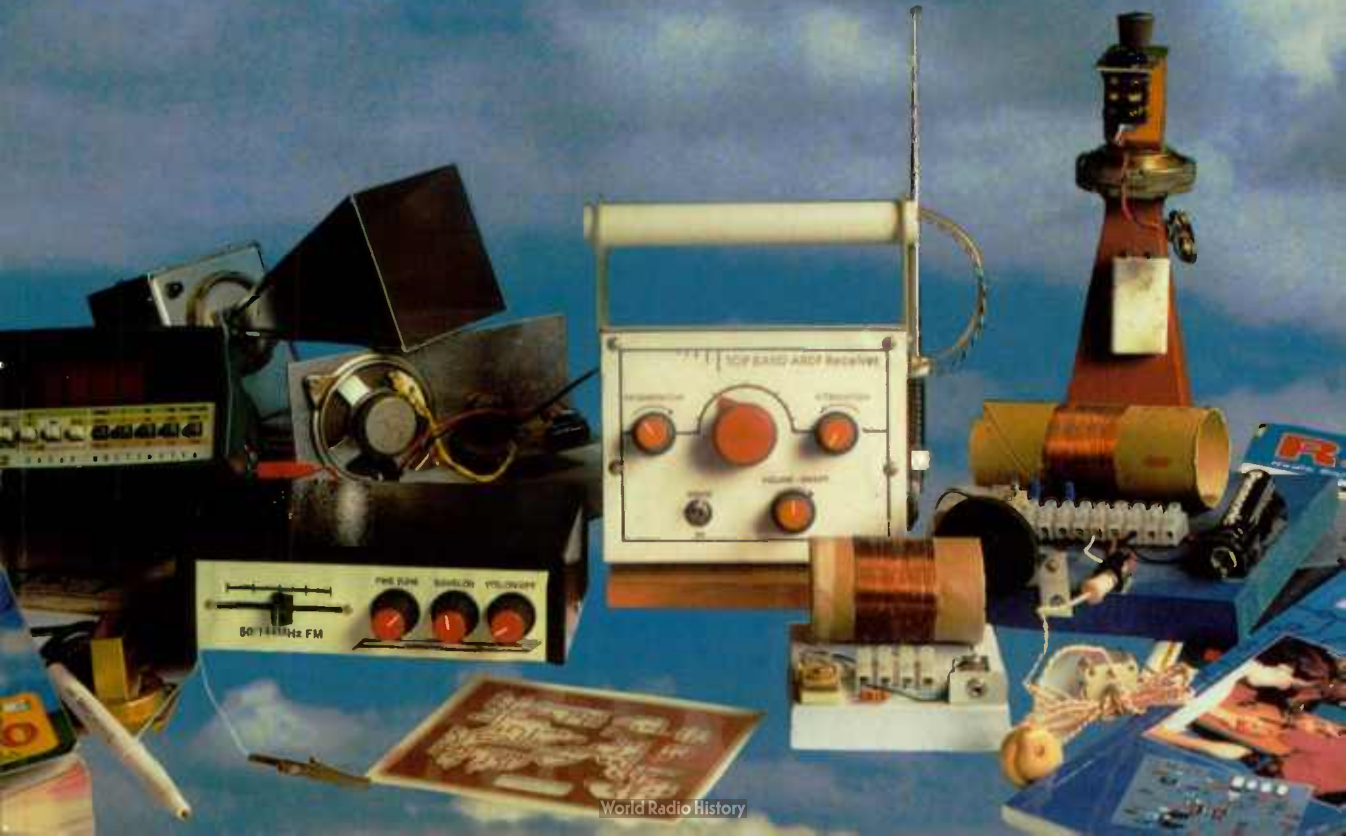
PRACTICAL RECEIVERS FOR BEGINNERS

John Case, GW4HWR



PRACTICAL RECEIVERS
FOR BEGINNERS

This book contains a selection of 'easy-to-build' receiver designs suitable for amateur bands (including microwaves), together with simple 'fun' projects and test equipment. The theory and practice of receiving techniques is also outlined to help with understanding the circuits presented. The book will be of interest to anyone who is building receivers for the first time or who is considering moving up to microwaves.

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Radio Society of Great Britain

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Preface

This is in the form of an autobiography of the author who has spent many hours as a shortwave listener as well as making receivers of all kinds. "Shortwave listening! How dull", I hear you say, but it is not so. There is tremendous satisfaction to be had from just listening to other people transmitting, especially if that listening is carried out with equipment which you have made yourself.

Way back in 1927 I ventured into the world of amateur radio by attempting to make a simple radio receiver – a crystal set. It did not work, possibly because there was some built-in fault, but more likely because the nearest transmitter was too far away. They were few and far between in those days and the aerial (antenna) I was using was not very good, but unfortunately there was no one around who could tell me that it mattered – as a nine-year-old I was convinced that it was something I had or had not done. The early failure did not put me off and a little later a second attempt worked, not very well but at least I could hear voices. By this time I was reading the latest publication *Popular Wireless* and found in one of the issues an article relating to an imminent RSGB field day for 5 metres. In addition to information on where and how to find competing amateurs, there was a design for a suitable receiver. It was very basic and virtually every component had to be home-made. The coils were about 5cm in diameter, almost self-supporting and as far as I remember had about five turns each. One triode valve occupied pride of place in the centre of the wooden baseboard and the tuning capacitor and reaction control were at the back of the board with very long spindles to 'connect' the capacitors to the control knobs on the front panel. All this was to keep the hands as far away as possible from the parts which mattered. Amazingly enough it worked, but with hindsight I suspect that it was a better transmitter than receiver. Great was the excitement when two amateurs were heard discussing the equipment they were using. It sounded a bit like the description just given for the receiver.

From then on there was no stopping me. A three-valve shortwave receiver was undertaken and, after many hours of improvisation to stretch the meagre pocket money, the thing started to work. With headphones clamped on my head I twiddled the tuning control, heard voices, listened carefully and then emitted an ear-piercing shriek. Both my mother and elder brother came running to see what all the fuss was about. "I've got a station from Australia". It was in fact an early broadcast station which even gave its callsign. "Let me hear", said my brother. Reluctantly I handed

"I hear no ships!" The author with the original 10GHz receiver

over the headphones. Even after all this time I can still hear his deflating comment, "It's a bit weak isn't it", and my equally stinging retort, "If you had come half-way round the world in less than a tenth of a second you'd be weak!" It is a source of sadness that the QSL card which was received some months later has got lost. These are just a few of the early experiences of a shortwave listener but as you can see are never to be forgotten. Even now when a new piece of equipment is completed and starts to work I still feel that inner excitement and satisfaction.

From that time on I became totally 'hooked' but strangely, at the time, felt no desire to tackle transmitters. There seemed so much to learn about receivers – and there still is! Many people think that the receiver is the easy part of an amateur radio station but I can assure you that most of the challenge of making equipment is in the design and completion of a good receiver. Perhaps that is why the book *Practical Transmitters for Novices* got written first. I have lost count of the number of receivers which have been built since those early days but I do remember that there has been at least one for virtually every band in which it is possible to receive signals. At the lowest frequency, about 16kHz, was one which received signals from the Rugby transmitter which is still operational and, among many other interesting things, sends out coded time signals. Together with another transmitter on 60kHz, it is reputed to be the most accurate time signal in the world. Incidentally, if the signal from the Rugby transmitter was an acoustic wave (a wave motion in air), many people would be able to hear it as it is about the same frequency as the whistle from the line-output stage of a colour television receiver. However, it is an electromagnetic wave and therefore inaudible.

All the broadcast bands were covered and many specialised ones such as that used by shipping for direction finding; all the way up through the spectrum to a simple receiver for 10GHz to 'listen' for ship's radar while messing about in a boat in Southampton water, where the majority of the users were very much bigger than my little craft. Incidentally it was this other hobby, boating, which led to my first experiments with transmitters and to an amateur radio licence. Morse code came much later, but that is another story. As you will have seen, most of my efforts were prompted because I wanted to explore more and more of that mysterious world of radio. The magic is still there after all those years and I hope that the reader may be encouraged to follow a similar route. The very best of listening.

John Case, GW4HWR

Acknowledgements

Like the companion volume *Practical Transmitters for Novices*, this book is rather more than a series of constructional projects. It attempts to provide some of the basic theory associated with the various aspects of receiver practice. It is hoped that the reader will find something of interest even if there is no intention of building the projects.

My thanks go to Mike Dixon, G3PFR, for the fine work he has done in providing Chapters 8 and 9 on the microwave section of the book. Similarly, thanks are due to Steve Price, GW4BWE, for permission to use his excellent series on the RC14 and the add-on units which appear in Chapter 4. Finally, thanks to my wife for putting up with the mass of paper work and my continued absence while poring over a hot computer.

Chapter 1

Basic requirements of receivers

Any radio receiver must have three basic properties:

1. There must be a means of receiving energy from a transmitter.
2. The energy must be converted to a frequency which can be 'understood' by:
3. Something which will enable the operator to 'read' the data which was sent out by the transmitter.

Now let's look at each of these requirements in detail.

There is nothing extraordinary about radio reception: it is just that. Energy must be received from the transmitter – there is a direct connection although there is no wire, hence the early name 'wireless'. A transmitter creates a disturbance in space, rather like a stone thrown into a pond makes a disturbance and produces waves. The transmitter makes waves but they exist in a vacuum and of course cannot be seen. The waves spread out and, if we are lucky, may reach the place where our receiver is to operate. It is necessary to collect as much as possible of the energy contained in the wave. As the amount collected increases so the work to be done at the receiver gets less.

The wave contains an electric field, the result of voltage existing between two points, and a magnetic field, the result of current flow. Either of these fields will generate voltage if they occur in the correct situation. Fig 1.1 shows how a voltage/current may be created from a magnetic field and Fig 1.2 similarly demonstrates the effect of an electric field.

The antenna is designed to 'capture' as much energy as possible from the transmitter. A simple example of this occurs in the case of a ferrite rod antenna like the one commonly used in a medium-wave and long-wave broadcast receiver. It consists of a rod of magnetic material which works well at medium frequencies (MF) – ferrite is the most common one in use, with a coil of wire wound over it. When a varying magnetic field exists in the rod, voltages are induced in the coil. Fig 1.3 illustrates this. Note how the magnetic field is distorted by the presence of the iron – this occurs because it is easier for a magnetic field to exist in iron than in free space.

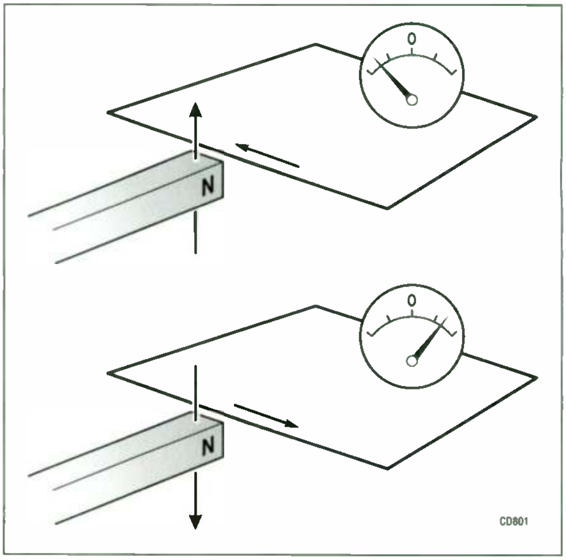


Fig 1.1. A moving magnetic field generates an EMF

The antenna does not just accept what is there but actually drags the field in from around itself.

All antennas should do the same sort of thing but it is not always easy to see how. Don't worry about the details, just accept the fact that the job of the antenna is to

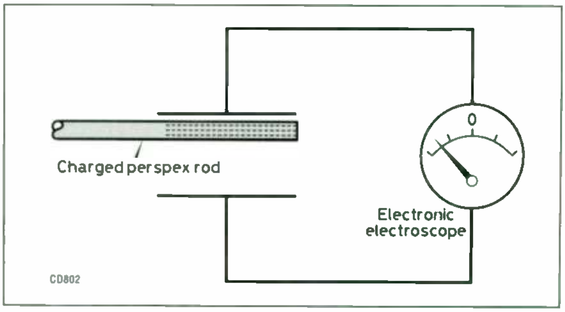


Fig 1.2. An electric field between the plates of a capacitor generates a voltage

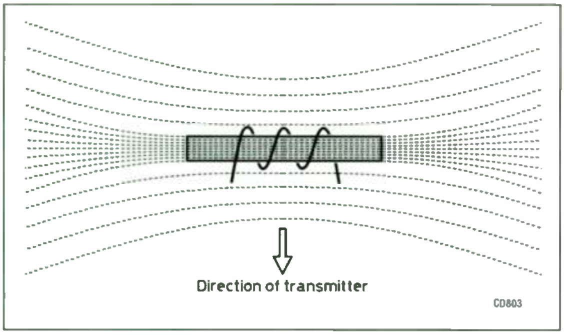


Fig 1.3. A ferrite rod offers an 'easy' path to the magnetic field from the transmitter

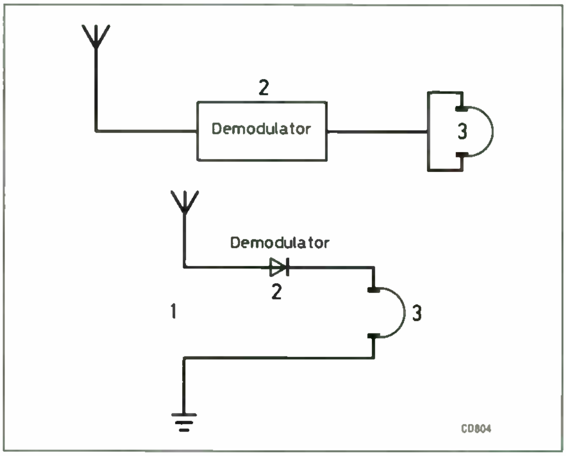


Fig 1.4. Basic radio system

perform the first of the three basic requirements of a radio receiver – to collect as much energy as possible.

So far nothing has been said about the sort of energy that is sent out by the transmitter except that it is electromagnetic. Theoretically any electromagnetic wave will propagate but in practice the amount of energy which leaves the transmitter antenna is very small if the frequency is less than 15kHz. The frequency of the transmitter at Rugby, mentioned in the preface, is 16kHz. As the frequency increases the efficiency of the antenna system also increases so that the wave from the antenna tends to travel further. All of this only emphasises the fact that the energy received is at a high frequency and, even if it was in the form of mechanical vibration, it would not be audible to us.

The second task of any radio receiver must be to convert the energy to a lower frequency, normally one which, if in the form of mechanical vibration, could be heard if received by the human ear. This is almost always carried out by the part of the radio known as the 'demodulator' and in its simplest form is the crystal detector of a crystal receiver. In rather more sophisticated equipment the demodulator may be a diode or a combination of components. These will be explained in a later chapter.

The statement "if the energy was in the form of a mechanical vibration" has appeared several times earlier in this chapter and identifies the third of the three basic needs of our radio receiver. We cannot hear either electrical or electromagnetic energy. The human ear has a diaphragm which responds to mechanical vibrations, that is changes in the pressure of the air surrounding it. It is therefore necessary to convert the electrical energy from the demodulator into mechanical energy. This is often done by means of loudspeakers or headphones and a full description of these items will be given later. Sometimes we do not wish to hear the data which is sent out by the transmitter – for example, when the signal comes from a television transmitter it will be necessary to convert the energy into a visual form. This will be done by the use of a cathode-ray tube and a host of supporting components which we do not need to worry about at this stage.

The very simple, basic system described so far can be summarised in the simple diagram shown in Fig 1.4. The three basic components listed at the beginning of the chapter are labelled 1, 2 and 3. It must be emphasised that if any one of these items is missing, even in sophisticated equipment, the device will not operate as a radio receiver.

Limitations

A simple system such as that described above cannot normally be considered as a practical receiver. A number of desirable functions which will help make the device work properly will be described but it must be born in mind that these are still basic and in a practical receiver there will be many more refinements.

Selection

The antenna will probably absorb energy from more than one transmitter in spite of the fact that it is often designed to favour the signal from one transmitter. If energy from more than one source reaches the demodulator the data contained in all such signals will be passed to the output and a 'Tower of Babel' effect occurs. If each transmitter sends out electromagnetic energy of a different frequency, it is possible to select the energy from one source by the use of frequency-selective circuits. The most common of these is the tuned circuit which has a natural frequency determined by the values of inductance and capacitance.

Two arrangements are used to give different characteristics. A parallel circuit as shown in Fig 1.5 offers a high impedance to current having the same frequency as that of the circuit and the series circuit shown in Fig 1.6 offers a low impedance to current at the natural (resonant) frequency. Fig 1.7 shows how these two circuits

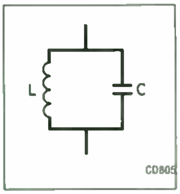


Fig 1.5. A parallel circuit

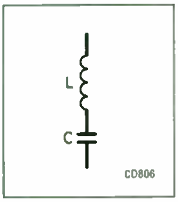


Fig 1.6. A series circuit

could be added to the simple circuit of Fig 1.4 to reduce the problem of unwanted signals reaching the demodulator. L2 and C2 have values which makes the circuit a high impedance at the frequency of the wanted station, while L1 and C1 could be arranged to offer a very low impedance to the signals from a transmission having a frequency different to the required one but close enough to cause interference. The low impedance acts as a partial short-circuit across the coupling coil L3 and reduces the amount of signal passed to L2 and to the demodulator D1. There will be many variations of this idea in the projects which follow later.

Another component which is often used to act as a selecting device is the quartz crystal. See the section describing the piezo-electric effect at the end of this chapter. By combining a number of crystals of slightly different frequencies, as shown in Fig 1.8, a highly selective filter which will pass a very narrow band of frequencies can be produced. Unlike the combination of L and C these circuits have the disadvantage of a fixed frequency whereas the L and C circuit can be adjusted to any frequency simply be changing the value of either (or both) L and C.

Types of modulation

Earlier the need for a demodulator has been mentioned but no explanation was given. It was stressed that the energy from the transmitter must be of high frequency (15kHz or above) in order that a reasonable amount of signal be radiated. This is normal throughout virtually all radio transmitting techniques and the radio frequency energy becomes known as the 'carrier'. In other words the radio frequency energy is used simply to get the signal from transmitter to receiver – it has no other job to perform. In some way or other the data (voice or music, picture information, computer data etc) must be impressed onto the carrier so that it also gets carried to the receiver. The action of impressing the data onto the carrier is called 'modulation' and at the receiver there is a demodulator which separates that data from the carrier.

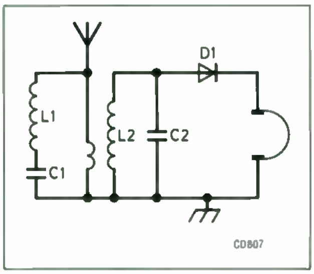


Fig 1.7. Frequency-selective components added to the circuit of Fig 1.4

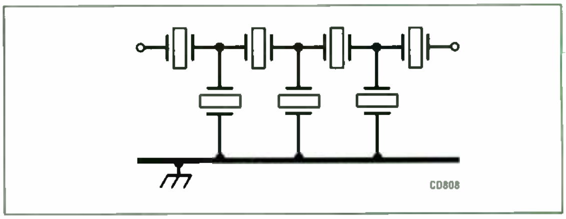


Fig 1.8. A band-pass crystal filter

The simplest way of modulating the carrier is by switching the transmitter on and off. This method is usually used in morse code transmitters. It has a number of advantages including the ability to get information through very difficult conditions where there is a considerable amount of interference from other signals. A good morse code operator can read the message while all sorts of other noises are occurring, and the transmitters are of simple design and are much more efficient. The disadvantage of the system is that the signal received is all RF (radio frequency) and therefore cannot be heard without some additional circuitry. The actual way in which this done will be described later, but for the time being think of it as a circuit which changes the frequency of the signal to a new value, one which falls in the range 100Hz to 10,000Hz, all of which can be heard if they are in the form of a mechanical vibration.

Most of the transmitters which operate in the medium-wave and long-wave bands make use of a method of modulation known as 'amplitude modulation' (AM). In this the audio frequency (AF) signals are used to make the amplitude of the RF carrier signal rise and fall in time with the AF. This is illustrated in Fig 1.9. The resulting signal is still completely RF (there is no AF actually present) but it carries the AF component in what is referred to as the 'envelope'. When this type of signal is received it is the job of the demodulator to 'extract' the AF from the composite carrier. More details of how this is done later but it is important to note that it is the diode D1 which carries out this task in the simple receiver shown in Fig 1.7.

Frequency modulation is another method which is commonly used to make the RF carry the information to the destination receiver. With this technique the AF is used to cause the frequency of the carrier to change – a large value of AF (loud noise) will make the frequency of the carrier change a great deal and the frequency of the AF will determine how quickly the frequency of the carrier changes. Fig 1.10 will help you to understand this idea. The advantage of this type of modulation is its ability to reject the type of interference caused by electrical machinery as this is mainly AM, and the FM receiver

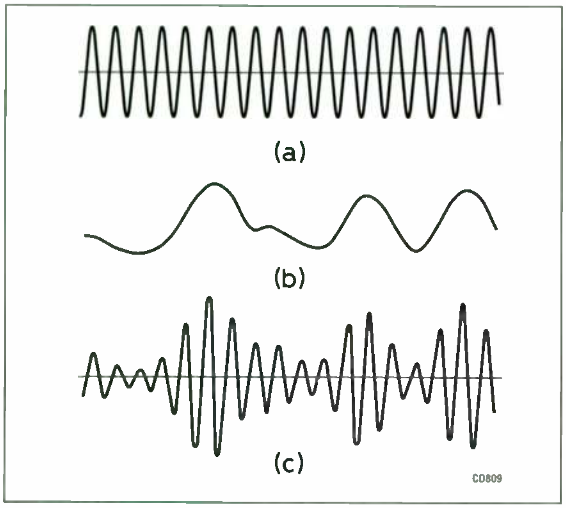


Fig 1.9. Amplitude modulation. (a) RF carrier. (b) AF. (c) Modulated carrier

should not respond to the interfering signal. The disadvantage of FM lies in the wide band of frequencies needed for the system to work well, especially if the system is used in broadcast transmitters where very good quality audio is expected. The bandwidth required by an amateur FM station is between 12 and 25kHz whereas a broadcast transmitter such as those used by the BBC needs a bandwidth of up to 150kHz. FM receivers need an entirely different type of demodulator which will also be described in a later chapter.

A rarer form of modulation is pulse modulation which is used mainly for computer-type data transmission. In some ways pulse modulation is very similar to morse code modulation except that it is not usual to switch the transmitter off completely between pulses as occurs in morse code transmissions.

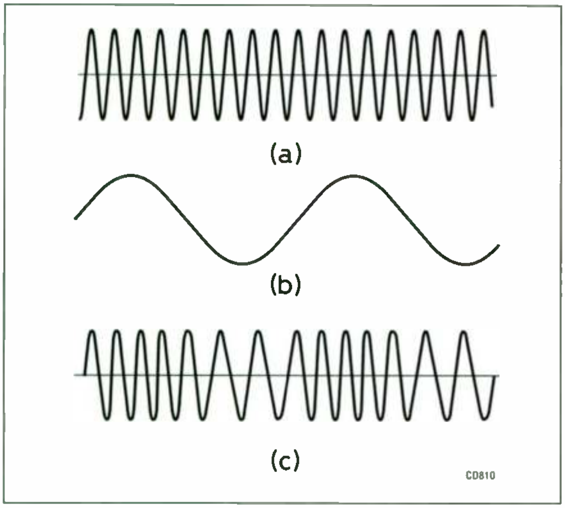


Fig 1.10. Frequency modulation. (a) RF carrier. (b) AF. (c) Modulated carrier

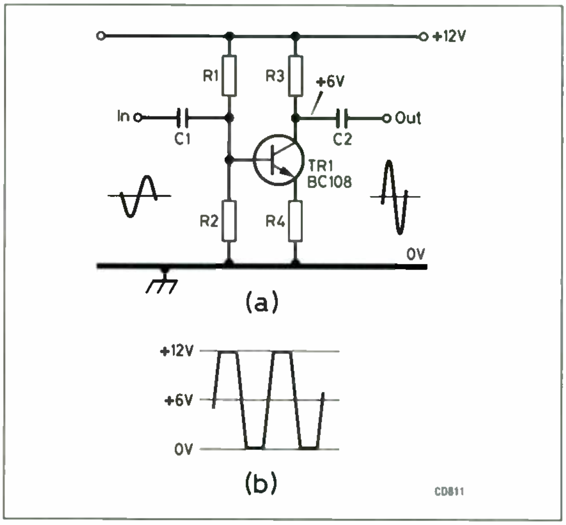


Fig 1.11. (a) A simple amplifier. (b) The effect of overdriving an amplifier

Amplification

Because the amount of energy received by the antenna is very small it is difficult to make a receiver which is capable of operating a set of headphones and quite impossible to drive a loudspeaker. The task of the amplifiers in a radio receiver is to provide bigger signals which are able to drive loudspeakers or television cathode-ray tubes. Amplifiers do not make the received signals bigger but make a 'big copy' of that signal in the same way as a photographic slide projector makes a big copy of the picture on the slide. It is possible to amplify the signal before demodulation while it is still RF, in which case we call the device an 'RF amplifier', or after demodulation when the signal has been 'changed' to AF – the amplifier is then called an 'AF amplifier'. There are various advantages of both methods which will become clearer later but for the time being look at the diagram in Fig 1.11(a). This shows the arrangement of components for a very simple general-purpose amplifier. The frequency at which the amplifier will operate is determined by the transistor type and the way in which the components are laid out. A transistor such as the BC108 (a general-purpose type) is only suitable for audio and low radio frequencies while a 2N2222 could be used in amplifiers up to 100MHz.

The transistor in the diagram is biased by R1, R2 and R4 so that with no signal applied to the input the voltage from the collector to ground (chassis) is about 6V. If a small AF voltage is applied between input and ground, capacitor C1 will allow most of the voltage to be applied between base and emitter of TR1. The collector current will rise and fall in step with the input voltage, and the voltage drop across R3, due to the collector current, will also rise and fall. If the component values have been chosen correctly, the change in voltage between collector and ground will be much bigger than the input voltage.

Note that the output waveform is out of step (phase) with the input. A transistor connected in this fashion (known as 'common emitter mode') will always cause the input and output waveforms to be 180° out of phase. Note also that the function has not been referred to as a 'phase shift' which normally occurs in networks such as resistor/capacitor combinations. If all is well with our amplifier the only differences between the input and output waveforms is in the size and phase relationship (the input signal may be positive-going while the output signal is negative-going or vice versa).

The shape of the input waveform has not been altered by the amplification process – in other words there has been no distortion. This is an ideal state and normally some slight distortion will normally occur but this is easily corrected by other circuitry. For example an RF amplifier will often have a tuned circuit in the place of R3 and, if this is tuned to the same frequency as the input signal, any distortion caused by the amplifier will be 'repaired' by the oscillatory action of the circuit.

With any amplifier it is important to avoid overloading by applying an input signal which is too large. In the circuit of Fig 1.11(a) it should be easy to see that the output voltage cannot vary either up or down by more than 6V. If the gain of the amplifier is 100 times then the biggest theoretical input voltage is only 60mV. In practice it is likely to be much less. Fig 1.11(b) shows one effect of applying too much input signal to the amplifier. With RF amplifiers the distortion takes the form of harmonic generation which may cause problems with interference but may also be put to good use in a process known as 'frequency multiplying'.

Output devices

Our receiver now begins to look much more practical with selectivity provided by tuned circuits and bigger signals because of the 'big copy' as a result of the amplifiers. However, the bigger signal at the output is still in the form of electrical energy and as such cannot be heard or seen. The task of the output device is to convert the signal to a form which can be 'read' by our own input devices – ears and/or eyes or by some computing device such as a packet network set-up.

Telephone earpieces, headphones and loudspeakers all serve the same purpose – to convert electrical energy into mechanical energy which the ear and brain will interpret as sound. They differ only in the manner in which this result is achieved. Sometimes earpieces and headphones are merely small loudspeakers so the construction and operation of the latter will be considered first. If current flows through a conductor which is lying in a magnetic field a force will be exerted on the conductor so as to try to move the conductor out of the field. Moving-coil loudspeakers (and moving-coil meters) make use of this effect. Fig 1.12 shows the construction of a typical loudspeaker. The coil attached to the point of the cone lies in a very strong magnetic field. When an AF current flows through the coil it moves in alternate directions and carries the cone with it. The large surface area of the cone causes waves to be set up in the surrounding air and these waves spread out and influence any ear drums within range. In order to allow maximum current to flow the coil is wound with rather thick wire and is normally just one layer which will fit in the gap of the magnet with sufficient clearance so that it can move without touching the sides of the gap. The construction of the coil means that its impedance is rather low – between 4Ω and 16Ω is normal for large loudspeakers while very small ones may have an impedance as high as 50Ω.

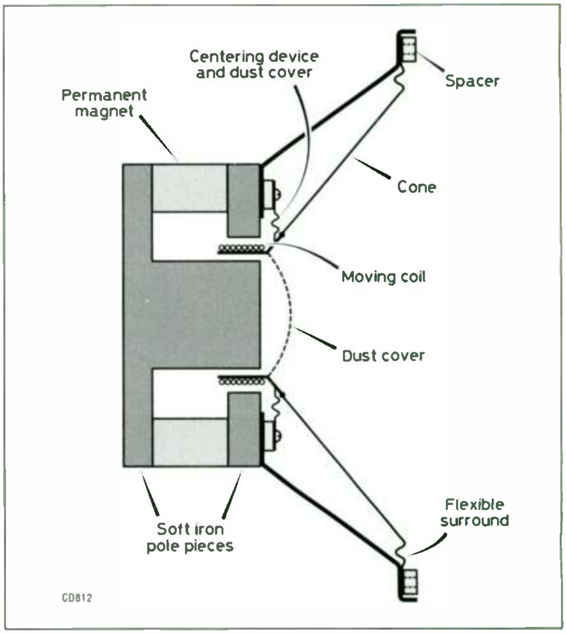


Fig 1.12. The construction of a moving-coil loudspeaker

In order to get maximum power transfer from the output stage of an amplifier and the loudspeaker the output impedance of the output transistor must be approximately equal to that of the loudspeaker. It is necessary to match the loudspeaker to the amplifier in the same way as the

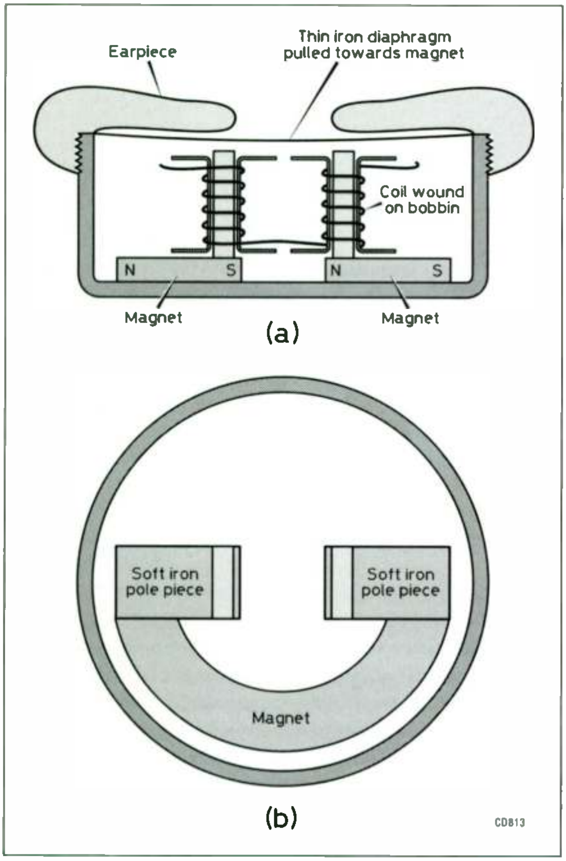


Fig 1.13. (a) Section through a moving iron earphone. (b) Plan view of the magnet arrangement

antenna of a transmitter must be matched to the output stage.

It was mentioned earlier that headphones are often a pair of very small loudspeakers arranged on a headband but an alternative type is sometimes used. A slice of piezo-electric crystal, if correctly cut, will expand and contract when alternating voltages are applied to it. The effect is used when it is necessary to make an earpiece which has a high impedance. The quality of the audio produced by these devices is not as good as the moving-coil type but is quite satisfactory for speech.

Yet another type of earpiece is shown in Fig 1.13(a). This style was very common in the early days of the telephone and radio, and a more sophisticated version is still in use by some domestic telephones. A strong permanent magnet has two soft-iron pole pieces which support coils, normally wound with many turns of very thin wire. A soft iron thin sheet, known as the 'diaphragm', is supported so that it is just clear of the magnetic poles. The magnet pulls the diaphragm towards the poles so that it

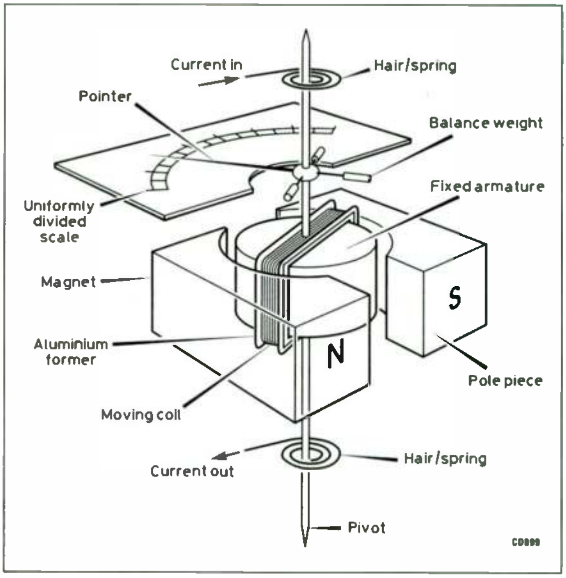


Fig 1.14. The construction of a moving-coil meter

takes up a bowed shape. Current through the coil in one direction increases the magnetic field and the diaphragm is pulled towards the magnetic poles, but a current in the opposite direction will decrease the magnetic field and the diaphragm moves away. AF currents passing through the coil will cause the diaphragm to vibrate at the same frequency. The large number of turns gives the device a moderately high impedance and the earpiece was a favourite with the early radio receivers when it was difficult to match the output of an amplifier to a low impedance. It is almost impossible to get a crystal radio to work with modern magnetic headphones but because of the high impedance the other type – 'crystal' earpieces – work well. 'Crystal' here relates to a quartz (piezo-type) crystal; the crystal receiver uses an entirely different type, which in radio's early days was often a piece of galena.

Sometimes it is necessary to know how much signal is present at the output rather than to hear it. In this case a meter capable of measuring AC voltages may be connected in place of the loudspeaker or headphones. The absorption wavemeter used to check the output of a transmitter is nothing more than a receiver with an AC meter used as the output device.

Like the moving-coil loudspeaker, most meters make use of the effect of current flowing though a conductor in a magnetic field. The coil in this case is wound on an aluminium former which is pivoted so that is free to rotate (between limits) in a strong magnetic field. Fig 1.14 shows the general arrangement. Light springs at either side of the coil are used to return the coil to its zero position when the current though the coils falls to zero and

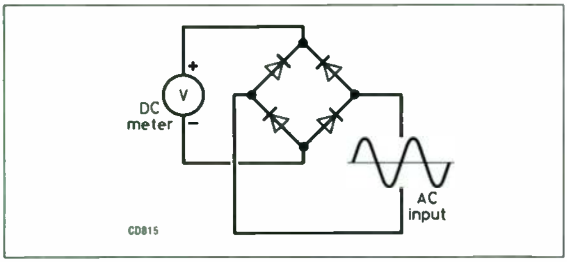


Fig 1.15. A bridge rectifier converts a DC meter to 'read' AC

also to act as the connections to the ends of the coil. As a refinement, the springs are arranged so that when the coil is turned, one spring winds up and the other unwinds so that tension on the coil is constant and the movement of the coil is directly proportional to the current. In other words the scale is linear. By precision engineering, meters can be made which are extremely sensitive and instruments which will give full-scale deflection for a current as low as 50μA are quite common.

Because the direction of the current flow through the coil determines the direction of rotation of the latter, in its present form the meter can only be used for indicating DC (or very-low-frequency AC when the needle will swing backwards and forwards). The addition of a bridge rectifier will overcome this problem but it must be appreciated that the action of the rectifier will cause the scale to be non-linear. Fig 1.15 shows how the bridge rectifier is connected.

When a visual output is required a cathode-ray tube (CRT) is normally used although in some very special applications light-emitting diodes (LEDs) may be used. Fig 1.16 shows a simplified picture of a CRT. The heated cathode emits electrons which are focussed into a thin beam, either by means of a focussing coil around the neck of the tube (as shown) or by an arrangement of electrostatic electrodes which form an electronic lens. The electrons are accelerated by a very high voltage on the final anode (25,000V in the case of a colour tube) and collide with the end of the tube at extremely high speed. The end of the tube is coated with a phosphor which glows when bombarded with electrons and the focussed beam produces a bright spot of light where it hits the screen. The beam of electrons will behave like a current-carrying conductor and if it passes through a magnetic field a force will be exerted on it to try to move it out of the field. By making use of this effect the coils on either side of the neck of the tube can be used to bend the beam and cause the spot on the screen to move. A second pair of coils (not shown) at right-angles to the others will allow the beam and therefore the spot to be moved in the other plane. The brightness of the spot can be controlled by altering the voltage between the control grid and the cathode or it can be switched on or off by swinging this voltage above and below the value known as 'cut-off'. A large number of supporting components are needed to make use of the CRT in an oscilloscope or a visual display unit (VDU), and an even greater number if it is to be used in a colour television receiver. These details are outside the scope of this book and may be found elsewhere.

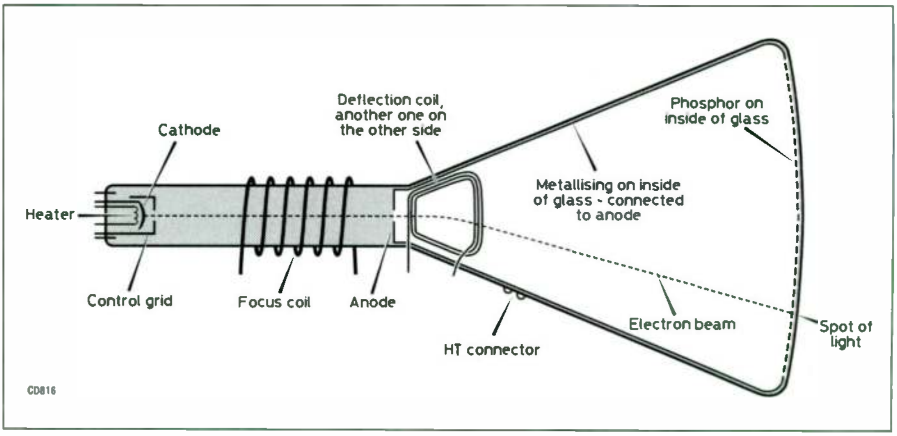


Fig 1.16. A cathode-ray tube

The piezo-electric effect

If a slice is cut in a particular way from a natural crystal of quartz it exhibits the following characteristics:

1. When the slice is deformed by pressure, such as when it is bent, a voltage occurs between the opposite flat faces. The voltage falls to zero when the slice returns to its normal, flat state and reappears with the opposite polarity when it is bent in the opposite direction.
2. If a voltage is applied between the flat faces, the slice becomes deformed and again returns to the original flat state when the voltage is reduced to zero. If the voltage is reversed in polarity the deformation is also reversed.
3. Like many other 'devices' the slice will have a natural frequency at which it will vibrate if mechanical stimulus is applied.

Fig 1.17 shows a familiar household item which 'rings'

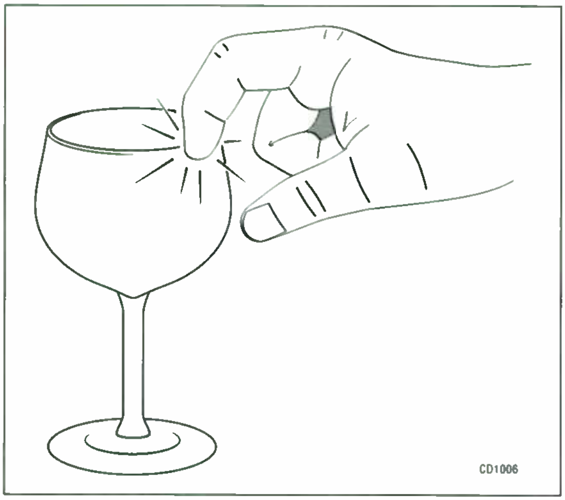


Fig 1.17. A wine glass 'rings' at a constant frequency

when it is tapped. The important feature is that the frequency of the note emitted will be the same next week or next year (unless the glass is altered in some way). The natural frequency of the quartz slice is determined by its dimensions and of course the frequency of the vibration (oscillation) will be much higher – typically from 1 to 20MHz. By using overtones (similar to but not exactly the same as harmonics), higher frequencies can be achieved.

A quartz crystal can be used where a tuned circuit comprising capacitor and inductance might be used. Two differences are that the frequency is remarkably constant (it can be varied only a little by the use of a series capacitor) and the losses of the crystal are very low – it is effectively a tuned circuit with a very high Q.

Similar effects occur with a number of other materials which allow the 'crystal' to be used as a microphone (see paragraph 1) and as an audio sounder or crystal pick-up (historical) (see paragraph 2).

Chapter 2

Types of receiver

The receivers to be described in this chapter are introduced to enable the function of various types to be examined and the functions to be explained. They are not practical circuits and there may be omissions and slight inaccuracies in order to make the underlying theory easier to understand. Please do not try to make any of these circuits unless you have enough knowledge to spot these simplifications. Practical versions of these circuits will be described in later chapters, commencing with Chapter 3.

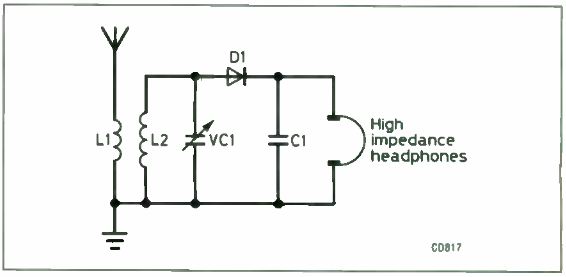


Fig 2.1. A simple crystal receiver

A crystal receiver

This type was the subject of one section of Chapter 1 and will receive limited cover here. Fig 2.1 shows a basic receiver in which you should already be able to identify most of the component parts. L2 and VC1 form a resonant circuit which is responsible for the selection of the required transmitting station. For the mathematicians – if the inductance of the coil and the capacitance of the capacitor are known, the frequency of the circuit (the frequency at which maximum absorption of signal will occur) can be calculated by substituting those values into the formula:

$$f_0 = \frac{10^9}{2\pi\sqrt{L \times C}}$$

where L is in microhenrys and C is in picofarads. The frequency will be given in hertz and will usually be a large number with many zeros.

To receive stations having different frequencies it is necessary to change the value of either the coil (L) or the capacitor (C). In the circuit shown in Fig 2.1 the capacitor is shown as being variable so in the practical circuit the tuning control knob would be fitted to the spindle of the capacitor.

Selectivity – the ability of the receiver to accept signals from one transmitter and to reject the signals from others – is determined by the 'goodness' of the tuned circuit. The technical term for this is Q, and if the losses in the circuit are high, the Q is low. Fig 2.2 shows the effect of losses on a tuned circuit. Curve (a) is that of a circuit with high losses – the curve is flat and the bandwidth, represented by the distance xx, is high which indicates rather poor selectivity. Curve (b) shows the effect of moderate losses and curve (c) very low losses and the resulting selectivity (bandwidth represented by the distance zz) is very good.

So what causes losses? In general it is the effect of resistance. If any of the oscillating current in the tuned circuit has to flow through resistance, heat is generated

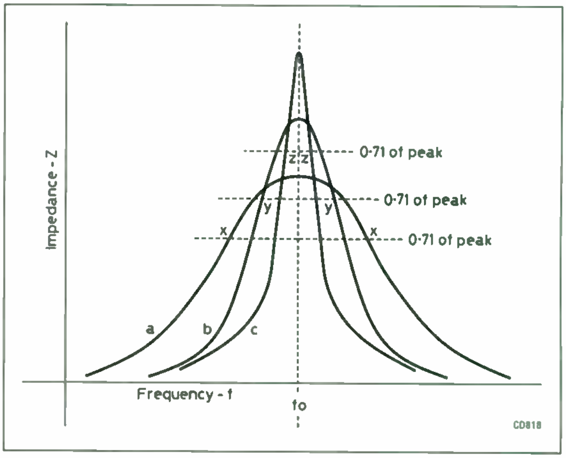


Fig 2.2. The effect of resistance on a parallel tuned circuit

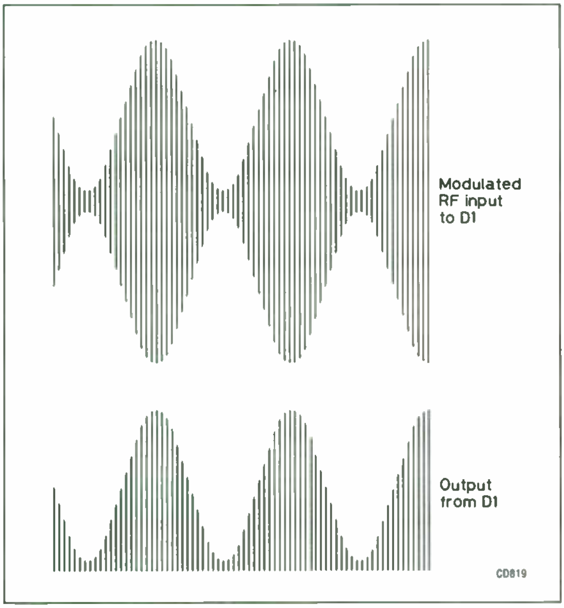


Fig 2.3. The effect of D1

and energy is lost from the circuit. Where is this resistance? The coil is wound with copper wire which has resistance, and this is kept as low as possible by using the thickest wire possible in the space available. Sometimes when the frequency is very high the surface of the wire is silver plated because at very high frequencies the current tends to travel on the surface of the conductor. This process is called 'skin effect'. Silver is a better conductor than copper and also does not tarnish (oxidise) as quickly as copper. Any oxide increases the resistance as the current will try to flow through it. The capacitor in parallel with the coil also contributes to the losses if the dielectric is not perfect (and it never is).

Also, any other items connected to the radio will place resistance in parallel with the coil. The antenna is one of the main causes of 'damping' losses and the other is the demodulator and the telephone earpieces. There are various ways in which these losses may be minimised but unfortunately every method results in loss of signal and in a crystal receiver there is very little signal to lose.

The last part of the circuit to be examined is the demodulator. First it must be emphasised that this type of receiver is only suitable for the reception of amplitude modulation. Reference to Fig 1.9 in Chapter 1 will show that although the signal contains a suggestion of the audio frequency, there are in fact two components which are of opposite phase and would therefore cancel each other. The diode D1 solves this problem by removing one half of the signal as shown in Fig 2.3. The components no longer cancel and the telephone earpiece can respond to the audio-frequency component. Capacitor C1 is included to remove most of the RF signal and therefore to increase the amount of AF presented to the telephone earpieces.

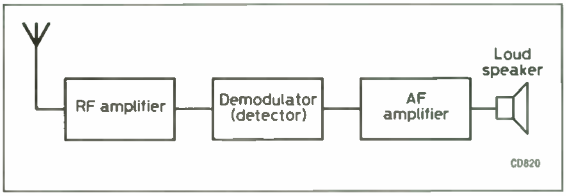


Fig 2.4. Block diagram of a TRF receiver

A TRF (tuned radio frequency) receiver

The name is slightly misleading as it includes quite a number of similar but yet different configurations, but all have one thing in common – any tuned circuits will be adjusted to the radio frequency of the signal received by the antenna. At this stage you may wonder how it could be tuned to anything else but as other circuits are considered the choice of name will become clear. The block diagram shown in Fig 2.4 and the circuit diagram equivalent in Fig 2.5 depict what can be considered a typical TRF receiver – an RF amplifier followed by a diode demodulator which is in turn followed by an AF amplifier. There are a number of important features included in the circuit diagram and these will be examined in turn.

