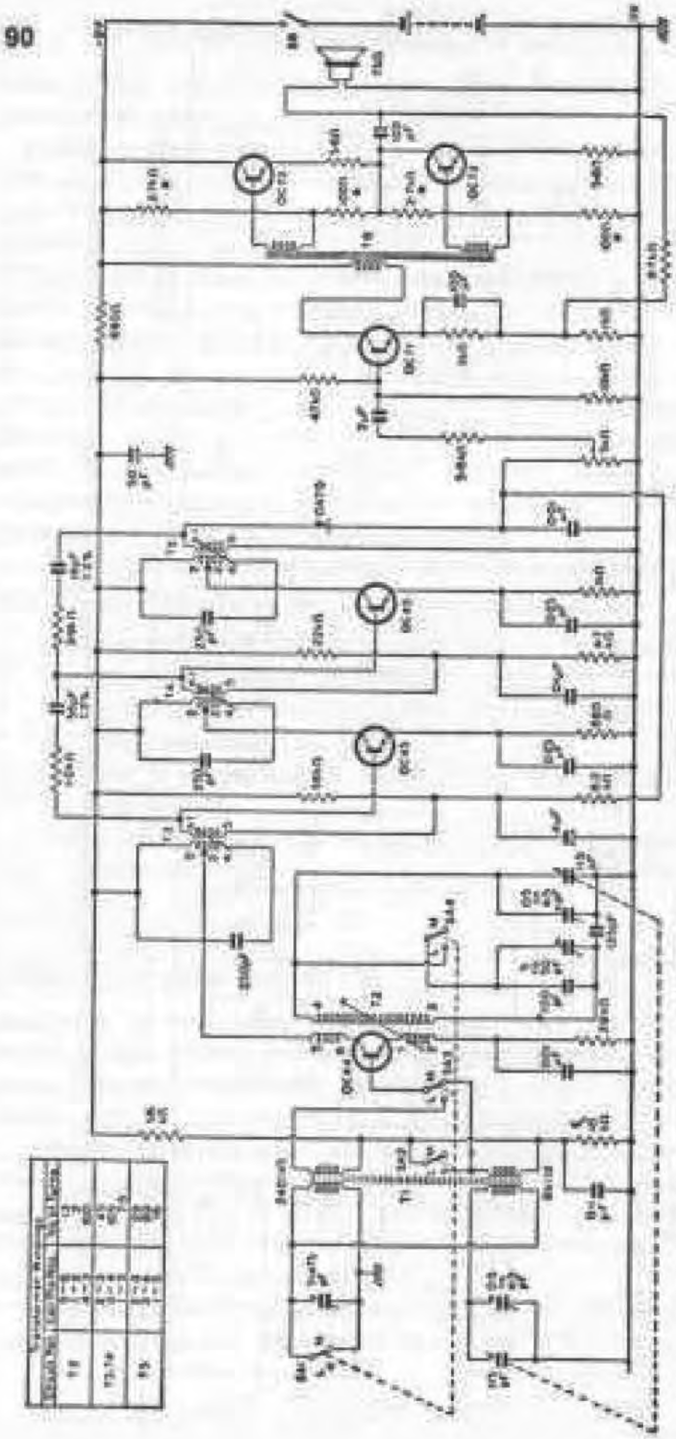


Fig. 10.5 *Circuit 25.* Mullard design miniature superhet. Tolerance of resistors marked with an asterisk should be 5 per cent; others 10 per cent.

generation of local oscillation feedback from the collector to the emitter. The IF is selected at the collector of the OC44 by the first IF transformer T3.

The IF amplifier comprises two OC45 common-emitter circuits operating unilateralized, with the choice of bandwidth compromising between quality and selectivity. The third IF transformer T5 is connected to the OA70 diode detector, with the d.c. output fed back to the first IF transformer to provide automatic gain control. Double-tuned IF transformers are recommended for optimum performance as regards frequency response and image rejection.

The Class B transformerless output stage requires a loudspeaker with a 35-Ω speech coil to provide the correct load for an output of 200 mW, with negative feedback applied to the emitter of the OC71 driver from the loudspeaker terminal.

All component values are shown on the circuit diagram (Fig. 10.4). The value of the tuning capacitance is not critical, but must be sufficient to provide the desired frequency coverage. The aerial section has a capacitance of 175 pF and the oscillator section a capacitance of 125 pF. A screen should be used between the oscillator and aerial sections of the tuning capacitor (i.e. the tuning capacitor so specified) to be sure of eliminating undesired feedback in the circuit. The possibility of feedback will be at maximum when the receiver is tuned to its highest frequency, and will also be increased when the tuning capacitor has a low value (e.g. as typically the case with a miniature tuning capacitor).

A miniaturized version of the original circuit is shown in Fig. 10.5, again with all component values marked. Here the output is reduced to 100 mW driving a 75-Ω miniature speaker. Current consumption of this circuit is reduced from 9 mA zero signal, 20 mA average, to 7 mA and 13 mA, respectively. This miniaturized circuit permits of further modification by substituting a Class A output with transformer drive to the speaker, reducing the number of transistors required to five, but increasing the battery consumption.

11 COMPONENTS

The following descriptions are intended to familiarize readers with the various basic components used in radio construction, as well as being a useful reference when selecting components for making a particular circuit.

Resistors

The first thing to remember about resistors is that their *size* is no indication of their actual resistance value; rather it is a rough indication of the *power rating*. Transistor circuits operate with low power ratings and so small (physical) resistors are commonly employed.

Actual *sizes* of resistors range from 4 mm long by 1.2 mm diameter (with a $\frac{1}{25}$-W power rating), up to about 50 mm long by 6 mm diameter (with a 7-W power rating); and even larger in the old-fashioned type of carbon rod resistors. A comparison of modern resistor sizes is given in Fig. 11.1; this diagram is also a useful method of identifying the various *types* of resistors by their shape.

There are five main *types* of resistors, classified by their construction.

(i) *Moulded-carbon type*, literally a rod made from a mixture of carbon and binder fired into a rigid form. This rod is usually protected with a lacquer coating, or a paper or ceramic sleeve. These are the old-fashioned type which are still available (usually as 'surplus' stock) and are suitable for any non-critical circuit. Ratings are usually $\frac{1}{4}$ W, $\frac{1}{2}$ W and 1 W.

(ii) *High-stability carbon resistors*, much smaller and compact, made from carbon film. These are miniature and sub-miniature in size and are

Fig. 11.1 Modern resistors.

1, $\frac{1}{20}$ W carbon-film
2, $\frac{1}{8}$ W carbon-film
3, $\frac{1}{4}$ W carbon-film
4, $\frac{1}{10}$ W metal-film
5, $\frac{1}{2}$ W carbon-film
6, $\frac{1}{2}$ W metal-oxide
7, 1 W carbon-film
8, 1 W wire-wound
9, 3 W wire-wound
10, 7 W wire-wound

the preferred type for general use because of their good stability, low noise, and quite low cost. Ratings are usually $\frac{1}{20}$ W, $\frac{1}{10}$ W, $\frac{1}{8}$ W, $\frac{1}{4}$ W, $\frac{1}{2}$ W and 1 W.

(iii) *Metal-film resistors*, which are made by depositing a film of nickel-chromium on a high-grade ceramic body and then cutting a helical track through the film to produce the required resistance values. End caps are fitted to carry the leads and the resistor body is protected by a lacquer coating. These are much more stable than carbon resistors but cost about four times as much. Ratings are from $\frac{1}{10}$ W upwards.

(iv) *Metal-oxide resistors*, made by depositing a film of tin oxide on a special glass rod, the whole being subsequently covered with a heat-resistant coating. Stability is again very high and this type is virtually proof against damage through overheating (e.g. when soldering) and is also unaffected by dampness. The usual rating is $\frac{1}{2}$ W.

(v) *Wire-wound types*, generally only required for special circuits where very low resistance values are required and/or very high currents have to be carried. Typical ratings may range from 1 to 5 W for a 0.5-Ω resistor to 25 W or more for higher resistance values.

Regardless of size, shape and type, the usual method of marking a resistor *value* is by coloured bands on the body, read in order 1, 2, 3

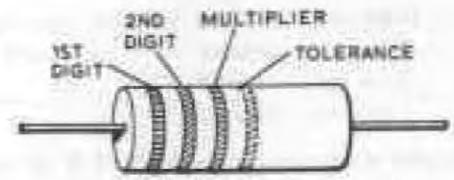


Fig. 11.2 Standard resistor colour coding.

from the band nearest one end–Fig. 11.2. The equivalent value is determined by:

Colour	1 gives first figure of resistance value	2 gives second figure of resistance value	3 gives number of noughts to put after first two figures
Black	0	0	None
Brown	1	1	0
Red	2	2	00
Orange	3	3	000
Yellow	4	4	0000
Green	5	5	00000
Blue	6	6	000000
Violet	7	7	0000000
Grey	8	8	00000000
White	9	9	000000000

Example: resistor colour code read as Brown, Blue, Orange.

	Brown	Blue	Orange
value read as	1	6	000

i.e. 16,000 Ω or 16 kΩ (kilohms).

On some old-type resistors the three colours are applied in a different manner–a coloured body, coloured tip and coloured spot on the body. The code is then read in the order body, tip, spot.

Many resistors have an additional (fourth) coloured band, which expresses the *tolerance* on the resistor value. The equivalent tolerances so indicated are:

Silver band	10 per cent tolerance
Gold band	5 per cent tolerance
Red band	2 per cent tolerance
Brown band	1 per cent tolerance

For most circuits resistors with a gold band (5 per cent tolerance) are the recommended choice; silver band (10 per cent tolerance) are good enough for general use. Finer tolerances (red or brown band) are not necessary, except for critical circuits. No fourth band implies a tolerance of 20 per cent.

Other variations which may be found on colour coding are:

a salmon pink band indicating a high-stability type;
a *double ring* of the first colour band, indicating a wire-wound resistor.

Some types of modern resistors are not colour coded but the values are marked directly on to them in numbers and letters. *Numbers* indicate numerical values and *letters* indicate multipliers, viz:

$R = \times 1$
$K = \times 1{,}000$
$M = \times 1{,}000{,}000$

Tolerances are also given by a second letter, viz:

M = 20 per cent
K = 10 per cent
J = 5 per cent
H = 2.5 per cent
G = 2 per cent
F = 1 per cent

The first letter ('multiplier') comes in a position which determines the decimal point. Thus:

rating *5R* designates 5 × 1 = 5 Ω
4K7 designates 4 × 1,000 and 0.7 or 4.7 kΩ
82K designates 82 × 1,000 or 82 kΩ

The tolerance letter comes at the end, e.g.

4K7J means a 4.7-kΩ resistor with a 5 per cent tolerance

Actual resistor *values* are also normally based on *preferred numbers* and not simple arithmetical steps. The reason for this is that preferred number steps give approximately constant *percentage* change in

resistance from one value to the next. The usual resistance values obtainable are thus:

Ω	kΩ	MΩ
10*	1.0	1.0
12	1.2	1.2
15	1.5	1.5
18	1.8	1.8
22	2.2	2.2
27	2.7	2.7
33	3.3	3.3
39	3.9	3.9
47	4.7	4.7
56	5.6	5.6
68	6.8	6.8
82	8.2	8.2
100	↓	
120		
150		
180		
220		
270		
330		
390		
470		
560		
680		
820		

*Typical values for *wire-wound* resistors below 10 Ω are: 0.33, 0.5, 1, 1.5, 2, 3, 3.3, 3.9, 4, 4.7, 5, 5.6, 6, 6.8 and 8.

Variable resistors (potentiometers)

Variable resistors, or *potentiometers*, are normally constructed from a resistive element, formed into a 270° arc, with a wiper arm connected to it, and turned by a central spindle. There are three external terminal tags; the outer ones connect to the ends of the resistance element and the centre tag to the wiper—see Fig. 11.3.

The resistance element may be a carbon track or a winding of resistance wire (wire-wound potentiometers). Carbon-track potentiometers are cheaper than wire-wound types and are suitable for most general circuit applications, at low power levels, e.g. $\frac{1}{4}$ to $\frac{1}{2}$ W for low

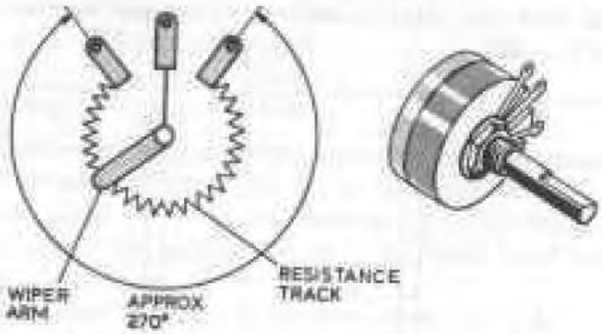


Fig. 11.3 Variable resistor or potentiometer.

resistance values, reducing with higher resistance values. Wire-wound potentiometers have a higher power rating—usually of the order of 1 to 3 W continuous for the whole track; they are also made in lower resistance values obtainable with carbon-track potentiometers.

The usual resistance values available in each type are:

Carbon-track: 100, 220, 470, 1 k, 2.2 k, 4.7 k, 10 k, 22 k, 47 k, 100 k, 220 k, 470 k, 1 M, 2.2 M and 4.7 M.

Wire-wound: 10, 22, 47, 100, 220, 470, 1 k, 2.2 k, 4.7 k, 10 k, 22 k, and 47 k.

The general appearance of typical carbon-track and wire-wound potentiometers is shown in Fig. 11.4; they are also made with a sliding

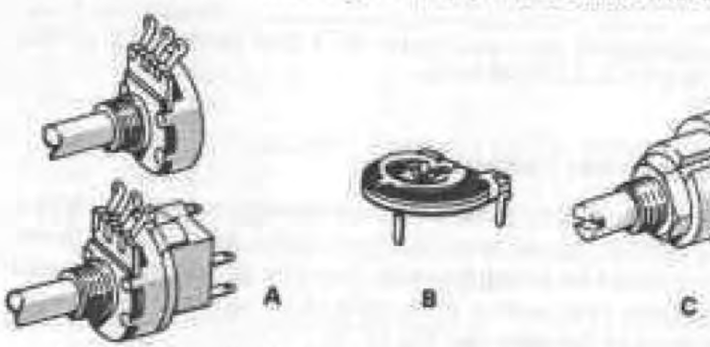


Fig. 11.4 Potentiometers
A, Typical small carbon-track, about 20 mm diameter;
B, Open-type carbon-track linear potentiometer, about 15 mm diameter;
C, Typical wire-wound potentiometer, diameter 25 to 35 mm.

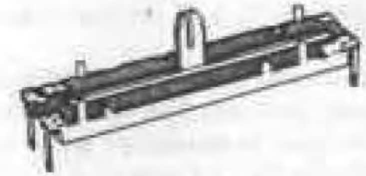


Fig. 11.5 Modern slider-type carbon-track potentiometer.

rather than a rotary movement. The old type consisted of a wire winding on a suitable cylindrical former, traversed by a sliding contact assembly. The modern miniature slider-potentiometer is much more compact and fully enclosed, except for the slot in which the slider arm travels—Fig. 11.5. The resistance track may be carbon, or wire-wound. Slider-type variable resistors have come into favour for volume controls on modern radio designs.

Potentiometers are also described as linear or non-linear, this referring to the manner in which resistance values vary with wiper movement and *not* whether the potentiometer is a slider or rotary-action type. With a *linear* potentiometer the resistance change is directly proportional to the actual movement, *e.g.* a 50 per cent

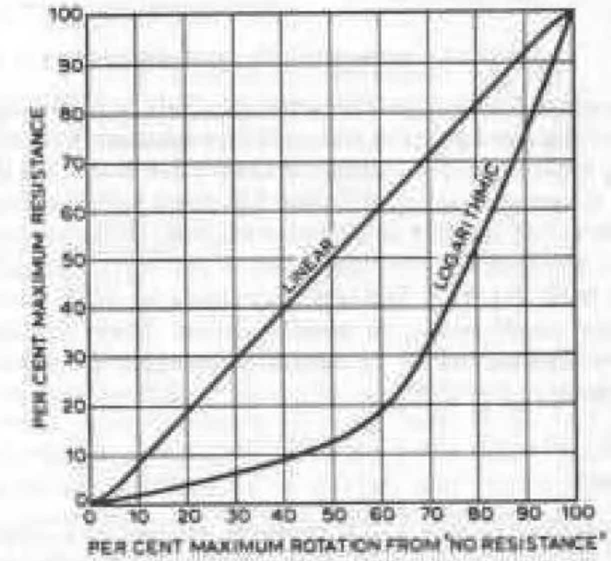


Fig. 11.6 Linear and logarithmic potentiometer characteristics.

movement will correspond to a 50 per cent change in resistance–see Fig. 11.6.

Slide-type potentiometers normally automatically provide linear characteristics. Rotary types may have linear or *logarithmic* characteristics, the latter producing an increasingly greater change in resistance with spindle rotation (see Fig. 11.6 again).

Potentiometers may also be designed with characteristics intermediate between linear and logarithmic, e.g. semi-log or linear-tapered; and also with inverse characteristics, e.g. anti-log. Either linear or logarithmic potentiometers are suitable for most volume control duties etc., although logarithmic types are generally preferred.

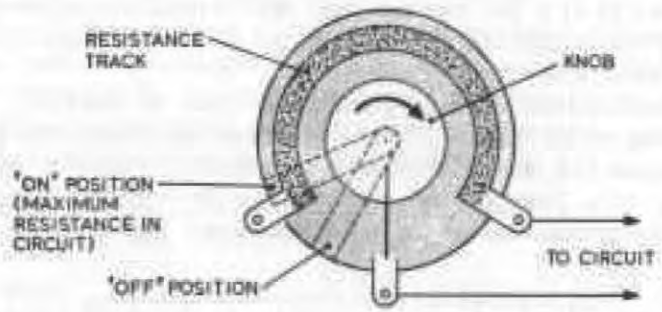


Fig. 11.7 Potentiometer with on-off switching.

Wiring connections to a potentiometer are simple, remembering that the two outside tags connect to each end of the resistance track and the centre tag to the wiper. For a simple volume control, connection is thus normally to one end tag and the centre tag. Some potentiometers are made with an 'off' location at one end of the wiper movement (usually maximum anti-clockwise movement) when the wiper runs off the resistance track–Fig. 11.7. This type can combine the duties of volume control and on-off switch, in suitable circuits. Power supplies are usually switched on and off by a switch mechanically coupled to the volume control.

Capacitors

Modern capacitors come in a wide variety of different types, sizes and constructions, many having overlapping values. The older *paper tubular* type, constructed of silver foil interleaved with mica sheets, have largely

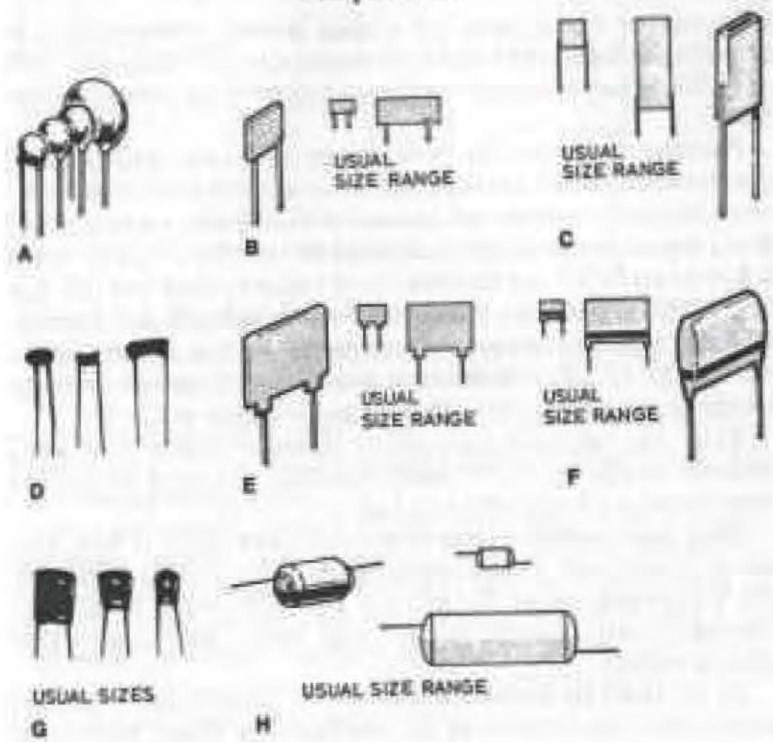


Fig. 11.8 Examples of modern miniature capacitors

A, Ceramic disc 1,000 pF to 0.1 μF (approx. actual size);
B, Ceramic plate, sizes from 4 × 2.5 mm to 12 × 5 mm;
C, Ceramic plate tubular;
D, Tubular ceramic, typical sizes;
E, Silvered mica;
F, Polyester;
G, Mylar;
H, Polystyrene.

been replaced by miniaturized ones, although they continue to be used in the capacity 0.05 to 2 μF (e.g. in preference to an electrolytic capacitor). Working voltages are of the order of 200 to 1,000 V for paper types, or up to 10,000 V with plastic-impregnated types.

Miniature capacitors are of ceramic, polystyrene, silver mica or mylar construction–see Fig. 11.8. *Ceramic capacitors* may be of 0.1 μF (but with working voltages generally substantially reduced above 5,000 pF capacity). *Tubular ceramic capacitors* have a similar value range and are usually rated for a mean working voltage of 350 V. *Silvered mica capacitors* with values ranging from 2.2 pF up to 10,000 pF (0.01 μF) are rather larger and have a higher voltage rating (typically 500 V).

Polyester capacitors are produced in two main configurations, cylindrical with offset end leads, and slab shape with radial leads for PC board mounting. Physical size increases with increasing capacity rating: thus a typical size for a cylindrical polyester capacitor of 220 pF or less is 8 mm long by 3.5 mm diameter. For the highest values with this type (e.g. 22,000 pF) size can be up to 32 mm long by 12 mm diameter. Polyester capacitors are usually constructed for high-capacity values, e.g. 0.01 to 2.2 μF, with size again increasing with capacity. Working voltage for these is normally 125 V for smaller values, or 250 V.

Mylar film capacitors are similarly constructed, with radial leads, produced specifically for PC board mounting. The range of values is more limited, e.g. from 0.001 to 0.2 μF.

Other types include *polycarbonate capacitors*, made in both rectangular ('box') and tubular configurations, with working voltages of 250 V for values up to 0.1 μF, and 100 V for values up to 1 μF, although special constructions for high values can accept higher working voltages.

All the above are *non-polarized capacitors*, meaning that it does not matter which way round they are connected in a circuit. Other types are *polarized* and must always be connected in a specific manner ('plus to plus'), otherwise they will be degraded and eventually destroyed.

The best known type of polarized capacitor is the *electrolytic capacitor*, originally based on an aluminium rod or foil plate in contact with a paste electrolyte. The capacitor is then formed by passing a direct current through it during manufacture, depositing a thin film of aluminium oxide on the aluminium surface by electrochemical action. This type of construction allows quite high values of capacitance to be produced in a relatively compact envelope, e.g. up to 1,000 μF. *Etched foil* electrolytic capacitors permit even greater capacitance values to be achieved for the same size, and so make it possible to produce miniature types with high capacity values. In the latter case the working voltage is generally reduced.