The antenna is shown as a ferrite rod and it must be assumed that the receiver is intended to work in the low-frequency (LF) and/or in the medium-frequency (MF) bands which are generally known as the 'long-wave' and

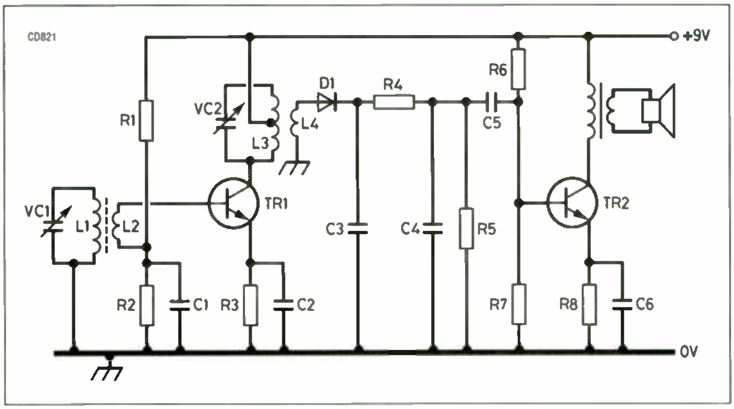


Fig 2.5. The circuit of the TRF receiver

'medium-wave' bands respectively. The ferrite rod antenna works best at these frequencies and is rarely used at HF. The RF amplifier (TR1) is biased by the conventional resistor network consisting of R1, R2 and R3. Capacitor C1 decouples R2 (it effectively connects the top end of R2 to earth as far as RF is concerned). This is very common practice and you will find the term 'decoupled' employed in many situations where there are different frequencies and/or DC involved. L1 is the main tuning winding on the ferrite rod while L2, with only a few turns, matches the high impedance of L1 to the low impedance of the input to the transistor. This in turn reduces the damping of the antenna tuned circuit and so improves the selectivity as explained previously. R3, part of the bias circuit, is decoupled by C2. L3 and VC2 form the collector load of TR1 and it should be noted that once again the damping of the tuned circuit is reduced by two things – the supply is connected to a tap on L3 so that the output impedance of TR1 is connected only across part of L3 and the feed to D1 is by means of a secondary winding L4 which has just a few turns and so reduces the damping on L3 by D1 and the immediate following circuits.

One of the problems of this circuit becomes apparent when is necessary to change from one station to another. Both VC1 and VC2 must be adjusted so that each of the tuned circuits is tuned to the frequency of the required signal. To make the operation easier the two variable capacitors are normally mounted on the same spindle and are made identical. A pair of capacitors of this type is referred to as a 'twin-gang capacitor'.

The demodulator becomes a little more complex with the addition of C3, R4 and C4 which comprise an RF filter to remove almost all of the RF – only AF appears across the diode AF load resistor R5. This ensures that no RF is passed to the AF amplifier where it might cause many undesirable effects such as the type of oscillation which is known as 'motor boating'. This takes the form of a 'pop pop pop' noise superimposed on the normal audio output.

The AF amplifier is entirely conventional and will not be discussed further at this stage. The receiver just described is suitable for amplitude modulation only.

TRF with regeneration

The block diagram in Fig 2.6 is almost identical to that in Fig 2.4 and differs only in the control from output to input of the demodulator. This is the regeneration control. Fig 2.7 shows the section of Fig 2.6 which is enclosed in a circle, drawn as a circuit diagram.

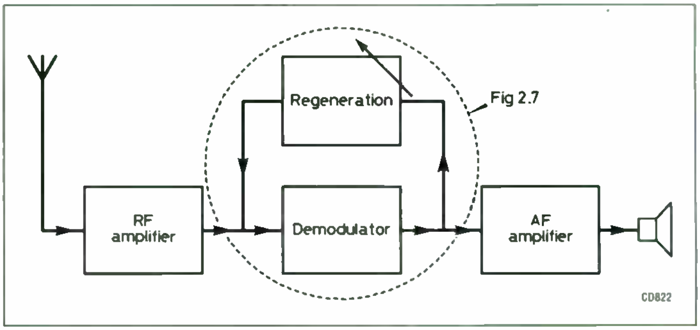


Fig 2.6. A TRF receiver with regeneration

As this is almost a museum piece it is felt appropriate to introduce the device which would have been used when the circuit was widely used. The triode thermionic valve is a relatively simple device. It has three electrodes. A heated cathode, which emits a stream of electrons, is surrounded by an anode, in the form of a cylinder, which attracts the electrons because the supply makes the anode positive with respect to the cathode. In between the anode and the cathode is a wire mesh known as the 'control grid'. It is normally at the same potential, or negative to, the cathode so that electrons are repelled by the negative charge and by varying the voltage between control grid and cathode the current through the valve may be controlled. In the circuit shown in Fig 2.7 the control grid and the cathode replace the diode in Fig 2.5 and together with R1 and C1 demodulate the AM signal. The RF choke (RFC) stops the RF from appearing across the AF load R2. Because the control grid of the triode is almost always negative with respect to cathode there will be no current flow in the grid circuit and consequently the input resistance is very high. It is for this reason that an ordinary (bipolar) transistor is not used in the circuit.

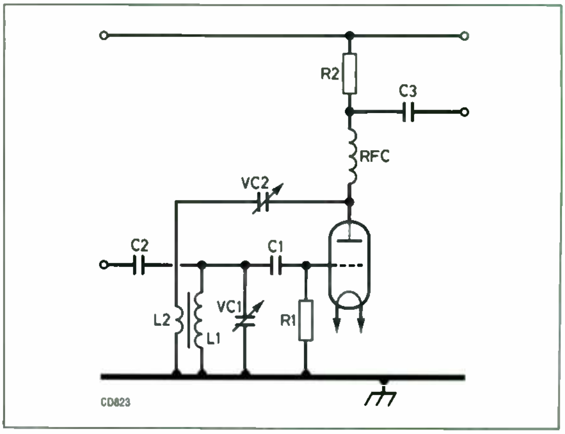


Fig 2.7. The circuit of the circled portion of Fig 2.6

A field effect transistor (FET) would work well if it was necessary to dispense with the thermionic valve. The effect is used in the ARDF (amateur radio direction finding) receiver described in Chapter 5.

The process of regeneration is provided by the components RFC, VC2 and L2. As the value of VC2 is increased the RF current flowing from the anode of the valve through L2 will also increase. The connections to L1 and L2 are such that the energy injected into L1 is in phase with energy already there; in other words it provides positive feedback. Some of the losses in L1 are cancelled out and the bandwidth is decreased. If VC2 is carefully adjusted a state will be reached when almost all of the losses are cancelled and the efficiency of the circuit becomes very high. In practice VC2 behaves as a kind of volume control which not only increases the signal but improves the selectivity of the receiver at the same time. Any further increase in the feedback will cause the circuit to become an oscillator. An oscillator can be defined as an amplifier which provides its own input by means of feedback which exceeds the losses of the circuit.

With the regeneration control adjusted so that oscillation does not take place the circuit will perform in exactly the same way as the one in Fig 2.4 and will receive amplitude-modulated signals only, but if the regeneration is advanced just a little more the demodulator will become an oscillator (indicated by increased background noise) and the receiver will now respond to continuous wave (CW) or morse code signals and probably a different type of amplitude modulation known as 'single sideband' (SSB) which will be explained later.

The heterodyne principle

When alternating voltages are mixed together they will continually get in and out of step unless they are of exactly the same frequency. A simple example occurs when three cycles per second are mixed with two cycles per second. Assume them to be in step at the beginning of the first cycles. See the diagram in Fig 2.8(a). After one and a half cycles of the three cycles per second waveform, the two are exactly out of step and after another one and a half cycles they come back into step again. When the two are in step they add together to produce a big voltage but when they are out of step one cancels the other and the resulting voltage is low – zero if the two signals being mixed have equal values. The rule is simple: when AC voltages are mixed together, a new frequency equal to the difference in their frequencies is produced. It takes the form of a variation in amplitude as with amplitude modulation. Fig 2.8(b) illustrates the effect. If the mixer is non-linear (in other words, if it is a demodulator as with a diode or the triode in Fig 2.7) the modulation frequency will appear at the output of the mixer.

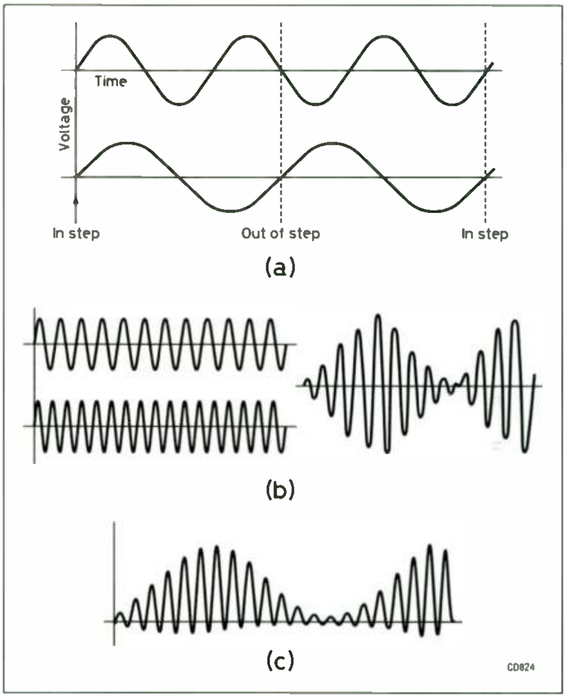


Fig 2.8. (a) Different frequencies go in and out of step. (b) Mixing different frequencies. (c) The effect of non-linear treatment (demodulation)

Fig 2.8(c) shows the waveform at the output of the mixer. There is also another frequency produced during the process which has a frequency equal to the sum of the two signals being mixed. This frequency is not shown in the diagram but it will also appear at the output of the mixer. The two frequencies are known as the 'sum and difference' frequencies and play a very important part in many of the applications which will be described later. The effect is called 'heterodyning'.

The direct-conversion receiver

A block diagram of the simplest form of this type is shown in Fig 2.9. The antenna is connected directly to the mixer – there is no tuned circuit as with the TRF. In practice there will be a wide-band circuit (the 'pre-selector') which will cover all required frequencies with no adjustment to the circuit. The selectivity is such that all required signals will be allowed to pass but those outside of the band will be attenuated (reduced) or perhaps stopped altogether. Station selection does not take place in this part of the circuit as it did in the TRF receiver. A variable frequency oscillator (VFO) will generate any frequency

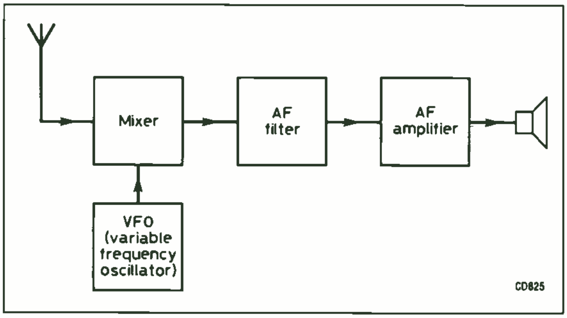


Fig 2.9. A direct conversion (DC) receiver

within the band in which reception is expected. Suppose the receiver is intended to cover the amateur 20m band (14.000MHz to 14.350MHz). The pre-selector will then have a bandwidth covering all these frequencies. In order to receive a CW signal of 14.050MHz the VFO could be adjusted to generate a signal having a frequency of 14.051MHz. This will react with the incoming signal within the mixer and the difference signal (0.001MHz = 1kHz) will appear at the output. As this is in the range of frequencies which can be heard, it will pass into the audio amplifier and operate the loudspeaker where it will appear as a continuous, fairly high-frequency AF note. The mixer has converted a radio-frequency signal into an audio-frequency one. It must be noted that if there happened to be another signal with a frequency of 14.052MHz this will also mix with the output of the VFO and again produce an output of 1.0kHz. This cannot be separated from the required signal and interference will result. However, a signal with a frequency of 14.053MHz or of 14.047MHz will produce outputs from the mixer with frequencies of 3.0kHz – if the audio amplifier cannot respond to frequencies above 2.5kHz, the interfering signal would not reach the loudspeaker. The selectivity of the DC (direct conversion) receiver is therefore that of the audio stages which precede the loudspeaker.

The superheterodyne

So far nothing has been said about the problems which come with the very weak signal normally received from the required transmitter. Radio amateurs often have to be content with less than one microvolt (1μV) at the input to their receiver. This is too weak for a crystal receiver but all other types try to make up for the lack of signal by providing amplifiers. In order to provide reasonable output power for the loudspeaker the output stage of an average amplifier requires an input signal of between 0.5 and 1.0V and therefore the receiver must give a voltage gain in the order of one million times.

High-gain amplifiers suffer from a tendency to become oscillators. Signals at the output cause a little radiation, and if any of this radiated energy is picked up at the input of the amplifier it is most likely to cause oscillation. Remember that an oscillator was defined as an amplifier which provides its own input. Capacitance between input and output provides the path and, as the frequency of the signals gets higher, so the impedance of that feedback path falls. To sum up, feedback will always occur to some extent with any amplifier – as the frequency rises so does the feedback. AF amplifiers are less likely to go into oscillation but as the frequency rises so does the danger of instability (oscillation).

The direct-conversion receiver has all of its gain at AF and a gain of one million times is just possible. The TRF receiver gets over the problem by amplifying at two different frequencies – oscillation will not take place if the feedback has a different frequency to that at the input. A TRF receiver with an RF amplifier with a gain of one thousand followed by an AF amplifier also with a gain of one thousand will give an overall gain of a million. Each amplifier could oscillate at its own working frequency but is less likely to as the gain is low; the combined amplifier is not likely to oscillate because the input and output frequencies are different. A TRF operating on 3.5MHz would probably be quite successful, but if it was to operate on a frequency of 50MHz there would almost certainly be problems because of the lower impedance of the feedback path from output to input.

The superheterodyne solves the problem of obtaining high gain by using the principle used in the direct-conversion receiver except that the output frequency is some other radio frequency, normally (but not necessarily) of a lower value. For example, a receiver intended to receive signals with a frequency of 145MHz might use a mixer which provided output signals of 10.7MHz. It is easier to provide stable (freedom from oscillation) gain at the lower frequency than it would be if the amplification had to take place at 145MHz. A block diagram of a very basic superheterodyne receiver is shown in Fig 2.10. The frequency given to each block is the operational value when an input signal with an input frequency of 145MHz is being received. If it becomes necessary to receive a new station with a frequency of 145.2MHz the frequency of the BFO (beat frequency oscillator) would be changed to 155.2MHz. The difference between the frequency of the BFO and the incoming signal is still 10.7MHz. This means that the 'radio frequency' amplifiers can be tuned to a fixed frequency of 10.7MHz. To distinguish the new RF amplifiers from others they are referred to as 'intermediate frequency' (IF) amplifiers.

You may feel that as no RF amplifier is used in the diagram there is no advantage in changing the frequency but it should be remembered that stable gain is more likely at a lower frequency than at the higher one. In early superheterodynes it is likely that an RF amplifier would

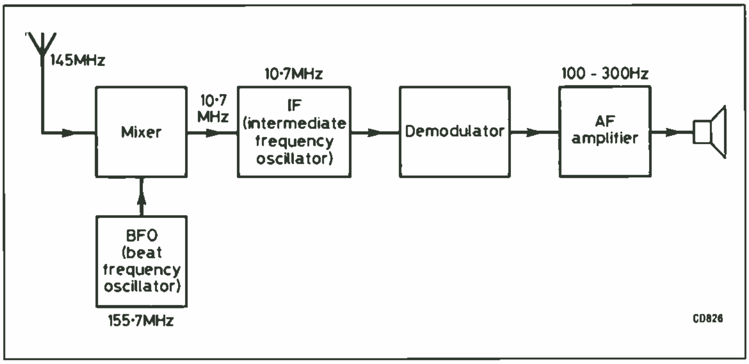


Fig 2.10. A simple superheterodyne receiver

have been used but we will see later that there are a number of disadvantages of doing so. The other advantage is that the following amplifiers have a fixed operating frequency. If the gain available is not enough there is no reason why the process should not be repeated. A second mixer and BFO could be arranged to change the frequency to something like 455kHz, the second IF. This double frequency changing is quite commonly used when the received frequency is very high.

As with many good ideas there is a snag. Mixers tend to be noisy, generating more noise than most other circuits. When we are hoping to amplify a signal of less than 1μV any noise introduced by the early stages of the receiver may make the difference between a readable and non-readable output. An ordinary transistor which we may have to use in our simple superhet is rather noisy as a mixer and this is a good reason to use an RF amplifier before the latter. A gain of 50 times would increase the 1μV signal to 50μV and if the mixer then introduces 2μV of noise it is not nearly so disastrous as it would have been if the same amount of noise was introduced when the signal was only 1μV. Later we will look at the reasons for not using the RF amplifier in spite of the apparent advantage. Much research has been done on very-low-noise mixers and there are now some excellent devices which can be incorporated in sophisticated designs – unfortunately these are outside the scope of this book.

Mixers are easily overloaded. If a fairly weak signal is being received and there is a rather strong station operating on a frequency just a few kilohertz different to that of the desired station, a large signal from the strong station will be applied to the input of the mixer. If this causes overloading, the two signals will modulate one another and the signal at the output of the mixer will contain the audio modulation of both signals – no amount of selectivity following the mixer will be able to separate the two. This effect is called 'cross-modulation' and will occur whenever two signals (or more) reach the input of any stage which is non-linear and where one signal is big enough to overload the stage. Ultra-linear amplifiers cannot normally handle strong signals and this is one of the reasons that RF amplifiers are not used before the mixer.

One of the major advantages of the superheterodyne lies in the fact that all wanted, received signals which appear at the output of the mixer have the same frequency and consequently all following amplifiers have a fixed frequency of operation. Their tuned circuits do not have to be adjusted when the receiver is adjusted to receive a signal on a different input frequency, and crystal filters can be used – in fact all of the amplifier from the output of the mixer onwards is a fixed-frequency amplifier. This makes it possible to introduce many frequency-selective circuits and to 'tailor' the response curve of the receiver to suit particular requirements.

Reference has been made to intermediate frequencies of 10.7MHz and 455kHz – what determines the value of IF which should be used in particular receivers? There are some simple rules which need to be followed when an IF is selected. The change in frequency given by the mixer should not be too great – a reduction (usually) of between 10 and 15 times is about right. The frequency chosen should be one which is relatively quiet – in other words there should be no powerful stations using it. A strong station using the frequency of the IF is likely to 'break through' into it and once it is there no subsequent selectivity will be able to reject it. A frequency which makes it easy to get the required bandwidth is useful. 10.7MHz is chosen for the IF of VHF FM broadcast-band receivers as the natural bandwidth of the IF amplifier is close to 150kHz which is required for high-quality sound reproduction. On the other hand, 455kHz lends itself to a bandwidth of about 10kHz which is the approximate bandwidth of LW and MW broadcast receivers. There are also some rather complex considerations which avoid spurious signals being introduced into the IF amplifier but these are outside the scope of this book.

Another problem which arises with superheterodynes is a peculiar form of interference known as 'second channel' (or 'image frequency') interference. This occurs if a station with a frequency of twice the value of the IF away from the required one manages to reach the input of the mixer. Using the example of the station on 145MHz with a BFO working on 155.7MHz which gives an IF of 10.7MHz, an unwanted station with a frequency of 166.4MHz reaching the mixer will also give an IF of 10.7MHz which will pass through the remainder of the circuit with no problem. It will be noted that in this example the required and unwanted stations are separated

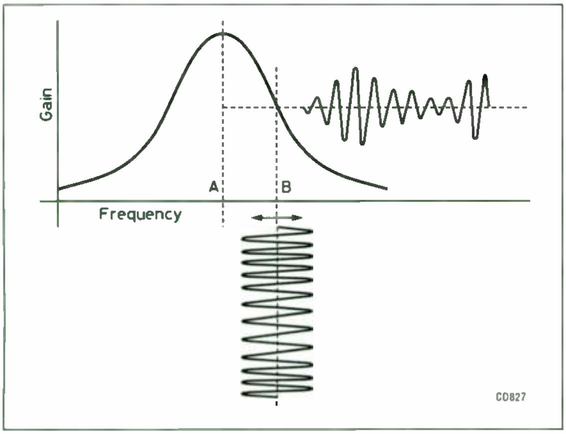


Fig 2.11. A slope detector – frequency discriminator

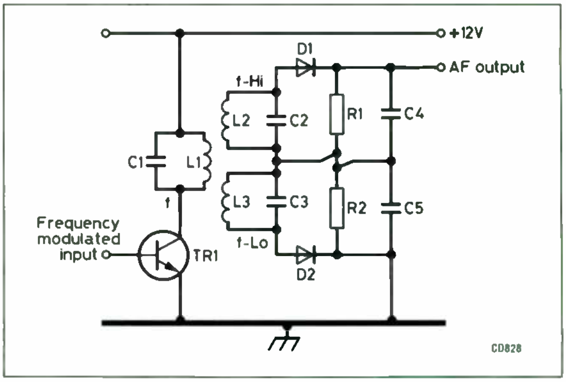


Fig 2.12. An Armstrong-type frequency discriminator

by 21.4MHz and the circuits before the mixer should be able to separate them. It should also be easy to see that the problem of second-channel interference will get less as the IF becomes higher. Second-channel interference with an IF of 455kHz will occur with two stations separated by only 910kHz. The simple rule is use the highest IF which will allow the required gain to be achieved. For this reason occasionally we may find an IF which is higher than the input to the mixer.

More about modes of modulation

CW and amplitude modulation have already been explained and so has the method of demodulation in each case. Frequency modulation has been mentioned and simple waveforms were shown in Fig 1.10. Actually any receiver can be made to receive FM and in fact any other mode. Everything depends on the demodulator but a crystal receiver would need a very strong signal from the antenna in order to operate an FM demodulator (frequency discriminator).

Perhaps the simplest FM discriminator is the slope detector. This is inherent in the TRF receivers already described. The response curve of the receiver is shown in Fig 2.11. Normally the receiver would be tuned to point A but if the tuning is adjusted to point B, which is approximately half-way up the slope of the curve, and an FM signal is applied, a conversion to AM will take place. When the frequency decreases the operating point will move to the left and the output signal will increase but when the frequency increases the operating point will move to the right and the output will decrease. It should be noted that if the left-hand side of the slope had been used the effect would be almost the same except that the rise and fall in amplitude will occur with the opposite change in frequency. This type of demodulator does not give very good audio quality because the slope of the response curve is rarely straight and there is some difficulty in tuning the receiver so that the operating point is half-way up the slope. However, the quality is good enough for the reception of speech.

A much better discriminator is shown in Fig 2.12. It is known as an 'Armstrong' circuit and has been chosen because the operation is easy to understand. In practice setting up is rather difficult but that does not have to concern us. The transistor TR1 may be considered to be the last IF amplifier and L1 and C1 are tuned to the intermediate frequency in the absence of any input signal. L2 and C2 are tuned to a frequency several kilohertz higher than the IF while L3 and C3 are tuned to a frequency exactly the same amount lower than the IF.

When an unmodulated signal is being received both L2 and L3 are off-tune by the same amount and so have equal voltages developed across them. These voltages are rectified by D1 and D2, and equal but opposite voltages are developed across R1 and R2. The resultant voltage from the top of R1 to ground is therefore zero. When a modulated signal is received and the frequency rises the voltage across L2 goes up and that across L3 goes down. The rectified voltages across R1 and R2 are also unequal and because R1 has the larger voltage the top end of R1 becomes positive. As the frequency falls below that of the carrier the voltage across L3 becomes the larger and the voltage across R1 plus R2 reverses, that is to say the top of R1 becomes negative. The AC voltage developed across R1 plus R2 has a frequency which is the rate at which the carrier frequency rises and falls; furthermore the amount of the voltage is proportional to the amount of deviation of the carrier. The AF quality obtainable from a correctly set up circuit is extremely good.

A discriminator which is more commonly used is called the 'ratio detector' – it is much easier to set up but is rather more difficult to understand. A typical circuit is shown in Fig 2.13. The quality of the AF is not so good

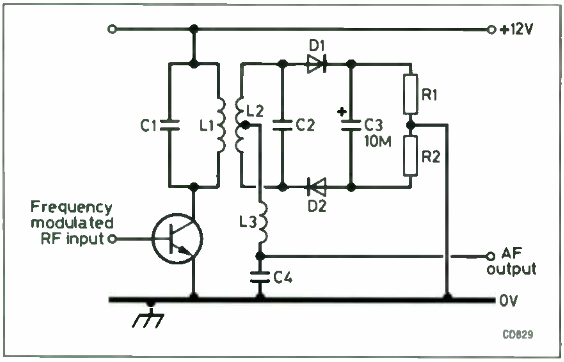


Fig 2.13. A simplified ratio detector

as from the Armstrong. Both tuned circuits comprising L1, C1 and L2, C2 are tuned to the carrier frequency which makes the circuit easier to set up than the Foster-Seeley. At resonance these circuits are resistive and current and voltage will be in phase. The voltage across L3 will be 90° out of phase with the voltage across L2 and the voltages applied to D1 and D2 will be equal. Equal currents will flow which will serve only to charge C3.

When the frequency of the carrier varies, the tuned circuit L2, C2 will become either capacitive or inductive and the phase shift will be more or less than 90°. The voltage across L3 will cause the voltage applied to one diode to increase and reduce the voltage to the other. The two diode currents will no longer balance and the excess current will charge C4 (or discharge it) – the voltage across that capacitor will rise and fall as L2/C2 goes in and out of resonance as the frequency of the signal rises and falls. The voltage across C4 will vary as AF; in fact C4 is the AF load for the circuit. This is a rather unusual condition – it is expected that a load should be a resistor. C3 is also an important component – as already mentioned it is charged by the current through D1 and D2 and because of its high value the voltage cannot change quickly. This prevents the circuit responding to changes in the amplitude of the input signal, providing a self-limiting action and eliminating the noise which is caused by amplitude modulation.

Single sideband receivers

It would be more correct to call these 'single sideband suppressed carrier receivers' but the term 'SSB receivers' is commonly accepted.

We have already said that when voltages having different frequencies are mixed together new voltages are produced with frequencies equal to the sum and the difference of those mixed. Amplitude modulation was explained as the result of audio signals causing the amplitude of the RF (the carrier) to rise and fall in step with the AF but this involves mixing the AF with the RF. Hence sum and difference frequencies will be produced. These new waveforms are called the 'upper sideband' and 'lower sideband'. This is not a contradiction of the previous explanation but another way of viewing the same thing.

The waveforms shown in Fig 1.9 could have been presented as those shown in Fig 2.14. A little thought should convince you that if the waveforms of (a) the upper sideband and (b) the carrier are mixed together the modulation envelope of Fig 1.9 will be the result. Exactly the same output would be obtained if waveforms of (b) the carrier and (c) the lower waveform were mixed together. All three waveforms are radiated by long-wave and medium-wave broadcast transmitters. If the highest audio frequency to be radiated is 4.5kHz then, in addition to the carrier, two sidebands will be radiated. The upper sideband is 4.5kHz higher than the carrier and the lower sideband 4.5kHz lower than the carrier – the whole transmission will occupy 9kHz. This is the allocated bandwidth for those stations on MW and LW. If one of these sidebands was suppressed at the transmitter and just the carrier and one sideband radiated, the bandwidth occupied would be only 4.5kHz.

If we are only concerned with the transmission of speech or low-quality music still greater savings can be made by suppressing the carrier as well. At the receiver the single sideband does contain all of the data from the original but the audio can only be demodulated if the

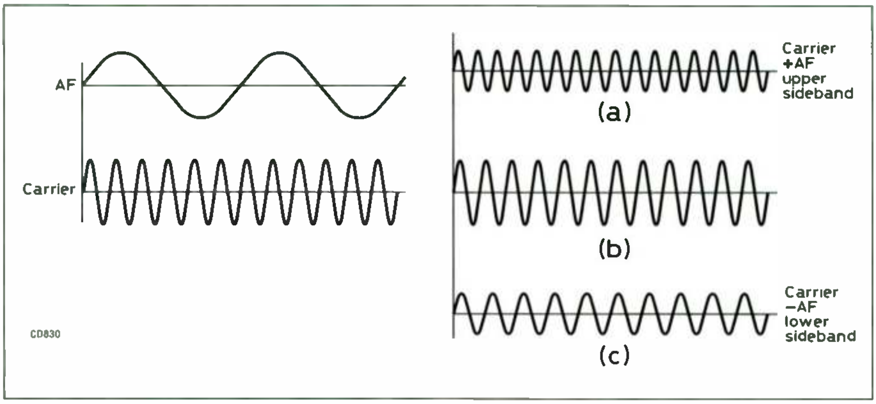


Fig 2.14. The production of sidebands during modulation

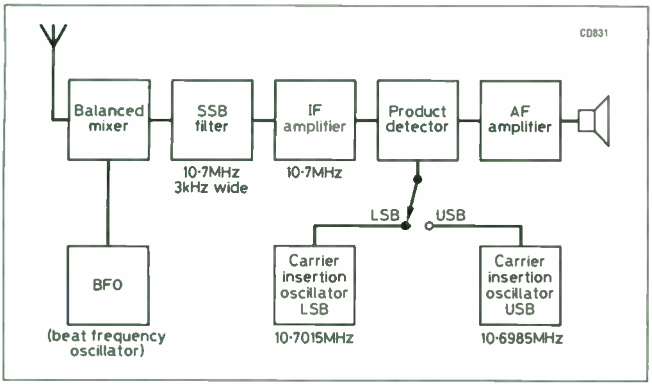


Fig 2.15. A simple SSB receiver

sideband can be heterodyned by a carrier of the original frequency. This carrier can be put in at the receiver by means of a 'carrier insertion' oscillator. In this way much better use is made of the power available at the transmitter and the occupied bandwidth is reduced to a minimum. Strictly speaking, this mode should be called 'single sideband, suppressed carrier' but it is usually referred to as 'SSB', and is one of the favourite modes employed by amateurs

SSB signals can be received by TRF receivers with regeneration and by direct-conversion receivers – in both these cases the heterodyne principle will result in the AF appearing at the output in the same way as CW is demodulated but the output will rise and fall as the frequency of the sideband goes up and down.

Fig 2.15 shows a simple arrangement of an SSB superheterodyne receiver but it is important to remember that the practical circuit is much more complicated. There are some similarities between this and the diagram shown in Fig 2.10, and only the additions will be described now. Between the mixer and the IF amplifier is a special filter made specifically for SSB. It is a band-pass type, centred in this case on 10.7MHz, and has a bandwidth of 3kHz and a response curve with very steep sides. Fig 2.16 gives the general shape.

The filter greatly improves the selectivity of the IF amplifier, and if the receiver is correctly tuned the signal which gets through consists only of the sidebands of the required station. The output of the last IF amplifier is applied to one input of a product detector which is just another form of demodulator. It makes use of a dual-gate FET and a simple circuit is shown in Fig 2.17. The second gate of the FET is fed from one of the two carrier insertion oscillators. These are usually crystal controlled and the crystals (one 1.5kHz higher than the IF and the other 1.5kHz lower) are often supplied as a package with the SSB filter. Two oscillators are needed to cater for the two modes available with SSB – upper sideband (USB) and lower sideband (LSB). As a general rule, amateur stations make use of LSB for the 7MHz band and below and USB for 14MHz and above. The sideband and the re-inserted carrier heterodyne one another within the product detector and the AF signal appears at the output of the FET.

Automatic gain control

As the name implies this is a system in which the gain of the receiver is controlled by the signal which is being received. A strong signal generates a voltage which is used to bias one or more of the earlier stages in the receiver, so reducing its gain. If the strength of the signal increases the control voltage rises and reduces the gain of the receiver still more but if the signal strength decreases the control voltage falls and the gain of the receiver rises. This enables the signal strength to be kept constant if fading of the input signal occurs. The control voltage is often obtained by rectifying the IF signal immediately before demodulation takes place but in some special cases it is the AF signal from the demodulator which is rectified. The overall result is the same. With CW reception and also with SSB the rate at which the control voltage can change is slowed down so that the gain of the receiver does not leap up and down as dot or dashes are separated by spaces (no carrier). A similar effect can take place with SSB signals as the amplitude

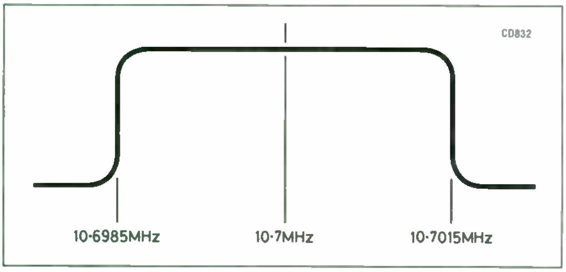


Fig 2.16. The characteristic of an SSB filter

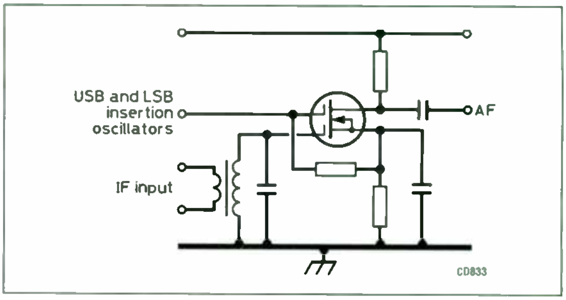


Fig 2.17. A product detector

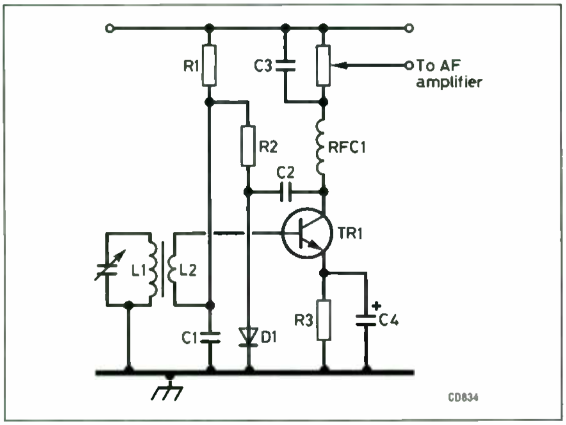


Fig 2.18. Part of a reflex receiver circuit

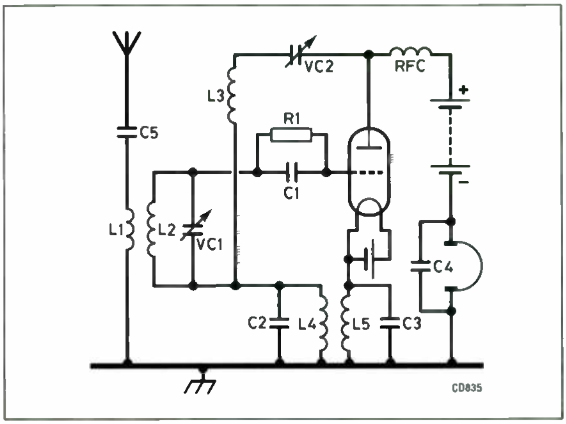


Fig 2.19. A super-regenerative receiver

of the sideband depends on the strength of the audio at the time.

Keep referring to these notes while any particular project is being examined – they should help you to understand what some of the parts of the circuit are expected to do.

To complete this section two types of receiver which will be considered historical have been included to demonstrate principles rather than practical circuits. Of course fashions in old electronics ideas can sometimes become resurrected.

The reflex receiver

This makes use of an economy measure – it uses a stage twice. Fig 2.18 shows part of a TRF radio in which TR1 is an RF amplifier. The RF signal is developed across RFC1, an RF choke in the collector circuit, and is applied to a diode demodulator D1. The AF output is developed across R1 and applied to the base of TR1. The RF choke has almost zero resistance to the lower frequency, and the AF signal is developed across R2 and applied to the AF amplifier via L2. A single transistor is therefore used as both an RF and AF amplifier.

A super-regenerative receiver

In the section describing the TRF with regeneration it was said that the use of regeneration increased the gain of the stage by reducing losses in the tuned circuit and consequently increasing the circuit Q, hence improving the selectivity. The super-regenerative receiver arranges that the positive feedback is greater than the amount which would normally cause oscillation but the oscillation is prevented by sweeping the feedback above and below the critical level at a high rate. In this way the losses of the tuned circuit are reduced virtually to zero and the gain and selectivity of the stage increased to quite an amazing level. Very simple receivers were designed using one thermionic valve in the early days of radio control of models. A typical circuit is shown in Fig 2.19. L4 and L5 are called 'quench coils' which cause a low-frequency oscillation and provide the sweeping action just described.

A simple analogy may assist understanding of the principle. When a milky food such as custard or porridge oats is being cooked the temperature of the 'hotplate' must be carefully controlled to prevent the food boiling over. Instead of adjusting the heat, the temperature could be adjusted well above boiling and the saucepan lifted off then replaced, lifted off again and so on. The excess temperature of the hotplate is similar to too much regeneration and the lift-off-and-replace action equivalent to the quenching action. In this way the food can be kept boiling in a way that would be almost impossible by a fixed-temperature hotplate.

Although the super-regenerative principle is generally regarded as a museum piece, the author discovered a practical circuit described in the RSGB publication *Amateur Radio Techniques* (third edition), dated about 1970. The circuit used an IGFET (insulated gate FET) so it is possible that a similar circuit may turn up again in the future.

Chapter 3

Some simple 'fun' projects

In this chapter a number of projects are described – they are intended to be an introduction to home construction, to give some experience in the use of tools and simple techniques and at the same time provide the reader with some devices, all of which should work and provide fun although they are not intended to be quality receivers!

The first two projects have been included for the benefit of absolute beginners or perhaps for younger members of the family of a more advanced reader. Both require little or no soldering and the language has deliberately been made very easy to read. The simple receivers were designed with Novice Licence students in mind, especially the younger ones, but that need not deter anyone from having a go.

An old-fashioned crystal receiver

This project (Fig 3.1) uses very simple constructional methods and no soldering is necessary. The only tools required are a small screwdriver, often referred to as a 'terminal screwdriver', a pair of wire cutters and something to make a few suitable holes. Step-by-step instructions for assembly are given later but first let's look at the things you will need.

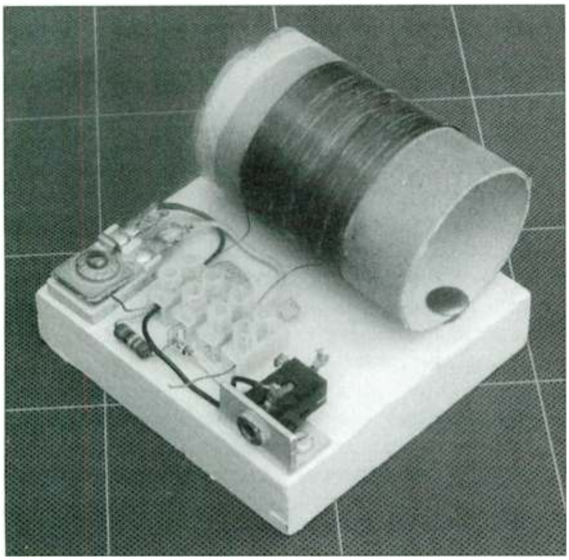


Fig 3.1. The crystal receiver

The coil

For this you will need some thin insulated copper wire. The diameter of the copper inside the insulation is less than 0.5mm. If you are buying from a shop such as Maplin ask for 0.4mm or 28 SWG (Standard Wire Gauge). The insulation is some form of enamel.

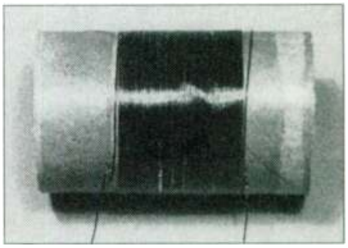


Fig 3.2. The coil

The coil is made by winding a number of turns of the wire onto a cardboard tube which is known as a 'former'. The tube from the inside of a toilet roll is ideal. The coil has about 80 turns but the actual number can be varied after the receiver is complete. Fig 3.2 shows the prototype coil.

The variable capacitor

Variable capacitors come in a variety of shapes, sizes and values. The physical size is not important as long as it can be fitted onto the baseboard. The value of a capacitor is measured in units known as 'farads' (after Michael Faraday) or small parts of a farad known as 'picofarads' (pF). This receiver requires a capacitor which has a value of 100 to 500pF and is a compression type. See Fig 3.3.

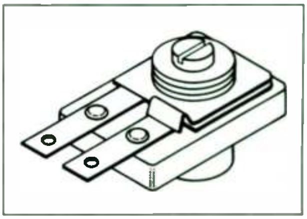


Fig 3.3. The compression trimmer

'Proper' variable capacitors, as used in commercial radios, are rather expensive, costing £5 or more, so the cheaper compression type is used in this design. It has a screw as a tuning control rather than a metal shaft and therefore cannot be fitted with a control knob. However, if you can afford a 'proper' capacitor you may be able to get one fairly cheaply at a radio rally. They come in two different types: solid dielectric and air dielectric which is more common but usually costs more. Chose whichever looks easier to fix or is the best price – it does not make any difference to the performance of this radio.

When you examine the capacitor you will see that it has several connecting tags or terminals. Some are connected to the moving plates of metal and the others to the fixed ones. The spindle enables the moving plates to be moved in and out of the fixed ones and in so doing change the capacitance from 100pF to 500pF, thus tuning the coil to the various stations. Some variable capacitors have a nut on a thread around the spindle to enable it to be fixed through a hole in the front panel of the radio. Others have some means of bolting the capacitor to a baseboard.

With a proper variable capacitor a knob can be fixed to the spindle to allow the plates to be turned without touching the metal with your hands – which can upset the tuning. Some of these knobs are fixed by being pushed on to a 'flat' on the spindle, while others have a small 'grub' screw which is tightened to hold the knob in place. Be warned, these tiny screws are very difficult to find if they are dropped, especially on a carpet.

Fixed capacitors

In principle these are similar to the capacitors described above – they have two sets of plates separated by an insulator but of course they have a fixed value and are usually encased in some insulating material. In this circuit both capacitors have a value of 100pF. Fig 3.4 shows a typical fixed capacitor.

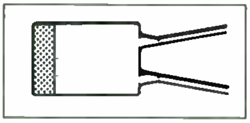


Fig 3.4. The capacitor

The diode

Early crystal radios depended on a 'detector' which was very tricky to adjust. A small piece of crystalline material – hence the name 'crystal set' – was held in a holder and was tickled with a fine piece of springy wire. This was called the 'cat's whisker' and it always seemed to have a mind of its own. Sometimes it found a good spot on the crystal and provided superb detection of the weak signals and at other times it simply did not work. Listeners would spend hours adjusting their detectors for the best results.

Detection can now be accomplished easily by using a tiny diode which will work without human aid! There are many different types, most of them cheap, and they come with wire ends ready to be fitted onto a terminal strip. Fig 3.5 shows the general form. Suitable types for use in a crystal radio are AA119, OA47, OA71 or OA91.


Fig 3.5. The diode

The resistor

This small component 'resists' the flow of current through it, hence its name. Electrical resistance is measured in 'ohms', named after another famous scientist, Georg Ohm. In this circuit the resistor has a value of 100,000 ohms (100 kilo-ohms or 100kΩ for short). Resistors have many shapes but a common one is shown in Fig 3.6. The value is marked by means of coloured bands as indicated in the caption.

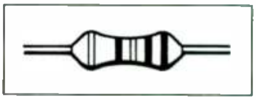


Fig 3.6. The resistor. In this circuit the first three bands should be coloured (left to right) brown, black and yellow

The earpiece

Earpieces or headphones are essential in order to listen to weak signals. Unlike a loudspeaker, they require little energy or power to produce a sound in your ears. For use with a crystal set they must have a high 'impedance' (opposition to AC) and therefore crystal types, as in Fig 3.7, are most likely to be used. Don't confuse the crystal in earpieces with the crystal used for the detector. For more information on this subject refer to Chapter 1 under 'output devices'. Older types of magnetic headphones can still be found in radio rallies and in second-hand shops. Hi-fi or personal stereo headphones are not suitable and will not work with this receiver.

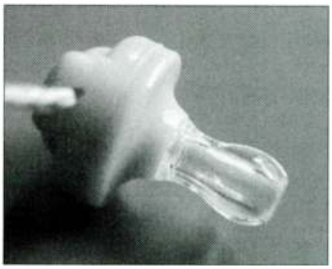


Fig 3.7. A crystal earpiece

Earpieces and headphones come with a plug on the end of the lead which is called a 'jack plug'. Two types of plug are in common use, the ¼in diameter type used for ordinary headphones, or the miniature 3.5mm diameter type used with earpieces and personal stereos. You will also need a matching jack socket to include in your circuit so that the earpiece can be simply plugged in. Just

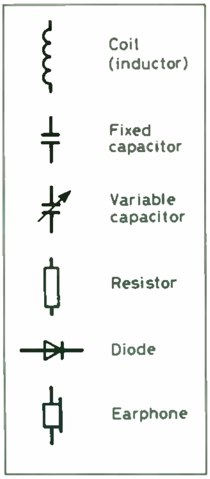


Fig 3.8. Symbols of the components used in the receiver

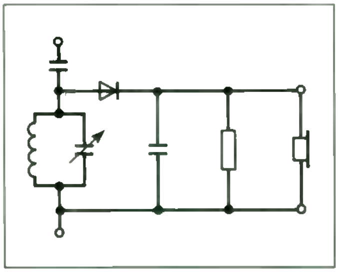


Fig 3.9. The simple circuit

Fig 3.10. More symbols

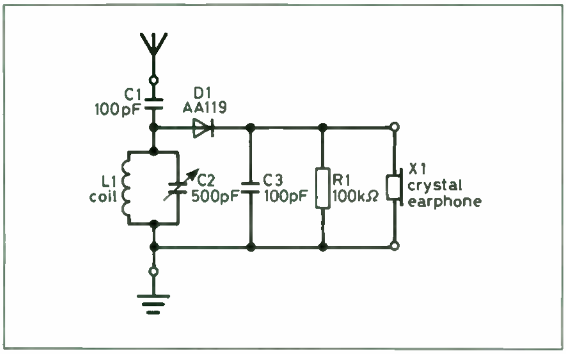


Fig 3.11. The complete circuit diagram

ask for a 3.5mm or a ¼in jack socket depending upon the type of headphone plug you have.

The circuit

It would be very difficult for designers of radio and TV receivers if they had to show pictures of all the components when designing the circuit of a new model. Instead they use symbols as a type of shorthand for every different component, which are recognised internationally. Fig 3.8 shows the symbols which are used in this circuit.

Using these symbols, Fig 3.9 shows the circuit of the crystal set. It shows the components and the wiring connections which will make the circuit come to life when the antenna (aerial) and earth are connected.

The symbols for antenna and earth are given in Fig 3.10.

By adding these to the original we end up with the circuit diagram shown in Fig 3.11 which all experienced amateurs will recognise immediately as a basic crystal radio receiver.

Table 3.1. Components list – crystal receiver

One four-way 2A terminal block (see text)
One 100 to 500pF compression trimmer
One diode, type AA119. Other suitable types are OA47, OA90, OA91 or OA95
One 100kΩ, 0.5W resistor
Two 100pF capacitors
One miniature jack socket
One crystal earpiece
5m of 0.4mm (28 SWG) enamel-covered wire
A few pieces of PVC-covered wire
A small bracket for the jack socket
A wooden block
Two drawing pins
Two thin buttons (shirt)
Four thin screws or nails (12mm)
Sticky pads or Blu-Tack™
Four miniature crocodile clips

Buying the parts

The components can be obtained easily if you are lucky enough to be able to attend an amateur radio rally or else you can order through the post from Cirkit or Maplin (they have branches in many big towns).

Tandy stores can be found in most towns and have a good supply of components.

Try to get the advice of an assistant with some knowledge of amateur radio and be prepared to accept equivalent or near-equivalent components as the values are not critical.

A shopping list appears in Table 3.1.

Building the set

Note that in this and later projects the leads of some resistors and capacitors may have to be shortened. Keep some of the longer off-cuts as they will be useful later.

Carefully examine the photograph of a completed receiver in Fig 3.1 and notice how the components are built onto the baseboard. Wire up your circuit using clips or soldering iron and odd pieces of wire by following these 10 easy steps. Read all the instructions before you start and then go back to the beginning and follow the steps.

1. The baseboard

Almost any piece of soft wood at least as big as the full-size drawing shown in Fig 3.12 will do. Sandpaper and paint the board with any household paint left over from the last decorating job. Leave to dry and while you are waiting you could carry on with step 2.

When the board is dry, trace the outline and crosses from the diagram in Fig 3.12, then transfer to the top surface of your board. This can be done quite simply by pricking the corners and the crosses with the point of a pair of compasses or something similar.

Drill a hole at 'A' using a 4mm drill. The hole should be at least as deep as the length of the thread on the back

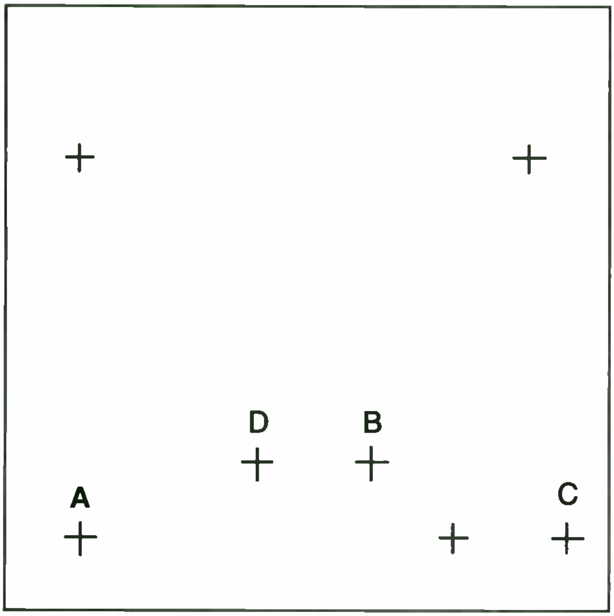


Fig 3.12. Marking the baseboard. Shown full-size

of the trimmer capacitor. Try to find someone who has a drill of the correct size and get them to drill the hole. If this is not possible make a fairly deep hole with the point of the compasses and enlarge it with a small screwdriver, then follow with a larger one. Prick fairly deep holes at positions 'B' and 'C'.