Modern electrolytic capacitors are usually of etched foil type, or the more recently developed tantalum construction, which are produced in both conventional cylindrical configuration with axial leads and *tantalum bead* form–see Fig. 11.9. Both types have low voltage ratings,

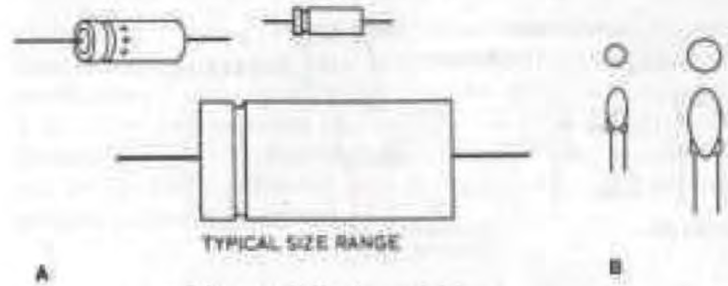


Fig. 11.9 Electrolytic capacitors

A, Metal-cased cylindrical with axial leads;
B, Tantalum bead, typical size range.

decreasing with increasing capacity value, e.g. from 35 to 40 V for 0.1 μF capacity; to 3 V at 100 μF capacity. *Tantalum* capacitors are also made in non-polarized form.

Values are normally marked directly on the body of the capacitor; some types, however, may be colour coded, the code adopted not necessarily being universal (it can vary from one manufacturer to another and from country to country in the case of older products).

Polyester slab-shaped capacitors are normally colour coded instead of marked, the colours following the same code as for resistors. Up to five bands can be used, the sequence being:

1st colour gives first significant digit in pF
2nd colour gives second significant digit in pF
3rd colour gives the multiplier
4th colour gives the *tolerance*, e.g. white 10 per cent, blue (sometimes black) 20 per cent
5th colour gives the voltage, red 250, yellow 400 V

The fourth and fifth colour bands may be missing; if only the fifth is missing, this implies a working voltage of 30 V.

Colour coding by rings may also be found on moulded-paper and some tubular ceramic capacitors. Some disc and slab-type capacitors may be colour coded by dots–see Fig. 11.10.

Variable capacitors

Variable capacitors are used for *tuning* or *trimming* to enable the capacitance in a critical circuit to be adjusted. There are physical

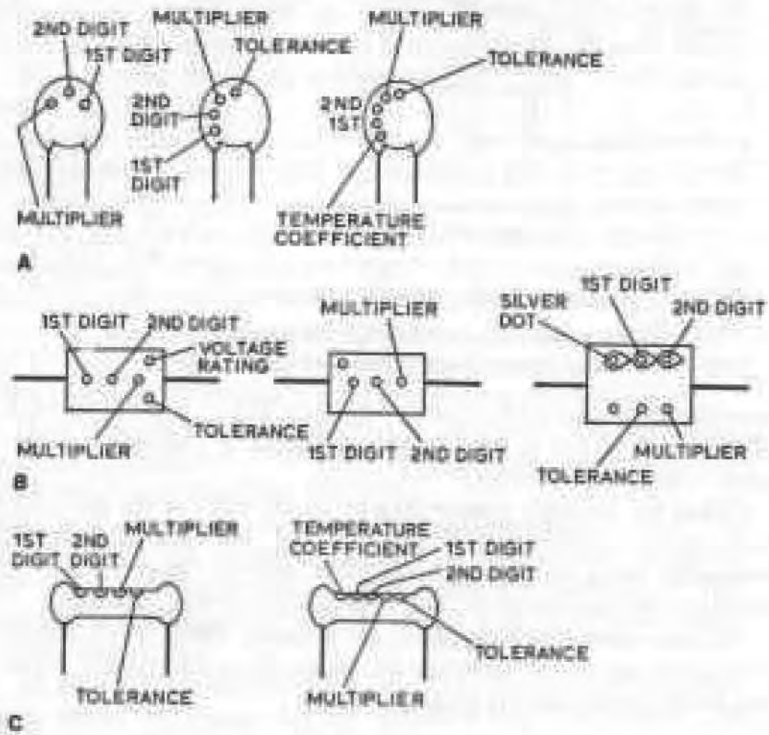


Fig. 11.10 Some capacitor colour-dot codes

A, Disc ceramic;
B, Moulded paper;
C, Phenolic and ceramic.

differences between a tuning capacitor and a trimming capacitor, both in size and construction, but both work on the same principle and could, in fact, be used for either duty.

Tuning capacitors are commonly of the air-dielectric type, consisting of two sets of intermeshing metal vanes, one set fixed and the other rotatable by about 180 degrees by means of a spindle. When fully closed (i.e. the spindle is turned so that the rotating vanes are fully in mesh with the fixed vanes) capacitance is a minimum, and when fully opened (i.e. turned to full movement the opposite way) a maximum.

The maximum capacity of air-dielectric variable capacitors of this configuration ranges from about 10 pF to 1,000 pF. Physical size may range from 'miniature', e.g. about 25 mm square and 13 mm thick, up

to 50 x 60 x 80 mm, or even larger, but is no indication of the working capacity range. It is largely a matter of convenience and compactness to use miniature tuning capacitors for transistor circuits and these may be of the solid-dielectric rather than air-dielectric type. Typical forms are illustrated in Fig. 11.11, showing single and ganged condensers, the latter used where two separate circuits are required to be tuned simultaneously from a single control.

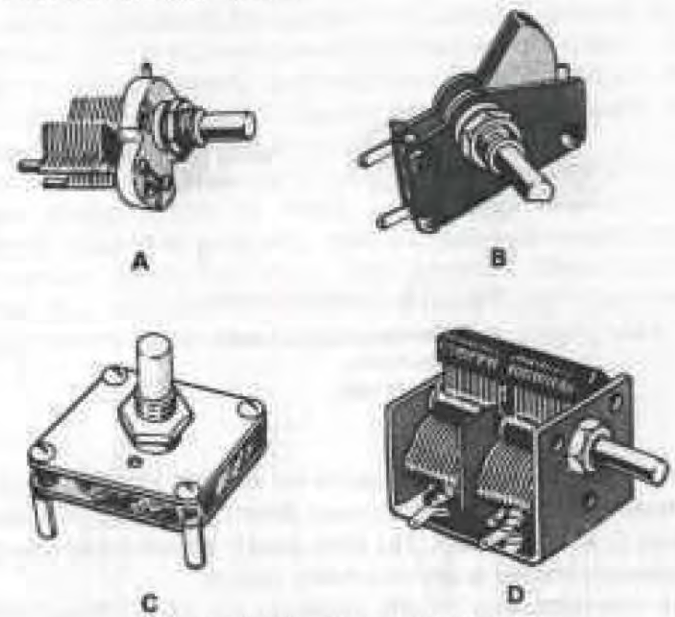


Fig. 11.11 Tuning capacitors

A, Air-dielectric;
B, Solid-dielectric;
C, Solid-dielectric, miniature;
D, Two-gang air-dielectric.

Trimming capacitors are usually based on a mica-dielectric and consist of two or more plates separated by very thin sheets of mica. Capacity is reduced by turning a central screw to adjust the pressure between plates and mica. They are designed primarily to be adjusted to a required capacity value and then left set in this position but can, however, be used as a tuning capacitor where their small physical size is an advantage (e.g. in a sub-miniature receiver); they are also cheaper than tuning capacitors.

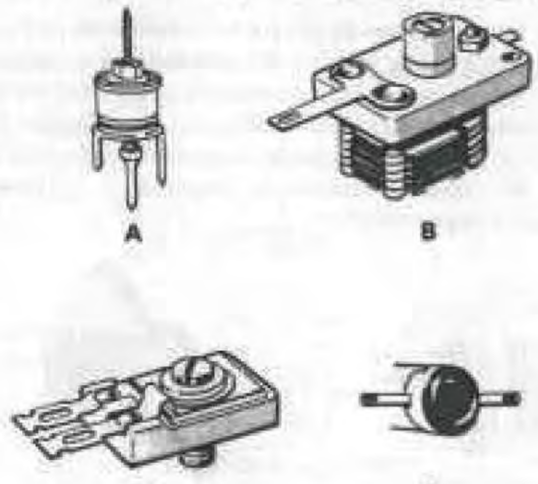


Fig. 11.12 Trimmer capacitors

A, Beehive type (air-dielectric);
B, Air-dielectric;
C, Mica-dielectric;
D, Ceramic.

Some forms of trimming capacitors are shown in Fig. 11.12. Not all such types have a mica-dielectric, some designs being based on a plastic dielectric or even air-spaced. The latter usually provide better response if a trimming capacitor is used as a *tuning* control.

Like potentiometers, variable capacitors can have different working characteristics, i.e. linear, logarithmic etc., depending primarily on the shape of the plates. These characteristics are usually:

(i) *Linear capacitance*, where each degree of spindle rotation produces an equal change in capacitance.
(ii) *Even frequency*, where each degree of spindle rotation produces an equal change in *frequency* in a tuned circuit.
(iii) *Square law*, where the change in capacitance is proportional to the *square* of the angle of movement.
(iv) *Logarithmic*, where each degree of spindle movement produces a constant *percentage* change in frequency.

Linear-frequency characteristics are usually preferred for a radio receiver tuning capacitor.

Transistors

Transistors are classified generally under two main types depending on the material used in their construction, germanium or silicon. Germanium transistors are the earlier type, but performance has been considerably improved by adoption of alloy-junction or alloy-diffusion methods of manufacture; silicon-junction transistors are normally made by the planar process. Where special characteristics are required (e.g. RF and IF applications), the manufacturing process is modified slightly to produce what is called an epitaxial (silicon-planar) transistor. There is also a third type known as a field-effect transistor (FET) in which both the construction and characteristics differ appreciably from germanium and silicon-junction types.

In general, germanium transistors are well suited to low-voltage AF circuits because of their low voltage losses and also because they can easily be matched in p-n-p/n-p-n pairs for push–pull output circuits; they are also cheaper than silicon-planar transistors. Silicon transistors, on the other hand, have lower leakage losses and higher voltage ratings, making them more suitable for higher output audio circuits, and for use

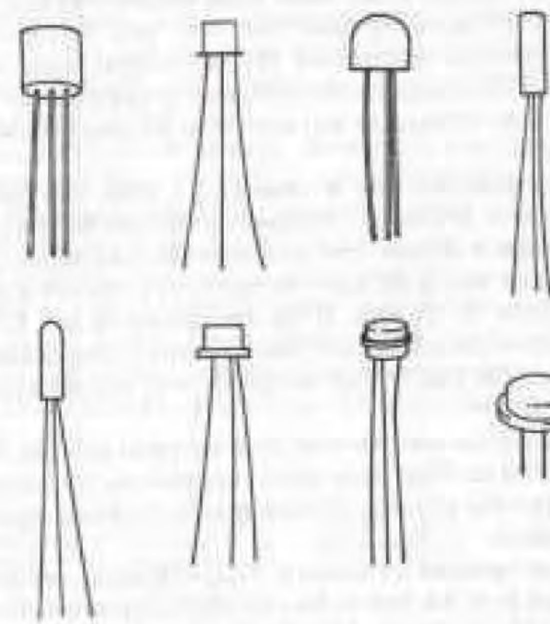


Fig. 11.13 Some transistor outline shapes.

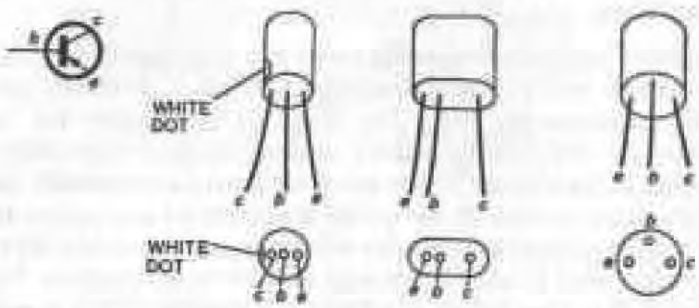


Fig. 11.14 Common transistor lead configurations.

at higher frequencies. They have the further advantage that they can operate successfully at temperatures up to 150°C or more, whereas the maximum working temperature for germanium transistors is normally below 100°C.