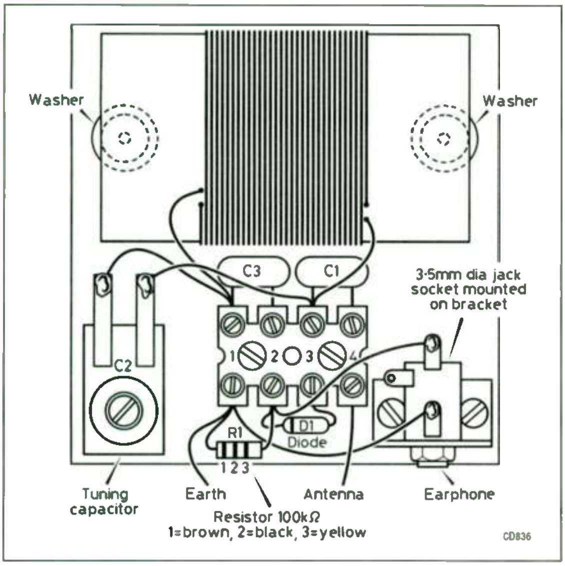


Fig 3.13. The layout of the components

2. Constructing the coil

As described before, this is wound using 0.4mm enamel-covered wire. The former is the cardboard tube from a toilet roll. Choose one which is not falling to pieces and has a diameter of about 40mm. Make two holes about 20mm from one end for the start of the winding. Thread the wire through these holes, leaving at least 100mm free, and then wind on 80 turns. These turns should be an even layer with the turns touching but not on top of one another – take your time. Finish with two more holes, again leaving a 'tail' of 100mm. If you have wound your coil carefully and with the correct-size wire, the length of the winding should be about 30 to 32mm. Give both the coil and the tube a coat of clear varnish. Leave to dry for at least 24 hours, then carefully cut the tube so that it is 70mm long, with the coil approximately in the centre. See Figs 3.1 and 3.13.

3. The terminal block

Examine it carefully. Inside the plastic there are four metal tubes with a terminal screw at each end. In Figs 3.13 and 3.14 these tubes are labelled '1', '2', '3' and '4'. It makes no difference if a connection is made at one end or the other but having two ends makes it easier to arrange the wires and components.

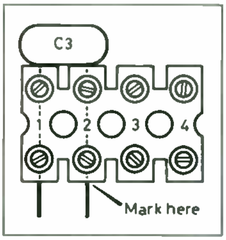


Fig 3.14. The terminal block

4. Marking the base again

Place the terminal block on your baseboard with the terminal screws facing up. Move it about until you can see the hole you pricked at 'B' through the right-hand fixing hole in the block. Put one of the nails into the hole and push it down gently. Move the block again and you should be able to see the cross marked 'D' in the left-hand fixing hole in the block. Get it to the centre of the hole or as near as possible, then put the second nail into the left-hand hole and press. Remove the block; the dent made by the second nail should be very close to the cross marked 'D'. Prick this dent fairly hard, again using the compass point.

5. Preparing the terminal block

Note that the components list specifies a four-way terminal block. This may not be available and you could be offered a 12-way block. This can easily be cut into three four-way pieces by the careful use of a 'Stanley' type modelling knife. One for you and two for your friends!

Take great care with this step. Spread out a sheet of newspaper or something to catch a screw if it should fall. Hold the terminal block so that you are looking into the tubes and with a thin screwdriver carefully unscrew the terminal's screws until you can see through the tubes. You may have to buy a suitable screwdriver (called a 'terminal screwdriver') but don't worry as they are quite cheap – about 20p. Don't unscrew too far as the screws may fall out and they can be very difficult to find – especially in a deep pile carpet.

6. Fitting the components

Keep referring to Fig 3.13 which shows the overall layout. Start with the two capacitors; they are the same so it doesn't matter which you use first – look at the diagram.

The capacitors C1 and C2 are fitted as follows. Pass the two leads of C3 through tubes 1 and 2, and press the component gently up to the plastic. Both leads will stick out on the opposite side of the block. Mark one lead where it comes out of the block. Refer to Fig 3.14. The arrow in the diagram indicates the point where the lead should be marked. A felt-tipped pen will be useful for marking the wire. Remove the capacitor and cut the lead at the mark using a pair of side cutters or an *old* pair of scissors. Put the capacitor back into the block but this time don't push it up to the plastic. Tighten the screw in tube 2 which is nearest to the capacitor. Note: the other lead of the capacitor must not be cut as it will form the earth terminal. Repeat the process with C1 and fit it to tubes 3 and 4. The long lead should come out of tube 4 and will be the antenna terminal.

The resistor is fitted to tubes 1 and 2. In this case both wires should be cut to 20mm, bent at right-angles to the body of the resistor.

Remove about 5mm of the plastic covering from one end of a 60mm length of wire and insert it into the end of tube 2, with the lead of the resistor. Tighten the terminal screw at the resistor end of tube 1.

The diode is a small glass tube which must not be confused with the resistor. Cut the leads to 20mm. Take great care as the snap when the wire cutters cut them may cause damage to the delicate junction inside. To avoid this, hold the wire in the jaws of a small pair of pliers and cut the wire on the side away from the diode (the pliers are being used as a mechanical shunt which will absorb the mechanical vibration, so preventing it reaching the delicate junction within the diode). Fit the diode to terminals 2 and 3. Tighten terminal 3 (nearest to the diode).

Remove 5mm insulation from another piece of wire, also 60mm long. Fit the bare wire to terminal 2 and tighten the screw. All terminal screws on the side of the block against the diode should now be tight. Terminals 1 and 3 (on the other side of the block) should not be tightened yet.

7. Fitting the tuning capacitor

Remove the nut and washer from the back of the trimmer capacitor. If you managed to get the hole drilled to the correct size you will find that the capacitor will screw into hole A. If the hole was made by 'other' means, probably the capacitor will not screw in. In this case make the hole big enough to allow the capacitor to 'sit' on the board and use a dab of glue to fix it. Don't use too much or the capacitor will not work correctly. If you can solder, fit two leads to the terminals of the capacitor and connect them to tubes 1 and 3 of the terminal block. If not, connect the wires to the capacitor terminals using small crocodile clips. To connect the wire to the clip, undo the little screw, thread the wire through the neck of the clip, wind it around the screw and tighten up.

8. Fitting the jack socket

Ideally, the jack socket should be mounted on a small aluminium bracket which is screwed to the baseboard as shown in the photograph in Fig 3.11 and Fig 3.13. The terminals of the jack must be facing up. If you don't have a bracket, use sticky pads or Blu-Tack™ to fix the socket to the board. Again, if you can solder, fix the two pieces of wire from terminals 1 and 2, to the solder tags as shown in Fig 3.13. Probably the jack socket will have three solder tags – if so, do not use the tag on the left-hand side. If you can't solder, use the crocodile clip method to fix the wires to the socket.

9. Connecting the coil

Fix the coil near to the edge of the baseboard using two drawing pins so that the wires come out of the coil near the terminal strip. Look at Fig 3.13 once again. Put a small washer around each pin under the coil so that the winding does not touch the board. If washers are not available, two small shirt buttons will do nicely. Cut the wires so that they will easily reach the terminal strip, then scrape off the enamel insulation from the last 10mm using a modelling knife or sandpaper so that the copper underneath shines brightly. Connect the wires to sockets 1 and 3 on the terminal strip and tighten the screws. Check that all eight screws are tight. The receiver is complete.

10. The antenna and earth

Ideally your antenna should be out of doors and as high as possible. Look at Fig 3.15. The picture gives a general idea but probably many other arrangements would be suitable. For a medium-wave receiver the length and height should both be as great as possible. The simple rules – more wire, more signal and higher wire, more signal. However, with this simple circuit, more wire also means less selectivity – that is the ability of the tuning to separate one station from another, although many of you

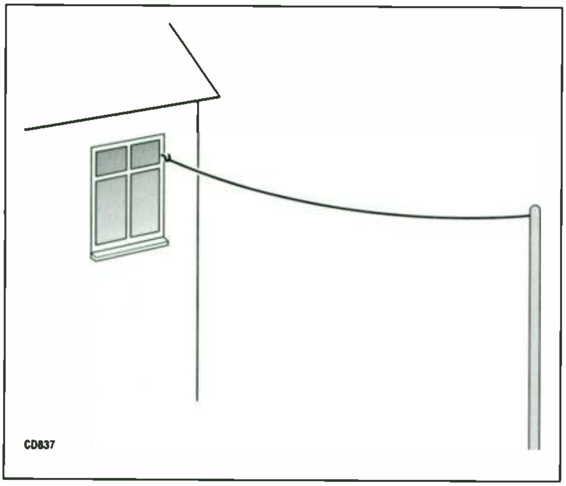


Fig 3.15. A small hook in the window frame can hold one end of your antenna and a post on the garden fence, the other

will be glad to receive just one station with no worries about separating two! Your location will dictate the 'size' of your antenna. About 15m of wire should be enough but be prepared to experiment with shorter or longer lengths. The location of the nearest transmitter is also important. If it is within five miles it may be possible to receive a good signal with a relatively short piece of wire, even indoors!

To make a reasonable earth, you will need to run a wire from your receiver to a copper or brass earthing rod which is driven into the earth (outside the house, not under the floor boards or in a flower pot) at the nearest point. Don't use an iron rod, as it will rust – a piece of copper water pipe about 400mm long would be ideal. Make sure that both the wire and rod (pipe) are scraped clean before you connect them together with a nut and bolt or a small 'jubilee clip' of the type sometimes used to join hose pipes. Wrap the joint with some PVC insulating tape to try to keep the weather out; copper rapidly oxidises and a bad connection could result. If you are in a flat or are too far up from the garden, try clipping your earth wire to a radiator or metal water pipe, choosing a point where bare metal is exposed. Get permission before you scrape off paint!

Testing the radio

Plug in the earpiece, connect the antenna to the wire coming from terminal 4 and the earth to the piece from terminal 1, again using crocodile clips for the connections. Listen very carefully as the screw on the tuning capacitor is adjusted. The signals are very weak so it is important to listen when there is no other noise.

If you hear nothing, count the number of wires going to each tube of the terminal block and compare with those shown in the layout diagram in Fig 3.13. Check that all other connections are correct. Look at the wires from the coil – make sure that the enamel has been scraped off where they go into the tubes of the terminal block.

If one or two stations can be heard but the screw of the capacitor is almost completely out, remove about five turns from the coil, being careful to remove the enamel from the new end before reconnecting it to the block. If the stations are still only heard with the tuning capacitor screw still very loose, remove a few more turns from the coil but not more than 10 in total.

It works? Great! Your first home-made radio and we hope that your very first signals will be remembered as long as those of the author!

Now that it is working, don't be afraid to experiment – what you have done once, you can do again. Try different antennas, reverse the diode and, if you are very close to a transmitter, even try to receive with the antenna disconnected – if you hear anything, try turning the receiver for the loudest sound. You will find that signals often get louder after dark but tend to fade in and out. Later you could make the AF amplifier described in this chapter. Connect the crystal radio to it and those very weak sounds could become a 'roar'! Information on the method of connecting the two units together will be found at the end of the amplifier section on p29.

If you can't get your circuit to work it may be worthwhile paying a visit to the nearest radio club – you may already know where they meet, but if not then get in touch with the Radio Society of Great Britain and ask for a list of nearby clubs. See Appendix 3 for the address and those of many firms who can supply everything you need to carry on with your radio work.

A MW TRF receiver

This design (Fig 3.16) is very simple and can be built at home in an hour or so. With the exception of the tuning capacitor, the parts are all very easy to obtain and many of them will be found in someone's junk box. As with the crystal radio receiver, most of the circuit is connected on an electrical terminal strip, the coil is wound on a cardboard toilet roll tube and the whole project mounted on a block of wood.

To complete the radio you will need the parts shown in Table 3.2.

One of the attractions of this receiver is that it can be completed with very few tools. You will need a small terminal screwdriver to tighten the screws in the terminal block and also a soldering iron to solder six pieces of PVC insulated wire.

A suitable tuning capacitor (30 to 300pF or 50 to 500pF) may be a problem. They are rather expensive to buy but if you are able to visit a radio rally you will almost certainly find one for about one or two pounds. You may find a tuning capacitor in an old LW/MW radio which has ceased to work. Try to get the help of a radio amateur or a radio repairer – they may suggest that a two-gang capacitor connected together to make up a 500pF capacitor be used in the place of a single one.

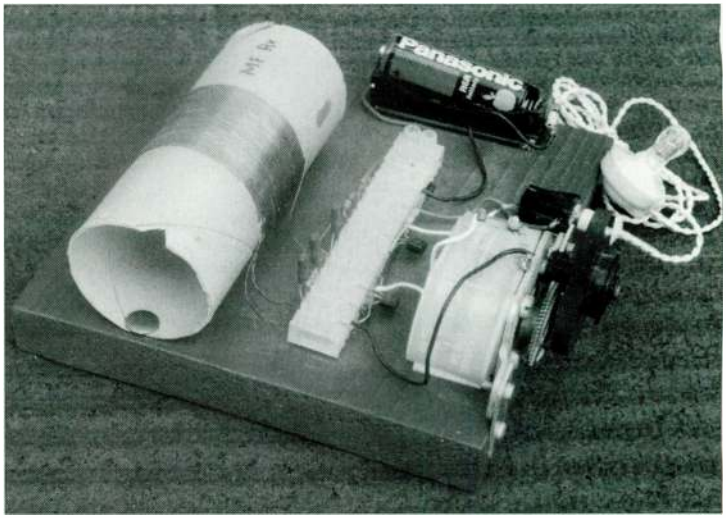


Fig 3.16. The medium-wave radio

1. Start by connecting the components on the terminal strip as shown in Fig 3.17, carefully checking the position and value of each one. The three capacitors are all the same and should not present a problem. The resistors are small cylinders with a wire coming from each end and the value will be coded by means of several coloured bands. Look at the first three bands – you should find:

Brown, black, yellow	=	100k	R1, R5 and R6
Green, blue, brown	=	560R	R2
Red, violet, brown	=	270R	R3
Brown, black, orange	=	10k	R4

   It is most important to note the exact position of the IC (integrated circuit) marked 'ZN414Z' and the transistor marked 'BC548'. They look alike so check the numbers carefully.
2. Now wind the coil. A standard toilet roll tube is about 42mm in diameter and 110mm long. Don't worry if yours is not exactly this size! Make two small holes in the tube about 40mm from one end. See Fig 3.18. Thread the enamel-covered wire through these holes, leaving about 100mm sticking out for the connections. Now wind on 80 turns of wire. Keep the turns close together but not on top of each other. This is one of the most important parts of the receiver so try to keep the winding tight. Be patient! When finished make two more holes and thread the end of the wire through them to hold the coil in position. If you have some clear varnish, give both the coil and the tube a coat and leave to dry.
3. The base can be any piece of soft wood about 150mm square and at least 10mm thick (an off-cut from a piece of floor board supplied by a friendly builder, perhaps). Look at Fig 3.18. Fix the terminal strip to the base with two small wood screws or, if you can't get any small enough, with double-sided sticky pads or even Blu-Tack™.

   Fix the coil near one edge of the base using two drawing pins and then connect the ends of the coil to the terminal strip as shown in Fig 3.18. Carefully scrape the enamel from the ends of the wire before putting them into the terminals. You will find it easier to remove the enamel if each end is held in the flame from a match for a moment or two – but please take great care and don't burn yourself!

   Fasten the battery box to the wooden base – small wood screws, double-sided sticky pads or Blu-Tack will do.

   Now you need six pieces of PVC-insulated wire,

Table 3.2. Components list for the MW radio

RESISTORS

R1, 5, 6	100kΩ
R2	560Ω
R3	270Ω
R4	10kΩ

CAPACITORS

C1–C3	100nF
Variable capacitor	300–500pF

SEMICONDUCTORS

ZN414Z
BC548

MISCELLANEOUS

Crystal earpiece
12-way, 2A terminal strip
22m of 0.4mm or 0.375mm diameter enamel-covered wire
A few short pieces of coloured PVC insulated wire
Miniature 3.5mm jack socket
1.5 battery (AA cell) and box
Toilet roll tube
A few double-sided sticky pads
Soldering iron and a little cored solder
Two drawing pins
A small screwdriver

two each for the tuning capacitor, the miniature jack socket and the battery box. (Use a piece of red wire for the battery box positive terminal, marked '+', and a black piece for the negative one, marked '–'. To connect one end of each piece you will need a soldering iron or a friendly amateur to do it for you (just this once – you must learn to solder!)

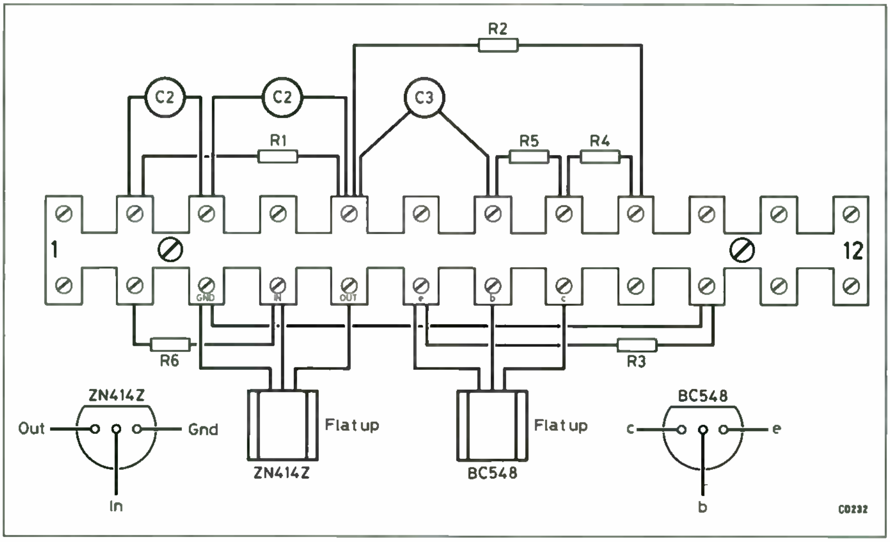


Fig 3.17. Terminal strip – position of components

Testing

4. Put the battery into the box (it must be the right way round – check Fig 3.18) and plug in the earpiece; you should be able to pick up some stations by altering the tuning capacitor. You may need to turn the whole radio to find the position which gives the strongest signal.

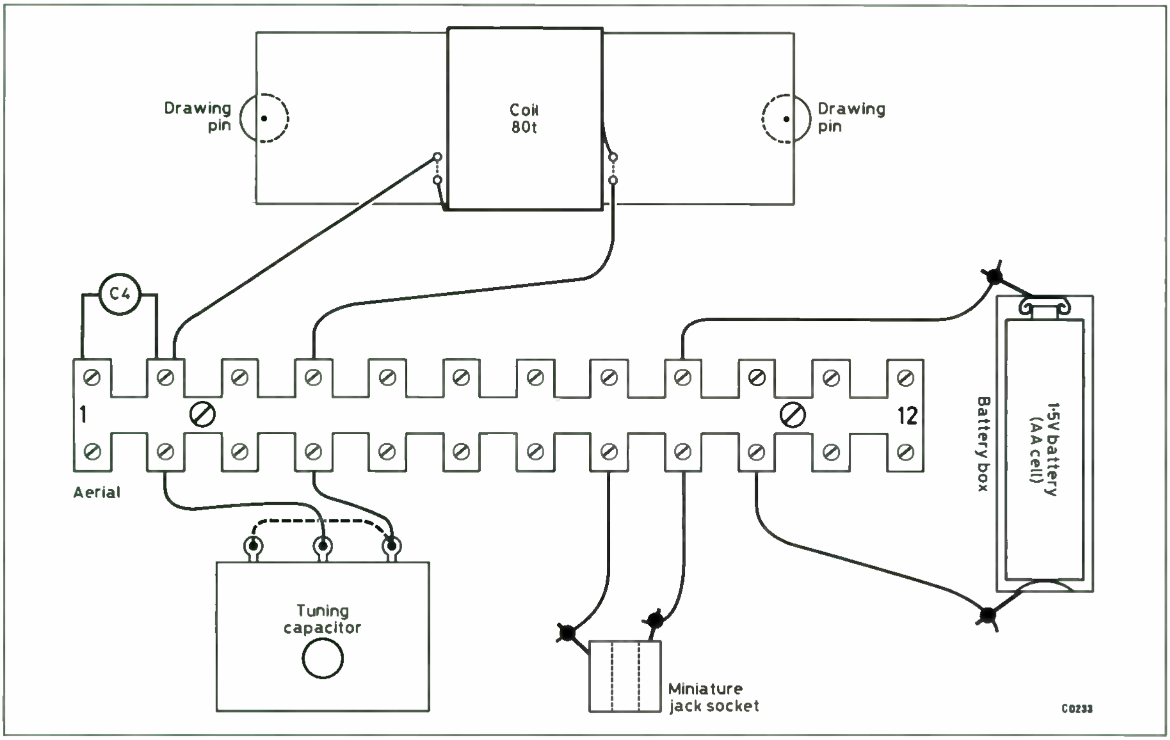


Fig 3.18. The layout of the parts on the wooden base

The receiver should work without any extra antenna but, if you live a long way from a medium-wave transmitter, try a long piece of wire, hung up as high as possible and connected to terminal 1 on the connector strip. If you do this it will be necessary to connect another capacitor (another 100nF one) between terminals 1 and 2 on the connector strip.

A crystal earpiece will give a reasonable output (no other type will work in this circuit).

When you have completed the audio amplifier project, the output of the radio can be fed into the amplifier and then everyone will be able to listen. Instructions for connecting the two units together will be found at the end of the AF amplifier section on p29.

The circuit of the radio is given in Fig 3.19 but you do not need to understand it or even to refer to it in order to complete the receiver; it is there for those who like to have a bit more information.

If you know a local radio amateur he or she may be able to help you to get the parts but if there is any problem, almost everything can be bought from:

- Maplin Electronic Supplies Ltd, PO Box 3, Rayleigh, Essex, SS9 8LR. They have branches in many big towns where you will be able to browse through the catalogue but if you wish to order by post you will need to buy one. They are normally on sale at W H Smith or of course, their own shops.
- Cirkit Distribution Ltd, Park Lane, Broxbourne, Herts, EN10 7NQ.
- Tandy. Shops in most medium and big towns.
- JAB Electronic Components, The Industrial Estate, Rear of Queslett Motors, 1180 Aldridge Road, Great Barr, Birmingham, B44 8PB.

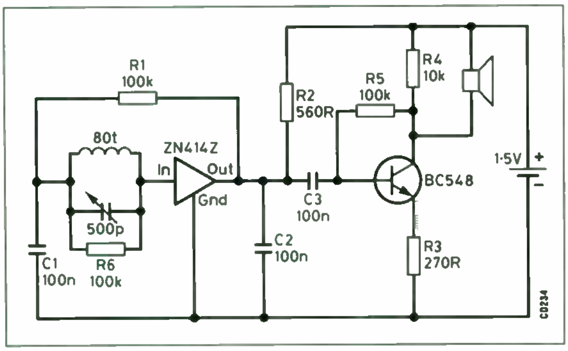


Fig 3.19. The circuit of the medium-wave radio

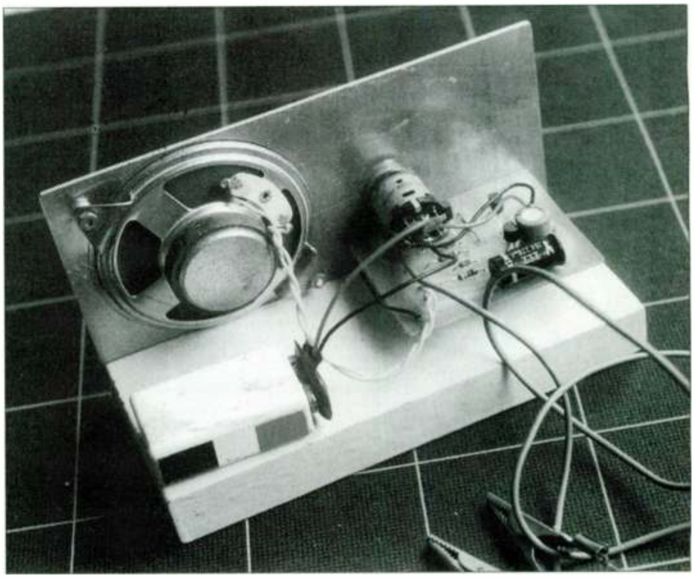


Fig 3.20. The audio amplifier

An AF amplifier

You will no doubt have noticed that this is not a receiver but a fairly-high-gain AF amplifier. You may already have a similar amplifier and in that case, provided that it is battery operated, you could use it instead of the one to be described. If you have attended a Novice Licence course you will have already made an identical amplifier as it is one of the projects in that course. It is a well-tried-and-tested design and there should be no difficulty in getting it working. In addition a kit of parts or just the PCB is available from Kanga Products at a very reasonable price. The address is to be found in Appendix 3.

Table 3.3. Components list for AF amplifier

RESISTORS	
R1	180R
R2	4k7
R3	1M2
RV1	25/47k log
CAPACITORS	
C1, 2	4µ7
C3	47µ
C4	220µ
SEMICONDUCTORS	
TR1, 2	BC548
TR3	BC558
D1, 2	1N4148
MISCELLANEOUS	
One PP3 battery clip and leads	
One small loudspeaker, 35Ω or more	
One PCB	

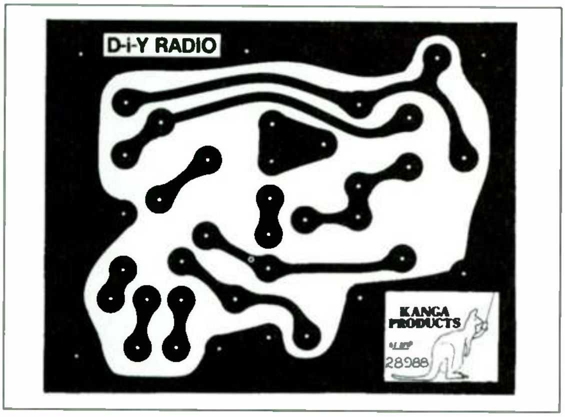


Fig 3.21. The foil pattern of the PCB – track side

It is a useful amplifier which can be used with many other projects such as a crystal radio or the MF receiver and will convert them into quite 'noisy' devices. As this is your first project it is important that you do not rush to get the amplifier finished. If you have not done any soldering before, a little time spent practising on any scrap materials will be well spent. You should not start work on the PCB until you are confident of your ability to solder well.

Make a start by examining the components – you should have:

- One PCB. The plain side is called the 'component side' and the other the 'track side'. Fig 3.21 shows the track side full-size.
- Three resistors. Look for a gold or silver band – turn the resistor so that this band is on the right-hand side. Now look at the three coloured bands at the left-hand end. Yellow, violet, red stands for 4700 ohms or 4k7. Brown, grey, brown stands for 180 ohms or 180R. Brown, red, green stands for 1,200,000 ohms or 1M2.
- Four capacitors. The two small 'beads' are tantalum capacitors and will be marked '4.7μF' or '4μ7' with a '+' above one lead. Then there is one large tube with a wire coming from each end (axial) which is marked '220μF' with a '+' or a '–' at one end. The last is a tube with two wires coming from the same end (radial) and this will be marked '47μF'. All these capacitors are said to be 'polarised' and must be connected the correct way round so it is important to find those '+' or '–' marks.
- Two diodes. These are small glass devices with a black band at one end and may be marked '1N4148'.
- Three transistors. Two of these will be marked 'BC548' or 'BC182' and the other 'BC558' or 'BC212'.
- One potentiometer (volume control).
- One loudspeaker – be careful with this and don't let anything press against the cone.
- One PP3 battery clip with two leads, one red and the other black.

Important – In some kits the capacitors C1 and C2 may be replaced by ceramic types with a lower value and somewhat smaller. These will work just as well and will fit under the volume control (potentiometer) with less trouble. They are *not* polarised and can be fitted either way round. The volume control may be marked '47k log' instead of '25k log'. Again this will be perfectly satisfactory.

The kit and/or the PCB can be obtained from Kanga

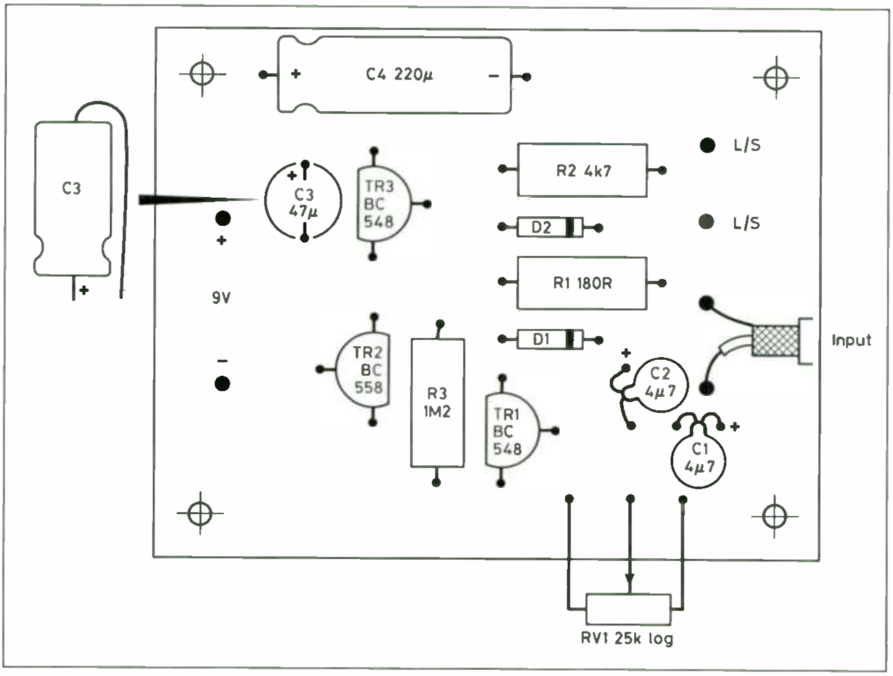


Fig 3.22. Position of the components on the printed circuit board (PCB)

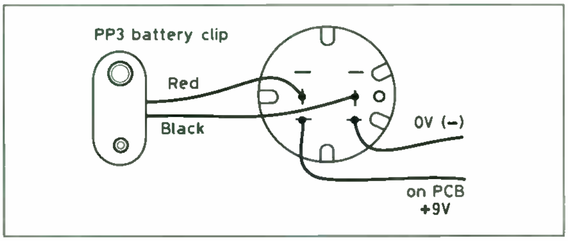


Fig 3.23. Connections to the switch on the back of RV1

Products at Sea View House, Crete Road East, Folkestone, CT18 7EG.

Construction

Lay the PCB on the track side so that the 'D-i-Y RADIO' lettering is at the top but hidden from view. Now compare the holes with the dots in Fig 3.22. Bend the wires of the three resistors at right-angles to the body (do not use pliers) so that they fit the holes in the board. When you are sure that they are in the right holes and that the value is correct push the resistors down so that they lie flat on the board. When you are satisfied that everything is correct, bend the wires apart on the track side of the PCB (just enough to stop the resistors falling out when the board is turned over) and solder each of the wires to the PCB. Cut off the surplus wire. If you are good at soldering you may cut the wires before soldering them.

Now fit the four capacitors. These must be connected the right way round – note the '+' and '–' signs on the component and on the drawing in Fig 3.22. Again the components should be close to the board, not standing up on stilts!

Note that C3 is mounted with the leads down. They are shown on top in the diagram to ensure that the positive one is put into the correct hole.

If an axial-type capacitor is supplied for C3 it must be fitted 'on end' – see the inset in Fig 3.22.

The two diodes can be fitted next but make certain that they are the correct way – note the band on the components and in Fig 3.22. Try to solder these components quickly as they can be damaged by excessive heat.

The three transistors should be mounted so that the body is about 5mm above the surface of the PCB. It is most important that the wires of each transistor go into the right holes and that the correct type is used in each position. If the flat on the body is in the same position as shown in Fig 3.22, there should be no problem. Fit the control so that the spindle sticks out from the front edge of the board.

Connect a piece of red insulated wire to the pad marked '+9V' and a black piece to the pad marked '–9V', then solder these to the switch on the back of the control. Connect the two leads from the battery clip to the other two tags on the switch as shown in Fig 3.23.

Finally, connect the loudspeaker using two pieces of insulated wire about 100mm long and twisted together.

Later you may wish to put the amplifier into a box. There is no problem – almost any box that is big enough will do. All that is needed is one hole big enough to accept the bush on the control. Pass the control through the hole, tighten the nut and the PCB will be supported by the control. The prototype was not put into a box but mounted on a piece of aluminium which was screwed to a piece of wood to form a right-angle. The loudspeaker was fitted to the aluminium by means of two small pieces of aluminium with 3mm holes drilled in them. These are used as clamps, just holding the edge of the speaker. To allow the sound to get out, a few holes will need to be drilled in the panel (before the loudspeaker is fitted!) within a circle of about 40mm.

The signal to be amplified can be connected to the two input 'pads' by means of two short pieces of wire but if the connection needs to be a long one, then screened wires must be used.

If you decide to use a different loudspeaker make sure that it is at least 35Ω (35 ohms) impedance – anything lower will probably damage the two output transistors and even if it doesn't, it will cause your battery to run down rather quickly.

Just for interest the circuit diagram of the amplifier is shown in Fig 3.24.

For the benefit of those who have made either the

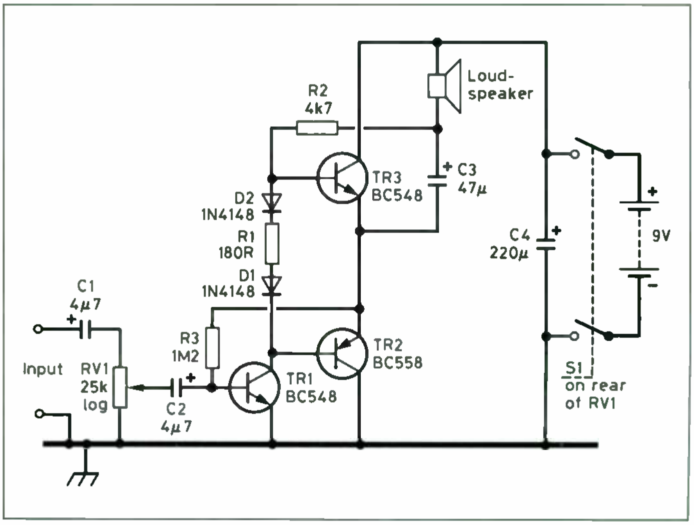


Fig 3.24. The amplifier's circuit diagram

crystal radio or the MW TRF receiver, the connections between the AF amplifier and these units are shown in Figs 3.25 and 3.26. The input lead to the amplifier should be of miniature, screened cable and it is most important that the braid of this cable is connected to the earth point on the receiver board/s – this is especially important when the MW TRF radio is being connected. If preferred the unit described in the next section could be used.

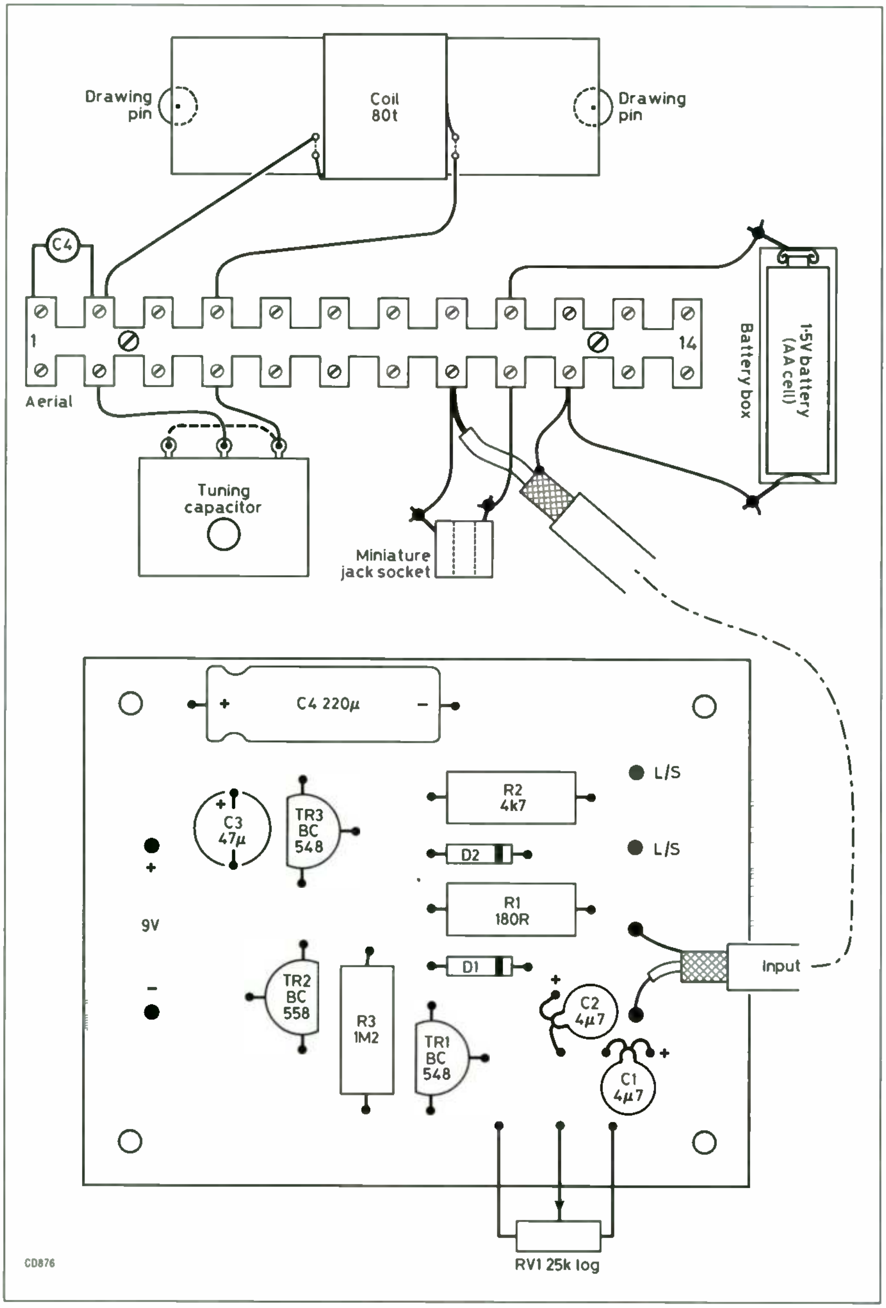


Fig 3.25. Connecting the AF amplifier to the medium-wave radio

An alternative AF amplifier using an integrated circuit

This project has been included for the following reasons:

- It is an example of the simplicity of projects using integrated circuits. In addition to the IC there can be as few as three peripheral components plus volume control and loudspeaker.
- It can be very small – the prototype panel is only 25mm × 37mm.
- Unlike the previous amplifier it will operate with loudspeakers in the range 4 to 16Ω, with 8Ω being the optimal value.

The IC is a LM386N-1 manufactured by National Semiconductor and more information can be found in Chapter 6 where it is used as the AF amplifier for the 50MHz FM superheterodyne receiver.

The IC is in what is known as an 'eight-pin DIL' (dual-in-line) package, and the pin connections and circuit diagram are given in Fig 3.28. In the simplest form C1 and C2 may be omitted although both are used in the project described here. To enable the decision to be made, C1 determines the amplifier gain. If it is not used the gain is set at 20 times – this rises to 200 times if C1 is included.

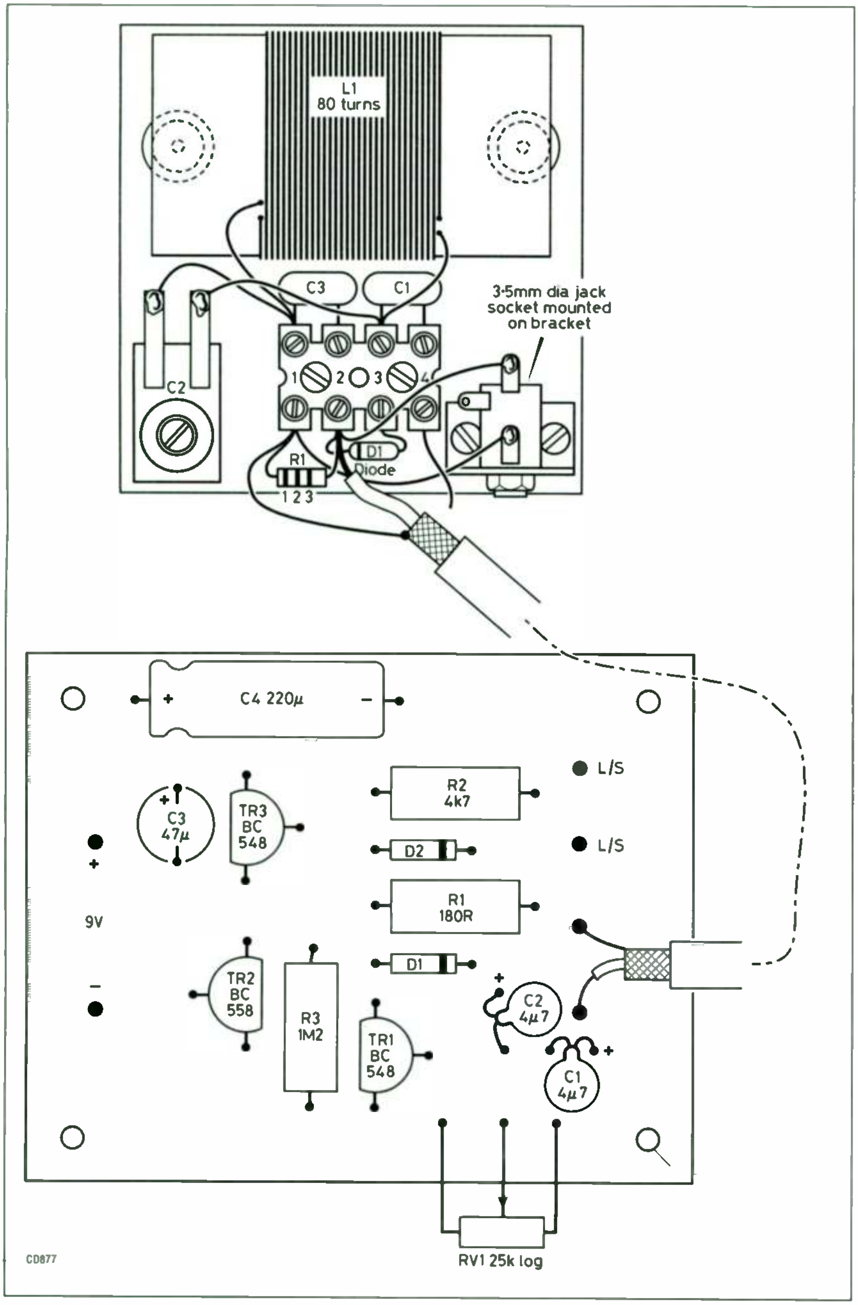


Fig 3.26. Connecting the amplifier to the crystal set

C2 helps to reduce noise from the power supply and is important if the amplifier is to be used with a mains operated power unit.

The components are arranged on a small piece of 0.1in matrix Veroboard™ which has 10 copper strips and 15 holes 'long'. Most suppliers have Veroboard but most do not stock small pieces. JAB Electronics offer a piece which has 10 copper tracks and is 24 holes long. At the time of writing the price is 40p. The address will be found in Appendix 3.

For those constructors who have not previously used Veroboard a few useful tips are included. Unlike a PCB, it is not always easy to trace the circuit because the copper strips are parallel to one another. Connections from one strip to another are made using 'jumpers' on the component side of the board with the result that reference has to be made continually from one side to the other. Also, it is sometimes difficult to transfer the location of components from the layout diagram (shown in Fig 3.29) to the piece of Veroboard.

The following method may help. The copper strips are labelled from top to bottom using the letters 'A', 'B', 'C' etc and the holes from left to right with the numbers '1', '2', '3' etc. Any hole can now be identified by giving the row letter and hole number. For example, in the layout diagram in Fig 3.29 pin 1 of the integrated circuit passes through hole C6, and the +9V supply pin through hole E15.

Construction

When working with any PCB or Veroboard the various operations will be much easier if there is some means of holding the board so that it does not slide about as it is being it is soldered. This is especially important when a very small piece of material is being worked upon. Commercial jigs are quite cheap and often come equipped with a magnifying lens but a simple and effective jig can

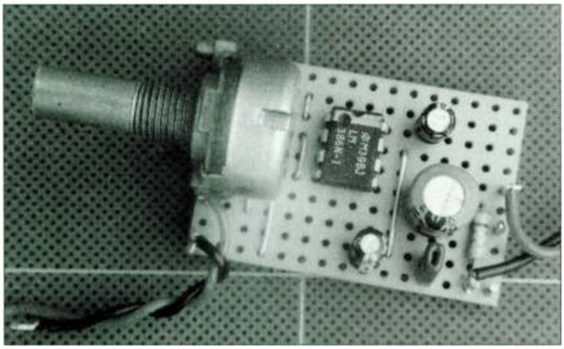


Fig 3.27. The IC audio amplifier

be made by drilling a small hole in the end of a clothes peg and screwing it to a lump of wood about 80mm square.

There are a number of ways in which the amplifier might be used:

- Without a volume control. This may be the case if the amplifier is used with the 10GHz receiver described later in this chapter.
- With a volume control in order to use it with either the crystal receiver or the MW TRF receiver described earlier in the chapter.
- With a volume control incorporating an on/off switch, as would be required if the amplifier is used in the ARDF radio described in Chapter 5.

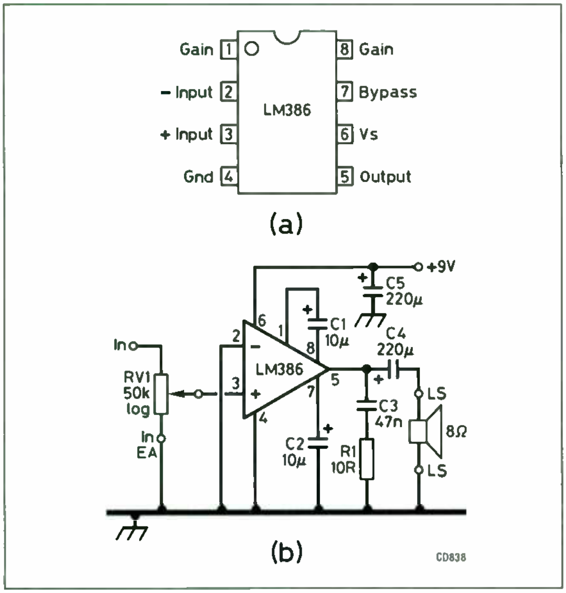


Fig 3.28. (a) LM386 pin-out viewed from above. (b) An LM386 amplifier

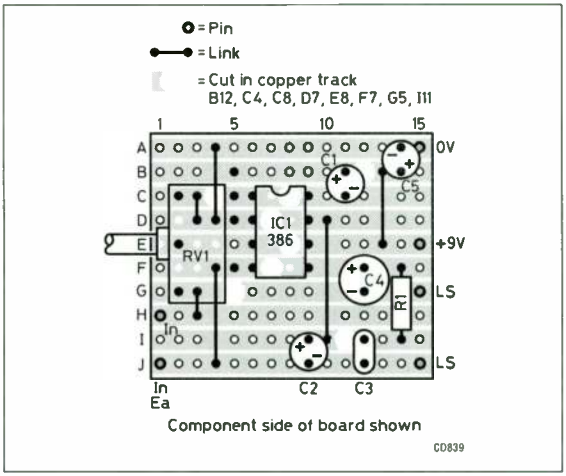


Fig 3.29. Layout of components

None of the above involve any drastic changes but will require minor alterations. The remainder of the construction will assume that option 2 is to be followed with the modifications necessary for the other options being detailed at the end of the section.

It is recommended that constructors who have not used Veroboard before should carry out the following steps.

1. Insert the eight jumpers. These can be made with the off-cuts of resistors or capacitors from this or earlier projects. Carefully bend the pieces of wire into a staple shape. The centre part must be adjusted so that it will exactly span the number of holes indicated in Fig 3.29 and the outside ends at least 4mm long. Insert the jumper into the correct holes from the plain side and ensure that it lies against the board. Bend the ends on the track side outwards a little, just enough to stop the jumper falling out when the board is turned over for soldering. Solder both ends and clip off the excess. Use a thin bit in the soldering iron (1.5mm or 2mm is

Table 3.4. Components list for AF amplifier 2

RESISTORS	
R1	10R
RV1	47k log, min PCB mounting
CAPACITORS	
C1, 2	10µ radial electrolytic
C3	47n ceramic
C4, 5	220µ radial electrolytic
SEMICONDUCTOR	
IC	LM386
MISCELLANEOUS	
Veroboard, 0.1 matrix 10 strips × 15 holes	
Loudspeaker, 8Ω	
Six pins	

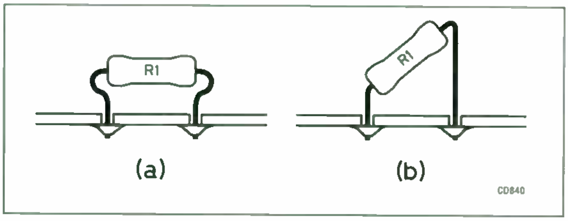


Fig 3.30. Alternative positions of R1

ideal) and use thin resin-cored solder – 22 gauge if possible and certainly not thicker than 18 gauge. Take care to avoid solder producing a bridge from one track to the next. It is recommended that all eight jumpers be fitted even if capacitors C1, C2 and C5 are not going to be used. The jumpers involved with these capacitors will be required if the components are fitted later and it is not too easy to put them in after all other components have been fitted.

2. The six terminal pins must be inserted from the track side of the board and pushed down until the head is against the copper strip. Solder the heads to the strips, again making sure that the solder does not make a 'bridge' to the adjacent strip/s.
3. Fit R1. The physical size of this component will determine how it should be fitted. A 1/8W component will lie flat on the board with no problems. Most ¼W resistors will fit if the leads are bent very close to the body, rather more than 90°, and then opened out so that the two ends are parallel. See Fig 3.30(a). Even larger resistors must be mounted as shown in Fig 3.30(b). Solder and clip off surplus leads.
4. C4 is an electrolytic type and must be inserted the correct way round. A radial type has been listed – that is one where both leads come out of the same end of the capacitor. The negative lead is normally marked by means of a stripe down one side of the case and this sometimes has a '–' sign printed on it. Push the component down onto the board and solder the wires as before. C3 is a small disc ceramic type and can be inserted either way round. Again push down to the board and solder. Clip off excess wire from both capacitors. C1, C2 and C5 are all electrolytic capacitors and should be fitted in the same way as C4, observing the correct orientation.
5. The integrated circuit (IC) should be fitted next. If the pins are too far apart, hold the IC with the pins flat against the bench and bend slightly inwards, then repeat with the other four pins until the IC will fit. Carefully check the position and ensure that the notch and/or dot in one end is in the same position as in the layout diagram. This is most important – the IC will be damaged if it is reversed. Bend pins 1 and 5 outwards a little (on the track side) to stop the IC

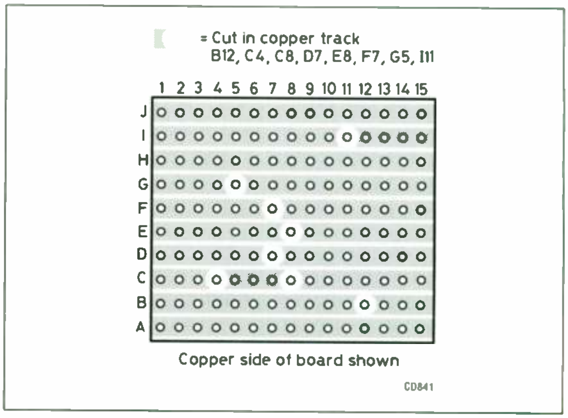


Fig 3.31. Where to cut the tracks – use this diagram if the cuts are to be made before components are added

falling out, check again on position and orientation and, when you are sure all is correct, solder pin 1. Ensure that the IC is right down on the board – if not touch pin 1 with the soldering iron bit while pressing the IC. Solder pin 5 followed by pins 2, 6, 3, 7, 4 and 8 in that order. This will help to avoid overheating the IC by distributing the heat. If in doubt wait a few seconds between soldering each pin.

6. Next insert the volume-control potentiometer. It may be necessary to increase the size of the three holes just a little using a round needle file. Take care because the file is brittle and has a sharp point. Solder one of the pins, then check that the control is correctly aligned. When satisfactory, solder the other pins.
7. Make the breaks in the copper tracks as indicated by dotted circles in Fig 3.29. It is much easier to do this operation immediately after inserting the terminal pins but if a mistake is made and a break created where a component lead should be soldered, things can only be rectified by considerable invention! Those constructors who wish to make the breaks first can refer to Fig 3.31 which shows the breaks from the track side of the board. To avoid confusion when the board is turned during the cutting process, it would be advisable to start by inserting the terminal pins 0V, +9V and the two marked 'LS'. These pins will allow the board to be placed in the correct position when referring to Fig 3.31. Use a special spot face cutter obtainable from most suppliers of Veroboard – a sharp drill bit about 3mm will do just as well except that it is a little more difficult to use. Apply light pressure to the spot face cutter and a bit more if a drill bit is used. Hold the bit in the fingers and turn in a clockwise direction until the copper strip is removed across the whole width.

When the cutting is carried out after the components have been soldered the drill bit or cutter will cut through the solder with no trouble.

8. If a PP3 battery is to be used, solder the leads of the connector to the supply pins – red lead to the positive and the black to the negative pins.

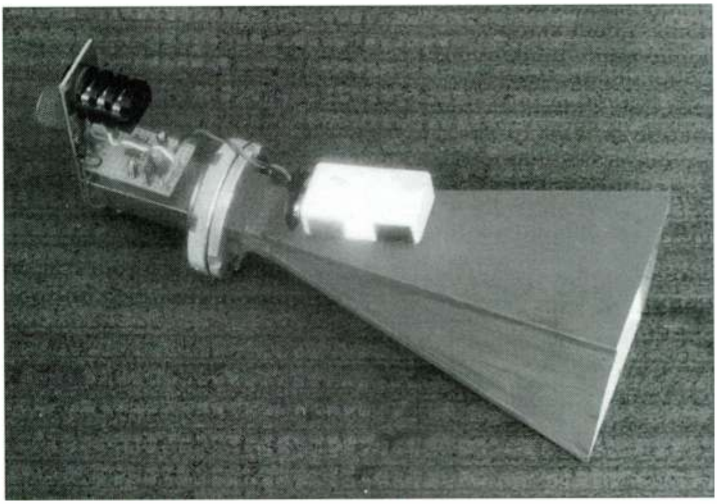


Fig 3.32. The 10GHz receiver showing the LM386 amplifier

The amplifier is complete and may now be tested. Spend a few minutes examining the board very carefully. Inspect the track side, looking for any solder bridges or dry joints, if necessary using a magnifying lens. Then look on the component side for components incorrectly placed, especially the IC and the electrolytic capacitors. When satisfied that all is well, connect a loudspeaker to the two pins marked 'LS'. Almost any speaker with an impedance between 4 and 16Ω will do. Use a piece of screened cable to connect some audio signal to the pins marked 'IN' and 'GND' with the inner connected to the 'IN' pin. The signal may be from a simple crystal radio, the MW TRF receiver described earlier in this chapter or any other AF source which needs to be amplified.

Set the volume-control potentiometer fully anti-clockwise, connect a PP3 battery to the connector and turn the volume control slowly clockwise. An output should occur almost immediately as the gain of the amplifier is very high if C1 has been connected.

To fit the amplifier in a box all that is required is an 8mm hole with a 3mm hole 9mm to the right of it to locate the spigot on the control. Fit a plain washer over the threaded part of the control spindle, push the control complete with the Veroboard amplifier through the hole and fix with the supplied nut. Complete the unit with a suitable 6mm control knob.

A very simple microwave receiver for 10GHz

Basically this is the receiver used by the author to detect the presence of any boat carrying and using radar apparatus, as mentioned in the preface. The output is just a series of bleeps and of course these will only be found in areas near the coast where there is plenty of shipping. The antenna used is rather directional and by sweeping the radio slowly in an arc it was possible to decide the direction from which the signal was arriving. With practice, it was also possible to get a good idea of the distance from the transmitter from the strength of the signal. It is assumed that in practice, all this was done when the visibility was rather bad!

Although this project is given the title of 'a very simple microwave receiver' there are a number of things to be considered before you start work. It *is* very simple, in fact it is just another crystal radio followed by a high-gain AF amplifier, but its construction requires considerable skill in metalwork and soldering. Anyone who attempts any project for the 10GHz microwave band must expect to learn to become a 'plumber' but the necessary skills are not difficult to acquire and, once learnt, will prove to be useful in many aspects of both the hobby and elsewhere. In addition, even when the device is complete, it won't do very much in the way of receiving interesting signals. However, in spite of these warnings, it is a worthwhile project as it gives an introduction to a 'new' branch of radio, and most of the work involved will provide a number of useful modules which could later be used for more advanced projects.

The antenna

The wavelength of a 10GHz signal is just about 30mm so that a half-wave antenna would be 15mm. To get this tiny antenna to collect as much signal as possible we are going to make use of a horn which acts rather like the ear trumpet used as a hearing aid before electronics made things a bit smaller. Fig 3.33 shows how signal is 'captured' from a broad front in a similar fashion to the way which occurs with a ferrite rod antenna as described in Chapter 1 (Fig 1.3). Another way of collecting even more signal is by means of a 'dish' which is a familiar sight on many houses where it receives signals at microwave frequencies from satellite transmitters.

The horn feeds the signal through a short piece of waveguide (similar to coaxial cable but with much less loss) to the antenna which is often the detector diode

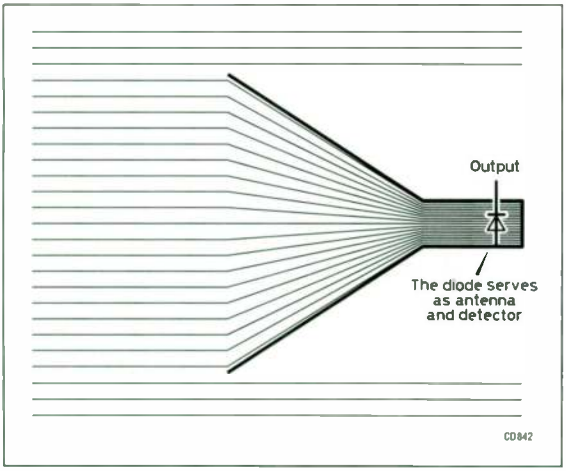


Fig 3.33. The horn concentrates a large area of the 'energy wavefront' onto the antenna

itself. The output of the diode is fed to a high-gain AF amplifier and to headphones.

Making a horn

This is not such a difficult task as it may appear at first sight. It is mainly a lot of hard work but is excellent practice – at the end not only will you have a practical 10GHz horn but you will have improved your metalwork very considerably. It is important that the dimensions should be very close to those given in Figs 3.34 and 3.35. The method of cutting will depend on the sheet material to be used but remember that in the case of the wide faces it is the bending line for the flange which is the important dimension. Ideally the horn should be made from sheet copper – 18 SWG (Standard Wire Gauge) which is about 1.25mm thick. The second choice would be sheet brass of the same gauge. These may be difficult to obtain and in any case will be rather expensive – a much cheaper material is tin-plate. This can be purchased in the same gauge but cutting is likely to be a problem. You may be lucky enough to find a small engineering firm which will be able to supply the small quantity required (of any of the three materials) and be prepared to cut it for you. If you are so lucky, the dimensions must be submitted exactly and you must stress that they are critical. A much cheaper option is to reclaim second-hand material from large cans of the type which once contained cooking oil, motor oil or a large biscuit tin. The five-litre size of oil can is ideal as the flat sides are big enough to provide sufficient flat material but note the test in the following paragraphs.

Table 3.5. Components list for the 10GHz receiver

100MΩ resistor
10nF disc capacitor
Three 15mm 6BA screws and full nuts
One Belling Lee type socket
80mm WG16 waveguide, brass or copper
Matching pair WG16 flanges
1N23 diode complete with 6.3mm flange
LM386 amplifier (optional)
6.3mm stereo socket
Small pieces of brass
Tin-plate biscuit tin or oil can

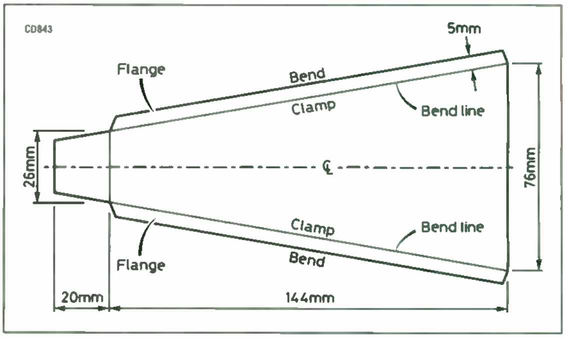


Fig 3.34. Dimensions for side 'A'

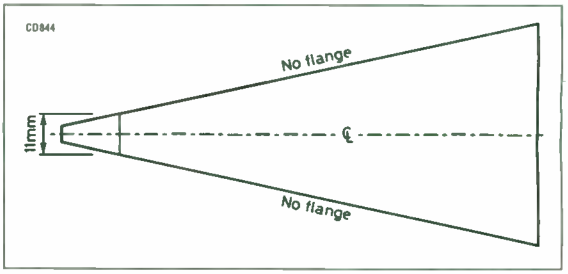


Fig 3.35. Dimensions for side 'B' (which differ from those in Fig 3.34)

Warning! When working with tin-plate be very careful of the extremely sharp, raw edges – in the early stages a stout pair of gardening gloves could help to avoid some nasty wounds.

Choose a can which has not been damaged and is free from rust, both inside and out. Use a hacksaw or tin snips to cut off both the top and bottom, then cut down the four corners to give two relatively flat pieces of tin-plate which were the larger sides of the can and two smaller pieces which probably will not be needed for this project. Make the sheets as flat as possible, then remove the sharp rough edges by careful use of a fine file. Beware of the splinters of metal left by the tin snips. Wash the metal pieces with water and washing-up liquid, rinse and dry them. Now carry out a very simple test – using a large bit in your soldering iron and some resin-cored solder, try to flow solder over the shiny side of the tin-plate. Choose an area at the side of the sheet so that the solder will not

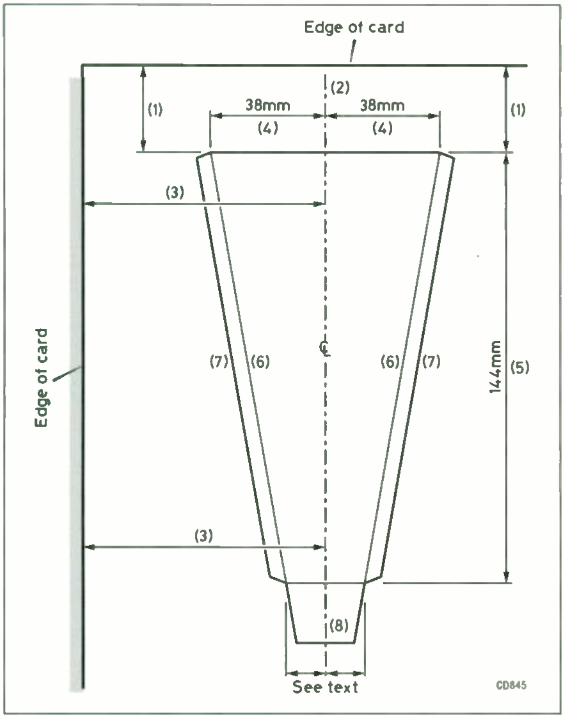


Fig 3.36. Making your own template

get in the way when the parts of the horn are cut out. The author discovered by bitter experience that some cans are not tin-plated and will not solder. This is the reason for the test. It is most frustrating to spend considerable time marking out, cutting and bending the parts for the horn, only to find that the material you have used will not solder. If the solder will not flow very easily, cut your losses and try another can.

Fig 3.36 shows the method of marking out the outline of the panels of the horn. Instead of trying to mark out the shape directly onto the metal you will find it easier to draw the outline on a piece of fairly thick paper. Something almost as thick as an ordinary postcard would be ideal. Either use a square to mark the wide end (1) or place two marks equidistant from one edge of the card and join them up. From this the centre line (2) can be drawn by marking off equal distances at both the wide and narrow ends (3) of each piece. Next mark 38mm on either side of the centre line to define the wide end of the panel (4). The narrow end is 144mm from the wide end and this distance is marked off along the centre line (5). The procedure just described is the same for all four panels but for the next step it is necessary to determine the width of the narrow end. This is the outside measurements of the piece of waveguide (WG16) to be used to connect the horn to the flange which will be described later. These dimensions are normally 25 × 12mm but it would be well to measure your piece.

Now draw lines by joining the ends of the long and short lines to complete the flare of the horn (6). These lines should continue beyond the short ends to allow for the tab which will be used to solder the horn to the waveguide. The next step is best carried out by the use of a steel rule and a sharp modelling knife or a scalpel. Cut out the two shapes you have drawn, being as accurate as possible. To avoid the problems of marking out the templates, two full-size diagrams are to be found in Figs 3.37 and 3.38. Place the two templates on one of the larger pieces of tin-plate so as to get them in the flattest regions of the sheets. Leave at least 10mm around the template and then, holding it completely still, mark around the outline using a sharp point such as that of a compass. Repeat using the other template, again using the best parts of the tin-plate. Finally mark out the flanges on the 'A' side (7) and the tabs (8) on both 'A' and 'B' sides.

If you are using 18 SWG material, cut out the four pieces using a hacksaw fitted with a fine blade – 22 teeth per inch is about right. It may be easier if the blade is turned through 90° in the frame so that the back of the saw doesn't get in the way as work progresses. If the material is tin-plate reclaimed from an oil can, use a pair of tin snips (the material is too thin for sawing to be successful) but beware that the cutting action tends to distort the metal. This can be minimised (although it takes longer) by making two cuts – one is made about 3–5mm away from the cutting line and a second one is made along the line to remove the thin strip. Remove the sharp edges and then remove any paint from the edges. It is not necessary to clean the paint from the whole surface, just the places where the metal will be soldered. Use wire wool or paint stripper or both – it is most important that the paint is completely removed because any remaining traces will prevent the solder flowing correctly during the following stages. Next the flanges on both of the 'A' pieces must be bent to 90°. Bending bars will be very helpful for this operation. See Appendix 1 for details of the method of construction of these. If you have a workbench of the Workmate™ type an alternative to bending bars is obtained by using two pieces of angle (iron or aluminium) held in the jaws of the bench. Clamp the 'A' pieces in the bending bars or Workmate with the flange sticking out. See Fig 3.34. It is most important that the bending line is just and only just visible so that the bend is made very accurately with the correct dimension. Carefully bend the flange using a hammer – do not bend all the way at one point but make it progressive by tapping at intervals along the flange and repeat until the metal is flat against the bending bar. Be patient with this operation – a little at a time is best and will avoid too much distortion of the side. When one edge is completely bent

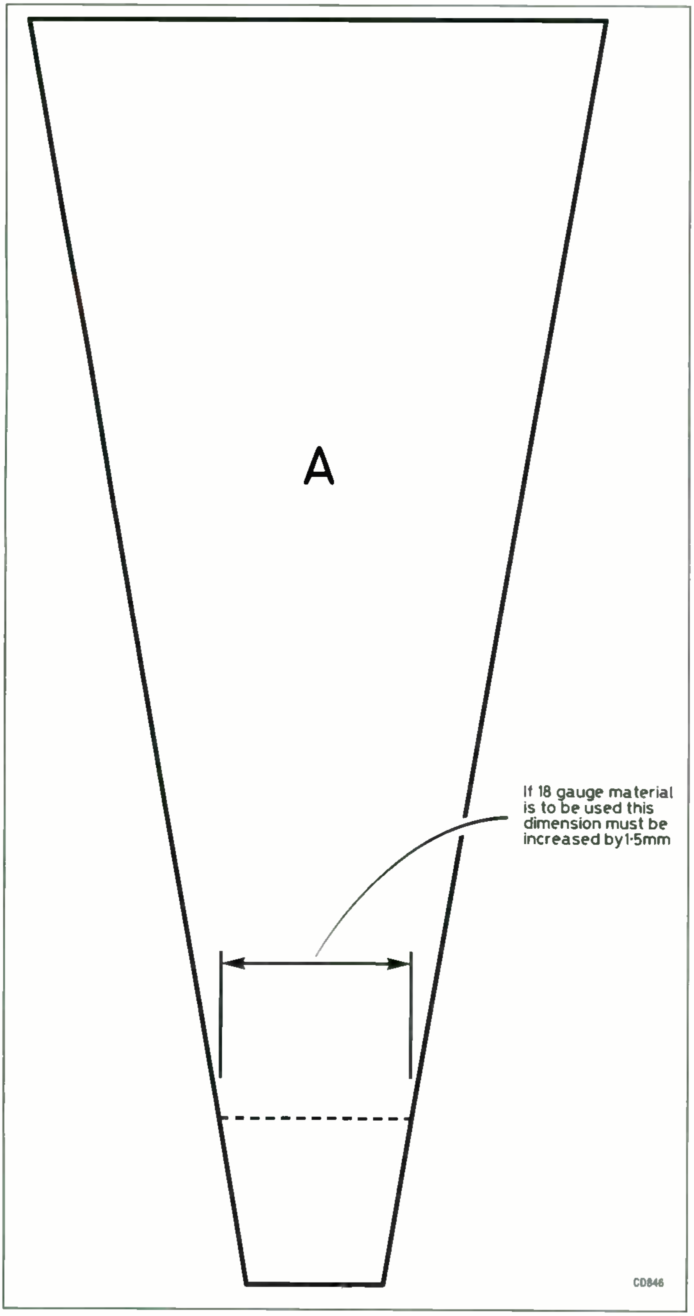


Fig 3.37. Template for side 'A'. Drawing is full-size – use the inside of all lines

remove from the bars and refit so that the opposite edge is sticking out. It may be necessary to use a piece of packing material to avoid crushing the flange just bent, as the bending bars or vice is tightened. Next bend the tabs at the narrow ends of the pieces through an angle of about 15°. The exact amount will be decided as the pieces are soldered together.

Now compare your pieces with those shown in the photograph in Fig 3.39 and again inspect the edges to make sure that all of the paint has been removed.

Soldering up

A soldering iron with a much larger bit than the one normally used will be required for this part of the operation. Soldering will be much easier if all the mating surfaces are tinned before attempting to join the pieces. A temperature-controlled iron and a bit of between 5 and 6mm would be ideal for this job. A smaller iron and bit may need some help in the form of a blow lamp to get the temperature high enough but great care is needed as too much 'help' from the blow lamp will cause all the solder to melt and then everything falls apart! Have some material such as wood or chip board on top of your work surface – this will not only protect the bench or table top but will allow pressure to be applied to the surfaces being soldered to ensure a close fit. Use something that will not solder such as a piece of stainless steel to press the edge of the 'B' piece against the flange of the 'A' piece when the heat is applied by means of the soldering iron (and blow lamp if necessary). Start by making a 'tack' at the wide ends in the correct position and then make a second tack as near as possible to the narrow end. Complete the joint from beginning to end. Make up the horn in two pieces by joining one of the 'A' sides to a 'B' to form two 'L'-shaped pieces which are then joined together to complete the horn. Do beware of too much heat – it can be most frustrating to have everything collapse just as the completion looks near.

Next, a short piece of waveguide is required. A second piece is required for the detector head so obtain a piece of WG16 about 80mm long. Choose brass or copper and avoid aluminium or steel – one won't solder at all and the other is very difficult. A matching pair of flanges is also needed – there are two basic types, square and round. Either will work equally well but the round flange is generally more expensive.

The photograph in Fig 3.40 shows both types and also one flange with a piece of waveguide fitted. If you are

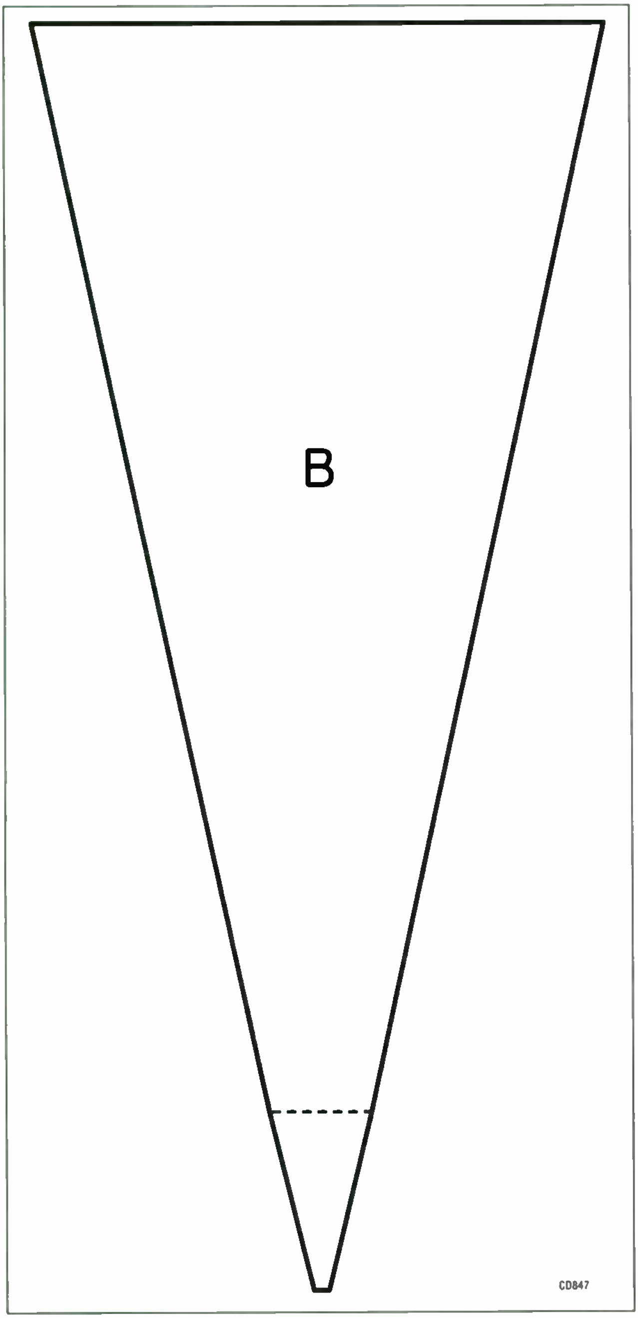


Fig 3.38. Template for side 'B'. Drawing is full-size – use the inside of all lines

lucky one end of the piece of waveguide will have been cut perfectly square but, if this is not so, proceed as follows. Remove any burrs from the edge of the guide so that it will pass through the slot in the flanges. Hold the waveguide in the jaws of a vice and adjust it so that about 3mm is sticking out from the end of the flange. It doesn't matter which half of the flange is used but it is important that the mating surface should be up against the jaws of the vice. The flange can now be used as a guide (no pun intended) for the hacksaw which is used carefully against the back of the flange. With care an accurate cut will result – the end of the flange will be scratched but as it is the back that has been used it will not matter. When the cut is complete, the same technique can be used to finish the end of the guide with a file, once more using the flange as a guide. This must be done before the guide is removed from the vice. Now adjust the guide in the vice so that 22mm are sticking out and repeat the above process. This time it is the piece which is cut off that is needed for the joint between the flange and the horn.

Clean the outside of the piece with wire wool and also do your best to clean the inside of the flange, then tin both the outside of the waveguide and the inside of the flange. A blow lamp will be necessary for this operation. Place the plain part of the flange, mating surface down, on to some non-solderable material – a piece of aluminium sheet or something similar – and enter the 'tidy' end of the piece of waveguide into the flange just a little way. It won't go in very far anyway. Now use the blow lamp to apply heat and with luck the waveguide will drop into the flange and end up flush with the mating surface. Apply a little solder to the waveguide and flange, using the soldering iron while everything is hot. *Leave everything to cool without any movement.*

When cool remove any excess solder and then fit the horn onto the piece of waveguide, adjusting the tabs as necessary. It is at this point that any errors in measurement, cutting and bending of the sides of the horn will become apparent. It is important that the 'transition' from horn to waveguide is as smooth as possible and to help with this, the outer edge of the inside of the waveguide should be filed as shown in Fig 3.41.

This is quite hard work but every bit of metal removed will improve the transition and reduce the amount of work to be done later. Use a medium flat file, about 20mm wide, preferably a new one but at least one which has not been used on steel.

The length of the piece of waveguide has been chosen so that the file will be at the correct angle when it is just touching the opposite edge of the guide in the flange. The horn can again be fitted to the waveguide when the edge has been reduced almost to a point on all

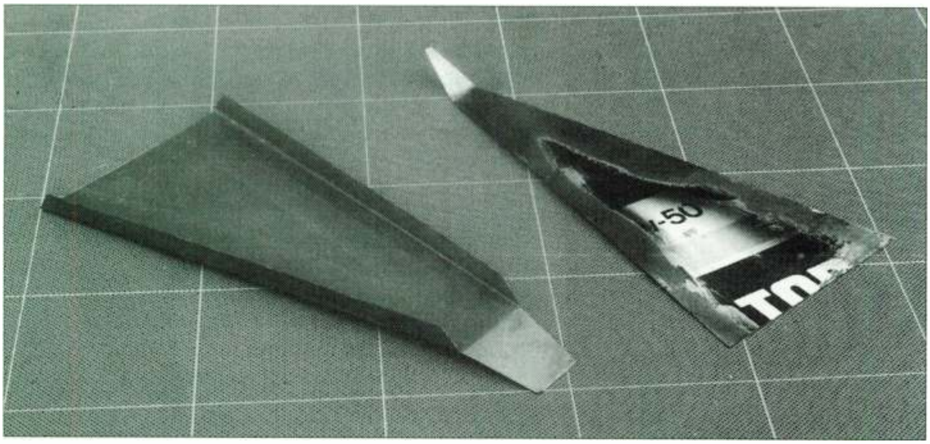


Fig 3.39. The 'A' and 'B' pieces

four faces. Stand the assembly on the face of the flange and by means of an engineer's square or a stiff piece of paper check that the horn is sitting centrally on the flange. The distance from the edge of the horn to the edge of the square (or paper) should be equal on opposite sides of the horn. See Fig 3.42 for guidance.

When satisfactory, the end of the horn can be soldered to the flange assembly. The blow lamp will again be necessary and a fair amount of solder will be used. Keep feeding solder into any gap between surfaces and make sure that the parts do not move in relation to one another. Allow to cool and carefully examine the joint, especially on the inside where horn and waveguide meet. Excess solder here doesn't matter as it can be filed away in the next step.

Hold the flange in the vice and repeat the filing operation to make a smooth transition. Remove as much excess solder as possible from the faces and corners of the horn and tidy up the outside. Finally give the outside of the horn a coat of paint (non-cellulose, to avoid problems with the old paint left from the original can). The photograph in Fig 3.43 shows the original finished horn – it used to be a biscuit tin! If yours looks anything like it, congratulations are due – not too many amateurs have made a 10GHz horn.

The detector head

The simplest possible design has been chosen for this as it is unlikely to be used for other purposes later whereas the horn can be used with a number of projects. Once again the work entailed is mainly metalwork and soldering. Fig 3.44 shows the layout and gives most of the critical dimensions. The diode, which is arranged across the narrow dimension of WG16 waveguide, acts as the actual antenna and it is the distance of the shorting end which determines the frequency. The remainder of the piece of waveguide should be about 55 to 60mm long which is just about right for the detector. Square off both ends using the method described earlier. Solder one end into the other part of the flange which will probably have two grooves in it – the outer groove is wide enough to accommodate an 'O' ring to waterproof the joint and the second grove is called a 'choke' which helps to prevent mis-match and RF leakage from the joint. The great advantage to constructors with limited machine tools is that the flatness of the end of the waveguide in the flange is not so critical.

The hole for the detector diode is

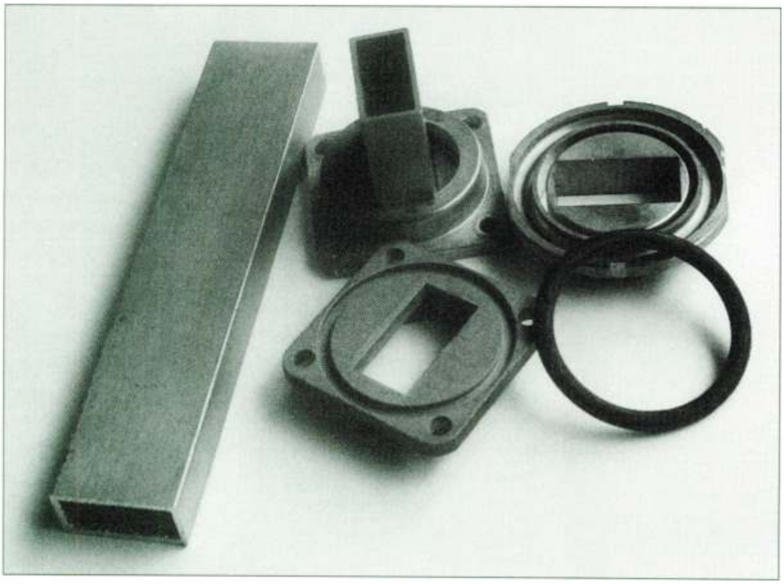


Fig 3.40. A selection of flanges

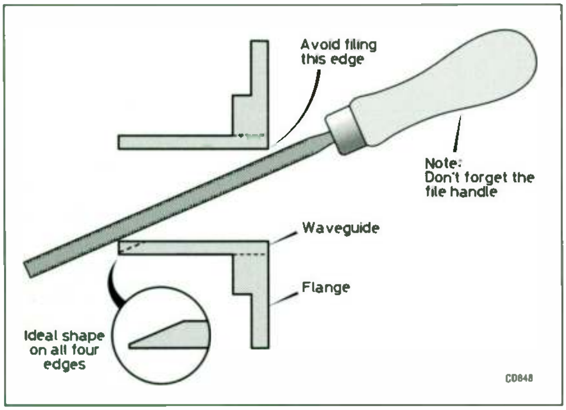


Fig 3.41. Filing the inside edge of the waveguide to produce a smooth transition between guide and horn

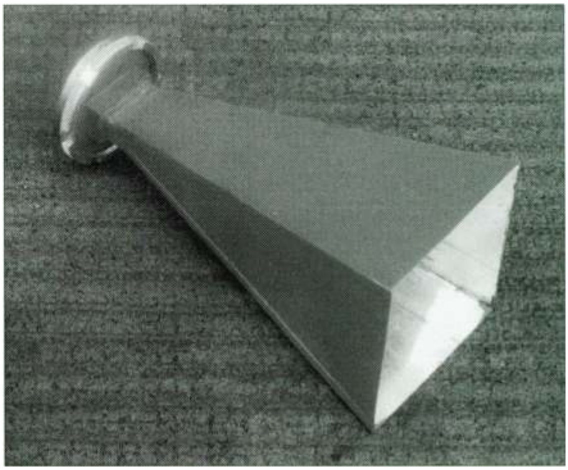


Fig 3.43. The completed horn

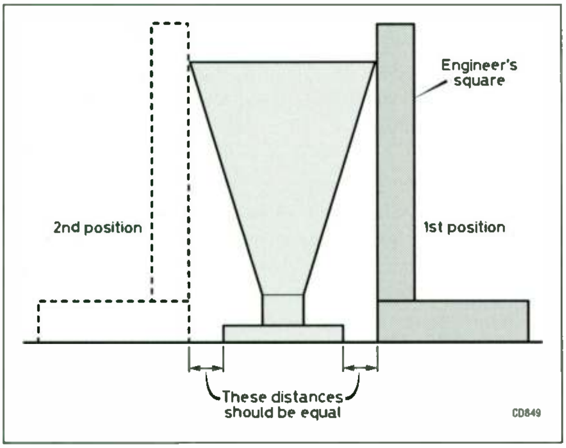


Fig 3.42. Checking the alignment of the horn before soldering to flange

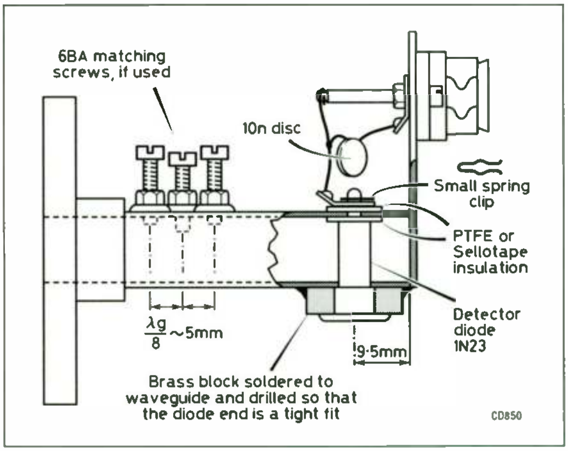


Fig 3.44. The detector head

the most critical dimension. It should be in the centre of the wide side of the guide and 9.5mm from the end. Mark the position of the hole very carefully and, when satisfied that it is correct, make a deeper indent either with a sharp centre-pop tool or the point of a pair of compasses. Do exactly the same on the other wide face of the guide. The next step really requires the use of a pillar drill or a power drill in a stand. Use a 3mm drill bit (a sharp one) and drill right through both faces of the guide. If no such tool is available and it is not possible to get help from an engineer proceed as follows. Using a hand drill with the 3mm bit, drill through one side only then turn the guide over and drill the other side. Use a square corner to try to keep the drill as vertical as possible.

Next a small piece of brass is soldered over one of the holes so that the hole is in the centre. To do this, place the piece of brass as near as possible in the correct position and draw around it with a pencil. When the brass is removed it should be possible to see what adjustment of position is required. When satisfied, scribe around the piece, again using the point, then tin the surface of both the brass piece and the area around the hole in the guide. Solder the brass to the guide using the scribed position lines to ensure that it is in the right position. When cool, again use the hand drill and 3mm bit to drill through the piece of brass by using the hole on the other side of the guide as a 'guide'. Do not use too much pressure – a sharp bit is essential. Turn the guide over once more and with a 6mm bit increase the size of the hole in the brass piece. Do not allow the drill to go through to the other side. The hole is now almost large enough to allow the diode to enter it. If you have a taper reamer (see Appendix 1) the hole can be gently increased in size until the diode is a

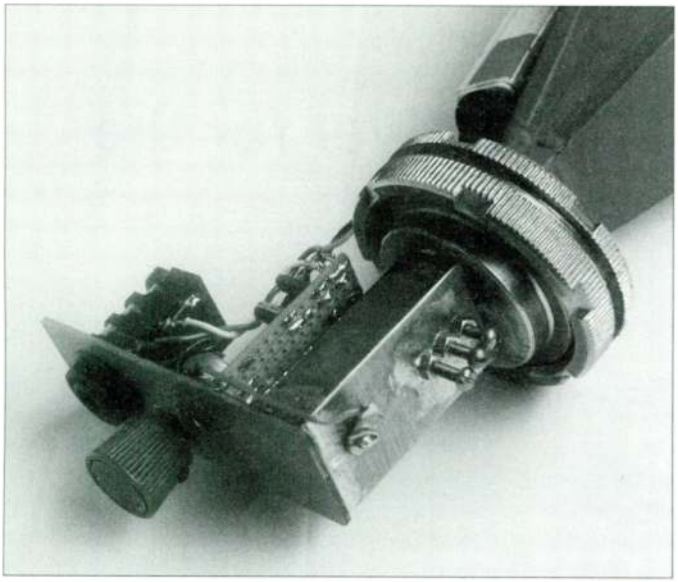


Fig 3.45. Close-up of detector head

tight fit. The other end of the diode should pass through the 3mm hole on the other side of the guide without touching.

Remove the diode and put it in a safe place. Clean any burrs or swarf from the inside of the guide. Stick a piece of Sellotape™ or similar on the inside of the guide so as to overlap the small hole and use your ingenuity to cut the tape away from the hole. This is to make an insulating washer on the inside of the guide. Another piece of brass of any thickness is cut to about the same width as the waveguide and holes drilled to accommodate the output socket to be used. Almost any type will do – television antenna type (Belling Lee), phono-plug socket or BNC. The plate is then soldered to close the end of the guide. Follow the diagram in Fig 3.44 during all of these operations.

If there is the possibility of the detector head being used as a mixer/detector at some later date the three matching screws should be fitted but if the detector is only to be used to 'listen' to radar transmissions they are unnecessary. If the screws are to be installed, carefully mark three points on the centre line of the wide face of the guide, separated by exactly 5mm. Make an indent with a centre-pop or point and then drill the three holes using a 3mm bit. Use a fine file to remove any burr from the inside of the guide. Clean the area around the three holes with wire wool and tin the surface. Obtain three 6BA brass screws (tin-plated will be just as good), thread a 6BA nut onto each screw (full nuts, if you can find them). Carefully file the six flat faces on each nut but try to avoid filing the underside of the nuts. Pass the three screws through the holes in the waveguide and solder the nuts to the guide, checking that the screws will still turn freely. The reason for not filing or cleaning the underside of the nut was to stop the solder running under it which would prevent the screw turning. With all of the soldering on the waveguide it is necessary to keep the temperature of the metalwork very near to the melting point of solder. If this is done a medium-size soldering iron will cause the solder to flow. Too much heat will cause all the joints to collapse!

Finally fit the diode. If a Schottky barrier diode is to be used great care must be taken to prevent damage by static. Have a metal sheet on the bench (baking foil will do), connect an earth wire if possible, stand the detector head on the foil and connect yourself to the sheet of metal if possible. If all this cannot be done (it is standard practice when handling static-sensitive devices), keep touching the metal sheet to make sure that your body is kept at the same voltage as the work. Pick up the diode but avoid touching the thin point. Push the diode into the hole in the guide and place an insulating washer over the pin (Sellotape™ or similar will do). Solder a high-value resistor (100Ω or higher) to a small solder tag and also to the earth point on the output socket. Place the solder tag over the pin of the diode and hold in position with a small wire clip. The diode is now relatively safe from damage. Connect a 10nF disc capacitor across the terminals of the output socket.

Fit an 'O' ring into the groove in the flange and fit the detector and horn together. The method will depend on the type of flanges used. Connect the output socket to the input of a moderately-high-gain amplifier (battery operated) – the one described earlier in this chapter will do nicely, fit a headphone rather than a loudspeaker and point the horn out to sea or, if you are lucky, at a port. Don't expect speech or music but you can have fun checking the very considerable direction-finding properties of the horn antenna!

Chapter 4

A direct-conversion receiver for the 20m and 80m bands

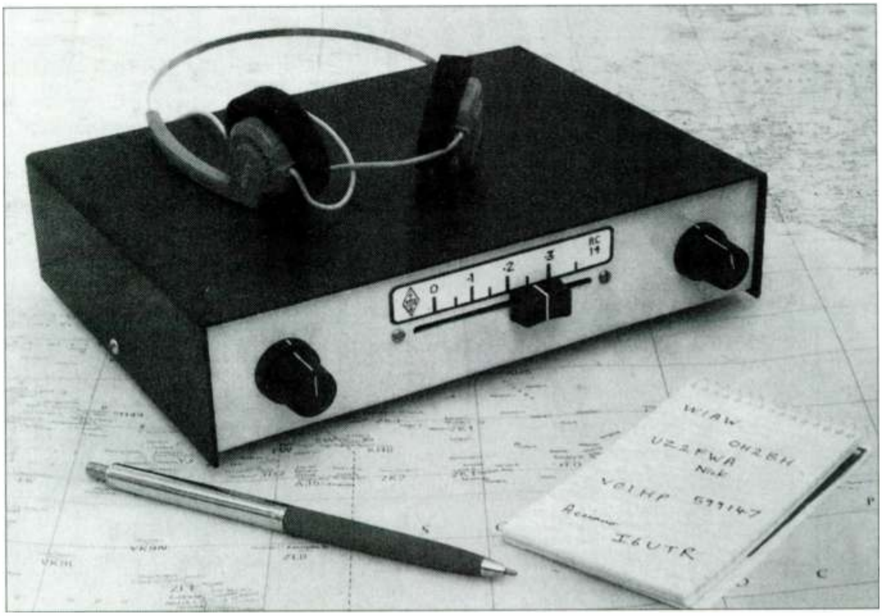


Fig 4.1. The RC14 receiver

As with a number of the designs in this book, this project has been published before, in this case as a series in *Radio Communication*. The author of the series was Steve Price, GW4BWE, who was also the designer of the 80m transmitter which appeared in the companion volume to this book (*Practical Transmitters for Novices*) published earlier.

There are some options in the project. A receiver for the 20m band which is suitable for the reception of SSB signals is the basic design but an additional filter can be added to give much greater selectivity for the reception of CW. The second option is a converter to allow the reception of SSB and CW signals in the 80m band.

The RC14 is a simple direct-conversion HF receiver for home construction. It will provide an exciting challenge to newcomers and is an excellent choice for a first home-constructed project. In order to help those who have little or no experience in the building of electronic equipment, the RSGB has arranged for a complete kit of parts to be made available (see below). The ever-popular 14MHz HF band covers the range 14,000–14,350kHz, and within this 350kHz allocation amateurs can enjoy worldwide communications using a variety of transmission modes, including morse (CW) and speech (SSB) which are the most used. The 14MHz band is a very crowded segment of the HF spectrum, and you could be forgiven for thinking that only a top-flight commercial receiver can provide the necessary performance. Fortunately for the budding home-constructor, this isn't really the case. Nevertheless, it would be foolish to assume that an extremely simple receiver which uses just a few junk-box components is going to prove adequate. In practice, such a design is unlikely to be capable of providing the necessary sensitivity, selectivity and stability. The RC14 therefore employs many 'state-of-the-art' techniques in order to achieve high sensitivity, adequate dynamic range and commendable frequency stability. The VFO (variable frequency) oscillator) is varicap controlled, which allows tuning to be carried out by the use of ordinary carbon-track potentiometers, thus avoiding the need for an expensive variable capacitor and reduction drive. The RC14 also boasts excellent selectivity due to the incorporation of a steep-slope active filter which has its pass-band optimised for clear reception of SSB. In order to avoid the complex switching arrangements found

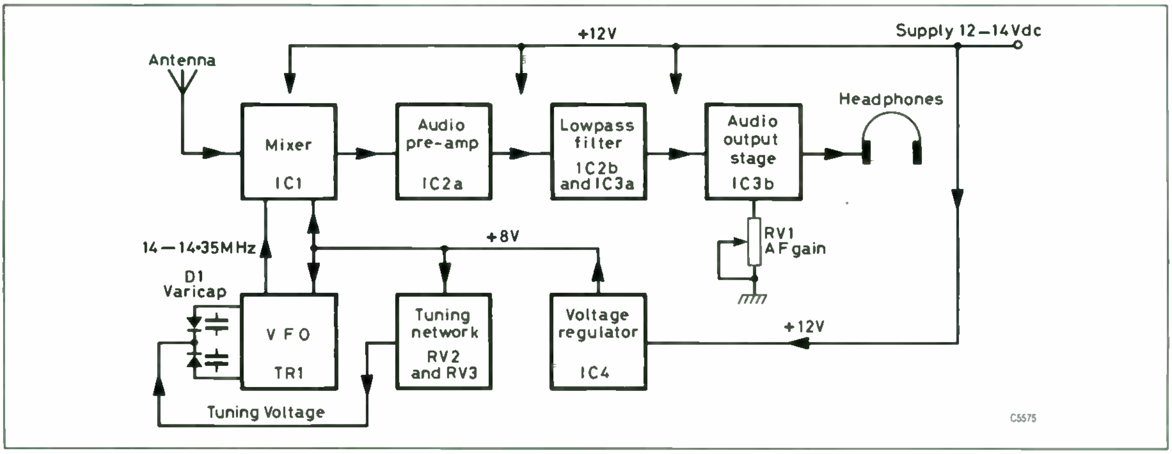


Fig 4.2. Block diagram of the RC14

in general coverage and multi-band receivers, the RC14 is restricted to 14MHz. Potential constructors should not be discouraged by this fact, however, as the very high level of international activity on this band almost guarantees that there will be a number of interesting contacts audible whenever it is open.

How it works

Figs 4.2 and 4.3 show block and circuit diagrams of the RC14. It will be seen that integrated circuits are used extensively, resulting in a straightforward design which offers consistent and predictable performance.

Signals picked up by the antenna are routed via the tuned circuit, L1, C3, and its associated coupling winding, L2, to the input of a high-level mixer IC1. The RC14 employs the direct-conversion principle, so the VFO operates at signal frequency; the VFO output is also fed to the mixer, thus providing IC1 with two inputs. Not surprisingly, IC1 has the task of mixing the signal with the VFO frequency to produce an output, or product, at audio frequency. This product, which appears at pin 14 of IC1, is then amplified by IC2a, filtered by IC2b and IC3a and then further amplified in IC3b before being fed to a pair of headphones.

In order to clarify the direct-conversion process, imagine that we wish to listen to a CW transmission on 14,050kHz. The VFO is tuned to 14,051kHz; that is, a frequency just 1kHz higher than the signal. The mixer will subtract these two frequencies and thereby generate an output at precisely 1kHz (14,051 – 14,050 = 1kHz). We now have a CW signal that has been converted to a much lower frequency and, following amplification, is audible to the human ear. Unfortunately, a CW signal at 14,052kHz also gives rise to a 1kHz product (14,052 – 14,051 = 1kHz) and so it is clear that a direct-conversion receiver will render audible signals appearing either side of the VFO frequency. The unwanted signal which is received is called the 'audio image' and means that the effective bandwidth of a DC receiver will be twice that of a properly designed superhet. However, a high-performance superhet is inevitably far more complex and normally requires an expensive crystal or ceramic IF filter, so the compromise involved is quite acceptable.

The DC receiver copes with SSB in a similar fashion, and will also render audible many other modes; eg RTTY (short for 'Radio TeleTYpe' where the signals are 'printed' by means of a computer), packet data (a system whereby signals are sent from station to station in an automatic mode) and SSTV (slow-scan television – similar to fax). The filters built around IC2b and IC3a are of the low-pass type and have the job of attenuating all frequencies above 2.8kHz; SSB speech is therefore unaffected, but high-frequency heterodynes (whistles) and 'splatter' from adjacent transmissions will either be significantly reduced or removed altogether.