Transistors are basically three-element devices, the connections to the elements being in the form of three wires emerging from the bottom of the transistor, the whole being encapsulated in a metal or plastic case. Transistor outlines and sizes vary enormously (see Fig. 11.13), but the arrangement of the emergent wires normally follows one of the standard patterns to assist in identification–see Fig. 11.14. The three connections involved are to the *base* (*b*), *emitter* (*e*) and *collector* (*c*).

When the transistor base is circular, the wires may emerge in triangular form or in line. In the former case the two bottom points of the triangle lie in a diameter line, and viewed in this position from the bottom the apex wire is the base, the emitter is to the left of the base, and the collector to the right. If the wires emerge in line, a white or coloured spot on the can or body marks the end corresponding to the collector lead. The base is then the middle one, and the emitter the other end lead.

With a rectangular base the wires again emerge in line. The collector lead is identified as being more widely spaced from the middle wire (base) than the other end wire, although specific types may depart from this configuration.

Some other variations are shown in Fig. 11.15. Some may have *four* wires emerging from the base in line; the additional wire is the middle one connected to an internal shield (*s*). This does not form part of any connection to a circuit and is either ignored or connected externally to

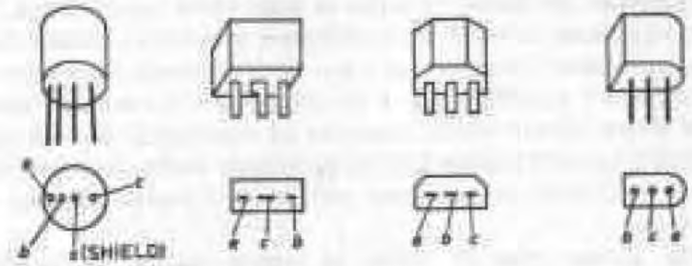


Fig. 11.15 Some other types of transistor shapes and lead configurations.

the case. Other types are designed specifically to plug into PC boards and have rigid terminal *strips* rather than wires–again connections can vary, so it is important to verify them for a particular type.

Power transistors are of more rugged construction and generally have different connections again. Some may have three wire connections, others just two terminal strips–see Fig. 11.16. In the latter case the collector connection is absent, the collector being connected internally to the case. Emitter and base leads are normally marked 'E' and 'B' respectively. The *collector* connection is then normally made to one of the screws mounting the transistor (or to an external terminal tag suitably connected to the case).

Power transistors are normally mounted on a *heat sink* to assist in dissipating heat from the case. It is usually necessary (except in a grounded collector circuit) to electrically insulate the transistor from this heat sink; at the same time this insulator must be a good conductor of heat. Suitable insulators are readily available to make heat sinks, consisting of a simple gasket or washer of mica, anodised aluminium or fabric. Fabric washers require greasing with silicon grease to make them heat-conducting. Some types of power transistors have tubular bodies when a finned cooling clip may be used to dissipate heat, instead of a heat sink.

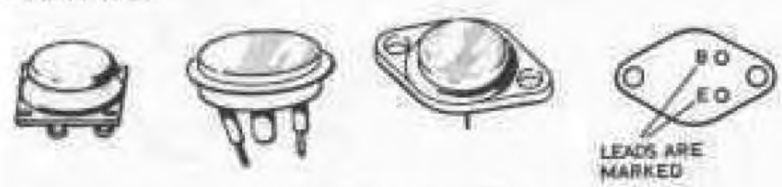


Fig. 11.16 Power transistors.

Transistors are further classified as being either p-n-p or n-p-n, the main significance of which is the difference in polarity of connections. Most germanium transistors are p-n-p types (although n-p-n ones are made for AF amplifiers and as the complement for matched pairs); most general-purpose silicon transistors are n-p-n types, although again p-n-p ones are also produced. If in the slightest doubt, the actual type should be checked as connection with reversed polarity can ruin the transistor.

The general rules to follow as regards polarity of transistor connections are:

with a p-N-p transistor the *collector* must be *N*egative;
with a n-P-n transistor the *collector* must be *P*ositive.

12 CIRCUIT CONSTRUCTION

The general rule for designing a circuit layout is to follow, as far as possible, the same disposition and relative positioning of the individual components as on the circuit diagram. This should eliminate over-long wires and avoid unnecessary crossing over of leads.

Tag strips form a convenient method of assembling simple circuits involving a relatively small number of components. Two tag strips, mounted an inch or so apart on a Paxolin panel, enable individual components to be soldered between pairs of tags with common components to be soldered between pairs of tags with common connecting leads where necessary–Fig. 12.1. Alternatively, ready-mounted tag strips can be purchased as *tag boards*. A component continuing a circuit from a 'common' point has its second lead soldered to a spare tag, which can become a 'common' connecting point for another component, and so on.

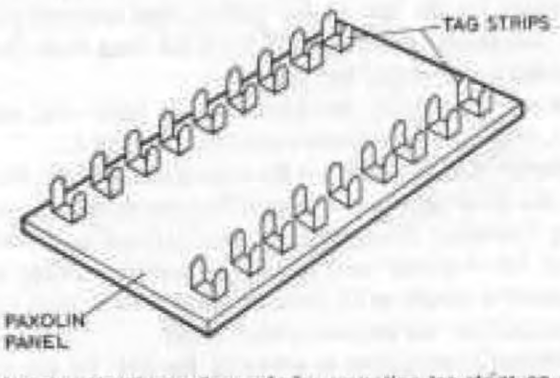


Fig. 12.1 Tag boards can be made by mounting tag strips on a Paxolin panel, or bought ready-made.

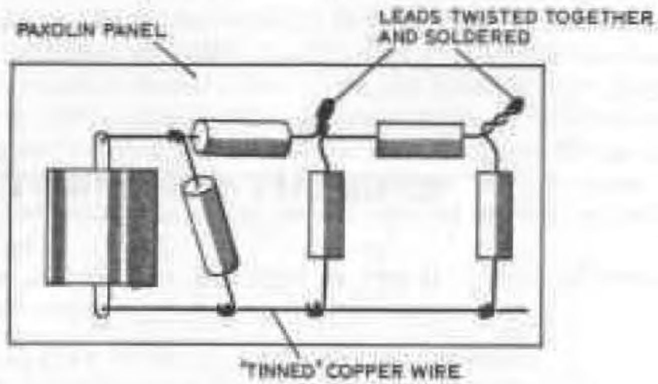


Fig. 12.2 Suitable method of circuit construction involving small number of components.

This technique was illustrated in the construction of simple crystal sets in Chapter 3. It is adaptable to more complex circuits, particularly for experimental work, but is generally untidy and unnecessarily bulky for general use. The greater the number of components, the more the circuit assembly tends to expand lengthwise, with lots of wasted space.

Direct assembly can be an attractive alternative where the components are laid out in order on a Paxolin panel. Connections are made by twisting appropriate leads together, then soldering (cutting off surplus length of leads where necessary). Larger common connections can be made to a length of 'tinned' copper wire of about 16 s.w.g. laid flat on the panel. One or two major components, such as aerial coils and the tuning capacitor, can be secured to the panel, forming an anchor point for the rest of the circuit. Main terminal point, e.g. for battery connectors, can be formed by 6-BA brass bolts fitted through holes drilled at one end of the panel.

Constructed correctly, the result can be quite neat and relatively compact, with the whole circuit quite rigid–Fig. 12.2.

'Christmas tree' layout is for the experimental or test circuit only; it follows the same principle of connecting components by twisting and soldering individual leads together, but without any attempt to lay them out flat or mount on a panel. The result invariably looks pretty messy, but it is simple and it works–provided leads do not accidentally touch one another and produce a short-circuit.

Breadboard construction is probably the best for the more serious experimenter, and can also be used for permanent circuits where overall

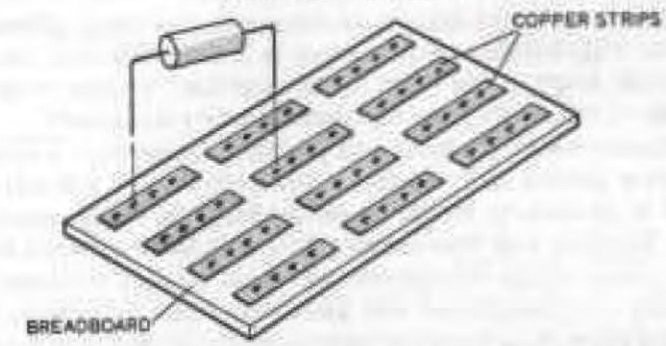


Fig. 12.3 'Breadboard' panel with pre-drilled contact strips. In some cases the copper is in long strips, sections being isolated by cutting through, as required.

size is not important. It is similar to tag-strip assembly except that the terminal points are laid out in the form of strips on a flat panel. Each strip has a number of holes into which individual component leads can be inserted for common connection, the other lead(s) connecting across to further separate strips as required to continue the circuit–Fig. 12.3. Some proprietary breadboards have small spring clips fitted under individual holes both to provide positive contact and hold the component in position without soldering–Fig. 12.4. In others the strips

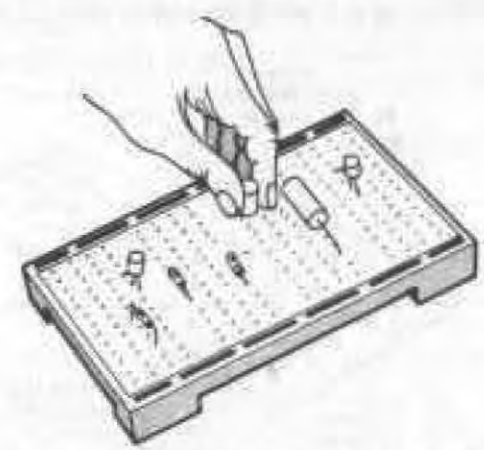


Fig. 12.4 Modern breadboard unit with spring location for components pushed in position.

are simply copper with drilled holes, component leads being soldered in position; strip lengths in this case may be in separate sections, or run the whole length of the panel, in the latter case the strip being cut through to isolate each group of connection points as required.

Pegboard assembly is based on a perforated baseboard of a suitable insulating material with terminal pillars which can be inserted into holes, as required, to provide connecting points for components–Fig. 12.5. The pillars may have a screw top for solderless assembly, or be of plain copper or brass for soldered connections. A similar technique can be allied to a 'breadboard' with prefabricated connecting strips, the terminal pillars being inserted in the pre-drilled holes, and strips isolated as necessary.

Proprietary constructional panels of these two types are designed for both amateur and general use and are widely favoured by many constructors who find designing their own component layout a tricky problem. A feature of many of these is that they can be used over and over again. The best advice regarding their suitability is to experiment and find by experience which appeals most to the individual builder, or is found easiest to use.

An alternative 'home-made' system, which would be regarded as crude by most professionals, is to cut a panel of ply or even hard balsa for the base, draw on the position of the components (as near to scale as possible) and clearly mark the common connection points required. A copper nail is then driven into the base at each end of these points, forming terminal posts to which component leads can be soldered–Fig.

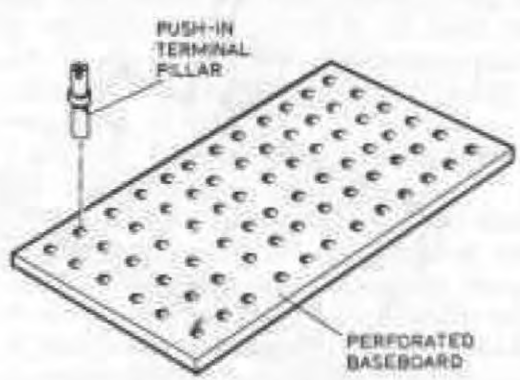


Fig. 12.5 'Pegboard' construction using a perforated baseboard and push-in terminal pillars.