The voltage regulator IC4 generates a stable 8V supply rail which has three uses. First, the mixer, IC1, requires a secondary supply, Vcc, which is fed to pin 4. Second, the VFO is powered from this regulated supply via R22. The remaining function of IC4 is to provide a stable voltage for the tuning network. D1, a variable capacitance diode or 'varicap' for short, is used to provide tuning of the VFO, and substitutes for the variable capacitor found in many other receivers. The voltage presented to D1 via R19 determines its precise capacitance, so altering this voltage achieves tuning over the desired range of 14,000–14,350kHz. A slider potentiometer, RV2, provides coarse tuning by enabling us to set a voltage of between approximately 3.5V, assuming R25 is adjusted midway (see later) and 8V.

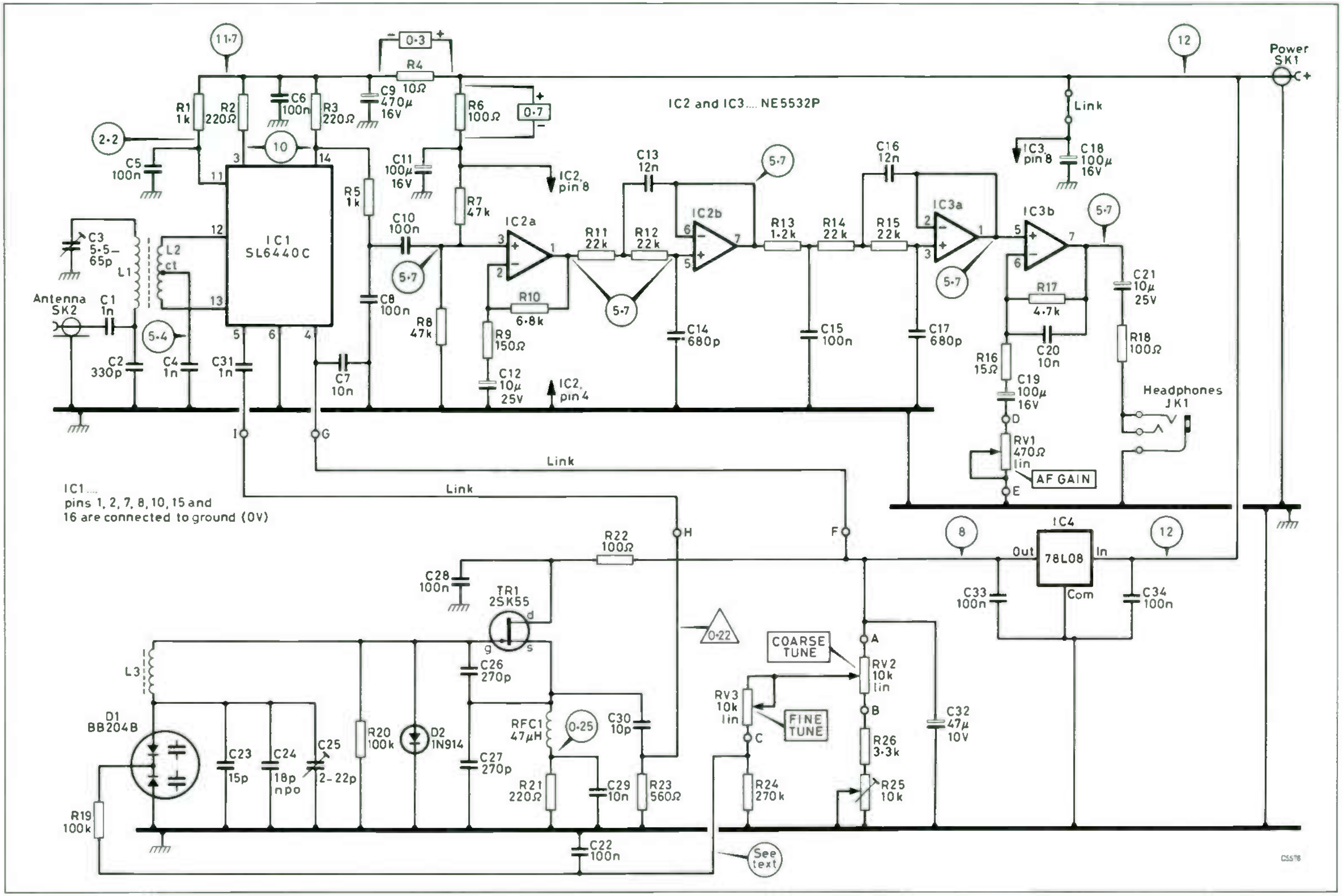


Fig 4.3. The complete circuit. Voltage measurements shown encircled are made with the negative test probe connected to ground (0V). The boxed measurements are obtained by using both test probes, as indicated. The triangle indicates a peak voltage reading using a diode probe

The tuning voltage thus developed can be very slightly modified using RV3 (FINE TUNE), giving a ±10kHz variation in VFO frequency. Incorporating a fine-tune control does away with the need for a reduction drive and/or expensive multi-turn potentiometer.

The RC14 kit

The RC14 kit comprises every conceivable item – right down to the last, nut and bolt, including a high-quality printed circuit board and pre-drilled aluminium case. All the constructor will need to possess are some basic tools (including a soldering iron) and a multimeter. At the time of going to press the price of the kit (including VAT and carriage within the UK) is £36. It can be ordered from: Cirkit, Park Lane, Broxbourne, Herts EN10 7NQ. Tel: 01992 444111.

For those constructors who do not wish to build from a kit the following should help.

Only the following tools are needed during construction:

1. A soldering iron of between 15W and 25W rating, unless thermostatically controlled, having a bit diameter no greater than 1.5mm.
2. A small pair of wire cutters.
3. A screwdriver, 100 by 4mm blade size suitable.
4. A brass, or plastic, trimming tool to adjust the preset components C3, C25 and R25.
5. A miniature flat file useful for removing enamel from the inductor tails prior to soldering.
6. A small pair of pliers.
7. A multimeter of at least 10kΩ per volt sensitivity.

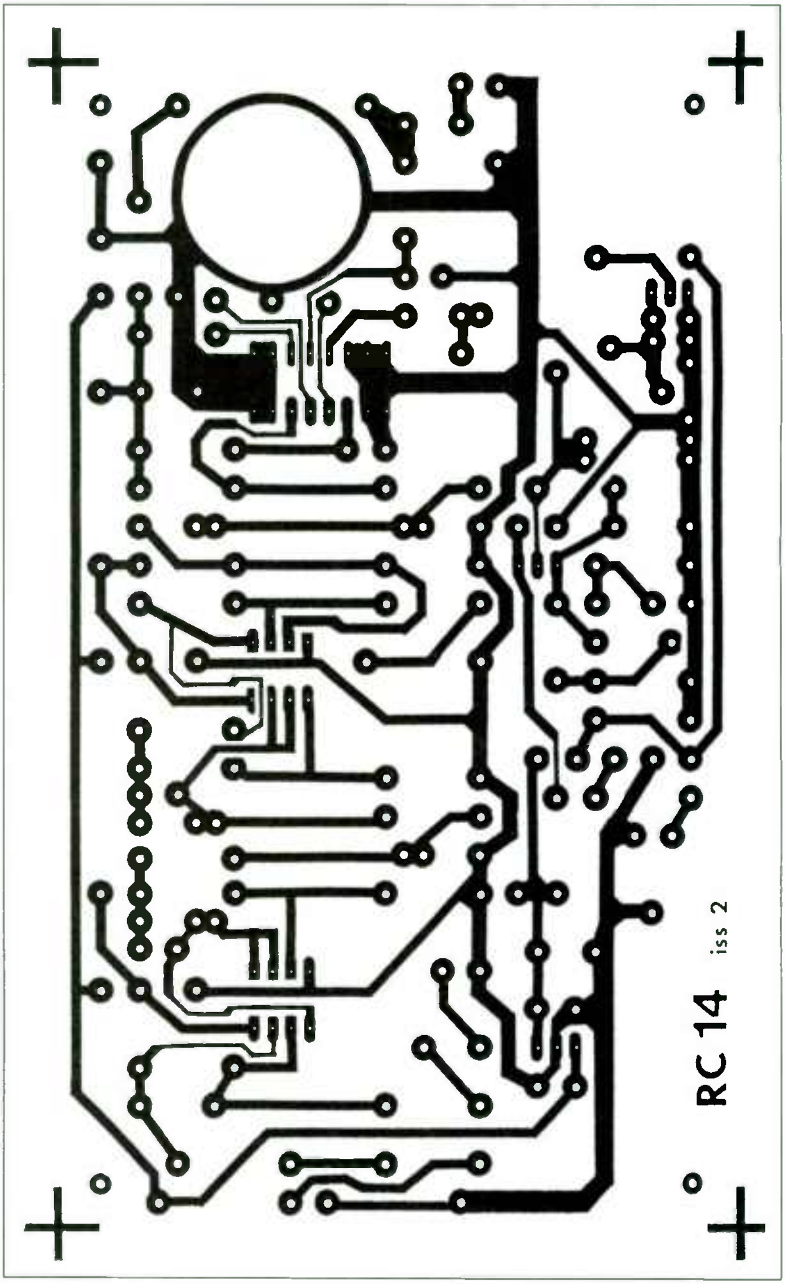


Fig 4.4. The foil pattern for the RC14 PCB

With the needs of the beginner firmly in mind, a detailed 'step-by-step' construction guide is given which will hopefully avoid any major problems. The foil pattern of the PCB is shown in Fig 4.4 and information on the identification of components and their correct mounting in Fig 4.5. A full list of components is given in Table 4.1.

Checking the components

Before starting to build the RC14 it is a good idea to sort the components and arrange them on your work surface in a logical manner.

Identifying the potentiometers, sockets, toroids and fixing hardware should be a simple matter – see Fig 4.5

for guidance. Now remove all the fixed resistors and check their colour codes using Fig 4.5. Isolate the preset components C3, C25 and R25 – Fig 4.5 gives a good indication of their physical appearance.

The semiconductors and ICs, D1, D2, TR1, IC1–4, are quite distinctive in appearance but you may find that they carry some additional markings, eg IC2 and IC3 may have a manufacturer's legend and batch number printed on them apart from 'NE5532' The electrolytic capacitors C9, 11, 12, 18, 19, 21 and 32 are easily identified by the crimp at one end of their tubular casing – the crimp also indicates the positive lead, see Fig 4.5. They will have their values (in microfarads) and working voltages clearly marked.

Finally, you should carefully identify the remaining capacitors. Each capacitor will have its value marked, but there may be other numbers (eg working voltages) which can be ignored. Don't worry if you cannot initially tell the difference between a 100nF ceramic and a 100nF polyester type; the RC14 uses six 100nF ceramics, but only three 100nF polyester types – this will make identification easy. Note that the 100nF value may be shown as '.1', ie to indicate 0.1µF, which is the same as 100nF. The polystyrene capacitors C2, 14, 17, 23, 26, 27 and 30 are of tubular construction.

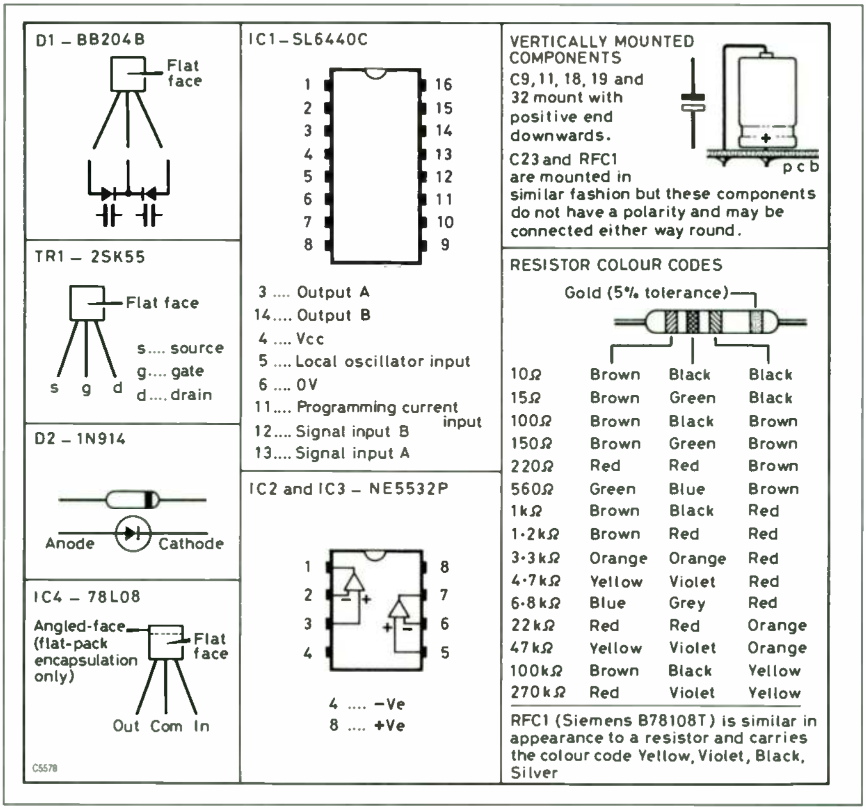


Fig 4.5. Component identification

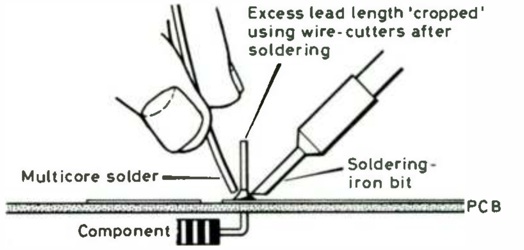
Step-by-step construction

Refer to Figs 4.6 and 4.7 for the correct position and orientation of components.

1. The first task is to wind the VFO inductor L3 using 0.7mm (approximately 22 SWG) enamelled copper wire. Cut a 550mm length of wire and stretch it slightly to remove any kinks. Now tightly wind 22 turns onto a T68-6 powdered-iron toroid so that the windings occupy about 80% of the core's diameter. The tails should be cut to 10mm approximately and gently filed to remove the enamel to make soldering

SOLDERING TIPS

Both the component lead and the PCB pad must be heated until the temperature is sufficiently high to melt the solder easily. This will only take two to three seconds if you are using a 15 to 25W iron. Now introduce the solder and allow a small amount to melt around the component lead. After removing the solder, immediately withdraw the iron, thus allowing the joint to cool. Avoid blowing on the joint in an attempt to accelerate this process.



For best results the PCB surface and component leads should be clean and free from grease. Also check the soldering iron bit at regular intervals and be prepared to file it back into shape after prolonged use. The bit will eventually need changing and spares are readily available for popular irons.

Table 4.1. Components list for the RC14 receiver

RESISTORS	
R1, 5	1k
R2, 3, 21	220R
R4	10R
R6, 18, 22	100R
R7, 8	47k
R9	150R
R10	6.8k
R11, 12, 14, 15	22k
R13	1.2k
R16	15R
R17	4.7k
R19, 20	100k
R23	560R
R24	270k
R26	3.3k
All fixed resistors are 0.25W, 5% tolerance carbon-film types.	
R25	10k preset potentiometer type PR10 (horizontal mounting)
RV1	470R rotary
RV2	10k slider
RV3	10k rotary
All potentiometers are linear.	
CAPACITORS	
C1, 4	1n ceramic
C2	330p polystyrene
C5, 6, 22, 28, 33, 34	100n ceramic
C7, 29	10n ceramic
C8, 10, 15	100n polyester
C9	470p electrolytic 16V
C11, 18, 19	100µ electrolytic 16V
C12, 21	10µ electrolytic 25V
C13, 16	12n polyester
C14, 17	680p polystyrene
C20	10n polyester
C23	15p polystyrene
C24	18p NP0 ceramic
C26, 27	270p polystyrene
C30	10p polystyrene
C31	1n polyester
C32	47µ electrolytic, 10V
C3	5.5–65p plastic film, PCB mounting trimmer
C25	2–22p plastic film, PCB mounting trimmer
SEMICONDUCTORS	
D1	BB204B varicap diode
D2	1N914 or 1N4148 silicon diode
TR1	2SK55 JFET
IC1	SL6440C high-level bipolar mixer
IC2, 3	NE5532P dual-operational amplifiers
IC4	78L08 100mA 8V regulator
MISCELLANEOUS	
RFC	47µH (Siemens B78108)
SKT1	2.5mm DC power socket and 2.5mm coaxial plug to match
SKT2	Single-hole mounting phono socket
JK1	6.3mm (¼in) stereo jack socket
Pre-drilled printed circuit board carrying the legend, 'RSGB RC14', and pre-drilled aluminium case and lid.	
Control knobs for RV1–3.	
Two toroidal cores, powdered-iron type T68-6. These are doughnut shaped.	
Lengths of Multicore solder, 22 SWG enamelled copper wire and PVC covered, standard cable (for flying leads).	
IC sockets. Two 8-pin and one 16-pin dual-in-line.	
Bolts for fixing SKT1 and RV2, plus spacers for RV2. Four nuts, bolts and spacing pillars to mount the circuit board.	
Two self-tapping bolts to fix case lid to base, plus four stick-on rubber feet for base.	

them easier. It's also a good idea to coat the finished inductor with clear nail varnish which will seal the windings firmly in place.

2. L1 and L2 are both wound onto a single T68-6 toroid, also using 0.7mm enamelled copper wire. First, cut a 480mm length of wire and tightly wind L1 with 20 turns occupying about 75% of the core's diameter. For L2 cut 250mm of wire and proceed to wind four turns over the top of L1, starting at a point six turns from one end of L1.

   Using pliers, now make a single twist in the wire; the twist will be used to provide a centre tap. Continue winding: another four turns. The tails of L1 and L2 should be cut to 20mm and the last 10mm gently scraped. It is much easier to strip enamel by heating it in a flame and then pulling it through a small bunch of fine wire wool. Alternatively, 'solder through' enamelled wire, which uses a solder flux as an insulator, may be used but beware of the fumes as it is soldered. Also, very carefully remove the enamel from the twist in L2. It is not necessary to varnish this inductor.

3. Put the inductors aside – they will be soldered onto the PCB at a later stage. Using the layout diagram in Fig 4.6 as a guide, mount the three IC sockets (one 16-pin, two 8-pin DIL) and solder them in place. Be careful not to bridge adjacent pins with solder, and notice that there are a few very thin tracks which actually run in between some of the pads that must be soldered. Note: do not insert the ICs at this stage.

4. Mount and solder into place R6–18 and C11–21. The resistors are all mounted *horizontally*, so their leads must be carefully bent at right-angles – check the relevant PCB hole spacing against the resistor bodies in order to gauge where the bends should be made. Resistor colour codes and other information appears at Fig 4.5.

   After soldering each resistor, cut off the excess lead lengths, using wire cutters. C12, C14, C17 and C21 are also mounted horizontally, and it is important

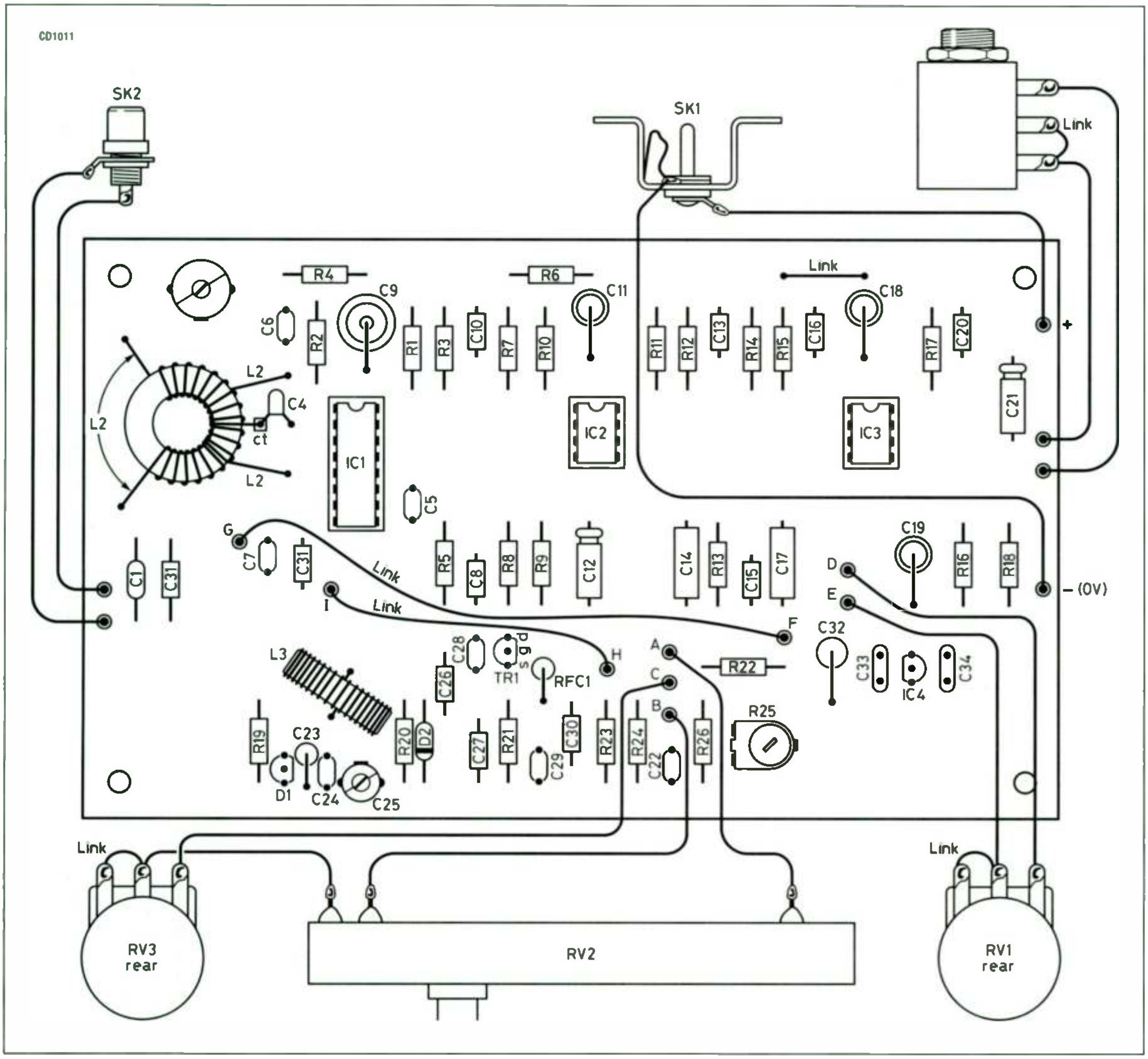


Fig 4.6. The components should be mounted exactly as shown above. See also Fig 4.7

to observe the polarity of C12 and C21 – look for the crimp in the capacitors' casing which appears at the positive end. The polyester capacitors (C13, C15, C16, C20) should simply drop into place – do not try to bend their leads as these can easily be broken off. C11, C18 and C19 are mounted vertically, as shown in Fig 4.5.

5. Insert the 12.5mm wire link at the top of the board next to C18. This can be made using one of the resistor lead off-cuts. Solder lengths of PVC-covered stranded wire to the positive and negative supply points at the right-hand side of the board – use red for positive and black for negative. Finally, solder flying leads, approximately 120mm long, to points D and E. The leads from D and E will eventually be used to connect to RV1 (AF gain) but at this stage the ends should simply be stripped and then temporarily shorted together.
6. Place the PCB on an insulated surface and connect a 12V DC PSU (or battery) to the supply leads, being careful to observe the correct polarity. Switch the PSU on and, using a multimeter of at least 10kΩ/V sensitivity, measure the voltage appearing at the link using the multimeter's positive test probe. Note: the negative probe should be connected to the negative terminal of the PSU. The reading obtained should be

equal to the PSU output voltage. If a reading cannot be obtained, immediately switch the PSU off and look carefully for any open-circuits or short-circuits.

Now measure the voltage at the junction of R7 and R8; the easiest way to do this is to touch the positive test probe onto the pin 3 contact of the middle IC socket (ie the eight-pin DIL socket which will eventually hold IC2). Assuming a supply of 12V, you should obtain a reading of between 4.5 and 6.5V at this point or 5 to 7.5V for a 13.8V supply. If the reading does not lie within the range, check the resistor colour codes. If there is no reading, or the voltage appears to be that of the power supply, investigate the possibility of short-circuits or open-circuits.

7. Switch the PSU off and insert IC2 and IC3 – Fig 4.6 indicates the correct mounting direction. You may need to bend the IC pins inwards slightly before pushing them into the sockets. Now switch the PSU on again and once more measure the voltage at the junction of R7/R8, ie pin 3 of IC2. The reading should be the same as before. Also measure the voltage on pins 1 and 7 of both IC2 and IC3; all four readings should be equal and approximate to half the supply voltage.
8. Disconnect the PSU and mount the following components: C1–10 (excluding C4), R1–5. The negative lead of C9 may need to be extended slightly by soldering a short length of tinned copper wire to it. Reconnect the PSU and check that a reading equal to the supply voltage can be obtained on both sides of R4.
9. Mount the inductor carrying windings L1 and L2 so that the tails of L1 (the 20-turn winding) are soldered at the extreme left-hand side of the board. Solder C4 into place so that one lead is connected to the centre tap of L2, as shown in Fig 4.6. Now mount IC4 (be careful to get this device the right way round) and C32–34 (note that C32 is mounted vertically). Finally, make the link between points F and G using PVC-covered wire.
10. Insert IC1 and reconnect the PSU. Check that the voltage on pin 4 of IC1 is 8V. Pins 3 and 14 should be at a potential of approximately 10V, and pin 11 at around 2V. As a final check that the mixer is functioning correctly, measure the voltage appearing across R4 – you will need to use both test probes for this measurement. A reading of only 0.3V (300mV) is to be expected, and this indicates that IC1 is drawing approximately 30mA from the 12V supply.

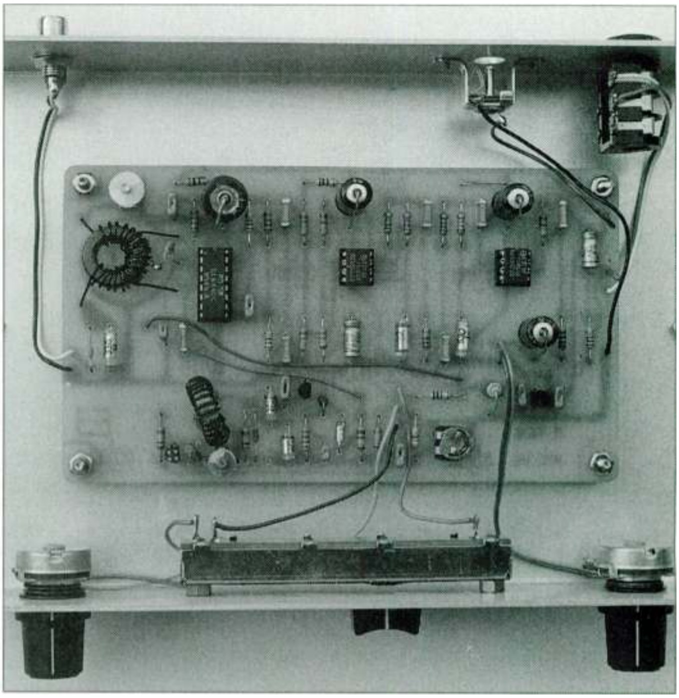


Fig 4.7. The interior of the completed receiver

11. Insert R19–26, C22–31, D1, D2, TR1 (see Fig 4.8 for the correct insertion of TR1 – the leads need to be crossed over due to an error in the original PCB layout), the RFC and L3. Fig 4.5 clarifies the semiconductor connections. C23, the RFC and L3 are mounted vertically. Make the link between points H and I using PVC-covered wire, and then solder the three flying leads to points A, B and C. Finally, connect the potentiometers RV2 and RV3 as shown in Fig 4.6.
12. Re-apply power and, with R25 set mid-way, measure the voltage appearing at point C. Manipulation of RV2 (COARSE TUNE) should cause this voltage to vary between 8V at one extreme, and approximately

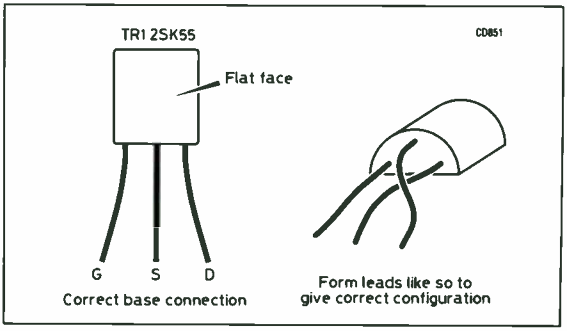


Fig 4.8. Forming the leads of TR1

3.5V at the other. Adjustment of RV3 (FINE TUNE) will make only a very slight difference to these readings. There should be 8V, or very nearly, at the junction of R22/TR1 drain, and approximately 0.25V (250mV) at the RFC.

The VFO should now be oscillating, so if you possess a diode probe it will be possible to measure the RF voltage actually being generated: a reading of around 220mV peak can be expected at pin 5 of IC1; this also confirms that VFO drive is arriving at the mixer.

13. Solder the remaining flying leads. Connect RV1 and the headphone socket as shown in Fig 4.2. Note that a stereo (two-circuit) jack socket is utilised with a 'short' between the 'left' and 'right' contacts – this enables ordinary stereo headphones to be used without having to rewire, or change, the headphone plug.
14. Before commencing final assembly it is a good idea to check that the receiver is functioning correctly. Plug in the headphones and set RV1 fully clockwise. With power applied there should be a distinct hissing sound in the phones which will drop noticeably in level as RV1 is rotated anti-clockwise. If all you can hear is a loud buzz, or hum, it is likely that the PSU regulation and/or smoothing is inadequate (see 'Using the RC14' later in this chapter).

    Now connect a temporary antenna. An 8.5m length of wire slung from an upstairs window will suffice. Set both C3 and C25 to half-capacitance; ie vanes 50% meshed. It should now be possible to hear a jumble of signals and heterodynes as RV2 is manipulated. RV3 can also be expected to have some effect. Remember, however, that the VFO has not yet been calibrated, so you are more likely to be listening on a broadcast band rather than 14MHz! If nothing significant can be heard it may simply be due to poor propagation conditions – check with another receiver or simply wait a few hours and try again.
15. Final assembly merely involves fixing the PCB, potentiometers and sockets into the case. The PCB is mounted on the four spacing pillars using nuts and bolts. There are corresponding holes drilled into the base of the RC14 case. It is essential to use the pillars, otherwise the underside of the circuit board will be short-circuited to the case.

    The sockets and potentiometers are mounted in the positions inferred by Fig 4.6. The obvious physical differences between each socket will make identification and positioning quite straightforward. If in doubt, have a look at the photograph of the RC14 on page 49. It may be necessary at this stage to shorten some of the flying leads, thus giving a tidier appearance.

    The slider potentiometer (RV2) is mounted using two small bolts which tap into its metal casing. Spacers are employed here in order to prevent the control lever protruding too far out of the slot in the front panel. The spindles of RV1 and RV3 will probably require shortening – they may be cut using a hacksaw blade or a junior hacksaw.

Final adjustments

The only remaining task is to calibrate the VFO and peak the mixer tuned circuit (L1, C3). These adjustments may be carried out with a digital frequency meter (DFM) and RF signal generator but if such luxuries are unavailable it is a simple matter to use a second receiver – providing it has either an accurately calibrated dial or digital readout – in conjunction with your ears! Proceed as follows.

Power-up the RC14 and allow five to 10 minutes for the VFO frequency to settle. Connect a short length of wire to the test receiver antenna socket and place it near to the RC14. Tune the test receiver to 14,350kHz and set the mode switch to SSB (preferably USB). Set RV3 midway and RV2 to the extreme right-hand end of its travel. Check with a multimeter that the top end of R24 (point C) is at a potential of almost exactly 8V – this measurement merely confirms that the track of RV2 has been wired the right way round. The setting of R25 is unimportant at this stage.

Now slowly adjust C25 using a brass trimming tool until a 'plop' is heard from the test receiver's loudspeaker. Further, careful adjustment around this point should give rise to a fairly strong heterodyne. More precise adjustment is unnecessary, and in any case it will prove almost impossible to obtain 'zero beat' using this method.

Retune the test receiver to 14,000kHz. Move RV2's slider to the extreme left-hand end of its travel and carefully adjust R25 until another heterodyne is obtained. RV3 should remain set at midway during this operation. The RC14 VFO is now calibrated for a tuning range of 14,000 to 14,350kHz with the facility to tune ±10kHz about any point within this range using RV3. Incidentally, the degree of fine tuning obtainable is directly proportional to the value of R24 – for example, if you feel that ±5kHz is more optimum, simply increase R24 to 560kΩ.

Should it prove impossible to obtain oscillation at 14,350kHz by adjustment of C25, take the following action. Set C25 with its vanes fully unmeshed. Carefully tune the test receiver until a heterodyne is heard. Confirmation that the heterodyne is in fact due to radiation from the RC14 VFO may be obtained by rotating RV3 which will cause the pitch of the heterodyne to vary quite distinctly. Note the frequency indicated by the test receiver dial or readout: if this frequency is lower than 14,350kHz by a significant margin (ie 30kHz) it will be necessary to desolder L3 and remove one or two turns. Now replace L3 and re-attempt calibration.

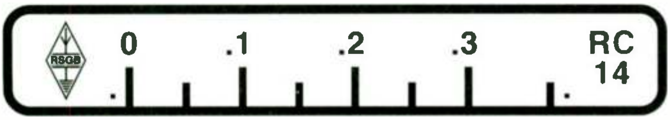


Fig 4.9. A suitable dial (actual size)

On the other hand, if the frequency is higher than 15.000kHz, L3 requires more turns. The soldering of additional turns onto L3 is not recommended, however, so it will be necessary to consider rewinding. In order to avoid this possibility, constructors may wish to wind L3 with 24 turns at the outset and then be prepared to reduce this number during calibration.

As a finishing touch, why not add a simple tuning scale similar to that shown in Fig 4.9? Make a copy on a piece of thin card and fix it above the coarse tune slot or use a piece of plain card and put on your own calibration marks. Remember to leave the FINE TUNE control set mid-way while doing this.

Using the RC14

In order to extract the highest performance from a communications receiver, and the RC14 is no exception here, we must provide an effective antenna. 'Effective' should not be taken to imply 'elaborate', as a single wire of between 6 and 10m in overall length can work wonders if correctly sited. Aim to get both ends of the wire as high as possible and try to avoid running it too near large obstacles such as trees and buildings. For safety reasons the antenna should not be allowed to pass anywhere near overhead power cables. Also, direct-conversion receivers are somewhat prone to hum pick-up, so keeping the wire clear of any mains wiring or electrical equipment – particularly items that contain large transformers and/or motors – is sensible. If the RC14 is operated in an upstairs room and placed near a window frame or ventilator grille through which the antenna wire can be threaded, it will normally be easy to meet the above requirements. The far end of the wire may be anchored to a tree or post, but for best results the anchorage should be insulated. A simple way of achieving this is to tie a suitable length of nylon fishing line (5–10kg breaking strain) onto the end of the wire and attach this to the support. The wire itself may be stranded, tinned copper with PVC covering.

An earth connection is desirable, and this can be made to the outer of the antenna phono socket – attach the earth wire to a convenient water pipe, having first removed any insulating layer of paint. If a mains PSU is in use this may already have an earth connection via the wall socket. Adding an additional earth is not dangerous but it may form a hum loop and cause buzzing in the headphones. If this should prove the case do not, under any circumstances, remove the PSU earth connection from the mains plug – simply dispense with the additional earth and rely on the mains earthing only. With the finished antenna connected, C3 should be trimmed for maximum signal level at the centre of the band. Details of alternative antennas such as the ever-popular half-wave dipole can be found in the *Radio Communication Handbook* and *Practical Antennas for Novices* by John Heys, G3BDQ, both published by the RSGB.

The RC14 requires a DC supply of between 12 and 14V at 60mA. A regulated PSU is strongly recommended because unregulated supplies can give rise to significant levels of background hum. A simple design based on the 7812 1A IC voltage regulator is perfectly adequate. As an alternative, the receiver can be run from batteries but bear in mind that the current drawn will be fairly high. For this reason rechargeable batteries are the most practical and cost-effective option; either nickel cadmium or lead-acid is suitable. If a battery supply is used it is important to provide a 500mA line fuse in the positive power lead as protection against short-circuits.

Any type of headphones (except electrostatics) designed for use with personal stereos and hi-fi systems is suitable. Do not worry about the precise impedance and frequency response characteristics. The photograph at the beginning of the chapter shows the RC14 being used with a pair of budget-priced Sony MDR-010 Roadrunner headphones.

If you haven't experienced the joys of HF reception before, listening to the RC14 will prove a real 'ear-opener'. Tuning SSB is a little difficult at first, but the FINE TUNE control really comes into its own here. First locate a strong signal with the COARSE TUNE control, and then employ FINE TUNE to complete the adjustment. It will not necessarily matter if you happen to tune past a signal using COARSE TUNE because the FINE TUNE control provides considerable latitude and will normally enable you to re-locate the transmission. The voice pitch varies markedly as RV3 is rotated – aim for a natural sound and remember that there will be both male and female operators! Most CW occupies the bottom 100kHz of the band and is particularly easy to tune.

Remember that propagation conditions vary enormously, depending on such factors as the time of day, season and state of the ionosphere. Indeed, the band will sometimes appear almost completely dead, but it normally springs back to life again a few hours, or perhaps a day, later. Also, if you wish to listen for stations in a specific country, remember to check what time it is there – the operators may well be sound asleep! Stations in contact with each other: will almost invariably use the same frequency, but because of propagation anomalies you may only be able to hear one of them. Paradoxically, it is often the closest stations which will not be heard. Finally, bear in mind that the RC14 does not have automatic gain control (AGC) – signals are therefore presented with their true relative amplitudes preserved, so you will often have to reduce the AF gain setting in order to prevent overloading by strong transmissions. Fading (QSB) is also more noticeable.

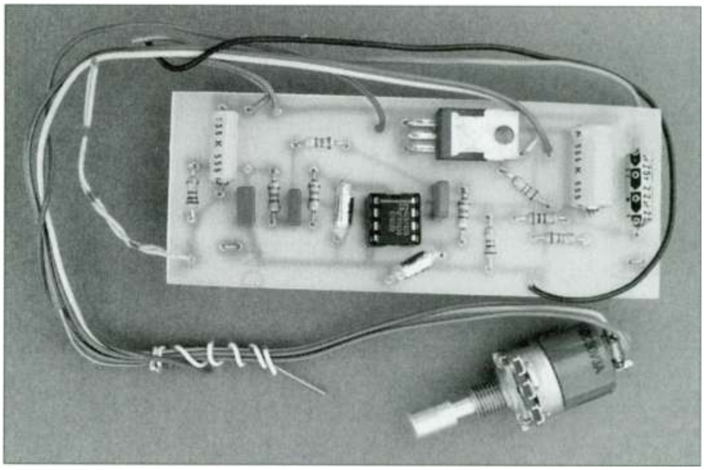


Fig 4.10. The CW filter

Adding a CW filter

The RC14 beginner's receiver contains an active audio filter designed primarily for the clear reception of SSB. This filter also copes reasonably well with CW (morse). Nevertheless, when the CW segment of the band becomes crowded, or when there is a very strong interfering signal close to the wanted transmission, it can prove difficult to concentrate on the QSO (contact) of interest.

Ideally, we could solve the problem by building a receiver that only responded to one CW signal at a time. Unfortunately, it is virtually impossible to achieve such a goal, but there is a very practical compromise based on the application of an additional filter. Use of the active CW filter described in this article cannot guarantee that only the wanted transmission is heard, but it will nevertheless improve CW reception quite considerably.

The filter, which is designed to fit inside the RC14 case, is available in kit form from Cirkit, Park Lane, Broxbourne, Herts EN10 7NQ. Tel: 01992 444111. The price (carriage within the UK) is £8.99 + VAT at the time of going to press. Check with Cirkit for the latest price.

How it works

The CW filter consists of a single IC (integrated circuit) and a handful of other components, all of which are mounted on a small printed circuit board. The RC14 audio output is routed via the filter so that the additional filtering can be applied to signals prior to them being fed to the headphone output socket. A bypass switch is also provided, thus enabling the user to disable the CW filter when listening to SSB. The filter module occupies some spare space to the right of the RC14 PCB and does not, therefore, require its own case. A few minor wiring changes and modifications to the RC14 are called for and these will be fully described later on. How can we improve CW reception by using a different filter? Take a look at Fig 4.11 which shows the frequency response of both the SSB and CW filters.

These filters are of the low-pass type which means that they will pass all frequencies below their respective cut-off points. The cut-off frequency of the SSB filter is approximately 2.6kHz (2600Hz) whereas the cut-off of the CW filter is considerably lower at around 750Hz. Incidentally, don't be fooled by the logarithmic frequency scale which makes the ratio between the two cut-off frequencies look a lot smaller than it actually is.

It is necessary to employ a higher cut-off when receiving SSB because speech contains a wide range of frequencies and most of this range must be preserved or the voice will become unintelligible. Looking more deeply, we find that speech is never just a single, pure tone, but rather a somewhat distorted vibration, the 'fundamental', accompanied by many overtones or 'harmonics'. As the harmonics of speech extend to at least 3kHz we cannot afford to use a cut-off below about 2.5kHz in a communications system.

CW is a different matter altogether. Whenever the key is depressed at the sending station the transmitter generates a carrier wave. The carrier consists of a single,

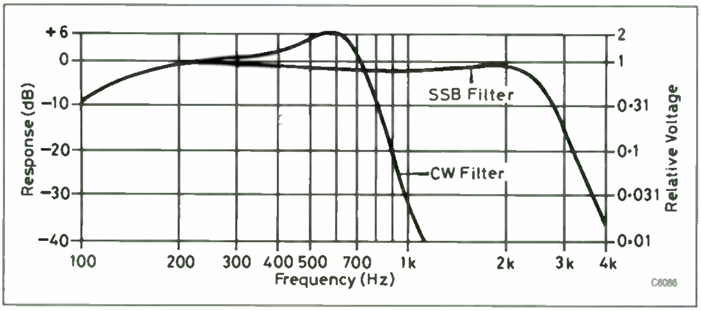


Fig 4.11. The active CW filter has a much lower cut-off frequency than the RC14 SSB filter. This means that interference can be attenuated far more effectively

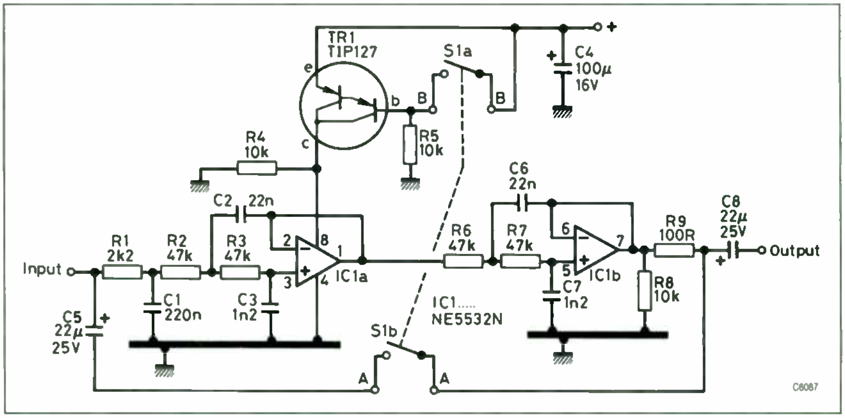


Fig 4.12. Circuit diagram

continuous oscillation at signal frequency. Messages are sent by interrupting this carrier to form the familiar dots and dashes of morse code.

When the RC14 VFO (variable frequency oscillator) is tuned to a frequency very close to that of a CW transmission, the receiver mixer simply subtracts these two frequencies and produces an audible output whenever the carrier is present. For instance, if the CW station is operating on 14,010kHz and the RC14 VFO is tuned to 14,010.6kHz, we hear a 600Hz tone (0.6kHz = 600Hz). Fig 4.11 shows that at 600Hz the CW filter will provide a voltage gain of 2 (6 decibels) which makes the tone louder than it would be if heard through the SSB filter alone. Now let us assume that another station begins sending CW on 14,009.7kHz, which is only 300Hz away from the first station and produces a 900Hz tone. Looking again at the graph we can see that the SSB filter will give the same gain as before and so if the signals are equal in strength there will be no difference in the volume of sound that they each generate. However, introducing the CW filter enables us to attenuate the 14,009.7kHz signal by 20dB (a factor of 10) – this is a useful degree of selectivity and will make it easier to concentrate on the wanted signal. As the graph clearly shows, the CW filter's attenuation continues to increase with frequency and at approximately 1200Hz (1.2kHz) it reaches 40dB (a factor of 100).

Although not shown by Fig 4.11, the attenuation continues beyond 40dB, and at a frequency of 2600Hz (2.6kHz), which corresponds to the SSB filter cut-off point, the CW filter will comfortably provide an attenuation of 80dB and that is equivalent to a voltage ratio of 10,000 to one! What this means in practice is that if an unwanted transmission appears on a frequency more than about 1kHz away from the station of interest, we can utilise the CW filter selectivity to almost completely eliminate the distracting signal.

Circuit diagram

Fig 4.12 shows the circuit diagram. IC1 is a dual operational amplifier of the same type as is employed in the RC14. The network of resistors and capacitors connected to each of the two amplifiers contained within IC1 (labelled 'a' and 'b' respectively) provide the low-pass filter function. This arrangement is very similar to the RC14 SSB filter but because the components have larger values, the cut-off frequency is correspondingly lower. The facility to bypass the filter (ie so that it is still possible to listen to SSB) is provided by S1. If S1 was a separate component it would be necessary to drill an additional hole in the receiver front panel. This inconvenience has been avoided by combining the bypass and FINE TUNE controls using a special potentiometer which has a built-in double pole switch. The switch contacts are closed by pulling the potentiometer's spindle out. This method of actuating the switch is advantageous in that S1 may be operated without altering the potentiometer setting. As it is not possible to fit a 'pull-on' switch to the original RC14 FINE TUNE potentiometer (RV3) it will be necessary to fit an entirely new component. This item is therefore provided as part of the CW filter kit and it is also available separately from Cirkit Ltd (stock number 48-10319).

The filter is brought into operation by opening S1. This does two things: Firstly, S1a disconnects the base of TR1 from the positive supply rail, thus allowing current to flow through R5 and into the base connection of TR1. TR1, a PNP Darlington power transistor, now turns on. When TR1 is in the ON state only a very low resistance exists between its emitter and collector connections. This means that power will be applied to IC1 via pin 8. Secondly, S1b breaks the bypass line so that signals can only reach the output by travelling through the CW filter circuitry. Conversely, closing S1 (done by pulling the potentiometer spindle out) will remove power from IC1 and also bypass the now-inactive filter via coupling capacitor C5.

Constructing the filter

With the exception of S1, all the components shown in Fig 4.12 are mounted on a small printed circuit board. For those constructors who do not wish to obtain the kit, the PCB foil pattern is reproduced at Fig 4.13.

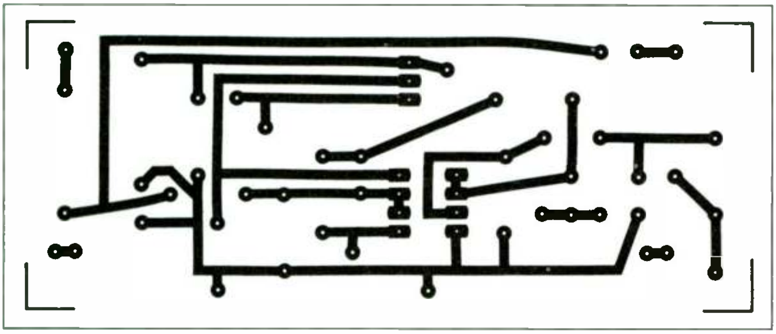


Fig 4.13. The PCB foil pattern

Very few tools will be required for this project. A 15–25W shouldering iron having a bit diameter of no more than 1.5mm, a pair of wire cutters, a small pair of long-nosed pliers and a screwdriver should suffice. Fig 4.14 features the circuit board layout and Fig 4.15 will help with the identification and preparation of components prior to mounting. A socket is provided for IC1 and this should be soldered in place first – do not insert IC1 at this stage. The resistors and capacitors except the three polyester types (C1, 2 and 6) are mounted horizontally – this will necessitate bending their leads. The polyester types, which may be coloured red, will simply drop into place. The polystyrene capacitors (C3 and C7) have translucent mouldings. Only the electrolytic capacitors (C4, 5 and 8) require mounting a certain way round – Fig 4.14 helps in identifying their leads. Now mount TR1, remembering to bend all three leads as shown in Fig 4.15 first. It is the marked (front) face of TR1 which rests against the circuit board – see Fig 4.16 for clarification.