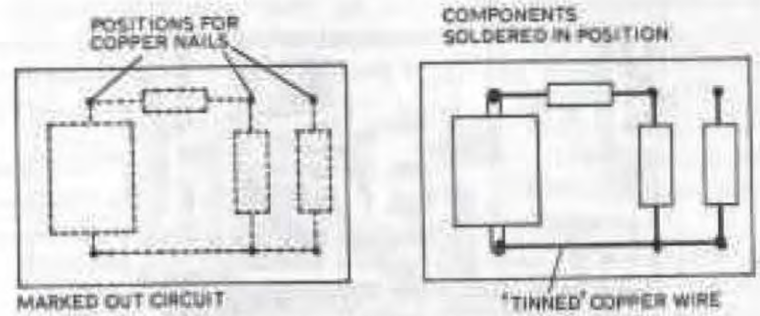


Fig. 12.6 'Copper nail' technique–again suitable for small circuits.

12.6. Longer common leads can again be a length of tinned copper wire soldered between two end nails.

A refinement of this is to use a Paxolin panel, and screw or bolt small individual tags to main and common connecting points; the longer common connections are formed from tinned copper wire soldered between two tags; individual common connecting points are formed by separate tags–Fig. 12.7.

The best technique, particularly where miniaturization of the circuit is required, is printed-circuit assembly–Fig. 12.8. Printed-circuit stock is invariably purchased in panels which can be cut to the overall size required, one face of which is coated with copper foil and the actual circuit pattern produced by etching. This involves transferring a drawing of the circuit on to the copper, coating all copper areas which are to remain with a suitable resist, and then immersing the panel in an acid bath to etch or dissolve away the remaining unwanted copper. The

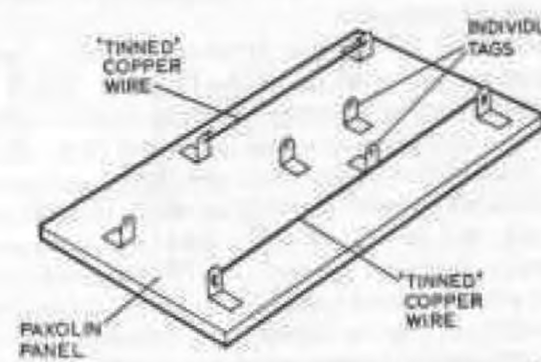


Fig. 12.7 Home-fabricated tag- and bus-bar panel.

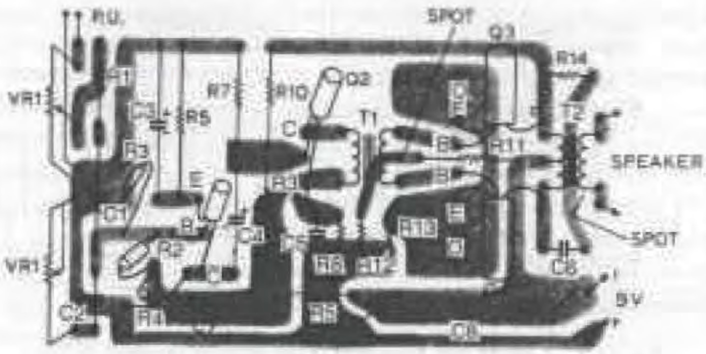


Fig. 12.8 Printed-circuit drawing layout for a push–pull amplifier.

resist is then removed with a solvent, when the PC panel can be prepared for component assembly by drilling, etc.

All this work is well within the scope of the amateur enthusiast, either working from a PC plan or designing a suitable printed pattern equivalent to a theoretical circuit design, although the latter can become quite an involved business. Alternatively, many standard radio designs etc., are available as kits or in component form for home assembly, including a complete PC, ready drilled as necessary; this latter feature saves a lot of time and effort, being a point of design on which the less experienced constructor is likely to go wrong. One of the basic essentials of PC design, in fact, is complete familiarity with component sizes so that mounting holes or holes for leads properly match the components to be accommodated, all arranged in logical order, both physically and electrically. Unlike ordinary wiring-up, PC conductors cannot be crossed over each other.

The important thing to remember is that the PC pattern has to be etched 'in reverse' on the copper side of the PC board. Simply make a tracing of the original drawing of the component layout and connections and turn this over to transfer on to the copper side of the PC board.

The layout should follow basically the same physical arrangement as the theoretical circuit. Where this diagram itself includes crossing conductors it may well be of considerable advantage to discover if it can be replanned so that these are eliminated. If this proves physically impossible, and a solution cannot be found by altering the arrangement of the components, it may be necessary to terminate certain connections on the PC lands and interconnect to cross other lands with an

insulated jumper wire. Whilst this may be considered bad design, it is perfectly suitable for one-off or amateur construction. Bear in mind, too, that components themselves can be used for bridging over adjacent conductors.

The current-carrying capacity of conductors varies with foil thickness but, since the current values in transistor receiver circuits are invariably low, conductor size is unlikely to be critical, although recommended minimum figures should be adhered to.

Minimum recommended conductor width is $\frac{1}{16}$ in., with at least $\frac{1}{32}$ in. clear spacing between adjacent conductors to reduce the possibility of accidental shorts or 'bridging' between them when soldering. The drawing should also allow for a minimum spacing of at least $\frac{1}{32}$ in. between the outside conductor and the edge of the PC board.

Where holes have to be drilled to take component leads, the diameter should closely match the lead size, e.g. with a typical resistor lead of 0.028 in. (22 s.w.g.) the corresponding hole diameter should be at least $\frac{1}{32}$ in. or No. 67 drill. Sufficient area of copper 'land' should be provided around each hole for a minimum width of $\frac{1}{16}$ in. (Fig. 12.9). The holes should be correctly spaced to match component leads, allowing for a 'finger bend' at each end or down the side of the component, according to whether horizontal or vertical assembly is to be used (Fig. 12.10). The former is to be preferred except where a minimum size panel is aimed at, when vertical mounting of resistors etc., will occupy minimum base area. At no point, however, should spacing between adjacent holes be less than twice the laminate thickness (i.e. normally not less than $\frac{1}{8}$ in. on standard laminate).

Other points to watch are that where conductors join at an acute angle they should be faired in with a generous fillet, increasing the area

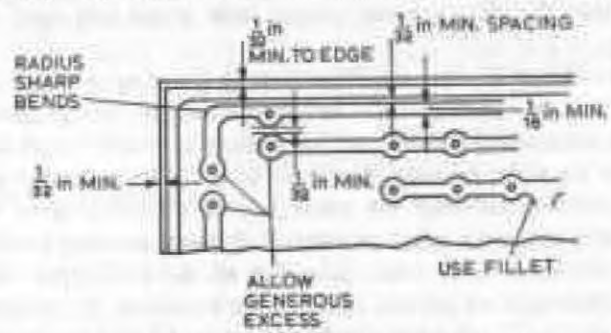


Fig. 12.9 Recommended proportions for conductors, spacing etc.

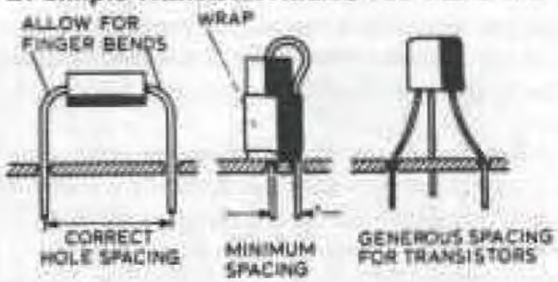


Fig. 12.10 Mounting of components on a printed-circuit board. Vertical mounting saves space.

bonded at the joint and making the copper far less liable to be lifted. Also, do not leave unnecessarily wide or large areas of copper as conductors as these may be subject to excessive heating and expansion, with the result that the copper tends to lift from the base. Either reduce the outline of such areas or relieve the surface area with slots to be etched away. This is not so important on low-voltage circuits, but on mains-operated ones no copper area of more than about one square inch should be left 'solid'.

The first step, having prepared a PC drawing, is to cut the laminate to the required overall size using a fine-tooth saw. The copper surface has probably become greasy and dirty through handling, and so should now be thoroughly cleaned by washing with a detergent and rubbing dry with a clean cloth. If the copper is discoloured through corrosion, use a domestic abrasive cleaner to bring it up bright clean.

A test of cleanliness is to hold the panel under a tap, copper side up, and allow water to run on to it. If the water flows smoothly over the whole area, the surface is clean and grease-free; if isolated patches of copper stay dry they are still coated with grease and need further cleaning.

Once completely clean the PC pattern is drawn or traced on to the copper. Cellulose paint or resist ink should then be used to paint in all the land areas, using a ruling pen for straight lines and a small brush to complete the wider sections; the whole of the pattern may be painted on, if preferred, although the result may be somewhat more ragged. Avoid using too much paint or resist, as this may overrun the outlines but, at the same time, make sure that all the land areas are fully covered. The painted pattern should then be left to dry, which may take an hour or more with cellulose paint or 10 to 15 minutes with resist inks.

The solution normally used for etching is ferric chloride mixed with a little hydrochloric acid, or straight dilute nitric acid. The former is generally preferred since it does not 'gas' as much as the acid alone, but either will be equally effective. This solution is poured into a suitable shallow container, and the laminate immersed in it. Rate of etching will depend on the temperature of the solution and also the degree of agitation. Thus, at a temperature of 10°C a ferric-chloride bath will etch the copper at a rate of about 1 thou. in 20 minutes—or nearly an hour to etch 3 thou. foil; at 20°C the rate of etching is increased to about 10 minutes per thou.; and at 35°C is almost twice as fast again. The rate can also be increased by gentle agitation, moving the board gently backwards and forwards in the bath, or gently rocking the container to swill the etching solution from end to end.

Etching should be allowed to proceed until all traces of copper have disappeared from the surface. The board can then be removed and rinsed under running water to remove any traces of etchant. The paint or resist ink covering the lands is then removed either with a solvent (e.g. cellulose thinners, for cellulose paint) or a cleaner (resist inks). After this, again wash and dry the board; then it is ready for drilling.

Three basic rules must be observed when drilling the PC panels:

(i) Always use a sharp drill (preferably a new one, or one which has been re-sharpened prior to use).
(ii) Always drill from the copper side (i.e. copper face up).
(iii) Always use a backing of hard material underneath so that the drill point will not tear out a section of the laminate when it breaks through.

Drilling may be done with a hand or electric drill, the latter being far less tiring to use when there are a large number of holes to be made, although the small size of drill required may lead to a high breakage rate unless special care is taken.

Notes on soldering

Electric irons are invariably used for electronic assemblies together with resin-cored solder (i.e. the solder is in the form of a hollow wire with the core filled with resin flux). Flame-heated irons are not satisfactory for they are usually too large and cumbersome, and also do not permit good temperature control. Equally, one should always use an electrical (cored) solder when no separate flux is required; an acid-type flux should *never* be used on electrical work as this will inevitably produce corrosion.

The basic rules for good soldering are extremely simple, although they are frequently ignored. They may be summarized as:

(i) The iron should be of the right size and type.
(ii) The iron should be hot enough to melt the solder freely.
(iii) The tip of the iron must be kept 'tinned' and clean.
(iv) The work surfaces to be soldered must be clean and grease-free.

The correct size of iron is important for if too small it will rapidly lose heat when applied to the work, and if too large may overheat adjacent components or be awkward to apply. For PC assemblies a $\frac{1}{8}$-in. bit diameter is about right for general work–not too large, but large enough to retain enough heat for more or less continuous work. It may be awkward to use when soldering up a miniature panel where the lands are close together, when a $\frac{3}{32}$-in. or even a $\frac{1}{16}$-in. bit may be preferred. This smaller size will, however, usually lose so much heat in completing a single joint that it has to be left to heat up again before it can be applied to the second joint.