Pairs of flying leads approximately 250mm in length are now soldered between pads AA and BB and the appropriate contacts of S1 (Fig 4.14). It will be a good idea to shorten the control spindle in preparation for final fixing before you solder the flying leads onto S1. Also solder red and black cables to the +VE and ground pads and a single lead to the output pad. Before fitting the filter into the RC14 it will be necessary to make a few minor modifications to the receiver itself:

1. The value of R4 must be increased from 10Ω to 22Ω. R4 is located close to C9 – the large 470μF electrolytic capacitor mounted next to the mixer IC. It is not necessary to remove the RC14 circuit board for this operation; simply cut both leads of R4 (colour code: brown-black-black-gold) as near to its body as possible and then dispose of it. The new resistor can now be soldered to what remains of the original resistors leads (you will need to cut and bend the 22Ω resistor leads appropriately beforehand). This modification will improve the receiver audio stability at high AF gain settings and thereby ensure that the additional 6dB of gain provided by the CW filter can be coped with. A suitable 22Ω resistor (designated 'Rm' in the

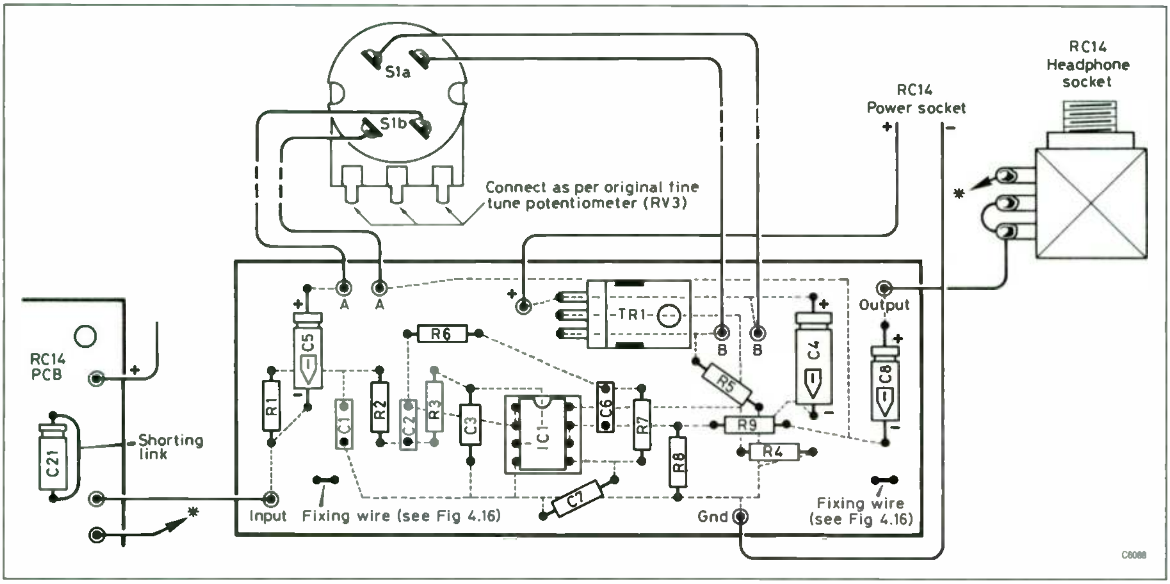


Fig 4.14. The locations of the components on the printed circuit board. Also shown are the off-board connections

Table 4.2. Components list for the CW filter

RESISTORS	
R1	2k2
R2, 3, 6, 7	47k
R4, 5, 8	10k
R9	100R
Rm	22R
All fixed resistors are 0.25W, 5% tolerance, carbon-film types	
CAPACITORS	
C1	220n polyester
C2, 6	22n polyester
C3, 7	1n2 polystyrene
C4	100µ electrolytic, axial
C5, 8	22µ electrolytic, axial
SEMICONDUCTORS	
TR1	TIP127 PNP Darlington
IC1	NE5532N dual operational amplifier
MISCELLANEOUS	
S1	10k linear rotary potentiometer with pull-push DPST switch (Cirkit Stock No 48-10319)
Printed circuit board	
8-pin DIL IC socket	
PVC-covered, stranded wire (for flying leads)	
100mm of 18/20 SWG tinned copper wire for fixing the PCB	
Two small washers	

Note: The 22n capacitors (C2, 6) may be marked '0.022' and the 220n value (C1), '0.22'.

components list) will be supplied as part of the filter kit.

2. C21, the RC14 output coupling capacitor, must be shorted out. Simply solder a length of tinned copper wire (eg an off-cut from one of the filter components) across C21. Fig 4.14 shows this modification clearly. If the filter is being built at the same time as the RC14, C21 may be omitted and the shorting link installed on the board.

The CW filter circuit board is mounted vertically to the right of the RC14 PCB – ie between the AF gain potentiometer (RV1) and the headphone socket. Fig 4.16 shows how this is achieved. Two short lengths of fairly stiff, tinned wire are soldered to the isolated double-hole pads on the filter PCB, These fixing wires are then clamped around the mounting bolts at the edge of the RC14 PCB – the use of washers above the wires will help here. Extra nuts are not required – simply use the existing ones. Prior to mounting the filter board, complete the wiring as shown in Fig 4.14. Desolder the RC14 audio output lead from the headphone socket and resolder it to the filter input pad. The filter output lead should now be soldered to the headphone socket. The other connections are shown well enough by Fig 4.14 alone, but remember to wire the new FINE TUNE potentiometer exactly as the original (RV3).

You will be left with a spare 10kΩ linear potentiometer – this may come in handy for another project!

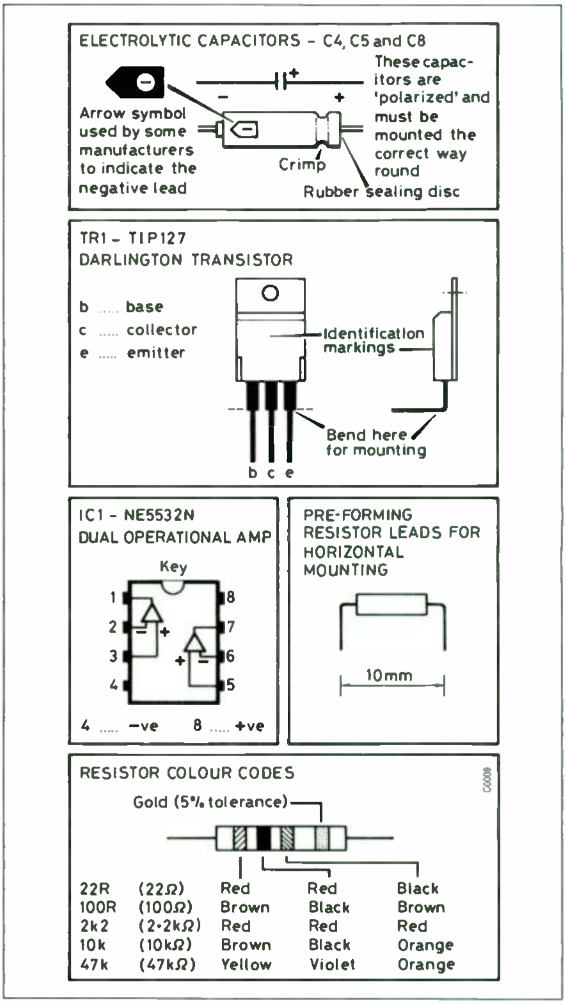


Fig 4.15. Component identification and pre-forming of leads

Testing and use

Before inserting IC1 into its socket, make the following checks:

1. Power-up the RC14 and check that everything operates normally. It is important that the spindle of the new FINE TUNE control is pulled *out* at this stage.
2. Push the FINE TUNE control *in* and check that the headphones go 'dead'. It should now be possible to measure a voltage just slightly lower than that of the power supply at the junction of TR1 collector and R4. If there is no reading, begin by checking that the filter power leads have been correctly wired to the RC14 power socket.

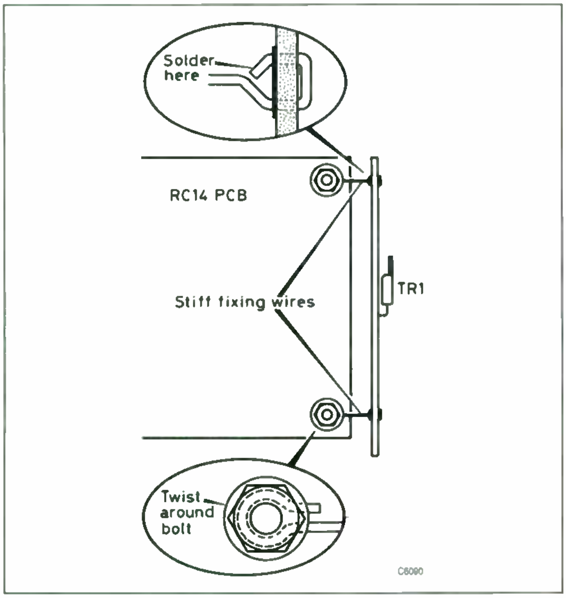


Fig 4.16. The CW filter circuit board is positioned vertically and to the right of the RC14 PCB

3. Having satisfied yourself that everything is OK, disconnect the power supply and allow about 30 seconds for the larger capacitors to discharge. Now insert IC1 and reconnect the supply. Check that IC1 is inserted the correct way round – look for the notch in its encapsulation and compare this with Fig 4.14. With the FINE TUNE control pulled *out*, locate a reasonably strong and stable CW transmission. Tune the signal to give a fairly low-pitched tone (if you are a musician, attempt to obtain a note near E above standard A-440) and then push the FINE TUNE *in* to activate the CW filter. You should still be able to hear the morse, but if it sounds quieter try carefully adjusting the FINE TUNE so as to bring the signal properly within the CW filter pass band.

Getting the most out of the CW filter will take a little practice, but after a few hours of tuning around you'll probably start to wonder how you ever managed without it!

Adding a converter for the 80m band

Probably the next most popular band after 14MHz is 3.5MHz (often referred to as 'Eighty') and so it was decided to produce a design for 80m. It would have been rather difficult to directly modify the RC14 for two-band operation, but fortunately there was an alternative solution which not only enabled the RC14 to be used on 3.5MHz but also preserved its 14MHz capability.

The 3.5MHz converter is an ingenious device that is simply inserted between the normal receiving antenna and the RC14. Signals which fall inside the 3.5MHz band are then shifted upwards in frequency by precisely 10.5MHz so that the unmodified RC14 can hear them. As a constructional project the 3.5MHz converter offers the chance to become familiar with a number of components which are not found in the RC14 – a quartz crystal, a light-emitting diode (LED), the Toko range of pre-wound inductors and last, but not least, a bipolar transistor. More experienced readers may be aware that the integrated circuits employed in the RC14 actually contain large numbers of such bipolar devices.

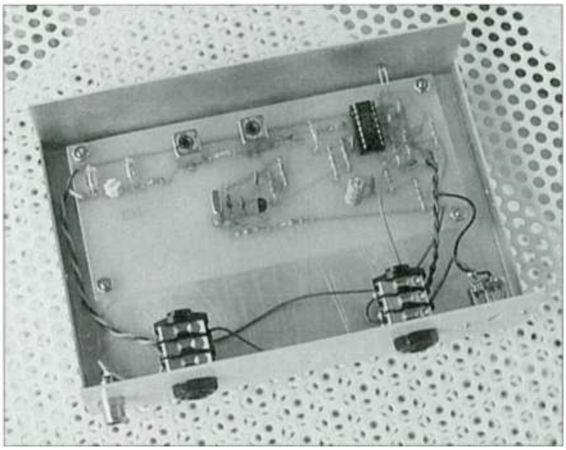


Fig 4.17. The 80m band converter

The 3.5MHz converter is available as a kit (from Cirkit Ltd of Broxbourne, Herts) which contains absolutely everything required, including the printed circuit board and a painted, pre-drilled case. Ordering details can be found at the foot of the components list. For readers who do not wish to purchase the kit full constructional details are given below. But first, a few words about 80m.

The 3.5MHz band

3.5MHz is very different to 14MHz. It covers the frequency range 3.5 to 3.8MHz and so is precisely 300kHz wide. As with 14MHz, you will find CW (morse) within the bottom 100kHz (ie 3.5 to 3.6MHz) and SSB (speech) above 3.6MHz. However, the similarity with 14MHz ends there!

It would require an entire chapter to cover everything that you might wish to know about 3.5MHz but a great deal can be learnt by just listening on the band. So that what should be an entertaining experience does not turn into a source of bewilderment, here are a few pointers:

- 3.5MHz is a shared band – you will hear a variety of signals (radioteletype being common) that do not originate from amateur stations.

- Propagation is generally more local – 3.5MHz is sometimes referred to as an 'inter-G' band with many UK stations chatting to each other. DX will sometimes make an appearance, however.
- Listen for RSGB news broadcasts which are made every Sunday morning on 3.650MHz and also, mainly at weekends, special-event stations using the callsign prefix GB.
- QRM (electrical interference) can sometimes obliterate 3.5MHz transmissions. Domestic TV receivers are a major source of such 'hash', and that includes your own TV.

Building the converter

Whether you are considering the purchase of the converter kit, or perhaps setting about building this project from scratch, it will prove a worthwhile and hopefully stimulating experience to spend a short time studying its design. Fig 4.18 shows a block diagram of the converter and the full circuit is featured in Fig 4.19. Ignoring, for a moment, the jack socket labelled 'JK1a' in Fig 4.19, it will be seen that signals picked up by the antenna are first routed through a fairly complicated band-pass filter which comprises an assortment of capacitors and inductors. The input filter consists of a low-pass pi-type section (C1, 2 and L1), followed by two parallel-tuned

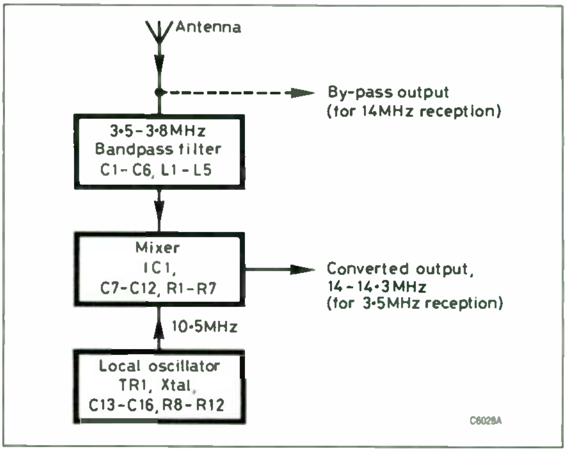


Fig 4.18. Block diagram of the 3.5MHz converter

circuits (C3/L2 and C5, 6/L5) which are coupled together via L3, C4 and L4. The parallel-tuned circuits are adjusted to resonate at frequencies falling within the 3.5MHz band and they will then work together in providing significant attenuation of all frequencies outside the desired band.

The pi-section is incorporated to ensure even greater rejection of signals having frequencies higher than

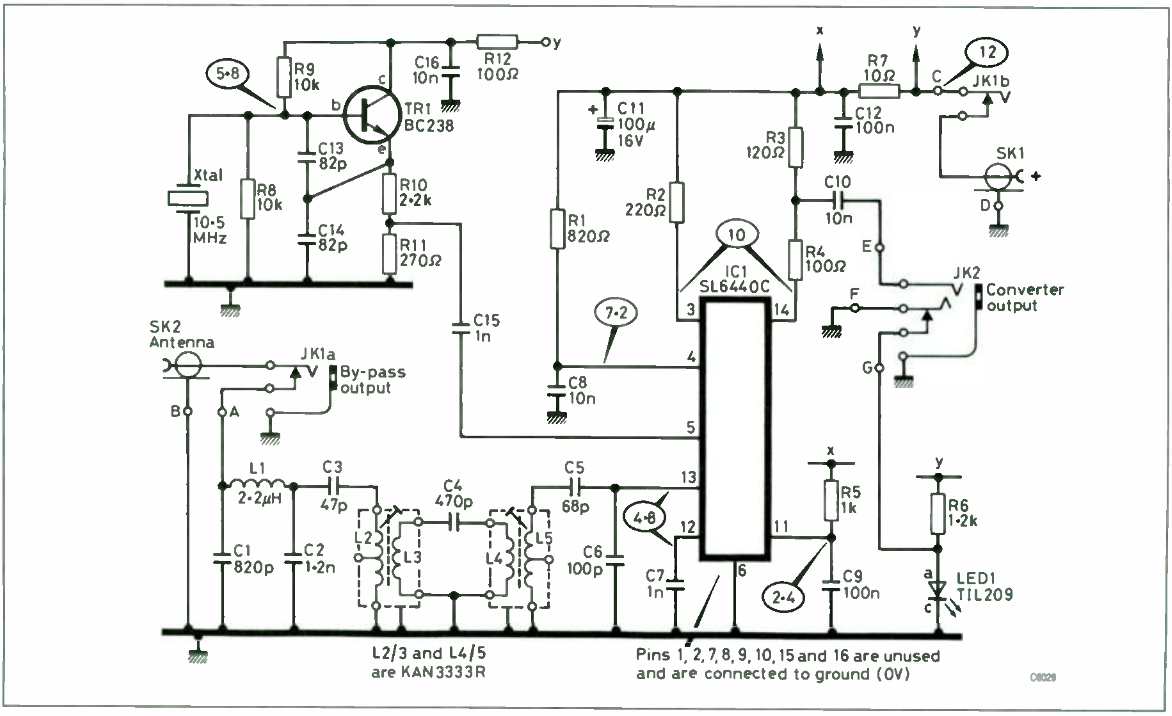


Fig 4.19. Circuit diagram – voltage measurements (circled) are made with the negative probe connected to ground/0V

3.8MHz – in particular, signals at 14MHz. It is most important that these latter signals are not let through to the converter's output, because we might then find ourselves listening to two bands simultaneously! In order to shift the 3.5MHz signals upwards in frequency the converter employs an integrated circuit mixer type SL6440C (IC1) which is the same as the device used in the front end of the RC14. The filtered 3.5MHz input signals are fed into pin 13 of IC1 and the frequency conversion is achieved by feeding an internally generated signal of 10.500MHz from the local oscillator into pin 5 of the mixer. The local oscillator comprises TR1 (a bipolar transistor) and associated components, the most important of these being a quartz crystal (abbreviated to 'XTAL' on the diagrams) which maintains the local oscillator frequency very precisely. The result of mixing these two signals is to produce a 'mirror image' of the 3.5MHz signals which fall within the 14MHz band.

For instance, a transmission at 3.630MHz will be mixed with the 10.500MHz local oscillator signal to produce an up-converted signal on 14.130MHz (3.630 + 10.500 = 14.130). The RC14 then receives these up-converted signals as normal.

The converter output is fed to the RC14 via a jack socket (JK2 – see Fig 4.19). A special patch lead must therefore be provided which has a jack plug on one end and a phono plug (to match the RC14 antenna socket) on the other.

However, if things were left at that then the converter would prove very inconvenient to use – imagine that we have been listening on 3.5MHz but now wish to try 14MHz. This would involve unplugging the patch lead from the RC14, and then removing the antenna from the input of the converter so that it can be plugged directly into the receiver's antenna socket.

Such a complicated band change procedure would quickly become tiresome and so things have been made considerably easier by the addition of a bypass socket JK1, which enables us to have the antenna permanently connected to the converter. Changing from 3.5MHz to 14MHz now only involves unplugging the patch lead from JK2 (converter output) and plugging it into JK1 (bypass). JK1 (see Fig 4.19) provides a direct connection to the antenna which is exactly what we require for 14MHz reception. Furthermore, there are cut-out contacts built into JK1 which are used to isolate the input filter and also disconnect the power supply to the converter whenever the bypass socket is in use. The converter output socket JK2 also has cut-out contacts and one of these is wired so that the light-emitting diode (LED1), which is arranged to protrude through a hole in the front panel, will illuminate whenever JK2 is in use. This feature provides a positive indication that 3.5MHz has been selected.

Construction

In order to build the converter successfully you will require a few basic tools:

1. A soldering iron of between 15W and 25W rating (no higher unless thermostatically controlled) having a bit diameter no greater than 1.5mm.
2. A small pair of wire cutters.
3. A screwdriver – 100mm long by 4mm blade size is suitable.
4. A small pair of long-nosed pliers.
5. A trimming tool suitable for adjusting the cores of Toko 10k inductors. (Note that this is provided with the kit.)

The first job for those constructors who are not building the kit will be the preparation of the printed circuit board. Fig 4.20 gives the foil pattern for this plus an explanatory note. There is also more information on making PCBs in Appendix 2.

Now proceed as follows:

1. Using Fig 4.21 as a guide, mount and solder the IC socket onto the PCB, but do not insert IC1 at this stage. Similarly fit L1 (this component has a light-coloured plastic encapsulation and will probably be marked '2R2K'), L2/3, L4/5 and the XTAL (this component is built into a sealed metal can). It does not matter which way round you mount L1 or the XTAL – the same applies to resistors and all the capacitors with the exception of C11. L2/3 and L4/5 can only be seated a certain way round because they both have three pins on one side of their base but only two pins on the other. Note also that the metal screening cans of L2/3 and L4/5 have two small lugs which will protrude through holes in the PCB – these must be soldered as well.
2. The resistors R1–12 are mounted next. These sit horizontally on the PCB and so their leads must be bent through 90° – see Fig 4.22 which shows this more clearly and also gives the relevant colour codes. Each pair of holes on the PCB intended for resistors is spaced 13mm apart. As the resistor bodies are only about 7mm long, leads will need to be bent at a point approximately 3mm from the component body. The best way of doing this is to hold the lead being bent in the jaws of a pair of long-nosed pliers. After soldering, the leads should be cropped using wire cutters.
3. The polystyrene capacitors (C1–4 and C6) are tubular in shape and have clear plastic bodies through which the silver foil construction may be seen. The value is printed on the outside surface, but not always very clearly. However, a process of elimination should enable you to sort things out. These components vary in size quite significantly and it is easy

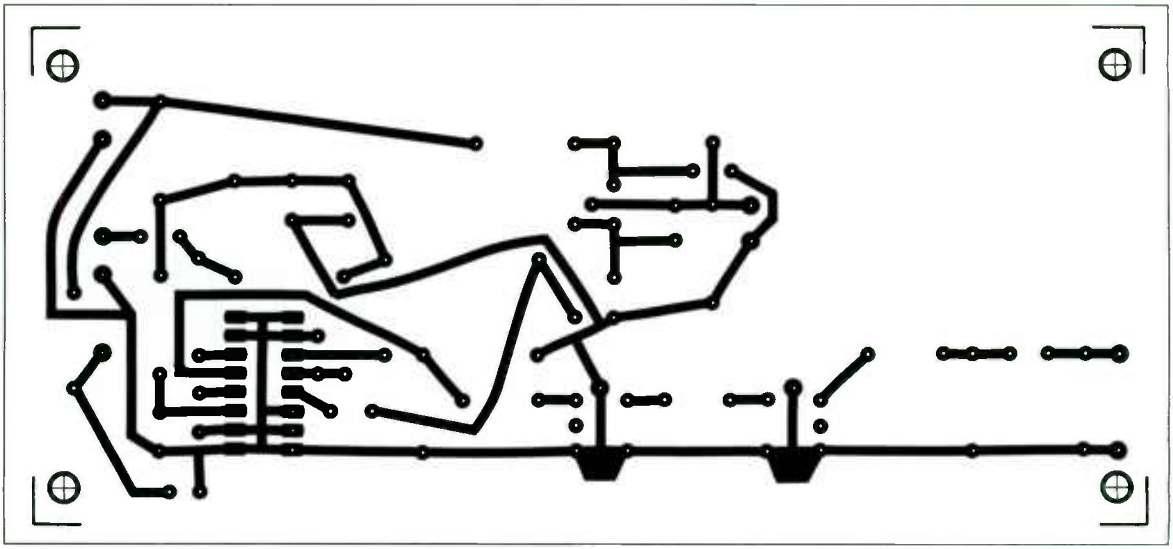


Fig 4.20. PCB holes are all 1mm diameter except for those intended for the screening can tags of L2/3 and L4/5 which are 1.5mm diameter. Use Fig 4.21 as a drilling pattern

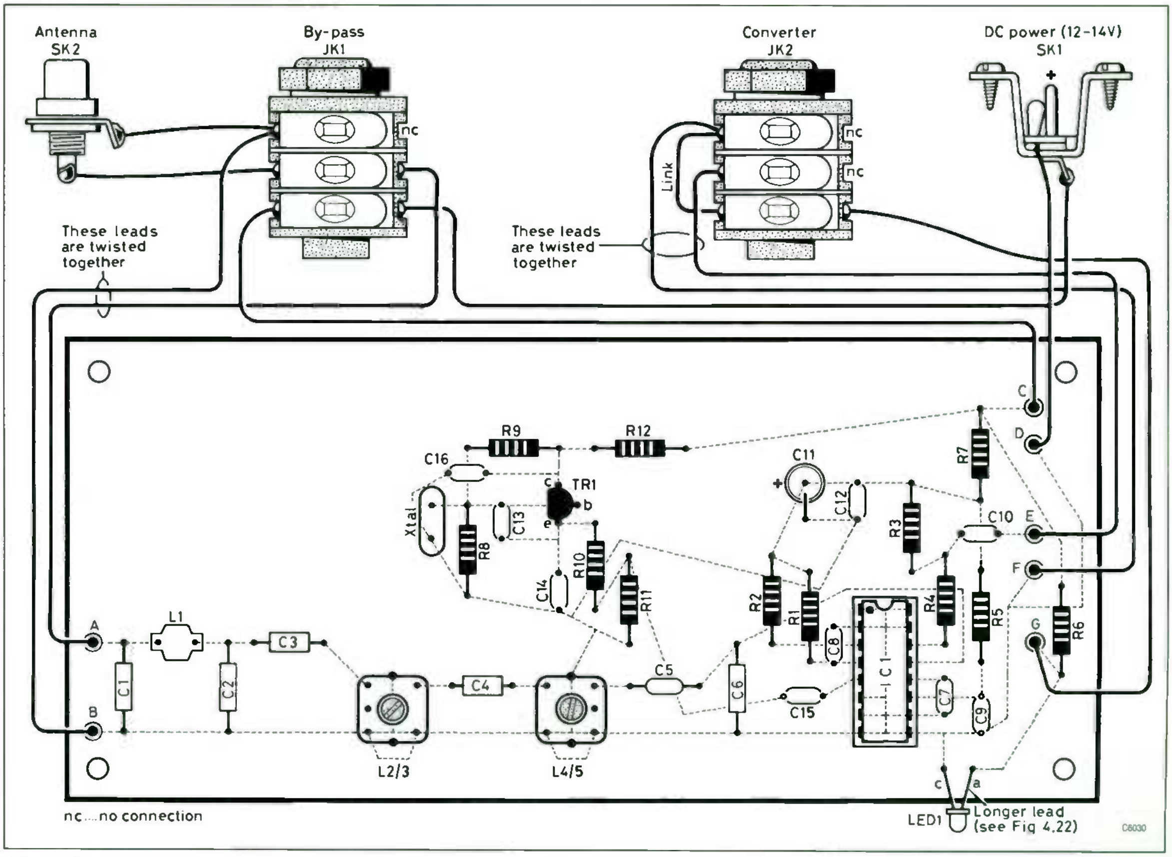


Fig 4.21. PCB component layout and flying-lead connections

Table 4.3. Components list for the 3.5MHz converter

RESISTORS

R1	820R
R2	220R
R3	120
R4, 12	100R
R5	1k0
R6	1k2
R7	10R
R8, 9	10k
R10	2k2
R11	270R

All resistors are 0.25W, 5% carbon film type

CAPACITORS

C1	820p polystyrene
C2	1n2 polystyrene
C3	47p polystyrene
C4	470p polystyrene
C5	68p polystyrene or ceramic
C6	100p polystyrene
C7, 15	1n0 ceramic plate
C8, 10, 16	10n ceramic plate
C9, 12	100n ceramic plate
C11	100µ 16V axial electrolytic
C13, 14	82p ceramic plate

INDUCTORS

L1	2.2µH Toko 7BS (part No 283AS-2R2)
L2/3, L4/5	Toko 10K (Part No KANK 3333R)

SEMICONDUCTORS

TR1	BC238
IC1	SL6440C
LED1	TIL209 red LED (or equiv)

MISCELLANEOUS

XTAL	10.500MHz quartz crystal. HC18V
SK1	2.5mm DC power socket
SK2	Phono socket, single hole mounting
JK1, 2	6.3mm stereo jack sockets with cut-out contacts

2.5mm coaxial plug
PCB and case with lid
¼in stereo jack plug
Phono plug – all metal
16-pin DIL IC socket
0.5m of RG174A/U miniature 50Ω coaxial cable
Four nuts, bolts and spacing pillars
Two self-tapping screws
Four stick-on feet
Trimmer tool (Cirkit part No 35-00002)

to assume that the larger ones have the highest values – don't be fooled, this isn't always the case! They are all mounted horizontally.

4. The ceramic capacitors (ie all of those remaining except for C11, which is physically very different and much larger) are mounted vertically. The PCB hole spacing for these is 5mm (10mm for C5 to allow for the possible use of a polystyrene type). C9 and C12 will probably have their leads spaced 5mm apart and so can be inserted without bending. The other ceramics, however, feature 2.5mm lead spacing and so

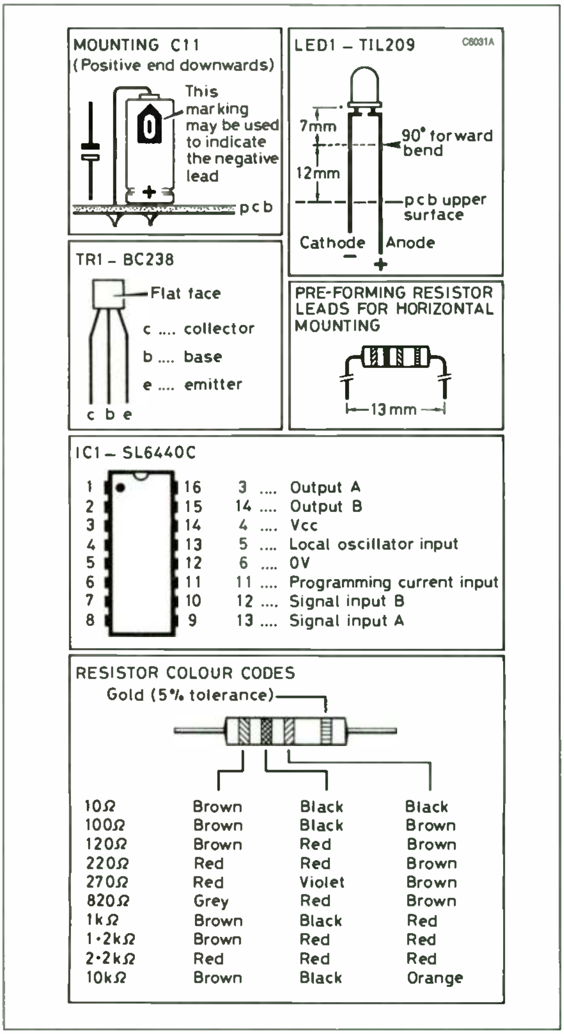


Fig 4.22. Component identification

their leads must be carefully bent outwards prior to mounting. Once again, the values of these components will be printed on their bodies. C5, 13 and C14 should present no problem in this respect but the other values may be represented in the following manner: 1nF shown as '102' or '0.001'; 10nF shown as '103'; 100nF shown as '104'. There may also be a suffix letter such as 'Z' or 'K' but this can be ignored.

5. Using Figs 4.21 and 4.22 as a guide, mount the remaining components: C11, TR1 and LED1. Be careful to get C11 the right way round (positive end downwards, as shown in Fig 4.22). Look for the flat face on the body of TR1 and mount it with this face towards the XTAL. LED1 is probably the trickiest component to mount as it must be soldered the correct

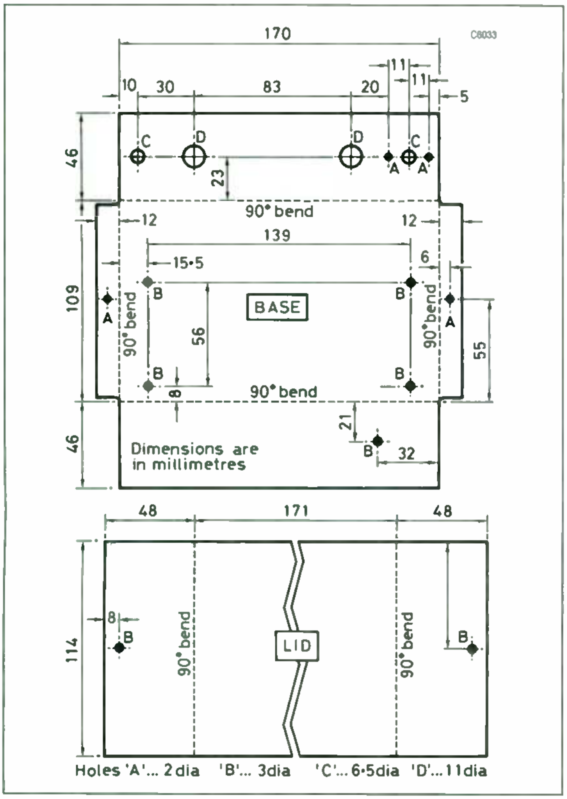


Fig 4.23. Dimensions of the aluminium case

way round and stand proud of the PCB surface so that it can be made to poke through the front panel – kit builders may wish to study the case at this point, but remember that the PCB will be mounted on the pillars provided, thus raising the upper surface of the circuit board nearer the hole.

6. Solder lengths of PVC-covered connecting cable (referred to as 'flying leads') at points A to G. You will of course need to bare the end of each cable first using wire cutters. Employ logical colour codes – ie red for positive (C), black for negative (D) and perhaps green for ground (B and F). The flying leads will be excessively long at this stage but they can be cropped later.
7. Fig 4.23 features plans of the case lid and base. This should be fabricated in 18 gauge aluminium sheet and the outside spray painted to match the RC14. This item is supplied pre-drilled and painted with the kit.
8. Final assembly of the converter involves bolting the PCB into the case and then connecting the far end of each flying lead to the appropriate socket as indicated in Fig 4.21. Note: remember to use the spacing pillars on the bolts supporting the PCB. You will now

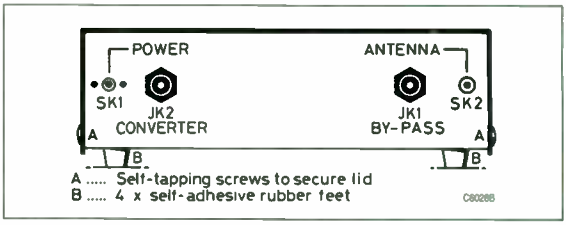


Fig 4.24. The converter rear panel

be able to see how long each flying lead needs to be, but don't be tempted to shorten these too much. The input leads A and B are twisted together, as are the output leads E and F. JK1 and JK2 are mounted with their solder tags pointing downwards, and you will find that it is far easier to solder the flying leads before bolting the jack sockets into place. Note that there is a link between two of the tags on JK2. This can be made using an off-cut from one of the flying leads. Fig 4.24 shows the rear panel of the completed converter.

9. The patch lead which is used to couple the converter to the RC14 is shown in Fig 4.25. Be careful when stripping the outer insulation from the coaxial cable because it is easy to cut through the braid as well.

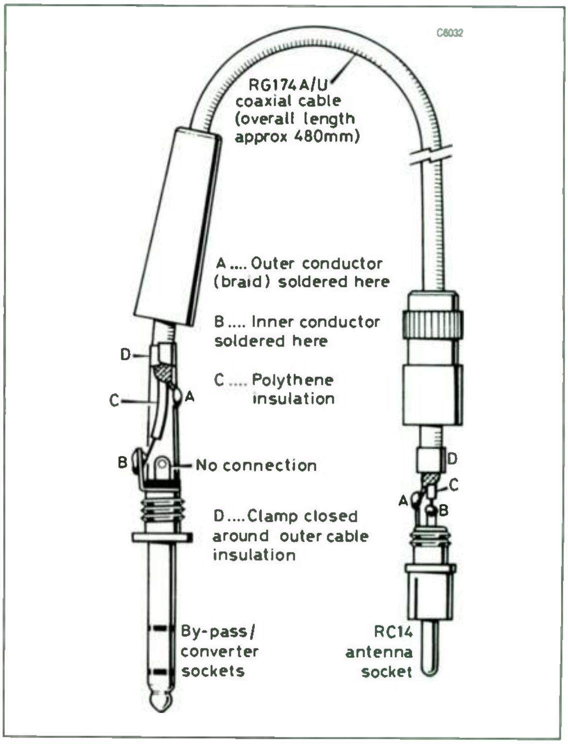


Fig 4.25. Patch lead details

Also, remember to thread the plug tops onto the cable before soldering!

Testing and use

Adding the finishing touches to the converter will merely consist of sticking the rubber feet onto the underside of its base and inserting IC1 into the DIL IC socket on the PCB. IC1 must be inserted the correct way round – look for the notch in its encapsulation and compare this with Fig 4.21.

The power supply used for the RC14 can also be used to run the converter. This means that you will need to make up an additional power lead and wire this in parallel with the existing one. Be careful to observe the correct polarity – the positive lead must be wired to the centre connection of the 2.5mm coaxial plug.

The converter may now be powered up for the first time. For those who possess a multimeter, the unit should draw approximately 46mA when operating from a 12V supply and typical DC voltage readings are given in Fig 4.19. It must be emphasised that these readings serve only as a guide and there are bound to be variations, particularly if a 13.8V supply is used.

Now check that inserting the patch lead into J1 causes the converter to be disconnected from the supply, and that insertion into JK2 results in the illumination of LED1. If you have access to an HF general-coverage receiver this can be employed to check that the local oscillator is functioning correctly. Simply tune the receiver to 10.500MHz, select SSB (either LSB or USB) and see if a heterodyne can be found – you may need to connect a short antenna to the receiver in order to hear this clearly. As long as the local oscillator frequency appears to be within ±2kHz of 10.500MHz then everything is fine.

A simple wire antenna such as that which you may have been using for 14MHz reception will also function on 3.5MHz. However, if you followed the recommendations given earlier concerning the RC14, it might be a good idea to try and lengthen your antenna somewhat – it's quite in order to bend it as necessary! Try to get the wire as high as possible – you will find that the lengthened antenna will still work as well on 14MHz.

Alignment

Having sorted out the antenna it's time to put the converter through its paces! First power up the RC14 and connect the patch lead between JK1 and the RC14 antenna socket. With the antenna plugged into the converter it should now be possible to listen normally on 14MHz. This test may not seem very exciting but it serves to prove that the bypass facility operates correctly. Now remove the jack plug from JK1 and insert it into JK2. Provided that the power supply is properly connected, LED1 will illuminate to indicate 3.5MHz operation as explained previously.

Tune the RC14 around the middle of the band until you find a signal – it doesn't matter at this stage what sort of signal you come across; a commercial teletype transmission will do just as well as an amateur contact. Using the special trimming tool, carefully adjust the cores at the centre of L2/3 – the core is made of an iron composition known as 'ferrite' and is shaped like a grub screw. It should be possible to find a point where the signal becomes noticeably stronger – this is due to the first tuned circuit being brought into resonance with the signal. Having resonated the first tuned circuit, proceed to adjust the core of L4/5 in a similar fashion. Note, however, that the tuning of L4/5 may not seem as 'sharp', ie the peak in response to the signal appears less well defined. You may now wish to re-check the peaking of L2/3 because there is bound to be a slight degree of interaction between the two inductors, but do not be tempted to continually re-adjust the cores as they are rather brittle. The converter is now ready for use and so the lid should be screwed on using self-tapping screws.

SSB stations will employ LSB (lower sideband) on 3.5MHz whereas it is the convention to use USB (upper sideband) on 14MHz. Operation of the RC14 FINE TUNE control may seem strange at first, but you will soon get the hang of it.

Chapter 5

An amateur radio direction finding receiver for Top Band

'Top Band' was the nickname given to the 1.8–2.0MHz band. In the days when wavelength was used, rather than frequency, it was the 'longest wave band', hence 'Top Band'. This is no longer true in the UK as in May 1996 the 73kHz band became available.

This original design (photo shown in Fig 5.1) is a simple TRF receiver with an RF amplifier and a demodulator with regeneration. It also has a switchable telescopic antenna which is used for sensing the received signal. In simple terms, it allows the direction of a transmitter along the bearing line to be established. More about this later. Although the design in receiver terms is simple it can demodulate all modes – CW, AM, SSB and FM. It would make an ideal receiver to use in short-distance DF work with the DSB/CW transmitter described in the companion volume *Practical Transmitters for Novices*.

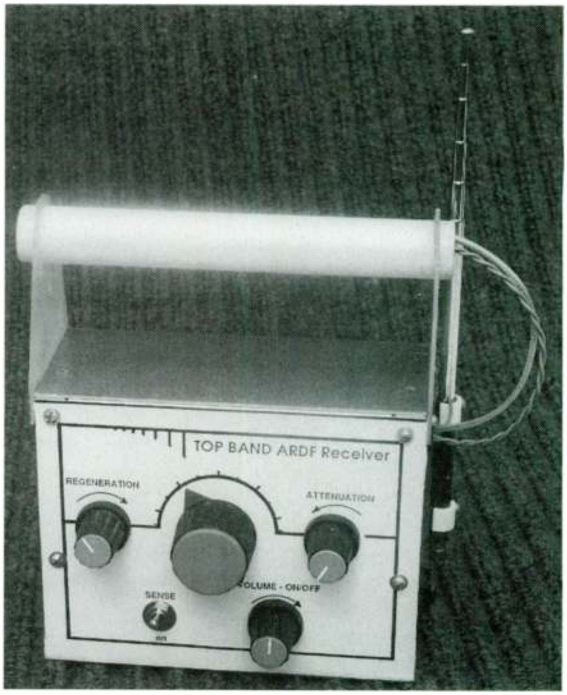


Fig 5.1. The completed receiver

The circuit

See Fig 5.2. L2, the main antenna, is wound on a ferrite rod and it is this which gives the receiver its directional properties. It is tuned by means of the capacitors VC1, C4 and TC1. C4 reduces the frequency range given by VC1 to about 0.3MHz, covering from 1.75 to 2.25MHz. The signal from L2 is applied to RV1 which acts as a rather crude attenuator. This control, which does not appear in most radio receivers, is necessary in a DF set to prevent the signal swamping the receiver as the operator gets close to the transmitter. The attenuator is then used to reduce the signal reaching the RF amplifier and demodulator, so preserving the directional and distance-measuring properties of the radio.

TR2, a dual-gate FET, is an RF amplifier which, in addition to giving RF gain, reduces the amount of radiation from the antenna when the regeneration control turns the demodulator TR3 into an oscillator. The signal from TR2 is fed via C7 to L5, which is tuned in the same manner as L2 by VC2 (the second capacitor of the two-gang capacitor), C15 and TC2. The signal from L5 is applied, via the parallel combination of C9 and R9, to the gate of TR3, a JFET (junction field effect transistor). These last three components provide the demodulation action.

Although demodulation has taken place, there is still some RF developed across R11 in the drain circuit of TR3. Some of this RF is passed through L4, RV2 and C8 and then, via the coupling between L4 and L5, back to the gate of TR3 where it provides positive feedback. The amount of feedback depends on the setting of RV2 (the regeneration control), giving increased gain and selectivity at first, then causing continuous oscillation as the feedback is increased when RV2 is turned further clockwise.

If the regeneration control is set so that oscillation does not occur, the receiver is basically only able to demodulate AM but because of the shape of the response curve of the tuned circuit, an interesting and useful effect takes

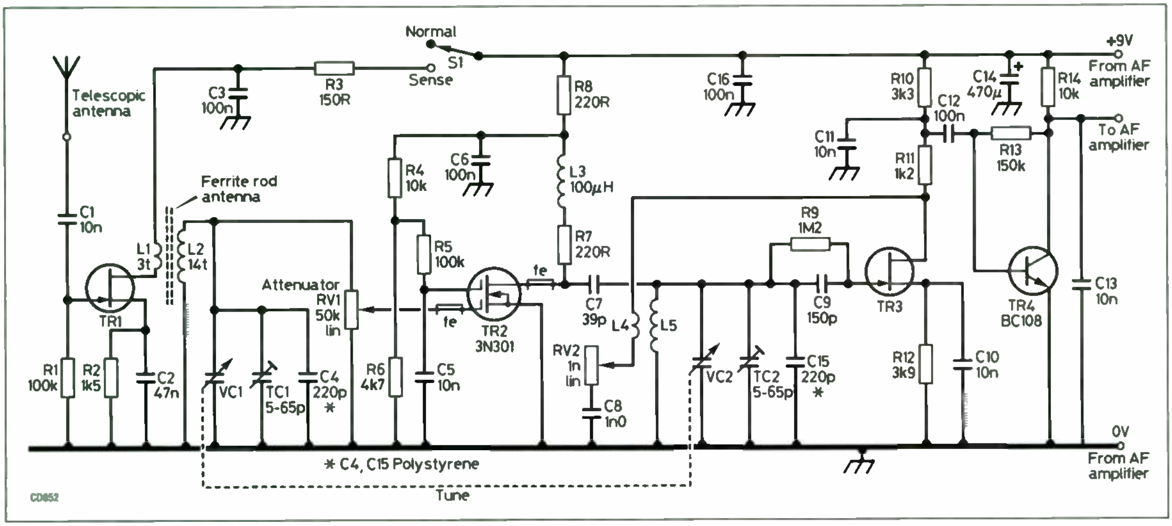


Fig 5.2. The circuit diagram of the 'Top Band' DF receiver

place which enables FM to be demodulated. If the receiver is detuned a little the demodulator becomes a slope detector and will then be able to demodulate FM. There is more information about slope detection in Chapter 2 in the section headed 'More about modes of modulation'. See p15.

If the regeneration control is advanced until oscillation occurs (indicated by a 'plop' in the headphones or loudspeaker), the receiver will be able to demodulate CW and SSB signals, the oscillation providing the necessary heterodyne or carrier re-insertion.

R10 is the AF load across which the demodulated signal is developed. The audio frequency signals are fed via C12 to the base of TR4, a conventional AF amplifier using a bipolar transistor. C11 removes most of the remaining RF so that it is not passed to the AF amplifier. Bias for TR4 is provided by R13 which also applies negative feedback to TR4, giving better stability (freedom from oscillation). The AF output is developed across the collector load R14. Further RF filtering is provided by C13 before the signal is fed to any moderately high-gain AF amplifier; once again it is suggested that this could be one of those probably already built from the designs in Chapter 3.

The primary function of TR1, another JFET, is that of a switch which connects the small telescopic antenna to the coupling coil L1 on the antenna ferrite rod. There will be some gain which will serve to improve the effectiveness of the short antenna. It is activated when the switch S1 is closed. Once a bearing of a transmitter has been found by twisting the receiver for the least signal, it is necessary to know which way along that bearing line the transmitter lies. The telescopic antenna provides a small signal which either adds to or subtracts from the signal from the rod antenna. With the receiver turned in one direction of the 'maximum' signal the output will be bigger than when the receiver is turned through 180°. By using the receiver to listen to a transmitter operating in a known location the 'sense' can be found and it will not change unless the connections to L1 and L2 are altered. Automatic gain control has been omitted deliberately from this design so that the strong and weak signals are not 'evened' out.

Construction

Some features of the construction of this project are related to the size of the box. It is therefore recommended that either the specified box (type AB24) be obtained or a home-constructed version, made to the same dimensions, be used. The AB24 is in the economy range of both Maplin and Cirkit and in this case there would be little, if any, saving in making a box. Any other box can be used provided that it is large enough to accommodate the PCB but it must be born in mind that a number of alterations will have to be made to make everything fit.

Make a start by winding L2 and L1 on the ferrite antenna rod. This is 140mm long and L2 should be approximately in the centre. L2 is wound with 0.56mm (24 SWG) enamel-covered wire and has 14 turns. A layer of 1in-wide Sellotape™ or similar put on in reverse, that is with the sticky side outside, will help to hold the turns in place while the coil is being wound. Wrap one and a half turns of 1in-wide PVC tape over the top of the coil and bend one end back over the tape so that both ends of the coil are at the same end. Cut the two ends so that they are about the same length but when one is folded back it

Table 5.1. Components list for the Top Band DF receiver

RESISTORS	
R1, 5	100k
R2	1k5
R3	150R
R4, 14	10k
R6	4k7
R7, 8, 15	220R
R9	1M2
R10	3k3
R11	1k2
R12	3k9
R13	150k
RV1	50k min linear potentiometer
RV2	10k min linear potentiometer
CAPACITORS	
C1, 5, 10, 11, 13	10n
C2	47n
C3, 6, 12, 16	100n
C4, 15	220p polystyrene
C7	39p
C8	1n0
C9	150p
C14	470µ electrolytic radial type
VC1/2	126p + 126p twin gang (Maplin No AB11M)
TC1, 2	5–65p trimmer (Maplin No WL72P)
SEMICONDUCTORS	
TR1, 3	2N3819 field effect transistor
TR2	3N301 dual-gate field effect transisitor
TR4	BC108
INDUCTORS	
L1, 2	Wound on ferrite rod, type 101 (Maplin No YG22Y)
L3	100µH type 7BS (Cirkit No 34-10104)
L4/5	Toko type 154AN7A6440E (Maplin No 35-64400)
MISCELLANEOUS	
S1	SPDT sub-miniature
Epicyclic ball drive (Maplin No RX42V)	
Stereo jack socket, 6.3mm	
Box type AB24 (Maplin No LF16S)	
Telescopic antenna, six-section 6mm diameter (Maplin No JM10L)	
AF amplifier as per Chapter 3 (transistor type)	
28mm knob for 6.3mm shaft	
Three 15mm knobs for 6mm shafts	
PCB (make or buy) – Badger Boards	

appears to be about 10mm shorter than the other. This shorter one is soldered to the inner of a piece of miniature coaxial or single-core screened cable. Fig 5.3 should make this clear. Another thin layer of PVC tape must cover the join. The outer of the screened cable is soldered to the other end of the coil. Although the completion of the antenna is described here it may be advisable to leave the remainder of the construction until the rest of the receiver is built and tested. If the number of turns on L2 needs to be adjusted the alteration can then be made with the least 'un-doing' of work already done! L1 is wound with thin PVC-covered wire. About 50mm is required. Fold the length in half to find the centre and wind three turns over the rod as close as possible to L2, at the same end as the screened cable. These turns can be held in position by twisting the PVC wire tightly and the remainder twisted not so tightly, and hopefully both ends will finish up in the same length. Another thin layer of PVC tape will hold everything in place.