Iron size is also specified by wattage, but this is more of a nominal rating than anything else, for irons by different manufacturers but of the same stated wattage can have a considerable difference in performance, e.g. differences in heating-up times and in bit temperature achieved (and variations in the latter can be as high as 100°C). To avoid the possibility of over-heating, an iron with a rating of more than 50 W should never be used for PC assemblies.

Iron voltage must be matched to the mains voltage available and it is usual to operate an electric iron on the middle voltage of the range, e.g. for a 240-V mains a 230/250-V iron would be correct. An iron should never be operated on a mains voltage below the lowest figure of its rating as in such a case it will not develop its correct bit temperature.

Typically, a good electric iron will achieve a saturation temperature of approximately 375°C. The time taken to reach this temperature will vary with the size and design, but very roughly should be of the order of wattage divided by four (in seconds), e.g. in the case of a 30-W iron the bit should reach its maximum or saturation temperature in about $30 \div 4 = 7\frac{1}{2}$ seconds. It should also take about one-third of this time (e.g. watts divided by 12) to reach a satisfactory bit temperature for

soldering (250°C), although this can readily be judged by trying the solder on the bit to see if it runs freely.

The *minimum* bit temperature required for satisfactory soldering is 40°C above the melting point of the solder used, which will vary with the composition of the solder.

Whether the temperature of the bit is satisfactory or not can readily be judged by the time it takes to complete a joint. This should be not more than three to four seconds, and the resulting joint should be bright clean, with the solder completely 'wetting' both surfaces. If the joint takes longer to make and/or the solder has a pasty or dull appearance, the iron is not hot enough. If the solder is reluctant to take or flow over the joint, or collects in blobs rather than spreading out, then the surfaces are dirty.

Before attempting assembly on a PC board the panel should always be cleaned so that the lands are bright all over with no dull spots, and subsequently should not be finger-marked by handling. An ordinary domestic powder cleaner is as good as anything for cleaning the PC lands, used wet or dry, the panel then being rinsed under running water to remove any traces of abrasive, and dried on a clean rag.

Component leads are normally 'tinned' and therefore in a suitable state for soldering. Almost certainly, however, the 'tinned' surface will have become dirty or partly corroded during handling and storage and it is generally recommended to clean leads immediately prior to assembly and soldering in position. A scrap of fine emery paper is excellent for this, simply wrapped around and pulled along the length of the lead, taking care not to impose excess mechanical strain; similarly with tags etc. Time taken in cleaning leads etc., is usually time saved, for one can then be sure of a satisfactory soldered joint at the first attempt.

Then there is the question of heat damage to consider. Provided the joint is completed quickly–i.e. within three or four seconds of application of the iron–no component is likely to suffer heat damage. This even applies to transistors which are normally rated to withstand continuous application of a soldering bit no closer than $\frac{1}{4}$ in. from the base for a period of up to ten seconds without damage. Thus if all goes well and soldered joints are completed quickly and neatly, it is seldom necessary to worry about heat damage.

It is still, however, commonly recommended that a 'heat sink' should always be used on each lead of a transistor when soldering in position. A heat sink, basically, is a mass of conducting material which will absorb heat from the iron rather than let the full heat flow up the lead. The jaws of a pair of pliers gripping the transistor lead form a suitable heat sink; or, if these are not convenient to use, a crocodile clip can serve the same purpose (especially if the jaws are filed flat to provide maximum surface contact with the lead).

The most likely cause of heat damage is re-working a joint which has not been made properly, or trying to unsolder a lead which has been wrongly positioned. This may entail leaving the iron in contact with the joint far longer than the 'safe' three or four seconds, when damage can result to the component. Excessive heat applied locally in this manner will also tend to 'lift' the copper land away from the base material on a PC panel.

Fig. 12.11 The safest way to remove a faulty component is usually to cut it off.

Removing a component which has been mounted on a PC can, in fact, be a tricky process. If it is a faulty component which is to be replaced the *safest* way to go about such a job is to cut it off, as shown in Fig. 12.11, leaving stub lengths of the original lead protruding from the plain side of the PC panel. The new component can then be soldered in place *to* these stub leads. Alternatively, having cut off the component, each lead can be removed in turn by laying the tip of the iron on the solder joint (PC side) and withdrawing the lead with pliers as soon as the solder has melted. Then, before it has had time to set again, blow surplus solder out of the hole (Fig. 12.12).

To remove a component intact usually means working on one lead at a time, lifting first one end of the component and then the other. This

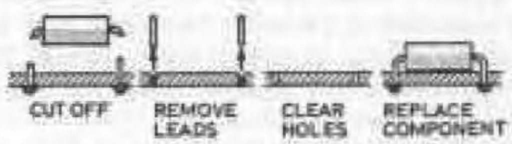


Fig. 12.12 Remaining leads can then be removed, ready to fit new component.

is not always possible when the component is mounted on rigid leads or tags, generally demanding working on pairs of tags at a time and gradually levering the component upwards. This usually entails considerable risk of overheating the component and of 'lifting' the PC lands if too much heat is applied to the tag side.

A trick which often helps in removing a rigidly mounted component, such as an IF transformer, is to heat the tags and remove the solder with a suitable stiff-bristled brush. This is repeated on each tag until the component is sufficiently loosened to be prised free. It is important, however, to avoid splashing excess solder on to other parts of the PC board.

Unless obviously faulty, transistors or diodes should not be removed from a PC board once assembled, as the possibility of permanent damage resulting is high. If imperative that they should be removed (e.g. if they have been connected up wrongly), a heat shunt should always be used (e.g. a pair of thin-nosed pliers gripping the lead between the transistor body and the PC board).

Where the board itself is damaged—e.g. foil has come unstuck through excessive local heating—loosened lands can usually be stuck back again by carefully heating the foil with the soldering iron and then pressing in place on the board until the adhesive has reset. If not, the loose land may have to be stuck down with an application of a general-purpose domestic or epoxy adhesive.

Mechanical damage to PC boards can be repaired by bridging breaks or cracks in the copper lands with 'jumper' wires soldered in place. These can be plain 'tinned' copper wire, but if a longer jumper is required which passes over adjacent lands, either insulated wire should be used or the wire length fitted with insulating sleeving. All repaired areas should then be coated with clear lacquer for protection.

Where a PC board is quite extensively damaged, or needs to have a number of components changed, it is usually more satisfactory in the long run to scrap the original board and start again with a new one; and preferably new components, rather than to try to salvage all the original ones, as these may be damaged in the process of removal from the old board.

13 FETs AND ICs

Field-effect transistors (FETs) have a construction, and characteristics, that differ from conventional junction transistors. Their behaviour, in fact, is more like that of a triode valve, although retaining the characteristic low-power requirements of a transistor.

The electrodes of an FET are designated gate, source and drain with the following approximate equivalents:

FET	Transistor	Triode valve
Gate	Base	Grid
Source	Emitter	Cathode
Drain	Collector	Anode

The standard symbol for an FET differs from that of a conventional transistor, with the gate carrying an arrow, which points outwards for a *P*-channel FET and inwards for an *N*-channel FET–Fig. 13.1. The general rule is that the polarity of the *drain* supply is negative for a *P*-channel FET and positive for an *N*-channel FET.

A simple regenerative receiver based on two *P*-channel FETs is shown in Fig. 13.2. This is adjusted for optimum working by the

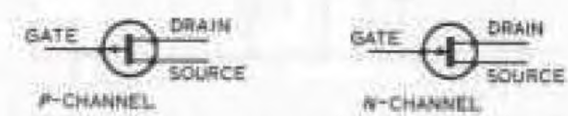


Fig. 13.1 Symbols for the two basic types of field-effect transistors (FETs).

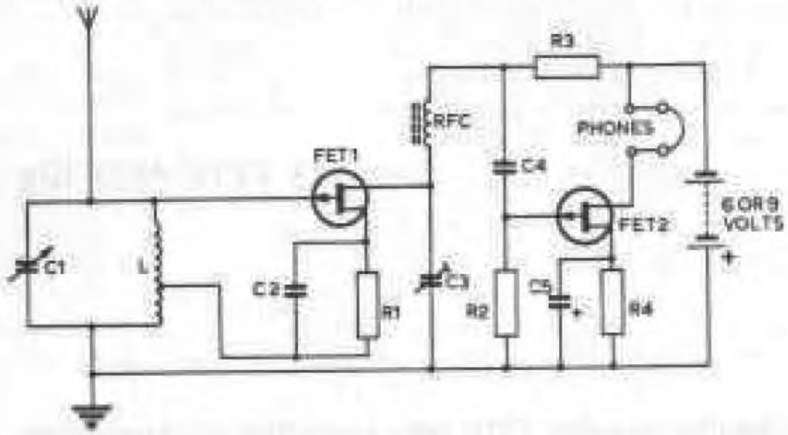


Fig. 13.2 *Circuit 26.* Simple regenerative receiver using *P*-channel FETs.

FET1, FET2, 2N3819, 2N5457, or similar

C1, 0–500 pF	R1, 22 k
C2, 8 or 10 μF	R2, 470
C3, 50 pF	R3, 22 k
C4, 0.01 μF	R4, 10 k
C5, 8 or 10 μF	RFC, 10 mH
	L, aerial coil

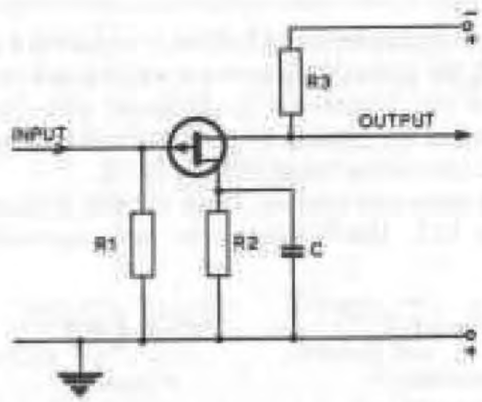


Fig. 13.3 Basic AF amplifier circuit using a *P*-channel FET. R1 is bias resistor; R2 and C stabilizing load; R3 drain resistor.

trimmer capacitor C3. L and C1 are a conventional aerial tuned circuit with tapping point.

Fig. 13.3 shows a typical arrangement for an FET amplifier stage. This could be added on to the receiver circuit to provide amplification which should be sufficient to power a small loudspeaker.

Integrated circuits

Integrated circuits (ICs) are one of the latest products of modern electronic technology–small integrated circuit modules in which a complete circuit duplicates the performance of perhaps a dozen or more active devices (e.g. transistors and diodes) and a similar number of passive components (e.g. resistors and capacitors) in a silica 'chip' only a few millimetres square.

Depending on their design function, ICs may be used as a complete stage or logic element in a circuit; or, more usually, associated with a number of conventional external components to complete the circuit. Fig. 13.4, for example, shows the equivalent circuit diagram of one IC (Siemens TAA 861), and Fig. 13.5 the incorporation of that particular IC in a 4-W amplifier.

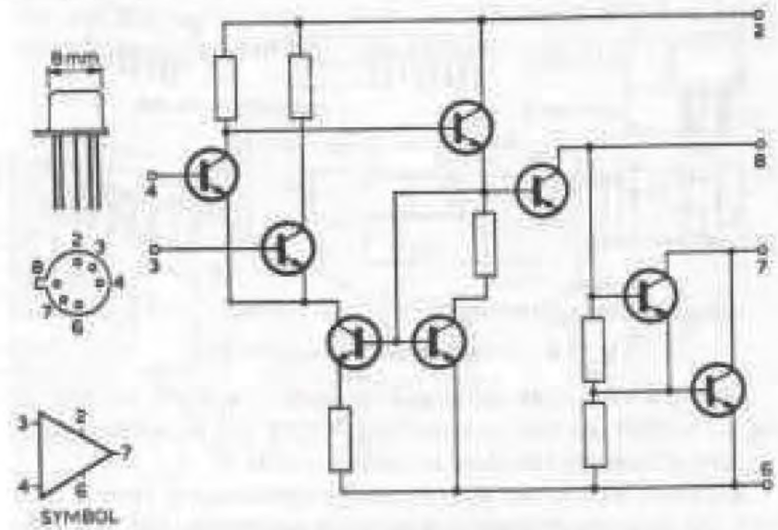


Fig. 13.4 Siemens TAA 861 integrated circuit together with diagram of equivalent circuit–i.e. embracing eight transistors and six resistors.

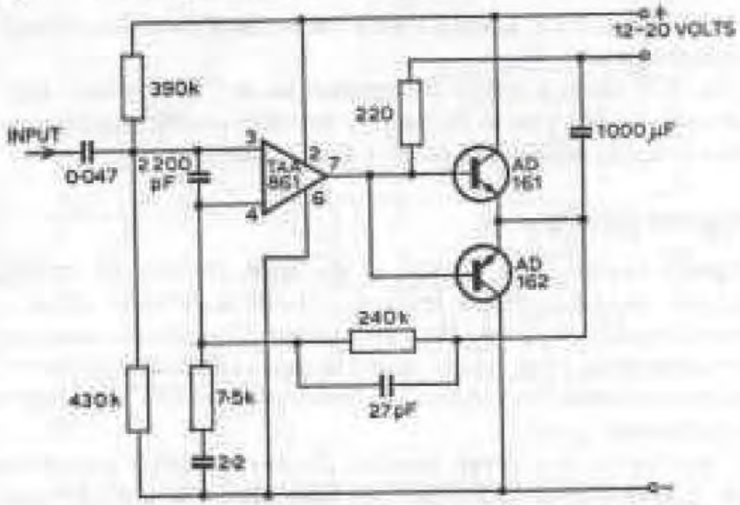
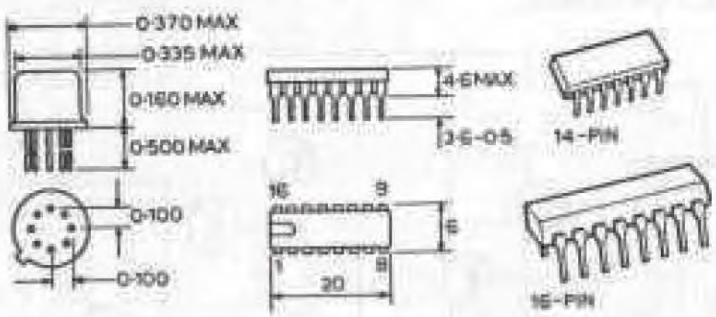


Fig. 13.5 *Circuit 27.* Siemens TAA 861 'chip' used in a complete circuit with external components. This circuit is actually that of a 4-W amplifier, working off 12–20 V.



DIMENSIONS IN MILLIMETRES

Fig. 13.6 Example of outlines of typical ICs.

Examples of outline appearance of some typical ICs are given in Fig. 13.6. They are best mounted by plugging into IC holders, which are normally designed for mounting on PC boards.

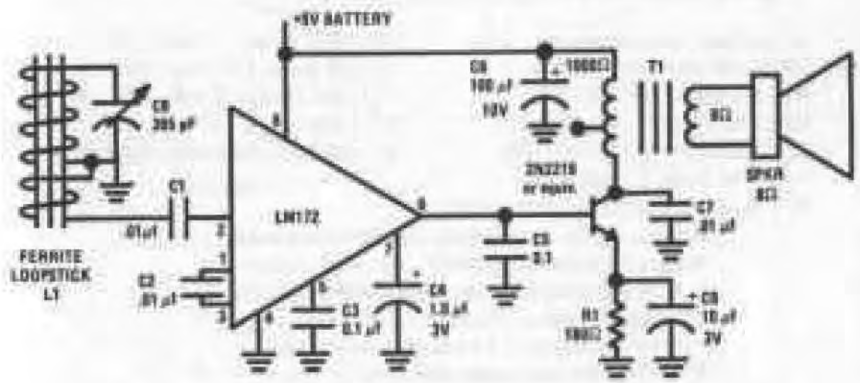
Integrated circuits are not necessarily expensive, e.g. from a little over 50p upwards, depending on type and complexity, and they offer an interesting new field of experiment for the amateur constructor. Manufacturers of ICs normally provide suggested applications for their various types.

Low Frequency TRF Receiver

Because the LM172 is a broadband functional module, it may be used to amplify and detect signals below 2 MHz directly, without the more complex frequency conversion of superheterodyne receivers. In the AM Broadcast Band (550-1650 kHz), the strip has sufficient sensitivity to operate alone in urban reception areas, since AGC action is useful down to about 50 microvolts at Pin 2. With additional gain either preceding the module, or inserted between Pins 1 and 3, it may also be useful in monitoring Loran (1.8-2.0 MHz), or the numerous directional and informational channels below 550 kHz.

While the complete TRF (Tuned Radio Frequency) broadcast receiver of Fig. 13.7 has relatively poor selectivity, because only a single, low "Q" tuned circuit is used in the entire receiver, it serves to illustrate the straightforward design possible in TRF construction. More sophisticated designs might use multisection tuning, ahead of the strip. The prototype was constructed using very inexpensive imported "transistor-radio" components.

A ferrite loopstick antenna, L1, resonates with a small, polyethylene dielectric tuning capacitor within the broadcast band. The LM172 performs its gain function just as it would in an IF application, but in this case, directly drives a class A power amplifier. Since the DC output voltage at Pin 6 is relatively constant (from 2.1 to about



L1 – Ferrite Loopstick – Philmore FF15 (packaged as set of 3 sizes)
C8 – Sub miniature variable capacitor – Philmore 1949G – 365 pF max.
T1 – Midget Audio Transformer, 1000Ω:8Ω – Archer 273-1380 (Radio Shack, Inc.)
SPKR – 2" PM Speaker, 8Ω, 0.1 watt – Philmore TS28

Fig. 13.7 TRF Broadcast Receiver

2.4 volts as a function of AGC). It is used to bias the class A stage directly, eliminating a number of components. C7 and C8 are needed to prevent regenerative audio oscillations with weak batteries. Total receiver drain from the 9-volt supply is 10 mA, of which only 1.9 mA is used in the LM172; the rest is needed for the audio amplifier.

A volume control was not provided in the prototype, as volume was excellent with the small (2" diameter) speaker used, and AGC was so effective that no perceptible difference in stations was heard. Volume control is possible by inserting a potentiometer between the emitter of the audio output transistor and R1.

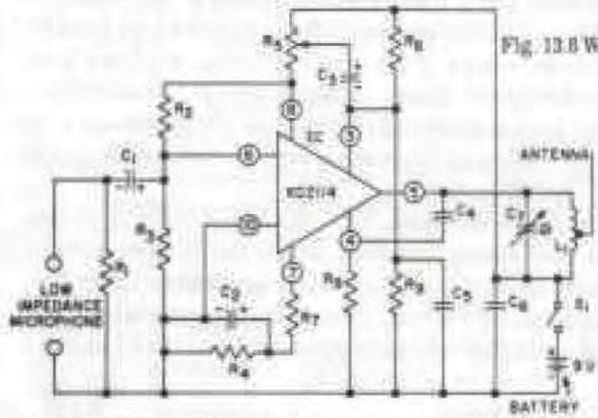


Fig. 13.8 Wireless microphone.

Microphone : low-impedance, 200 to 600 ohms, RCA HK-99
R_1 : 270 ohms, 1/2 watt, 10%
R_2 : 150,000 ohms, 1/2 watt, 10%
R_3 : 22,000 ohms, 1/2 watt, 10%
R_4 : 1200 ohms, 1/2 watt, 10%
R_5 : 10,000 ohms, trimmer potentiometer
R_6 : 8200 ohms, 1/2 watt, 10%
R_7 : 68 ohms, 1/2 watt, 10%
R_8 : 330 ohms, 1/2 watt, 10%
R_9 : 6800 ohms, 1/2 watt, 10%
S_1 : switch, single-pole single-throw slide type
Antenna : 3/16-inch-diameter rod, 2-1/2 inches long
Battery : 9 volts; RCA VS323
C_1 : 25 microfarads, 6 volts, electrolytic
C_2 : 200 microfarads, 6 volts, electrolytic
C_3 : 20 microfarads, 10 volts, electrolytic
C_4 : 15 picofarads, silver mica
C_5 : 1000 picofarads, 25 volts or greater, ceramic
C_6 : 0.1 microfarad, 25 volts or greater, ceramic
C_7 : 3 to 30 picofarads, trimmer type,
IC : integrated circuit; RCA KD2114
L_1 : 6 turns No. 12 wire; coil I.D. 5/16 inch, length 3/4 inch

Wireless Microphone

This wireless microphone (Fig. 13.8) transmits on any desired FM broadcast-band frequency from 88 to 108 MHZ (tuning controlled by C_7). The range of the wireless microphone is 50 to 150 feet depending on the location of the receiver and its antenna. Circuit features include small size, high quality, and low current drain; the antenna length has been limited to keep radiation within FCC wireless-microphone regulations. The low-impedance microphone to be used with this circuit is the RCA HK-99.

Marine-Band Converter

This marine-band converter (Fig. 13.9) converts any standard AM broadcast receiver to one capable of receiving transmission in the 2 to 3-MHz marine band. The output is connected to the AM receiver antenna terminals. If the receiver does not have antenna terminals the output is connected to 10 turns of No. 32 wire wound over the loopstick antenna in the receiver.

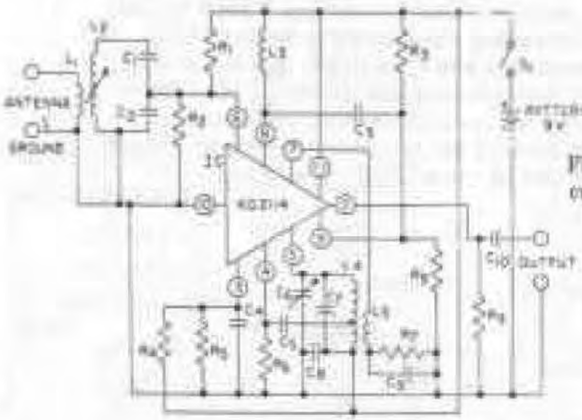


Fig. 13.9 Marine-band converter.