If you are building for fun the next stage can be ignored but for serious direction finding it is well worth the trouble. A normal ferrite rod antenna is influenced by both the electric and magnetic fields but the electric field tends to reduce the directional effect of the antenna. Considerable improvement will occur if the coil assembly is screened so that the electric field does not reach the coil. The screen is a layer of very thin brass foil. A piece about 40mm square is required. If there is any trouble obtaining foil, try a car repair garage and ask for brass shim (steel must not be used) – anything in the region of 0.075 to 0.1mm (3 thousandths of an inch) will be fine. Wrap the foil around the rod on top of the windings. The piece will probably be big enough to completely encircle the coil but it is most important that the two edges do not touch one another – this would constitute a shorted turn which would reduce the inductance and efficiency of the antenna coil L2. If there is a chance of the foil edges overlapping, insert a piece of tape in the join to insulate the edges. Another thin layer of tape will hold things together. Solder a thin piece of wire to the edge of the foil screen nearest to the output leads and connect it to the outer of the coaxial cable or screened lead. A final layer of tape completes the assembly. Once again it must be stressed that only the minimum amount of tape must be used in the construction as the whole antenna unit will be slid into a piece of plastic water pipe which has an internal dimension of 15–16mm and which forms the carrying handle. See the photograph at the beginning of the chapter (Fig 5.1).

For those wishing to make their own PCB the foil pattern is given, full size, in Fig 5.4.

Examination of the layout diagram (Fig 5.5(a)) shows that with the exception of the AF amplifier almost all the components are mounted on the PCB – in fact the only items which are not are the ferrite rod, associated coils and the sense switch. This enables the receiver to be reproduced with considerable accuracy. In view of this it is advisable to try the larger components in the respective positions as it is much easier to make adjustment to hole size and position before any components are fitted. This applies especially to the following components: VC1/2 (don't forget the two fixing holes for the variable capacitor – if necessary the position of these may be

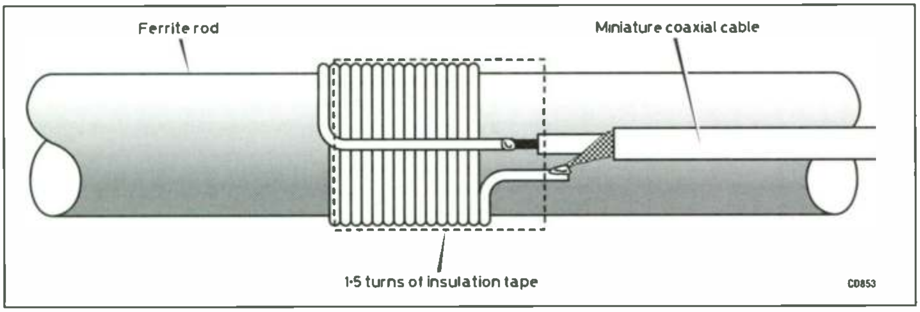


Fig 5.3. The connections to L2 on the ferrite rod

modified by careful use of a round needle file), RV1, RV2, TC1, TC2 (note the holes in the board allow for either of two types of pin configuration) and the coil can containing L4 and L5. Check also that the 3mm hole to the right of VC1/VC2 (on the component side) has been drilled.

Before fitting any components, place the PCB, component side up, in the correct position in the case. This is in the centre of the wide side and about 3mm from the top edge. The legend 'TOP BAND ARDF Receiver' on the PCB must be furthest from the box edge.

Carefully mark the position of the four 3mm fixing holes and drill them. Remove any burrs, then temporarily bolt the PCB in position. Scribe around the outline of the three larger holes for VC1/2, RV1 and RV2. This last operation is important because the three components are fixed to the PCB and cannot be moved to effect registration with the case. Remove the panel from the case.

Insert the nine terminal pins in the holes marked on the layout diagram by means of a circle with a dot in the centre. Notes on inserting pins appear in Appendix 1. Following the general rule, next insert the 15 resistors. The spacing is 13mm and if each resistor is held in long-nosed pliers with the jaws just touching the body the bend will be in the correct position. Follow with the 16 capacitors with C14 last, making sure that this is connected with the correct polarity. The pitch of the holes and the capacitor leads will vary and each capacitor will need to be adjusted individually.

Now fit L3, T4, TC1, TC2 and VC1/2. The later is fixed to the PCB by means of two M2.5 screws which must not be longer than 3mm. (For information on cutting screws see Appendix 1). In the case of T4 and VC1/2 ensure that all solder points are filled.

RV1 and RV2 are fixed in position and the connections made with short pieces of tinned copper wire from the ends of resistors (off-cuts). Make a small loop in one end using long-nosed pliers, pass the plain end through one of the appropriate holes in the PCB and then put the loop over the control's solder terminal. Solder both ends and repeat with the other five connections using exactly the same technique.

TR1 and TR3, both 2N3819 JFETs, are fitted with the flat on the body in the position indicated in the layout diagram of Fig 5.5. Similarly TR4, a BC108, can be inserted. Note the position of the tab on the metal can.

TR2 requires a little more attention. It is a high-gain, dual-gate MOSFET (metal-oxide silicon field effect transistor) and is prone to parasitic oscillation. It is also sensitive to static and should be treated as any other static-sensitive device – earth yourself and the soldering iron. To guard against parasitic oscillation both the gate 1 and drain leads are threaded through a small ferrite bead before they are fitted to the PCB. Strip the insulation from a piece of thin PVC wire.

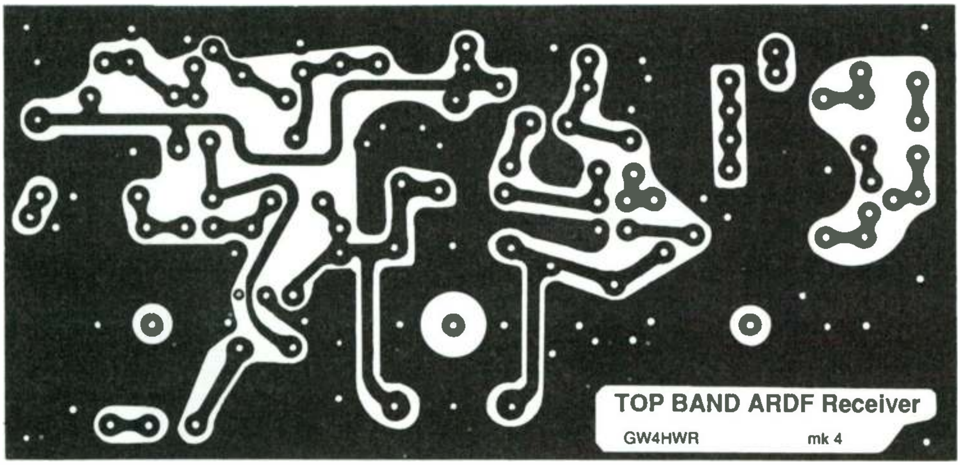


Fig 5.4. The PCB foil pattern

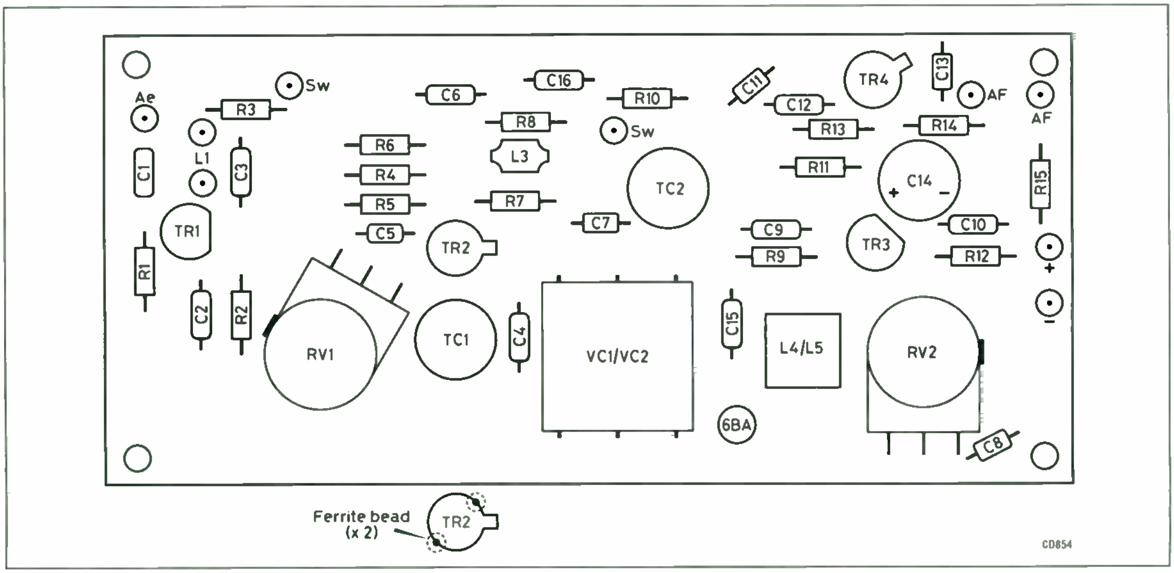


Fig 5.5. The layout of components on the PCB and the position of ferrite beads on TR2

Three pieces about 5mm are needed – slip one piece over the gate 1, gate 2 and drain leads.

Now a ferrite bead can be slipped over the top of the PVC on the gate 1 and drain leads with no danger of the bead shorting to the other leads. TR2 can now be soldered in place.

Check the panel carefully for solder bridges (short-circuits between tracks and or pads). Also check all components for correct orientation and dry joints. If you have already built an amplifier as described in Chapter 3 the PCB assembly can be tested before going on to the next stage.

Testing

Refer to Fig 5.6 and the make the following temporary interconnections. The main coil of the antenna (if both windings have been put on) should be connected so that the inner of the screened cable goes to the pin on RV1 nearest to the trimmer. Link positive and negative supply pins on the PCB to the positive and negative on the AF amplifier. Connect appropriate headphones or loudspeaker – this will depend on which amplifier is to be used. The transistor amplifier needs a medium-impedance speaker (about 35Ω) while the LM386 IC amplifier uses an 8Ω one. Add some supply leads. Connect the output terminals on the PCB to the input of the AF amplifier. Set the attenuator control fully clockwise and the regeneration control fully anti-clockwise. Set both trimmers so that the moving vanes are half enmeshed.

Connect a 9V supply and turn the volume control about three-quarters fully clockwise. Advance the regeneration control until a 'plop' is heard, slowly turn the tuning control and with luck some signal will be heard, probably only a whistle but anything will do. Stations are more likely to be heard after dark so if possible do these tests at night. The same applies to the final setting up which is described later. If possible choose a signal which is in the centre of the tuning range. Turn the rod antenna to find the strongest output, and adjust TC1 to see if a maximum can be found. If the maximum occurs with the vanes of TC1 fully out, the number of turns in L2 is too great and one turn should be removed.

Don't worry about any further adjustments – they can be done when everything is boxed up. If none of the above results are obtained check everything carefully, especially the value and positions of the various components. To identify the faulty stage, with the volume control at maximum, touch the base of TR4 (the end of R13 furthest from the transistor would be safer). A low hum should be heard in the headphones/loudspeaker. If all is well repeat at the gate of TR3 (again use the end of R9 nearest to the transistor) – a louder hum should be heard. If the last test gives the required result it should be possible to hear a 'plop' when the regeneration control is turned clockwise – if so the fault almost certainly lies in the circuitry of TR2. Touch the centre connection of RV1 – a loud click or hum should be apparent. If not, check the position of the attenuator control and the connections to it. Disconnect the centre of the coaxial cable from the control and again touch the centre pin of RV1 – if a hum is heard the fault lies in the antenna coil or the coaxial cable from it.

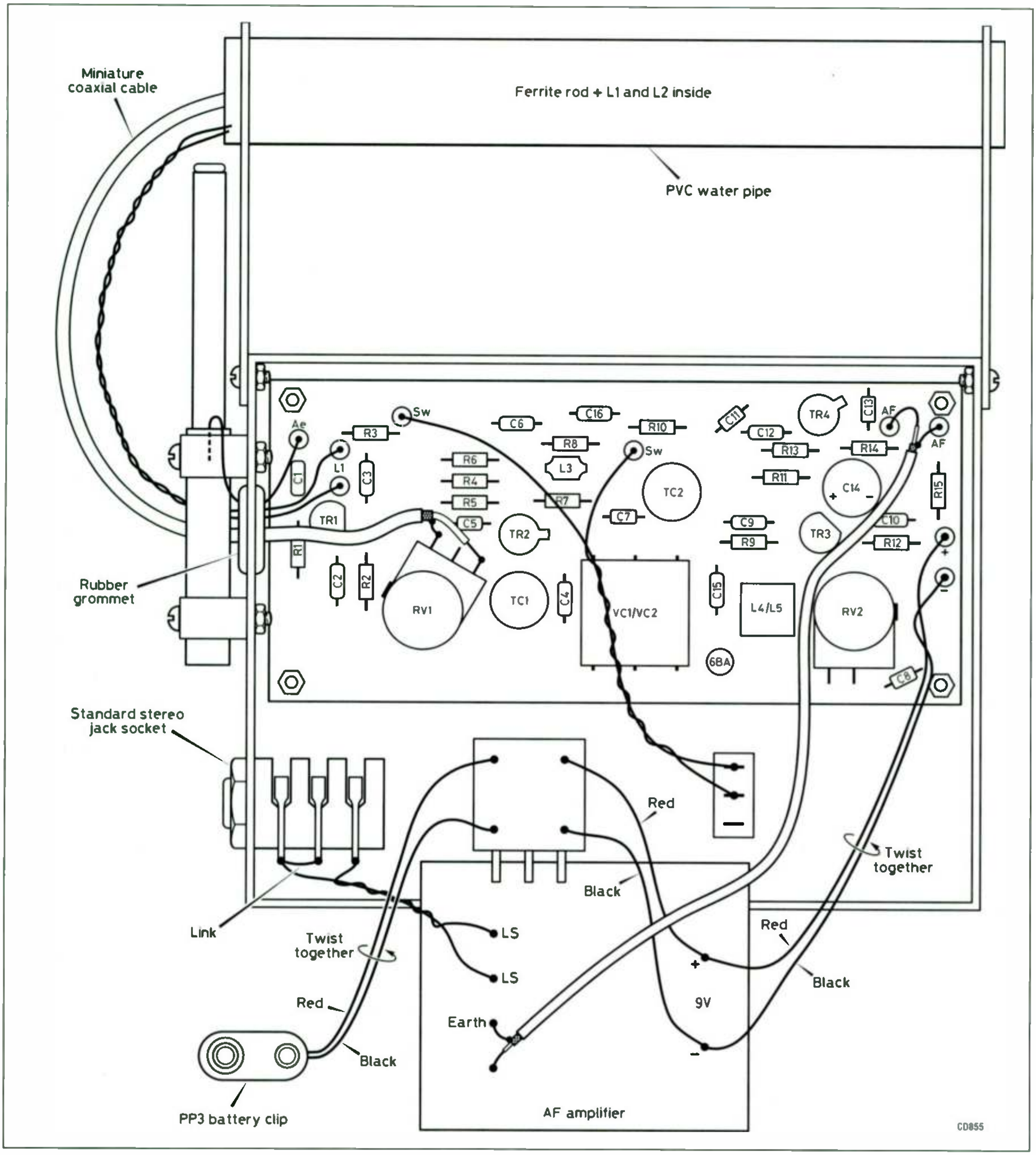
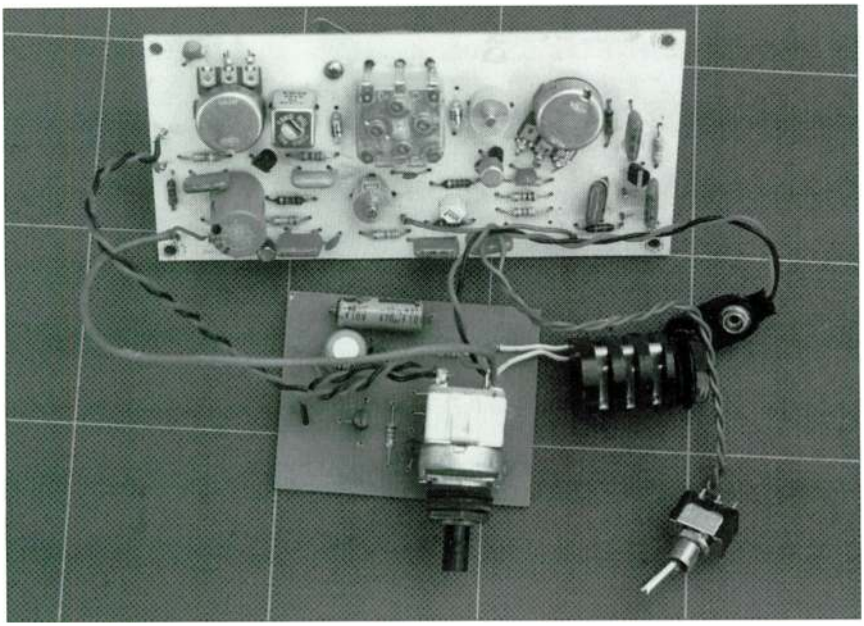


Fig 5.6. The interconnection of PCB, antenna and AF amplifier

The box

Drill 3mm holes in the positions marked on the inside case before work was commenced on the PCB. The holes for the attenuator and regeneration controls should be enlarged to a little more than 6mm. Keep trying the PCB to ensure that the holes are in the correct position. The size is not critical as long as the spindles of the controls can turn freely and the knobs will cover any small gaps. If the slow-motion (SM) drive has not been fitted, do it now. (The receiver can be used without an SM drive but it will



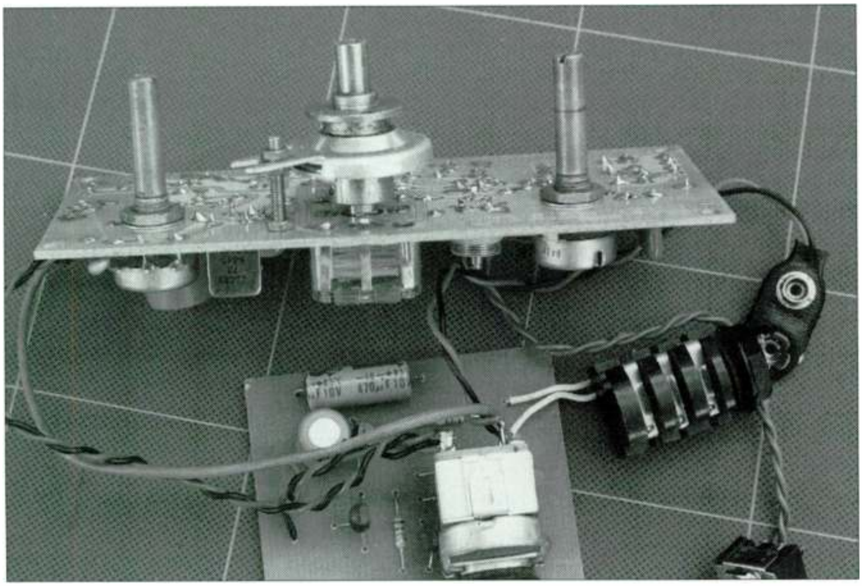


Fig 5.7. The interconnections (top) and the reverse side of the PCB showing the arrangement of the slow-motion drive (bottom)

too much clearance between knob and pointer, should be shortened to 10mm (measured along the 6.3mm shaft – do not include the bush). Care in cutting is necessary to avoid damage to the drive. Clamp the end of the shaft in the jaws of a vice so that 11mm is visible between the vice and the bush on the shaft. Cut with the blade of the hacksaw rubbing against the jaws of the vice. Remove any burr from the end of the shaft.

With a drive proceed as follows. Fit the extension piece to the spindle of VC1/2 (make sure that it is supplied with the capacitor). It must be fixed by means of a M2.5 screw, 10mm long. Fit the slow-motion drive with the holes in the brass disc vertical when the capacitor is at one end of its travel. Tighten both screws in the drive bush. A 20mm M2.5 or a 1.0in 6BA screw is put in from the component side of the PCB in the hole between the variable capacitor and the coil can. Lock it in position on the PCB with an appropriate nut, then thread on another nut so that it is just below the slotted arm on the drive. When satisfied that it is in the correct position, thread on one more nut so that the drive is locked. Use drills, reamer and a large round file (if you can find one) to get the hole for the drive disc to the correct size. Keep trying the PCB with the slow-motion drive attached to the spindle to check that the holes are of the correct size and in the right position. It is possible to make adjustments to the hole position before they have been enlarged but difficult if not impossible after. Photographs of the completed PCB in Fig 5.7 show the arrangement of the SM drive and the positions of the main components.

be more difficult to tune and in practice the tuning will have to be adjusted while the operator is on the move!). If it is not to be fitted the centre hole will need to be just over 6mm in diameter. With an SM drive the hole for the tuning control must be enlarged to about 22mm to give clearance for the brass disc on the drive. Note: The shaft of the SM drive is too long for most knobs and, to avoid

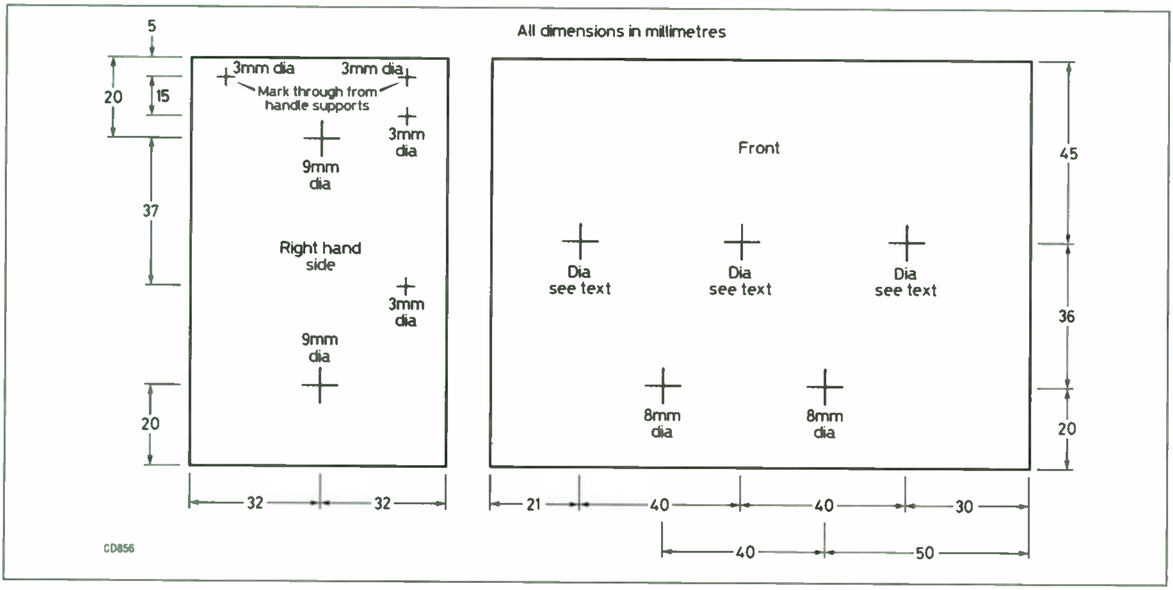


Fig 5.8. Drilling detail for the front and side panels of the box

Two more holes are required in the front panel – Fig 5.8 shows their position and size. A number of holes are also required on the right-hand side, also indicated in Fig 5.8. The two larger holes are for the rubber grommet through which the leads from the antennas pass into the PCB and the lower one is for the telephone jack socket, both being 3/8in diameter. The remaining holes are all 3mm in diameter but before drilling them cut out the two handle support pieces. Fig 5.9 gives an idea of the dimensions but they may have to be modified if a box other than the AB24 has been used. Almost any thin insulating material will do – the larger hole must be made so that the piece of plastic water pipe is a tight fit. Drill the 3mm fixing holes and then mark the position of the holes in the case by 'scribing through' the holes in the support bracket. Drill the four holes 3mm. Cut the water pipe 8mm longer than the width of the box, remove any roughness from the ends and then push one bracket onto each end. The handle unit can now be bolted to the case. If the antenna has not been completed, it should be done now and gently pushed into the tube. Note that the two fixing screws nearest the front of the box must be short enough to avoid touching the PCB when it is fitted.

Mounting the PCB in the box is quite critical if an SM drive is installed as the brass disc on the drive must pass through the large hole in the box and be about 1mm proud of the front of it. There are a number of ways of achieving this: the easiest is to obtain four stand-off pillars 18mm long – these may be threaded (6BA) at both ends or have a plain hole which is M2.5 (6BA) clearance. The method of use depends on the type available. Incidentally, the author hardly ever throws away any old pieces of equipment before they have been completely stripped of nut and bolts, spacer pillars and many other small but very useful bits of hardware. This type of material can be quite expensive to buy new! If plain pillars are used and they are of the correct height, four 6BA screws can be passed through the fixing holes in the front of the box, the panel located over the screws and everything held in place by means of four 6BA nuts. If the pillars are less than 18mm

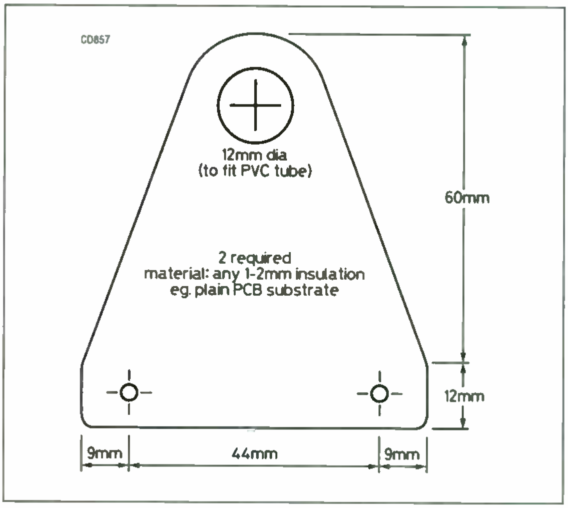


Fig 5.9. The handle supports. Two required. Material – any 1 to 2mm thick insulation such as plain PCB substrate (no copper)

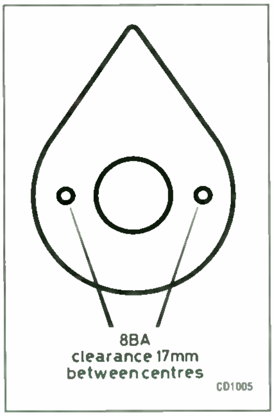


Fig 5.10. Template for SM drive pointer

the PCB can be packed out with washers to bring the drive disc to the correct position.

If threaded spacers are to be used, the pillars are first fixed in the box with four short screws of the correct size and the PCB then fixed using four more short screws. If it is impossible to obtain suitable spacers the same result can be obtained by using four 25mm × M2.5 (1in 6BA) screws and nuts which are first installed in the box and tightened up. Four more nuts are threaded on to the screws and adjusted until the PCB is of the correct height and everything fixed by another four nuts. The drive can be completed by a simple pointer which can be cut from stiff card or thin sheet metal such as tin plate (a template is provided in Fig 5.10). It is then bolted to the drive disc using two 8BA screws about 3 to 4mm long. When the knob is fitted the pointer should be just clear of the inside of the knob so that it can move freely. The tuning knob must be for 6.3mm (¼in) shafts while the others need to be for 6mm shafts.

If a front-panel trim is to be used it should be 'installed' at this stage. Remove the pointer and the PCB, putting the screws in a safe place. Fig 5.11 shows an example full-size and is the used on the sample of the receiver shown in Fig 5.1. Note that it assumes that a SM drive is to be used. If an original design is preferred, it may help to get the holes in the correct position if Fig 5.11 is photocopied and edited as required.

If Fig 5.11 is to be used unaltered a pleasing effect can be produced by getting a copy made on coloured, semi-art paper. Cut out on the outside of the of the outline, place in the approximate correct position on the front panel and hold up to a strong light. It should be possible to align the crosses on the 'diagram' with the holes in the front of the box.

When satisfied that all is correct, pierce the four PCB fixing holes with a sharp pencil or ball pen. Coat the inside surface with suitable adhesive (spray on, repositionable, is the easiest to use) then locate the trim, using the four

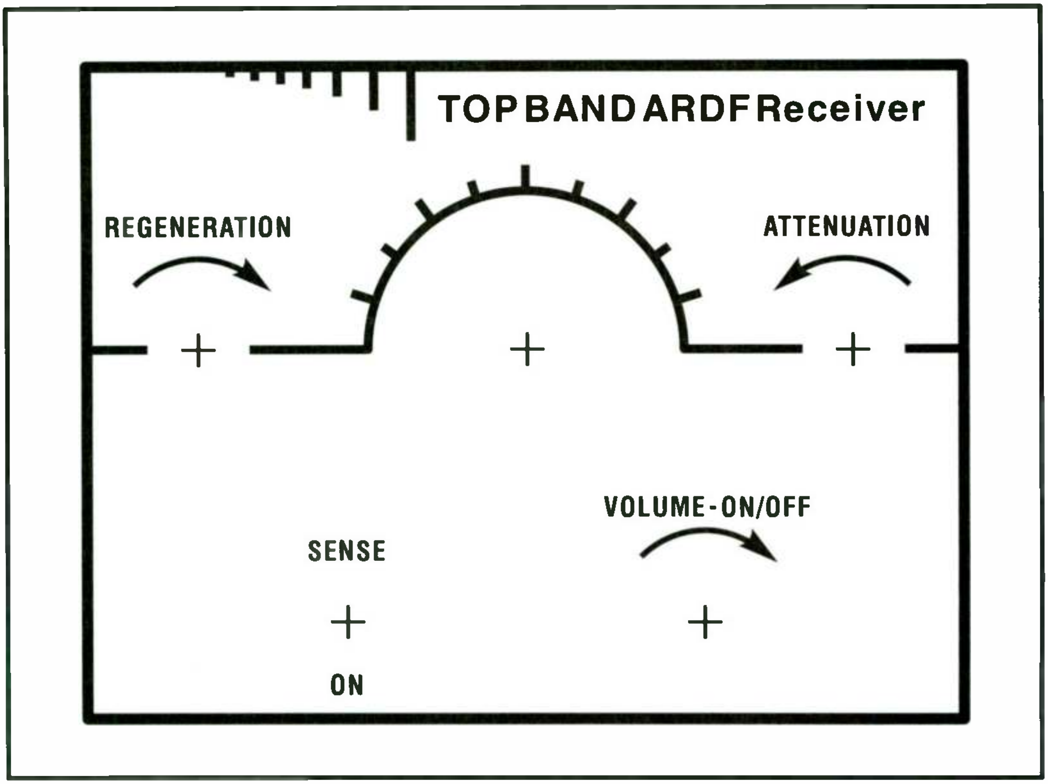


Fig 5.11. A suggested design for a front-panel trim

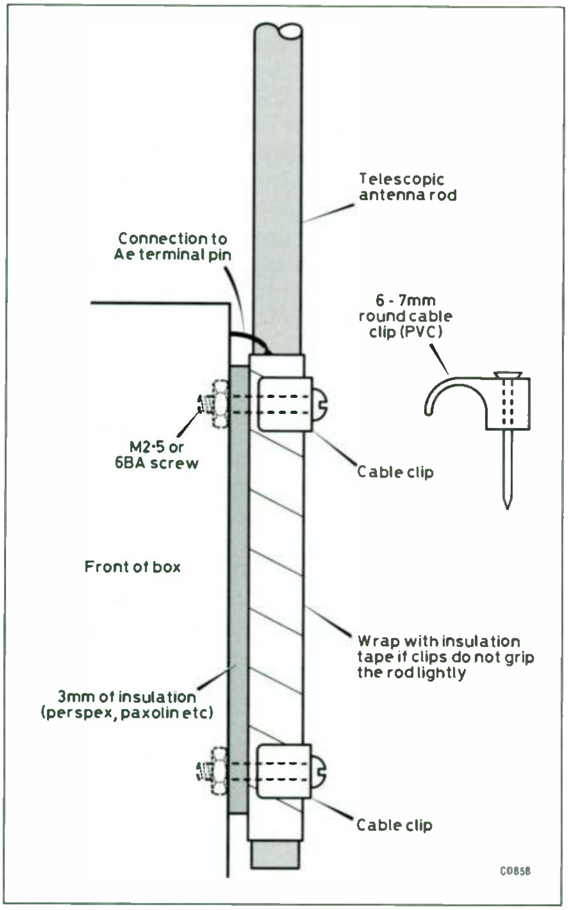


Fig 5.12. Mounting the telescopic antenna

pierced holes, on the front of the box. Press down firmly over the whole area. (Alternatively, you could have the whole design copied on to the self-adhesive paper called 'Crack-back'). When dry, the remaining holes can be cut out with a sharp knife (a scalpel with a pointed blade is ideal), using the holes in the aluminium as a guide.

If the receiver is to be used for its intended purpose it is advisable to waterproof the trim. A variety of clear varnishes are available, best results being obtained by a light coat, sprayed on. When dry, refit the PCB and the pointer.

Feed the leads from the antenna through the grommet and make the connections, again referring to Fig 5.6. Note: for clarity the amplifier PCB is shown laid down. It must not be put into this position as damage to the potentiometer leads will occur.

Fit the sense switch and connect it to the PCB by means of two pieces of PVC-covered wire, twisted together. The volume control complete with AF amplifier must be fitted with leads before fitting it into the box. Once more refer to the interconnection diagram in Fig 5.6. Note that the battery leads are connected to one side of the switch and the supply to both amplifier and PCB are connected to the out-going side. For the protection of the semiconductors, use red leads for all positive connections and black for the negative ones. Short leads from the speaker pins of the amplifier are required to connect the jack socket. If the socket is a stereo type, the two connections nearest to the bush should be shorted together. This will ensure that both mono and stereo headphones will operate correctly. The amplifier is supported by the volume control but it may be necessary to put one or more washers on the bush before inserting in the hole to give clearance between the amplifier PCB and the box.

To complete the construction the telescopic antenna is fitted. Again the method will depend on the type used. The prototype made use of a six-section antenna which was 6mm diameter at the bottom section. It was bolted to the case using two 6mm plastic cable clips and in order to give clearance of the handle brackets was mounted on a piece of paxolin about 2.5mm thick. Fig 5.12 shows the arrangement used but almost any method of fixing the antenna can be used provided that it doesn't come into contact with the case or the handle. The connection to the antenna can be made by stripping the insulation from the end of a piece of PVC-insulated cable and trapping the bare wire under the clip but in contact with the antenna, before tightening the cable clip. The wire is passed through the grommet and connected to the terminal pin nearest to C1. Connect the other wires from the antenna as shown in Fig 5.6.

Testing and setting up

Using the correct trimmer tool, set the core of L5 (in T1) until it is level with the top of the can then turn it clockwise one turn. The range should now be set to about 1.75 to 2.15MHz. Connect a PP3 (a rechargeable type is strongly recommended) or similar battery. No fixing clip has been provided and in practice a piece of Blu-Tack™ is quite effective. Plug in a pair of headphones. Set the attenuator control fully clockwise and the regeneration control fully anti-clockwise. The sense switch should be up (off). Switch on, and leave the volume control at about three-quarters of maximum. Headphones are advised rather than a loudspeaker as the muffs on the headphones reduce extraneous noises and make the minimum and maximums much more pronounced.

Slowly turn the tuning control – some signals should be heard. Turn the receiver for the maximum signal and adjust TC1 for maximum. If the tests described earlier were correctly carried out the vanes of TC1 should not be completely enmeshed but, if they are, there is no alternative – the antenna must be stripped and another turn removed from L2. The receiver should now be covering most of the amateur band but don't be disappointed if no amateur stations are heard. It is quite possible that ship-to-shore stations will be received – these are normally SSB signals and will only be heard if the regeneration control is set so that the demodulator is oscillating. The only signals to be heard without oscillation will be FM and AM, both of which are not too common, so operate in the oscillating condition and turn the regeneration control back if you think there is one of these signals present. To resolve SSB signals requires some skill in the operation of the tuning control – it must be moved very slowly and if you have not fitted a slow-motion drive it will be very difficult. Best results are obtained if the regeneration control is adjusted so that the demodulator is only just oscillating. As the tuning control is turned in a clockwise direction, that is towards the high-frequency end of the band, the oscillation may cease so that it will be necessary to keep adjusting the regeneration control as the band is searched.

To use the receiver to obtain a bearing, turn it for the least signal, reducing output by means of the attenuator control if necessary. The bearing of the received station is along a line from the front to back of the receiver. The sense control must be used to determine which way along that line the station lies. Extend the telescopic antenna about half way, turn the receiver for *maximum* signal, then turn it through 180° – one position will give a much bigger signal than the other. The effect will be more pronounced if the length of the telescopic antenna is adjusted. If a test has already been made on a station of known location the position of the unknown station can now be determined.

To calibrate the receiver to cover the band accurately, some frequency-determining device is required. This can be a signal generator, a dip meter or the transmitter of another amateur (if you do not have one yourself). Set the signal source to 2.1MHz and adjust TC2 so that the signal is heard with the tuning control fully clockwise. Change the signal source to 1.75MHz and retune the receiver until the signal is heard. This should occur with the tuning control almost fully anti-clockwise. When satisfied with the calibration, marks for 1.8, 1.9 and 2.0MHz can be added in pencil until the positions have been confirmed. More information on ARDF can be found in the RSGB booklet *Amateur Radio Direction Finding*.

To complete the project fix four small, self-adhesive feet near the corners of the box cover.

Chapter 6

An FM receiver for the 50MHz band

This project (Fig 6.1) employs the double superheterodyne principle which was briefly mentioned in Chapter 2. Although the circuit is quite complicated, the construction has been kept relatively simple by employing four integrated circuits, some of which contain several hundred components. Although basically a 50MHz receiver, the design is such that with a minimum number of modifications it can be changed to receive 144–146MHz if that band is of greater interest to the constructor.

Fig 6.1. The completed 50MHz receiver

Circuit description

The complete circuit diagram is shown in Fig 6.2. The preselector consists of a band-pass circuit provided by L1, C4 and L2, C5. This will pass a band of frequencies from a little below 50MHz to just above 50.2MHz and prevents strong out-of-band signals reaching and overloading the RF amplifier or mixer circuits. (Overloading of either of these circuits could cause interfering signals to be mixed with the required one and nothing would be able to separate them.) These components will need to be modified if it is decided to modify the receiver to the 144/146MHz band. TR1 is an RF amplifier which is biased by R1, which also gives a degree of negative feedback. The output is fed via C6 to the mixer within IC1. This IC also contains the elements of an oscillator which, with the external components including L1 and D1, is caused to oscillate at a frequency 10.7MHz higher than the received signal. (In the 144–146MHz version it oscillates at a frequency 10.7MHz lower than the incoming signal.) D1 is a varicap diode which is used to tune the oscillator to the required frequency. The capacitance of D1 is determined by the voltage applied to it. RV1 provides the variable control voltage and gives a tuning range of something in the order of 2–3MHz. In the higher-frequency version the range will be between 4–5MHz and a slot is provided on the PCB to accommodate R18 which will reduce the range to a little over 2MHz. RV4 is optional and if used provides fine tuning. This is especially useful in the 144–146MHz version.

The incoming signal and the local oscillator output are applied to the mixer. Sum and difference signals are generated and appear at the output of the mixer. A 10.7MHz filter FL1 removes all other signals except the first IF at 10.7MHz which is passed to another amplifier TR3. This is biased in the same way as TR1, by R7.

The output of this amplifier is passed to a second mixer

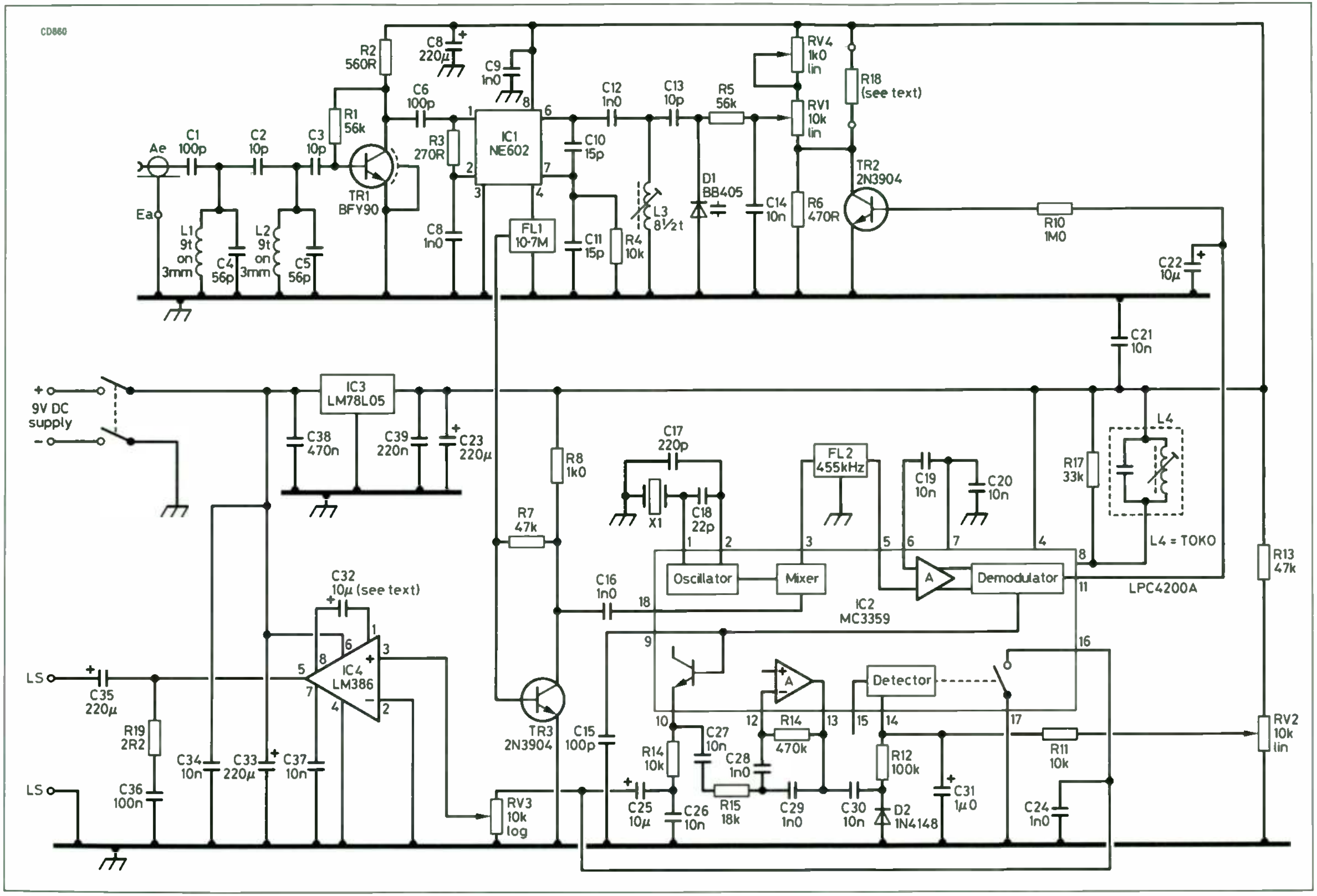


Fig 6.2. Circuit of the 50MHz receiver

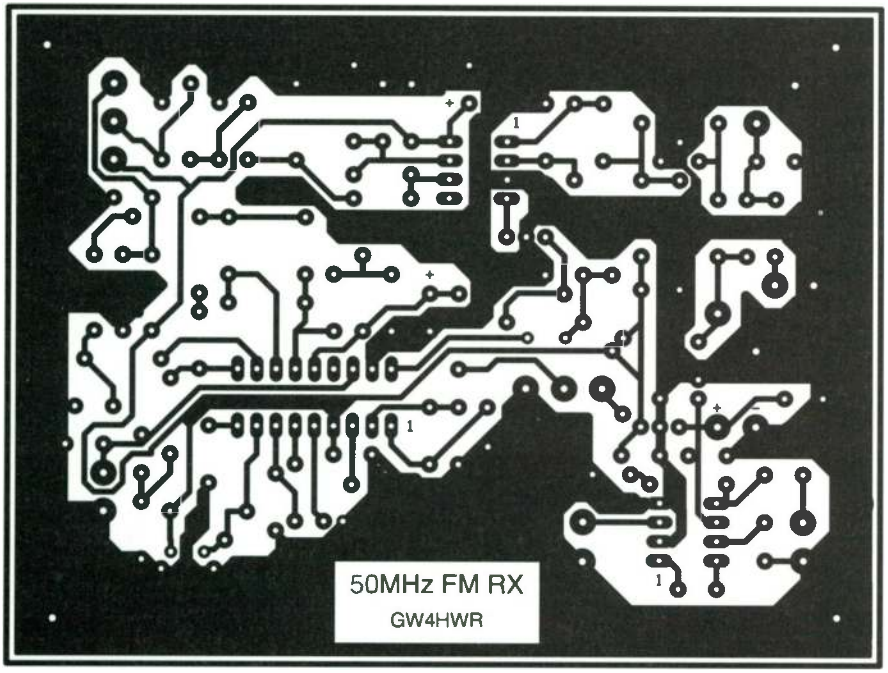


Fig 6.3. The PCB foil pattern – shown full-size

across an internal attenuator resistor within the IC. In this design the gain is determined by pins 1 and 8. If C32, a 10μF electrolytic capacitor, is used the higher gain is achieved, while if it is omitted then the gain is only 20 times. It is suggested that C32 be omitted unless higher AF gain appears to be necessary.

IC2 also contains a muting switch which provides 'squelch', a facility usually provided in an FM receiver to enable the noise which occurs between useful signals to be removed or greatly reduced. The threshold level is set by RV2. When the switch is conductive it becomes a low resistance across the volume control, so reducing the output of the AF amplifier to zero and removing the annoying noise when no signal is being processed. The AF at pin 10 of IC2 is fed via C27 to a filter provided by the resistors and capacitors connected to pins 12 and 13 and to an amplifier in IC2. The AF signal at pin 13 is fed via C30 to D2 and the rectified signal is used to inhibit the muting switch and allow the AF to pass to the AF amplifier.

Pin 11 of IC2 provides a control voltage which varies if the frequency of the local oscillator in IC1 changes due to random variations in component values. The voltage is applied to the base of TR2 which acts as a variable resistor across R6 (in series with RV1) and any change causes the voltage at the junction of RV1 and R6 also to change. This change is passed to D1 causing a change in capacitance which compensates for the frequency change which caused the effect.

IC3, a 78L05, is a low-current voltage stabiliser which provides a constant voltage of 5V and supplies all circuits with the exception of IC4 – the AF amplifier which runs directly from the 9V supply rail. A stable supply for IC1 and IC2 is most important to prevent frequency drift in the oscillators involved in frequency changing.

which is contained in IC2. This very complex integrated cicuit, a Motorola MC3359, has many circuit elements and allows a complex superheterodyne to be made with very few other components. Almost all of the amplification is obtained from this IC. For those advanced constructors who would like more details, extracts from the maker's 'Advanced Information' is provided at the end of this chapter. Circuits in IC2 form an oscillator which is crystal controlled at a frequency of 10.24MHz. This is applied to a second mixer (inside IC2) and output signals including 450kHz appear at the output. A second filter FL2 removes all signals except a band centred on 450kHz, and these are passed to a limiter (also within the IC) to remove any variations in amplitude. The FM signals from the limiter are demodulated by a type of discriminator known as a 'quadrature detector' which is aligned by L4. The way in which this functions is rather complex but it is not necessary to understand the details at this stage.

The AF output from IC2 is fed via R16 and C25 to the volume control and the AF amplifier IC4. The LM386 is a simple amplifier which requires only six additional components (and one of those is optional) to give a moderate AF output. In spite of this apparent simplicity, it is an ideal amplifier for a battery-operated radio. The quiescent current drawn is only 4mA but it is capable of about 300mW. The voltage gain can be varied between 20 and 200 by changing the capacitance shunt-connected

Construction

For those wishing to etch their own PCB, the foil pattern is given in Fig 6.3. Some information which may help with this process is given in Appendix 2.