Battery : 9 volts; RCA VS323
C_1 : 180 picofarads, 25 volts or greater, silver mica
C_2 : 680 picofarads, 25 volts or greater, silver mica
C_3 : 470 picofarads, 25 volts or greater, ceramic
C_4 C_5 C_{10} : 0.01 microfarad, 25 volts or greater, ceramic
C_6 : 50 picofarads, variable; Hammarlund HF-50 or equivalent
C_7 : 56 picofarads, 25 volts or greater, silver mica
C_8 C_9 : 0.05 microfarad, 25 volts or greater, ceramic
IC : integrated circuit; RCA KD2114
L_1 : 10 turns No. 32 enameled wire wound on the same form as L_2 and close to L_2

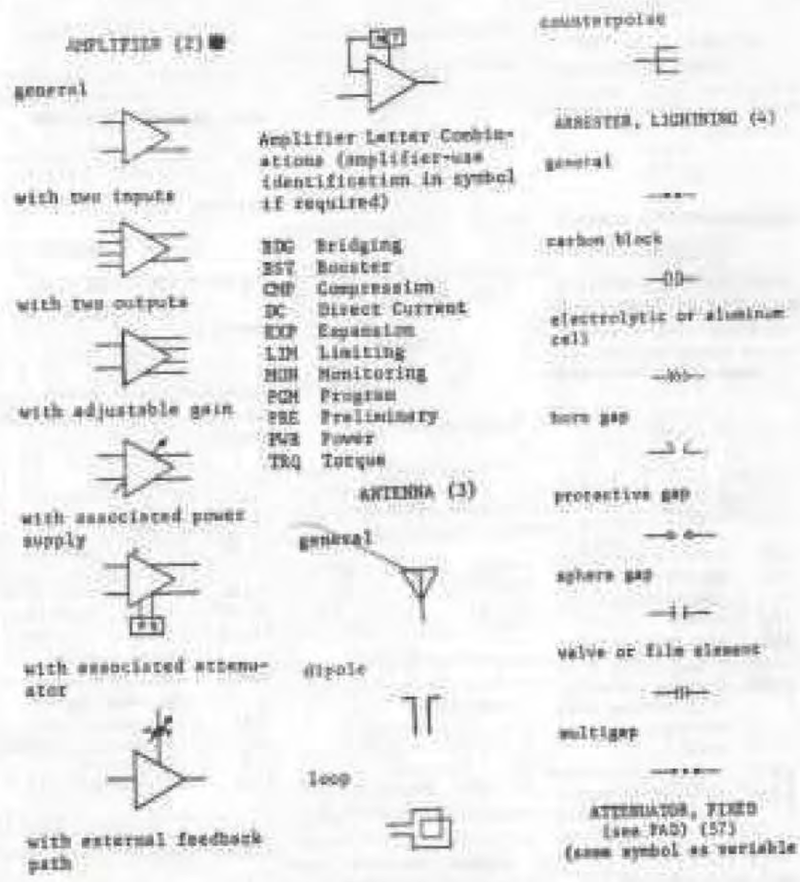
L_2 : Miller No. 4206 or equivalent
L_3 : rf choke, 2.5 millihenries; Miller No. 70F253A1 or equivalent
L_4 : 40 turns of B and W coil No. 3012 or equivalent; see Note
L_5 : 9 turns of B and W coil No. 3012 coil stock (or equivalent) spaced 1 turn from positive end of L_4; see Note

R_1 : 82,000 ohms, 1/2 watt, 10%
R_2 : 4700 ohms, 1/2 watt, 10%
R_3 : 150,000 ohms, 1/2 watt, 10%
R_4 : 47,000 ohms, 1/2 watt, 10%
R_5 : 22,000 ohms, 1/2 watt, 10%
R_6 : 2200 ohms, 1/2 watt, 10%
R_7 : 1000 ohms, 1/2 watt, 10%
R_8 : 100,000 ohms, 1/2 watt, 10%
R_9 : 470 ohms, 1/2 watt, 10%
S_1 : switch; single-pole single-throw

Note : L_4 and L_5 are made from coil type B and W No. 3012 (or equivalent) coil stock cut to 50 turns. Allow enough extra wire at the outside ends to form leads. The 50-turn coil is cut at turn 40-1/2; this forms a 40-1/2-turn coil (L_4), and a 9-1/2-turn coil (L_5). The extra 1/2 turn on each coil is lifted (or unrolled) and used as a lead. L_4 is tapped at turn 31.

Appendix

ELECTRONICS SYMBOLS



● NUMBER IN PARENTHESES INDICATES LOCATION OF SYMBOL IN MIL-STD PUBLICATION attenuator, without variability)

ATTENUATOR, VARIABLE (5)

balanced

unbalanced

AUDIBLE SIGNALING DEVICE (6)

bell, electrical; ringer telephone

buzzer

horn, electrical; loudspeaker; siren; underwater sound hydrophone, projector or transducer

Horn, Letter Combinations (if required)

*HN	Horn, electrical
*HW	Howler
*LS	Loudspeaker
*SN	Siren
‡EM	Electromagnetic with moving coil
‡EMN	Electromagnetic with moving coil and neutralizing winding
‡MG	Magnetic armature
‡PM	Permanent magnet with moving coil

identification replaces (*) asterisk and (‡) dagger)

sounder, telegraph

BATTERY (7)

generalized direct current source; one cell

multicell

CAPACITOR (8)

general

polarized

adjustable or variable

continuously adjustable or variable differential

phase-shifter

split-stator

feed-through

CELL, PHOTOSENSITIVE (Semiconductor) (9)

asymmetrical photoconductive transducer

symmetrical photoconductive transducer

photovoltaic transducer; solar cell

CIRCUIT BREAKER (11)

general

with magnetic overload

drawout type

CIRCUIT ELEMENT (12)

general

Circuit Element Letter Combinations (replaces (*) asterisk)

EQ	Equalizer
FAX	Facsimile set
FL	Filter
FL-BE	Filter, band elimination
FL-BP	Filter, band pass
FL-HP	Filter, high pass
FL-LP	Filter, low pass
PS	Power supply
RG	Recording unit
RU	Reproducing unit
DIAL	Telephone dial
TEL	Telephone station
TPR	Teleprinter
TTY	Teletypewriter

Additional Letter Combinations (symbols preferred)

AR	Amplifier
AT	Attenuator
C	Capacitor
CB	Circuit breaker
HS	Handset
I	Indicating or switch board lamp

L	Inductor
J	Jack
LS	Loudspeaker
MIC	Microphone
OSC	Oscillator
PAD	Pad
P	Plug
HT	Receiver, headset
K	Relay
R	Resistor
S	Switch or key switch
T	Transformer
WR	Wall receptacle

CLUTCH; BRAKE (14)

disengaged when operating means is de-energized

engaged when operating means is de-energized

COIL, RELAY and OPERATING (16)

semicircular dot indicates inner end of wiring

CONNECTOR (18)

assembly, movable or stationary portion; jack, plug, or receptacle

jack or receptacle

plug

separable connectors

two-conductor switchboard jack

two-conductor switchboard plug

jacks normalled through one way

jacks normalled through both ways

2-conductor nonpolarized, female contacts

2-conductor polarized, male contacts

waveguide flange

plain, rectangular

choke, rectangular

engaged 4-conductor; the plug has 1 male and 3 female contacts, individual contact designations shown

coaxial, outside conductor shown carried through

coaxial, center conductor shown carried through; outside conductor not carried through

mated choke flanges in rectangular waveguide

COUNTER, ELECTROMAGNETIC; MESSAGE REGISTER (26)

general

with a make contact

COUPLER, DIRECTIONAL (27) (common coaxial/waveguide usage)

(common coaxial/waveguide usage)

E-plane aperture-coupling 30-decibel transmission loss

COUPLING (28)

by loop from coaxial to circular waveguide, direct-current grounds connected

CRYSTAL, PIEZO-ELECTRIC (62)

DELAY LINE (31)

general

tapped delay

bifilar slow-wave structure (commonly used in traveling-wave tubes)

(length of delay indication replaces (*) asterisk)

DETECTOR, PRIMARY; MEASURING TRANSDUCER (30) (see HALL GENERATOR and THERMAL CONVERTER)

DISCONTINUITY (33) (common coaxial/waveguide usage)

equivalent series element, general

magnetic core

tapped

adjustable, continuously adjustable

KEY, TELEGRAPH (43)

LAMP (44)

ballast lamp; ballast tube

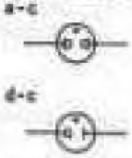
capacitive reactance

inductive reactance

inductance-capacitance circuit, infinite reactance at resonance

lamp, fluorescent, 2 and 4 terminal

lamp, glow; neon lamp
a-c



d-c

lamp, incandescent

indicating lamp; switchboard lamp (see VISUAL SIGNALING DEVICE)

LOGIC (see 806B and Y32-14) (including some duplicate symbols; left and right-hand symbols are not mixed)

AND function

OR function

EXCLUSIVE-OR function

((*) input side of logic symbols in general)

condition indicators

state (logic negation)

a Logic Negation output becomes 1-state if and only if the input is not 1-state

an AND func. where output is low if and only if all inputs are high

electric inverter

(elec. invtr. output becomes 1-state if and only if the input is 1-state) (elec. invtr. output is more pos. if and only if input is less pos.)

level (relative)

1-state is less +   1-state is more +

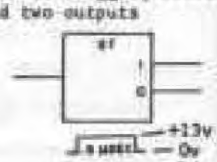
(symbol is a rt. triangle pointing in direction of flow)

an AND func. with input 1-states at more pos. level and output 1-state at less pos. level

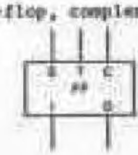
single shot (one output)

(waveform data replaces inside/outside (*))

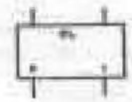
schmitt trigger, waveform and two outputs



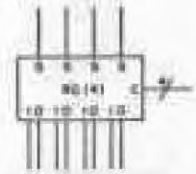
flip-flop, complementary



flip-flop, latch



register



(binary register denoting four flip-flops and bits)

amplifier (see AMPLIFIER)

stereo

RECTIFIER (65)

semiconductor diode; metallic rectifier; electrolytic rectifier; asymmetrical varistor

mercury-pool tube power rectifier

fullwave bridge-type

RESISTOR (68)

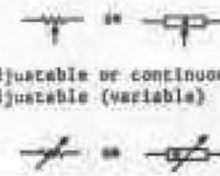
general

tapped

heating

symmetrical varistor resistor, voltage sensitive (silicon carbide, etc.)

(identification marks replace (*) asterisk) with adjustable contact



adjustable or continuously adjustable (variable)

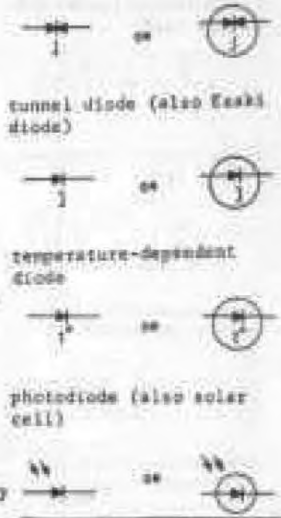
(identification replaces (*) asterisk)
SEMICONDUCTOR DEVICE (73) (Two Terminal, diode)

semiconductor diode; rectifier

capacitive diode (also Varicap, Varactor, reactance diode, parametric diode)

breakdown diode, unidirectional (also backward diode, avalanche diode, voltage regulator diode, Zener diode, voltage reference diode)

breakdown diode, bidirectional and backward diode (also bipolar voltage limiter)



tunnel diode (also Esaki diode)

temperature-dependent diode

photodiode (also solar cell)

semiconductor diode, PNPN switch (also Shockley diode, four-layer diode and SCR)

(Multi-Terminal, transistor, etc.)

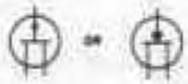
PNP transistor

NPN transistor

unijunction transistor, N-type base

unijunction transistor, P-type base

field-effect transistor, N-type base



field-effect transistor, P-type base

semiconductor triode, PNPN-type switch

semiconductor triode, NPNP-type switch

NPN transistor, transverse-biased base

PNIP transistor, ohmic connection to the intrinsic region

NPIN transistor, ohmic connection to the intrinsic region

PNIN transistor, ohmic connection to the intrinsic region

NPIP transistor, ohmic connection to the intrinsic region

SQUIB (75)

explosive

igniter

sensing link; fusible link operated

SWITCH (76)

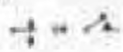
push button, circuit closing (make)

push button, circuit opening (break)

nonlocking; momentary circuit closing (make)

nonlocking; momentary circuit opening (break)

transfer



locking, circuit closing (make)

locking, circuit opening (break)

transfer, 3-position

wafer

(example shown: 3-pole 3-circuit with 2 non-shorting and 1 shorting moving contacts)

safety interlock, circuit opening and closing

2-pole field-discharge knife, with terminals and discharge resistor

(identification replaces (*) asterisk)

TRANSFORMER (86)

general

magnetic-core

one winding with adjustable inductance

separately adjustable inductance

adjustable mutual inductor, constant-current

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