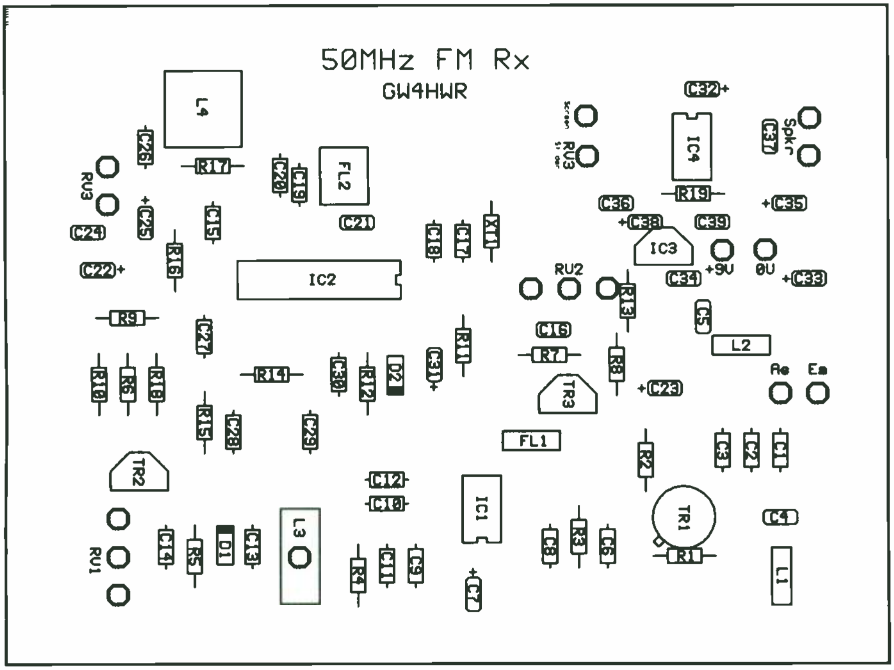


Fig 6.4. The layout of the components on the PCB as viewed from the plain side of the board

If the box in the components list is to be used, the fixing holes for the PCB should be marked at this stage. Refer to Fig 6.1 for the position in the box. Note that the legend '50MHz FM Rx' on the track side should be at the back edge of the box. If an alternative box is to be used the dimensions must not be less than those of the WB2 – the box from Maplin which is about the smallest which will accommodate the board and all the controls.

1. Make a start by inserting the 16 terminal pins. The holes for these are indicated in the component layout diagram shown in Fig 6.4 by a ring. The pins should be inserted from the track side of the PCB and pushed down so that the heads are resting on the copper. Help with this operation is given in Appendix 1. Solder the heads to the board, taking care that the solder flows freely over both the pin head and PCB pad. It is advisable to insert two more pins in the holes intended for R18 – these are not marked with a ring in Fig 6.4. If fitted they will allow this resistor to be inserted (and changed if necessary) with the least upset after the receiver has been installed in its box.
2. If IC holders are to be used (they are strongly recommended), they should be put in next. The holders have a notch in one end, and this should be in the same position as shown in Fig 6.4. As an additional check the notch should be at the same end as the pin marked '1' on the track side of the board. These holders will help to locate the remainder of the components as well as helping to protect the IC's but it must be remembered that their use introduces about 34 non-soldered connections which could cause malfunction of the circuits. However, the ability to remove and change any of the three ICs (without the need to de-solder) probably outweighs this disadvantage.
3. Insert IC3 (check the number carefully so that it is not confused with the 2N3904s which are the same shape) with the flat side in the same position as shown in Fig 6.4, and push it down so that it is standing about 3mm above the surface of the PCB. Solder the leads and clip off the excess.
4. Next, four capacitors, C33, C23, C34 and C39, are fitted. Note that the first two are electrolytic types and must be correctly oriented. They are radial types and the negative lead is normally marked by a strip carrying a '–' sign down the side of the can. Check continually with the layout diagram (Fig 6.4). The capacitors can be pushed down on to the PCB. The other two can be fitted either way round and should be pushed down as far possible. Some adjustment of the lead-out wires may be necessary as various types may have different lead pitch. Note that the above fitting instructions apply to all of the remaining capacitors.
5. Solder the battery connector to the supply terminal pins – the red lead to the positive pins and the black to the negative pins respectively. This is a temporary connection which enables the circuit to be tested progressively as the work proceeds. Check once again that the orientation of IC3 is correct. With an ohmmeter ascertain that there is no short-circuit across the supply terminals, then connect a 9V supply (PP3) to the battery clip. The resistance indicated should be in the order of 30Ω or open-circuit, depending on the connection of the meter. With a DC voltmeter set to a suitable range, measure the voltage between the

Table 6.1. Components list for the 50/144MHz FM receiver

RESISTORS	
R1, 5	56k
R2	560R
R3	270R
R4, 11, 16	10k
R6	470R
R7, 13	47k
R8, 9	1k0
R10	1M0
R12	100k
R14	470k
R15	18k
R17	33k
R18	see text
R19	2R2
All fixed resistors are 0.25W, carbon film type.	
RV1	10k lin slider (Maplin No JM85G)
RV2	10k lin min (Maplin No JM71N)
RV3	10k log min with DPST switch
RV4	1k0 linear min (Maplin No JM69A)
CAPACITORS	
C1, 6, 15	100p
C2, 3, 13	10p
C7, 23	220µ electrolytic radial type
C8, 9, 12, 16, 24, 28, 29	1n0
C10, 11	15p
C14, 19, 20, 21, 26, 27, 30, 34, 37	10n
C17, 33, 35	220p
C18	22p
C22, 25, 32	10µ electrolytic radial type
C31	1µ0 electrolytic radial type
C36	100n
C38	479n
C39	220n
All capacitors are min disc unless otherwise stated.	
SEMICONDUCTORS	
TR1	BFY90
TR2, 3	2N3904
IC1	NE602 (Cirkit, Maplin, JAB)
IC2	MC3359 (Cirkit, Maplin, JAB)
IC3	LM78L05 (Cirkit, Maplin, JAB)
IC4	LM386 (Cirkit, Maplin, JAB)
D1	BB405/105
D2	1N4148
FL1	10.7MHz red spot (Maplin No HX99H)
FL2	CFU455E2 (Cirkit, JAB)
X1	10.245MHz quartz crystal
INDUCTORS	
L1, 2	See text
L3	8½ turn Type 18
L4	TOKO LPC4200A (Cirkit No 35-42001)
MISCELLANEOUS	
PCB	
8Ω speaker, 57mm dia 20mm deep (Maplin No WB09K)	
Two 8-pin DIL IC sockets	
18-pin DIL socket	
Fourteen 1mm pins	
Phono socket, single-hole fixing	
PP3 battery clip	
Case, WB2, 152 × 114 × 44mm (Maplin No LH37S)	
Knob for slider potentiometer (Maplin No YG09K)	
Three 15mm knobs, 6mm	
Two 8mm M2 screws for slider pot	
Two spacers, 4BA nuts or similar	
Six 6BA or M2.5 nuts and bolts	
Small quantity of miniature screened cable and PVC insulated wire	

pin marked 'Ea' on the overlay diagram in Fig 6.4 and the following points: pin 8 on the IC1 socket and pin 4 on the IC2 socket. In each case the voltage should be almost exactly 5V. If it is not, IC3 is almost certainly faulty or reversed. The voltage at pin 6 of IC4 socket should be 9V. Note that, if making these tests on the component side of the board, the pin numbering of the IC sockets starts at 'one' on the right-hand side of the notch and proceeds around the socket in an anti-clockwise direction.

6. Insert C1, C2, C3, C4, C5, C6 and C8, carefully forming the leads so that the capacitors sit as nearly as possible on the PCB. Solder each lead and clip off the excess. R1, R2 and R3 are all mounted flat against the PCB – simply bend the leads at right-angles to the body and they should fit. C7 is a 220µF radial electrolytic and must be connected the correct way. The negative lead is indicated by means of a strip down the length of the case which usually has a '–' sign printed on it. The spacing of the leads is such that the capacitor will sit down on the board.

Next fit TR1 which has a metal can and four leads. It is most important to get the orientation correct. Look again at the overlay diagram in Fig 6.4 and also at the pin connections to the transistor in Fig 6.5. Remember that it is conventional to show the connections from the underside, that is, looking at the pins as they point towards you. The little tab on the case is vital in getting things right. Starting at the

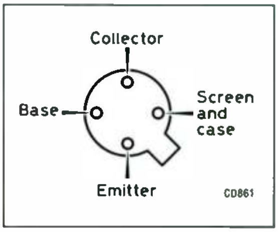


Fig 6.5. The pin connections of a BFY90 viewed from the underside

tab and going around the pins in a clockwise direction, the connections are emitter, base, collector and screen – this last one is connected to the metal can. Look at the foil on the PCB – both the emitter and the screen must go to the earth plane (the large area of copper). Use this as an additional check on the position of TR1. When satisfied that everything is correct, push the transistor down so that it is no more than 3mm above the surface of the board.

The last task in this operation is to wind and fit L1 and L2. Each coil has nine turns of 24 SWG (0.5588mm or 0.022in diameter) wire, close wound on a 3mm drill shank, a 3mm knitting needle or even the round part of a standard terminal screwdriver, although in the last case it may be a little difficult to slide to coil off because the 'business end' will probably be a bit wider than the shaft. About 120mm of wire will be needed for each coil. Refer to Fig 6.6 for the final shape of the coils. Trim the ends to leave tails of 10mm below the bottom of the coils. Unless the wire is self-fluxing, remove the insulation from the last 4mm. A sharp knife is usually the best way to do this. It is worth a little extra time to ensure that the ends show bright copper all the way round. Tin the cleaned surfaces and then slide off the mandrel. Insert the coils in the position shown in the overlay diagram. The coils need to be approximately at right-angles to one another to reduce the amount of inductive coupling between them and should stand off the board by about 4mm. Do not be tempted to mount the coils close to the board because the spacing of the turns will need to be adjusted later.

7. This part of the construction can only be carried out if a signal generator covering 50MHz is available. Alternatively it is possible to use a dip oscillator connected as shown in Fig 6.7. The dip meter should not be used by holding its coil close to L1 as energy will also be picked up by L2. The dip meter needs to be enclosed in a metal box and the coupling made by means of a one-turn coil. The piece of coaxial cable enables the meter to be operated at some distance from the receiver. It must be emphasised that this is not a very reliable method of obtaining an input signal. In addition an RF diode probe and preferably a digital voltmeter will be required. The construction of a diode probe is described in Appendix 1 and such a probe is a very useful and simple tool to make. If these items are not available proceed to section 8. It must be emphasised that setting up will be much easier if the above items can be borrowed.

Connect the output of the signal generator to the pins marked 'Ae' and 'E' with the outer of the feed cable connected to E. Select the range on the signal generator so that 50MHz is available. Set the output of the generator to about 100mV. With the 9V supply not connected carry out the following test. Plug the leads from the probe into a digital voltmeter

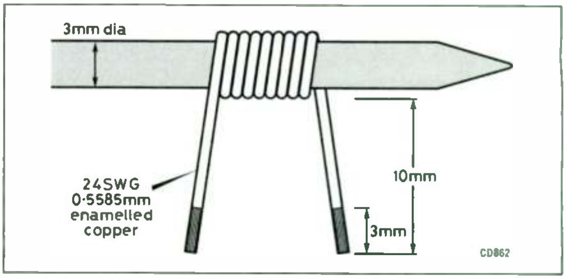


Fig 6.6. Winding L1 and L2 on a 3mm mandrel

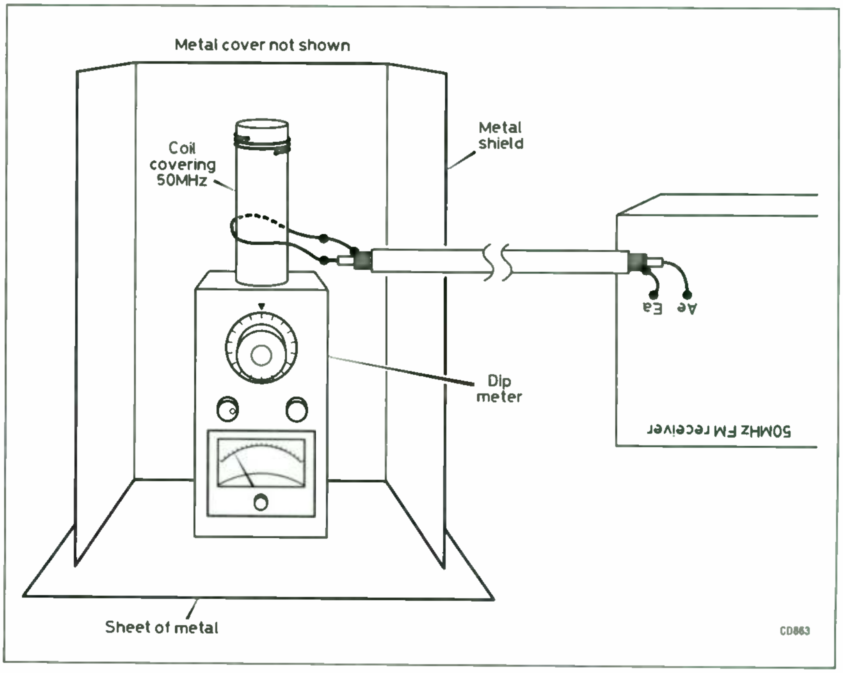


Fig 6.7. Using a 'dip' meter as a substitute for a signal generator

(DVM) and switch to the lowest DC voltage range. Switch the DVM on. Connect the flying lead of the diode probe to any convenient 0V point, switch on the signal generator and touch the point of the probe to the Ae pin. This is to ensure that the signal generator is giving an output. Transfer the probe to the end of R1 nearest to L1 and, while holding the probe in position, slowly change the frequency of the generator to obtain a maximum reading on the DVM. Check the frequency output of the generator from the dial setting. If the frequency is near to 50MHz carry on to the next test. However, it is more likely that the maximum will occur at some lower frequency. Gently pull the turns of both L1 and L2 slightly apart then do the test again. Continue until the maximum output as indicated by the probe and DVM occurs at about 50MHz. It may be necessary to remove one turn from each of the coils L1 and L2 to achieve the above result. The band-pass circuit is now aligned.

Connect the 9V supply to the PCB and test the RF voltage at pin 1 of the holder for IC1. The voltage should be several times higher than the input, indicating that TR1 is amplifying. If this result is not obtained, check the position of TR1 and the values of R1 and R2 very carefully. The DC voltage between collector and 0V should be in the order of 3V, and about 0.7V at the base.

8. In this step the additional components required to complete the VFO (variable frequency oscillator) inside IC1 are fitted. Install resistors R4, R5, R6, R9 and R10 – in each case bend the wires at right-angles to the body and fit close to the PCB. Solder and trim the excess leads. Follow with capacitors C9, C10, C11, C12, C13, C14 and then C22 which is an electrolytic so ensure the correct orientation. All capacitors should be mounted as close to the PCB as possible – adjust the lead-out wires as necessary. Next fit D1 – this may be either a BB105 or a BB405. Obtain the latter if possible – both will do the job correctly but the BB105 has very short leads which will only just protrude through the holes in the PCB. In either case the polarity must be observed with the band pointing towards the centre of the board. Refer to Fig 6.4 for confirmation of position. TR2 can now be fitted, although it will be inoperable for the next test as its base will be open-circuit. Make sure that the flat is in the same position as shown in Fig 6.4. L3 completes the fixed components in this step. Check that it has eight and a half turns on a white former, then note the small ridge which runs down one edge and mount the coil so that this ridge is towards the edge of the board. It is important that the coil should be fitted as tightly as possible to the PCB as this helps to ensure the frequency stability of the oscillator. Push the coil down as far as it will go and then solder one pin. Check that it is firm – if not, melt the solder while pushing the coil down. When satisfied, solder the other pin.

   Before the oscillator can be tested RV1 must be temporarily connected. The easiest way to do this is to use the 10kΩ potentiometer which will eventually be RV2 and solder it directly to the three pins on the PCB so that the spindle points outwards. The control will work the wrong way round but it doesn't matter at this stage. Finally insert IC1. The pins are normally splayed and should be bent inwards until they are parallel. Do this by holding the IC with the pins resting on a flat surface and bend the body so that all four pins are bent. Repeat with the pins on the other side. Before inserting the IC it is advisable to gently push an ordinary pin into each of the sockets in the IC holder to ensure that the individual sockets are not too tight. When satisfied, check both the number on the top of the IC (because IC4 is the same shape) and the position of the notch which must be in the position indicated in Fig 6.4. Locate all pins in the holder sockets and gently push the IC down without using too much force – if it won't slip in, check the pin alignment and the sockets again. RV4 and R18 will not be fitted until later.

9. If a frequency meter is available, now is a good time to set the VCO within IC1. Using the correct trimming tool, adjust the core of L3 so that it is level with the top of the coil former. Note: do not use any other tool for this purpose as it will almost certainly break the very brittle core and the presence of a metal trimmer will upset the frequency. Connect the input to the meter across R4, set the temporary RV1 to approximately its central position and connect a 9V supply to the battery clip. The frequency meter should register something in the region of 60MHz. Adjust the core of L3 until a frequency of 62.7MHz is obtained. Don't worry about a precise setting at this stage as things will alter when TR2 becomes operative later. Any receiver which covers 62MHz could be used in the place of the frequency meter and a strong heterodyne will be heard when the correct frequency is obtained. If neither of these aids are available the above adjustment will have to wait until the receiver is completed. If you have made the RF diode probe it could be used to verify that the oscillator in IC1 is working. With the tip of the probe at pin 7 a well-defined reading should be obtained. If no indication is present check the position of IC1 and its location in the holder. Also check all components installed while following section 8, especially the orientation of D1.

10. Now fit the following resistors – the actual order

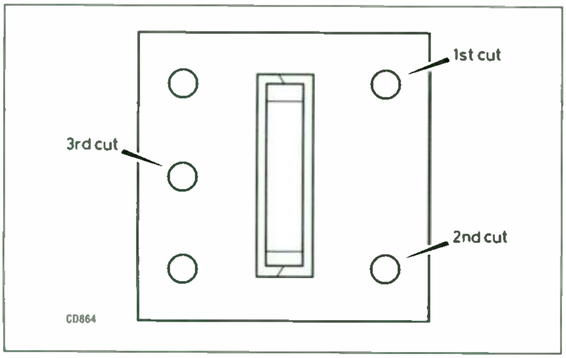


Fig 6.8. The order of 'cutting out' the pins from L4

doesn't matter but beginners would be advised to adopt this order: R9, R10, R7, R8, R13, R11, R12, R14, R15, R16 and R17. Follow with capacitors C16, C17, C18, C21, C19, C20, C15, C27, C28, C29, C30, C26 and C24. Electrolytic capacitors C31 and C25 must be fitted the correct way round. Filter FL1 has three pins and can be fitted either way round. Filter FL2 has three staggered pins which are rather flimsy so take care when fitting this component. The position of the holes is so critical that a small variation in drilling can make it difficult to fit this component so that it sits down on the PCB. Increasing the size of the three holes just a little using a round needle file or a slightly bigger drill will solve the problem. L4 has five pins and, in order to fit the component, three of these need to be cut out. Refer to Fig 6.8 and take care to cut the redundant pins in this order: pins 4 and 6 followed by the central pin 2 on the other side. If this pin is removed first it will be difficult to decide which of the remaining pins need to be cut. Cut the pins as close as possible to the base of the coil can. Push the can right down to the PCB, then solder the two active pins and the larger earth pins to the screening can. The crystal should be mounted close to the board and can be fitted either way round. D2 must be correctly oriented – if it is not, the squelch circuit will not work correctly. Finally fit TR3, carefully observing the position of the flat as indicated in Fig 6.4.

This completes the RF sections of the receiver.

11. The AF amplifier is completed as follows. Fit R19, C36 and C37. Fit C35 which is an electrolytic capacitor and which must be fitted the correct way round. Capacitors C32 and C38, both electrolytics, are not required at this stage.
12. The receiver can now be tested but final adjustments will be made after boxing up. Examine the PCB very carefully to ensure that there are no short-circuits caused by excess solder. This is especially important in the regions where the solder pads are close together, such as the IC holders and TR1. The volume control should be connected by means of two pieces of screened lead about 200mm long (this is greater than the length required and will be shortened when the receiver is boxed up). The outer of one piece is soldered to the pin nearest to L4 of the RV4 pair and is taken to the right-hand pin of the control when viewed from the spindle with the terminals on top. Refer to Fig 6.9 to verify these connections. The second piece is used to connect the centre pin of RV3 to the pin marked 'RV3 slider' with the outer soldered to the pin marked 'Screen'. RV2 is not used at this stage but the centre of the three pins marked 'RV2' is connected to the pin nearest to the crystal using a short piece of tinned copper wire. Connect an 8Ω loudspeaker to the pins marked 'Spkr' using a pair of PVC-insulated conductors twisted together. Insert IC2 and IC4 using the same technique as described for IC1, carefully observing the position of the notch. Connect an antenna (a 50MHz dipole if possible) to the pins marked 'Ae' and 'Ea'. Turn RV3 fully anti-clockwise and connect a 9V supply to the battery clip. Advance RV3 – some noise should be heard. Adjust the core of L4 for maximum noise. If you are lucky a station may be heard when the tuning control RV1 is adjusted – if not, either the signal generator or a friendly amateur with a 50MHz transmitter will be required. Check that the range 50 to 52MHz can be covered when RV1 is turned from one end of its travel to the other.
13. Now for boxing up the project. The following description assumes that the listed box is to be used and any other will need some modification to the layout etc. Fig 6.10 gives the marking out detail. Because the cover has a lip which covers part of the two sides at the top edge it is important to use the top and left-hand edges for reference when making any measurements. The only problem will be the slot for the tuning potentiometer RV1. For this a thin file known as a 'warding file' is required. It is about 2mm thick and is given the name because it is sometimes used in key cutting. The box base has a protective covering of thin polythene to help to prevent scratching. Do not remove it yet. To make it easy to mark the various drilling points use this dodge. Make a mark 25mm from the top edge at each end of the front panel. This will be covered by the lip in the cover. Fix a piece of PVC sticky tape between the two marks so that it makes a removable line across the front of the box. Mark off on the tape the positions of the various holes according to the dimensions given in Fig 6.10. When it is certain that the marks are in the correct

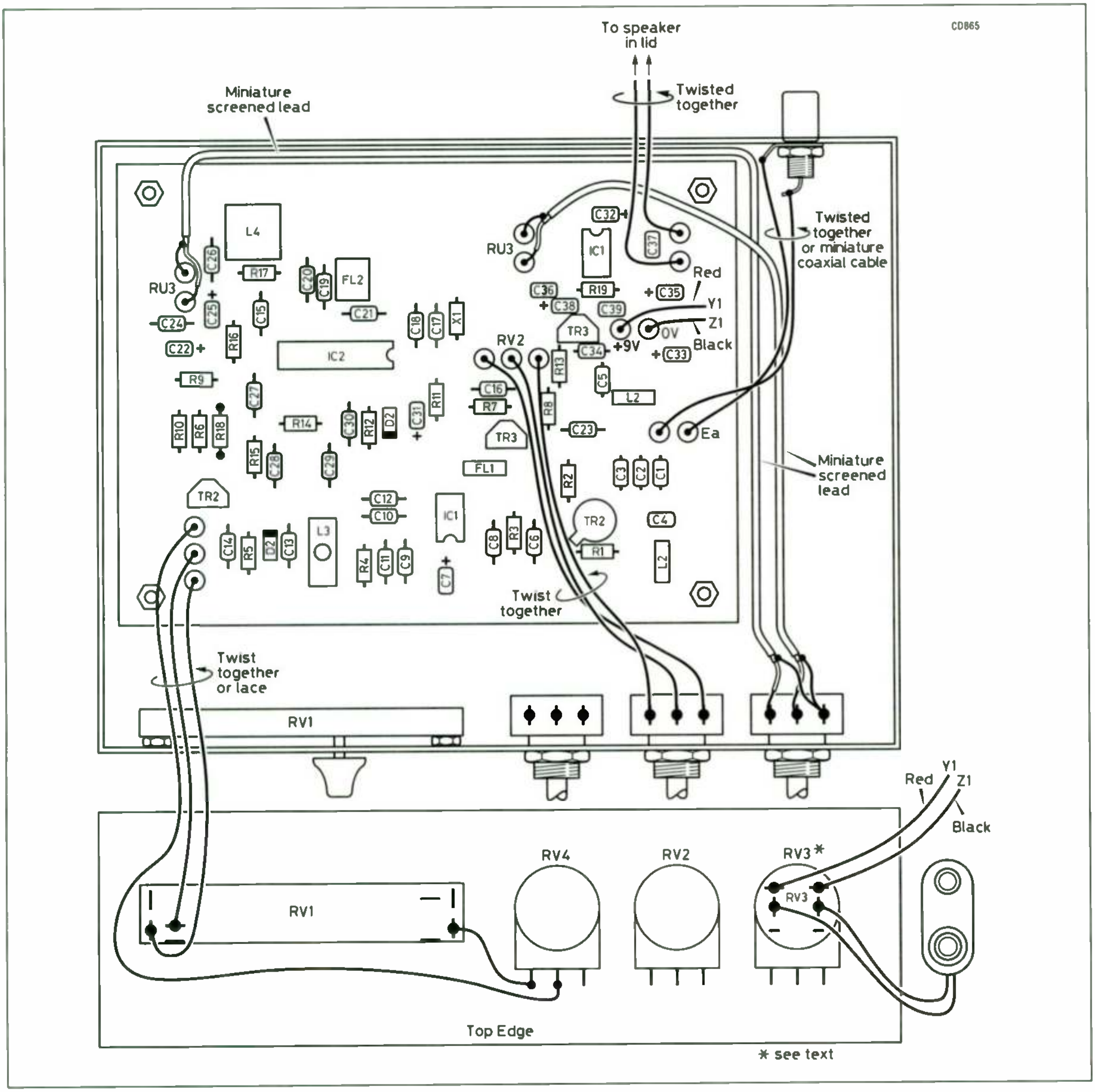


Fig 6.9. Interconnections between controls etc and the PCB

position make a deeper dent by using a centre pop, while supporting the inside of the box base on a flat surface such as the edge of the bench or table. Refer to the section on drilling holes in Appendix 1 for more information if required. Five holes are needed: two for the slider potentiometer and one each for the other three controls.

Drill the four fixing holes for the PCB (3mm) – these should have been marked in the box before any components etc were fitted to the board. Drill pilot holes for the three rotary controls and also for the antenna socket in the rear panel. These four holes should be enlarged to 8mm (or to the appropriate size if non-standard controls are to be used). Remove the burrs from the back of the holes. This may be done using a larger drill bit rotated between the fingers or by means of a sharp modelling knife.

The slot for the slider control must be made with great care and lots of patience. Start by drilling the two 3mm fixing holes – then, 3mm from one fixing

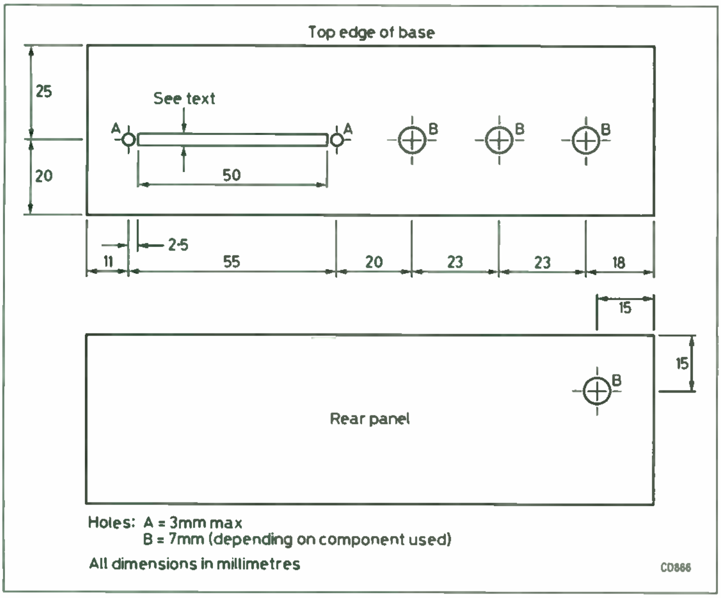


Fig 6.10. Drilling and cutting detail of front and rear panels

hole, centre pop about six points along the centre line and as close as possible to 2mm apart. Using a 1.5mm or 2mm drill bit, drill these six holes. By means of a sharp modelling knife, cut the web between the holes and pare the metal away so that a flat needle file can be inserted in the slot. File the slot until a standard hacksaw blade can be inserted. Release the blade from the hacksaw, pass it through the slot and reconnect the blade into the hacksaw frame. Hold the box firmly and, using a sloping cutting angle, cut through to the other end of the required slot. Take care not to cut too far – it is better to stop short and file to the end of the slot when the slot is almost complete. Remove the hacksaw blade and reassemble the saw. Now, using the warding file, carefully open up the slot following the saw cut just made. Ensure that the ends of the slot are about 1.5mm from the two fixing holes. Remove the burr from the edges of the slot by careful use of the modelling knife. Cut the spindles of the three rotary controls to about 10mm from the threaded bush. Reduce the length of the tang of the slider control to 10mm and file the width so that the knob just slides on. Fit the slider control using two M2 bolts which will need to be shortened to about 8mm. Two spacers are required to keep the body of the control away from the panel – 4BA nuts or similar will do the job quite well. Make sure that the tang of the slider can move freely, then tighten the screws. Next fit the three rotary potentiometers. The volume control together with the on/off switch is fitted at the right-hand end of the row. The antenna socket can be fitted to the back panel.

The PCB should now be fitted into the box. Four 12mm 6BA or M2.5 bolts are required – they are passed through the holes in the bottom of the case and secured with the appropriate nuts. Add an extra nut to each and adjust the level so that the copper side of the PCB is clear of the floor of the box. When all is well, place the PCB in position and fix with a further four nuts which should be tightened securely.

Refer to Fig 6.9 to make the interconnections between the PCB and the various controls. Use the screened leads already used to connect the volume control, shortening them as required. Allow the leads to lie along the edge of the board, not crossing it diagonally. The wires to RV1 and RV4 should be neatly bunched and it will make a neater job if they are laced together as shown in the photograph in Fig 6.11. A simple clip to secure the battery is made from a piece of tin-plate bent into a U shape and bolted to the box on

Fig 6.11. The PCB fitted in the box

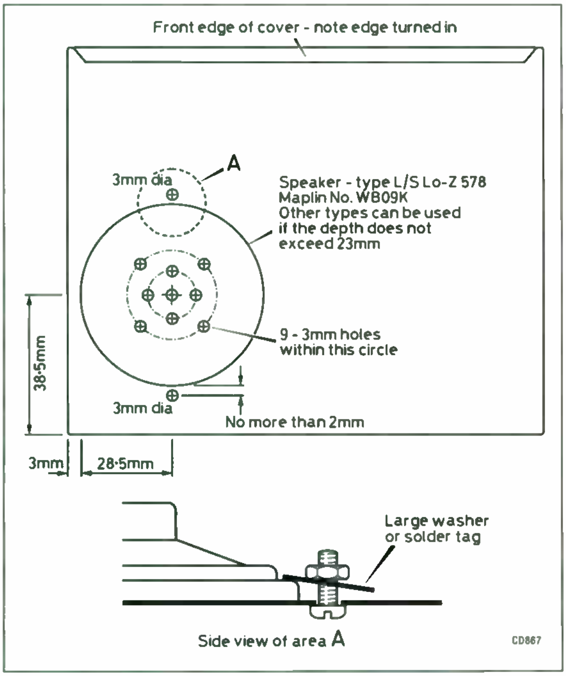


Fig 6.12. Fitting the speaker inside the cover

the right-hand side of the PCB. The antenna and earth pins can be connected by means of two short pieces of PVC-insulated wire, lightly twisted together, but if preferred a short length of coaxial cable can be used. The use of a volume control with a double-pole switch makes the connection of the battery simpler and tidier. There are many different types of switch on the back of suitable potentiometers. Fig 6.9 shows just one type. An ohmmeter should be used to verify the switch connections of the component to be used. Solder the leads to the battery clip to the switch and use twisted red and black leads to the power supply, taking care to check that the polarity is correct.

The small 8Ω loudspeaker is connected with PVC-insulated leads twisted together and long enough to allow the speaker to be laid in the cover while the latter is lying to one side of the box. Drill nine 3mm holes in a group in the position marked in Fig 6.12. Also drill the two speaker fixing holes. The speaker is held in position by means of two M2.5 screws and washers – if the holes have been drilled accurately the washers will lock the speaker in place.

The connection to the antenna in the prototype is by means of a single-hole-fixing phono socket – this may be replaced by any other type of socket to match any plugs that are already fitted to suitable antennas.

The 144MHz option

L1 and L2 are wound on a 3mm mandrel but consist of only two turns. They should be spread out so that the coils are about 4–5mm long. C4 and C5 are 37pF and L3 is a type 18 two-and-a-half turn coil. All other fitting instructions are the same as for the 50MHz version. Use the same techniques to adjust the spread of the coils L1 and L2. Keep repeating the adjustments until the maximum output is obtained at pin 1 of IC1 when the input frequency is 145MHz.

Testing and setting up

Provided that the initial adjustments to L1 and L2 have been made earlier, these procedures apply equally to either option.

Check all of the interconnections to ensure that they are correctly connected and that all joints have been satifactorily soldered. Set the volume and squelch controls fully anticlockwise and the fine tuning about mid-travel. Once again, use an ohmmeter to ensure that there is no short-circuit across the PP3 battery connector. Connect a battery (as always, a rechargeable type will prove much more economical after the initial outlay – very often no more than about three times that of the high-quality ordinary types).

Switch on and advance the volume control until some noise is heard in the speaker. Using the correct trimming tool, adjust L4 for maximum noise. If the VCO has already been set as described in section 9, the radio should now be able to receive some signals. The activity on 50MHz is quite low in some parts of the country and it may be necessary once again to use either a signal generator or dip meter set to about 51MHz. Carefully move the tuning slider from one end to the other – the presence of any signal will probably be indicated by a break in the noise. If such a break occurs, use the fine-tuning control to resolve any modulation which may be present. The signal from a dip meter is not modulated so there is no point in spending too much time if one is being used. Some signal generators have an FM facility and this should be used if available. If no signal appears to be present it is almost certain that the VCO is not tuned to the correct frequency. Also check the second oscillator in IC2.

A general-coverage receiver tuned to 10.24MHz, placed close to the PCB, will produce a strong whistle as it is tuned through 10.24MHz.

If the 144MHz option has been followed, a 144MHz band antenna will almost certainly provide some signal – in some areas the repeaters are very busy and provide very useful signal sources.

Reduce the coverage of the band to a little more than 50 to 52MHz or 144 to 146MHz, depending on the option

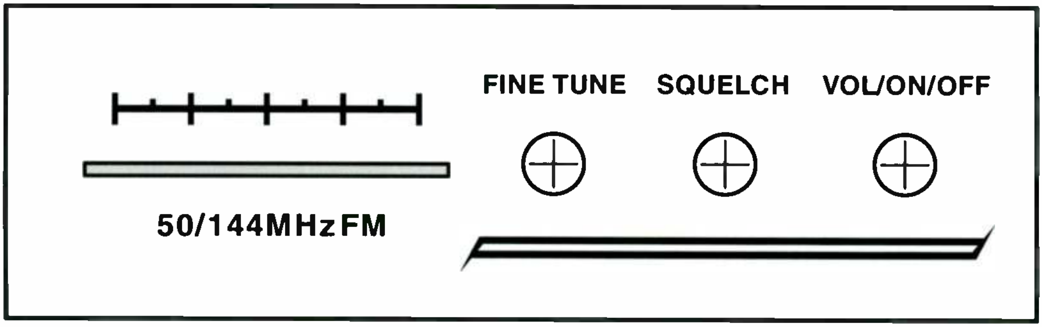


Fig 6.13. Front panel trim (full-size) as used on the sample in Fig 6.1

chosen. This is carried out by selecting the value of R18 which is soldered across the two pins fitted at the beginning of the construction. The value used in the prototype was 1.5kΩ. Remember that the setting of the core of L3 will need to be adjusted when the resistor is added and will probably need to be screwed in about half a turn. A signal generator is needed if an accurate setting is required but it is generally sufficient to make use of a helpful amateur with a 50MHz or 144MHz transceiver.

The final touch is the addition of the front panel trim. This can be a copy of the one shown full-size in Fig 6.13. The method of fixing is described fully in Chapter 5. The four controls need to be released from the front panel just enough to allow the holes to be cut in the trim, using the slot and three holes of the rotary controls as a guide after the trim has been glued on.

The actual calibration marks can be made once their position has been finally determined. Add marks for 50MHz, 51MHz, 52MHz and at 51.51MHz, the calling frequency. If the 144MHz option is adopted, make calibration marks at 144MHz, 145MHz, 146MHz and the output of the local repeater.

For more advanced constructors who may wish to experiment further with this versatile IC, here is some useful information on the MC3359 (extracts from the Motorola Advance Information Sheet). Fig 6.14 refers. Our thanks are due to Messrs Motorola for permission to use the data.

MC3359 circuit description

The MC3359 is a low-power FM IF circuit designed primarily for use in voice-communication scanning receivers.

The mixer-oscillator converts the input frequency (eg 10.7MHz) down to 455kHz where, after external bandpass filtering, most of the amplification is done. The audio is recovered using a conventional quadrature FM detector. The absence of an input signal is indicated by the presence of noise after the desired audio frequencies – this 'noise band' is monitored by an active filter and a detector. A squelch-trigger circuit indicates the presence of noise (or a tone) by an output which can be used to control scanning. At the same time, an internal switch is operated. This can be used to mute the audio.

The oscillator is an internally biased Colpitts type with the collector, base and emitter connections at pins 4, 1 and 2 respectively. A crystal can be used in the place of the usual coil.

The mixer is doubly balanced to reduce spurious responses. The input impedance at pin 16 is set by a 3.6kΩ

Table 6.2. Electrical characteristics of the MC3359

Characteristic	Pin	Min	Typ	Max	Unit
Drain current	—	—	4	—	milliamps
Squelch off	—	—	3.0	6.0	milliamps
Squelch on	—	—	4.0	7.0	milliamps
Input limiting voltage (–3.0dB limiting)	18	—	2.0	6.0	microvolts
Output voltage at AFC balance	10	2.4	3.4	4.4	volts DC
Recovered audio output voltage (V_{in} = 3.0mV)	10	450	700	—	millivolts RMS
Filter gain (10kHz) (V_{in} = 5.0mV	13	40	—	—	decibels
Mute switch resistance (I_{test} = 2.5mA)	16	—	4.0	10	ohms
Scan source current (Mute off, V15 = 0)	15	2.5	—	—	milliamps
Mixer conversion gain (Fig 6.14)	3	—	28	—	decibels
Mixer input resistance	18	—	3.6	—	kilo-ohms
Mixer input capacitance	18	—	2.2	—	picofarads

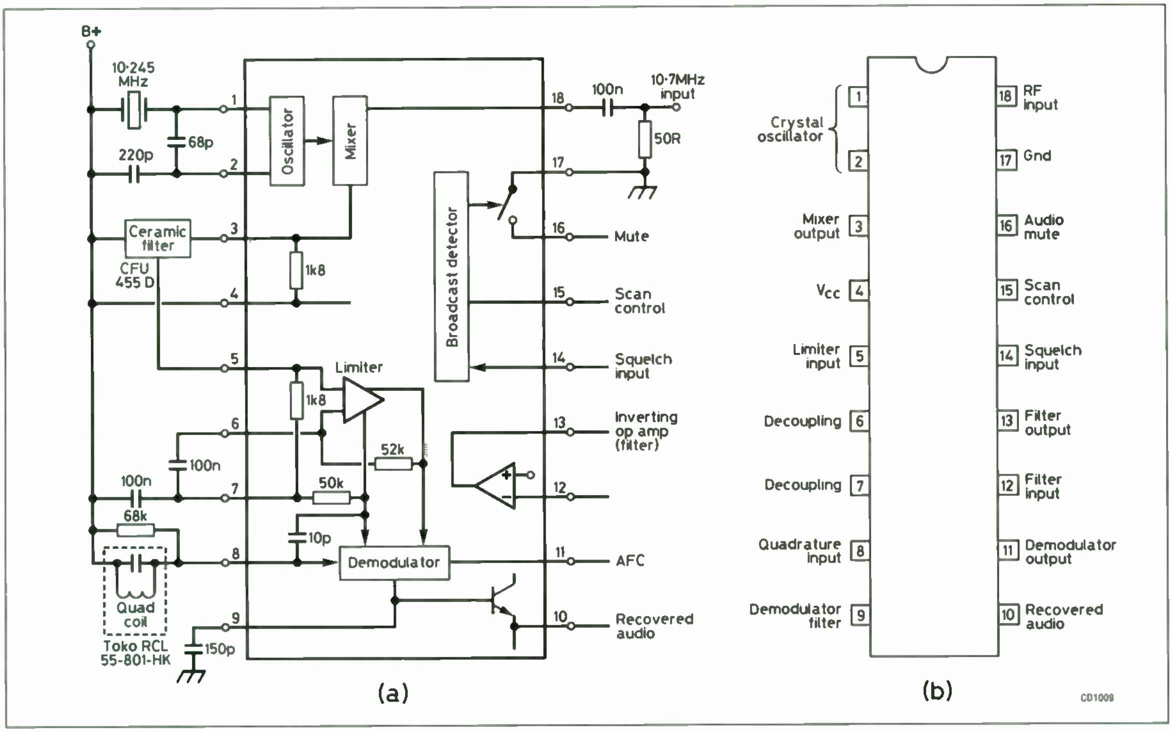


Fig 6.14. MC3359 functional block diagram (a) and pin connections (b)

Table 6.3. Maximum ratings of the MC3359

Rating	Pin	Symbol	Value
Power supply voltage	4	V_{cc} (max)	12V DC
Operating supply voltage range	4	V_{cc}	4 to 9V DC
Input voltage (V_{cc} > 6.0V)	18	18	1.0V RMS
Mute function	16	V16	–0.5 to 12V peak
Junction temperature	—	Tj	150°C
Operating temperature range	—	Ta	–30 to +70°C

internal biasing resistor and has low capacitance, allowing the circuit to be preceded by a crystal filter. The mixer output at pin 3 has a 1.8kΩ impedance to match an external ceramic filter.

After suitable band-pass filtering, the signal goes to the input of a six-stage limiter at pin 5 whose impedance is again 1.8kΩ. The output of the limiter drives a multiplier both directly and through a quadrature coil, in order to detect the FM.

An external capacitor at pin 9 can combine with the internal 50kΩ resistor to form a low-pass filter for the audio. The audio is delivered through an emitter follower to pin 10, which may require an external resistor connected to ground to prevent the signal from rectifying with some capacitive loads.

Pin 11 provides AFC (automatic frequency control). If AFC is not required, pin 11 should be grounded or it can be tied to pin 9 to double the recovered audio.

A simple inverting op-amp is provided with an output at pin 13 providing DC bias (externally) to the input at pin 12, which is referred internally to 2.3V. A filter can be made with external impedance elements to discriminate between frequencies. With an external AM detector, the filtered audio signal can be checked for the presence of either noise above the normal audio band, or a tone signal. The result is applied to pin 14.

An external negative bias to pin 14 sets up the squelch trigger circuit such that pin 15 is high, at an impedance level of about 2.5kΩ, and the audio mute (pin 16) is open-circuit. If pin 14 is raised to 0.7V by the noise or tone detector, pin 15 will go open-circuit and pin 16 is internally short-circuited to ground. There is no hysteresis. Audio muting is accomplished by connecting pin 16 to a high-impedance ground-reference point in the audio path between pin 10 and the audio amplifier.

Chapter 7

The 'Super 7' – a simple receiver for the 7MHz band

The 7MHz (40m) band is a most useful one, as it enables communication to be established when the higher frequencies are virtually unusable due to atmospheric conditions being unfavourable. Many UK stations can be heard during the daytime and after the Sun sets stations from all over Europe can be received. It is a very narrow band, covering only 100kHz from 7.0 to 7.1MHz, and has one serious drawback – it is 'next door' to a popular broadcast band (41m) containing a number of high-power stations.

Fig 7.1. The Super 7 receiver

This design by Paul Lovell, G3YMP, was originally made for publication in *D-i-Y Radio* and appeared in the March-April 1994 edition, Vol 4, No 2. While the design is unaltered, the text has been completely rewritten in order to cover the circuit description and some aspects of construction which did not appear in the original article. Also, a new PCB has been designed as the original used the PCB (with a number of modifications) from a similar design – the D-i-Y Radio Yearling. The finished receiver is shown in Fig 7.1.

The design is different to all of the others so far described. It is a combination of a superheterodyne and a direct-conversion (DC) receiver. Fig 7.2 shows a block diagram of the receiver. The blocks to the left of the dotted line form the front end of a superheterodyne. The first mixer is fed from the antenna via a filter which can pass the narrow band of wanted signals and a fixed-frequency (crystal-controlled) oscillator operating at a frequency of 4.608MHz. The output of the first mixer will contain signals in the range 2.392 to 2.492, the difference between the input at 7.0 to 7.1 and the oscillator frequency of 4.608MHz. The blocks to the right of the dotted line make up a standard direct-conversion (DC) receiver with the filter at the front end centred on the band of frequencies from the first mixer. In other words, the DC receiver gets its signals from the output of the first mixer instead of from an antenna.

Circuit description

Fig 7.3 is the circuit diagram which shows the above features in greater detail. RV1 serves as the gain control and is linked mechanically with the on/off switch. This rather unusual position for a gain control is used in an attempt to avoid overloading of the first mixer in IC1 by the strong broadcast signals from the nearby broadcast band. The secondary of L1 is tuned by C1 to the centre of the input band – 7.05MHz. Because the damping of the antenna and the input of IC1 is reduced by a step-down ratio of the primary of L1 and the tap on the secondary, the

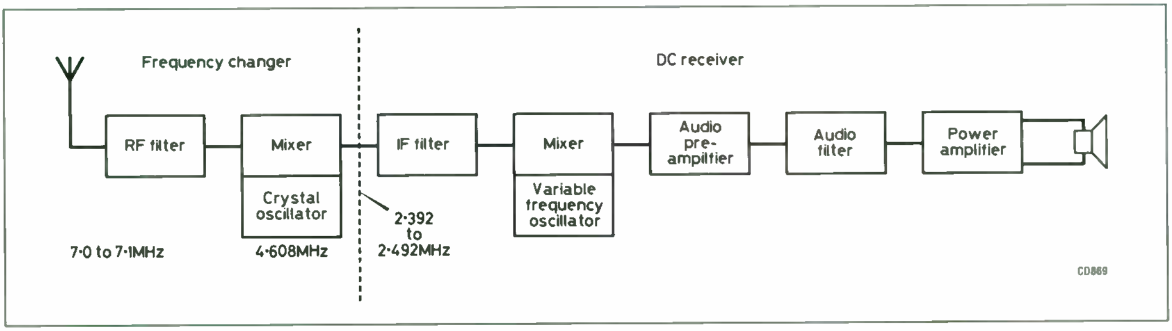


Fig 7.2. Simple block diagram of the Super 7

circuit Q is high and consequently the bandwidth is rather narrow. This allows the wanted signals to pass and most of the unwanted ones will be attenuated. The signals in the amateur band are passed to the first mixer within IC1.

The oscillator portion of IC1 is tuned by the quartz crystal X1 and the combination of C3 and C4, together with the circuit elements in IC1, form a stable oscillator having a frequency of 4.608MHz. The signals from L1 are mixed with the oscillator output and the sum and difference signals appear at the output of the mixer. The primary of L2 is tuned by C5 to 2.442MHz which is in the centre of the band of difference signals from the output of IC1. The sum frequencies are rejected, as are most of the out-of-band signals. It must be remembered that the bandwidth of the receiver at this point is still great enough to pass any of the signals within the 7.0 to 7.1MHz band – these will include the amateur stations.

IC2 and the additional components constitute the direct-conversion part of the receiver. The signals from the secondary L2 are passed to the second mixer inside IC2. The oscillator portion of IC2 (the variable frequency oscillator – VFO) is tuned by L3 and the resultant capacitance of C8, C11, C9 and the variable-capacitance diode D1. The capacitance of D1 is determined by the DC voltage applied across it and this voltage can be varied by the settings of RV3 (the coarse tuning control) and RV2 (the fine tuning control). The value of C9 has been chosen to restrict the range of the oscillator to a little over 2.392 to 2.492MHz.

When the frequency of the VFO is almost equal to a wanted signal at the input of IC2 (pins 1 and 2) AF signals will appear at the output of the second mixer at pins 4 and 5. These AF signals are amplified by IC4a before being applied to a low-pass filter, having a cut-off frequency of

Table 7.1. Components list for the Super 7

RESISTORS

R1, 4	100k
R2, 3	1k5
R5	220R
R6, 7	12k
R8	10k

All resistors are 0.25W, 5%.

RV1	4k7 linear variable with switch
RV2	4k7 linear variable
RV3	47k linear variable

CAPACITORS

C1	470p polystyrene, 5% or better
C2	47µ electrolytic
C3	47p polystyrene, 5% or better
C4, 5	100p polystyrene, 5% or better
C6, 7	100n ceramic
C8	2n2 polystyrene, 5% or better
C9, 10	1n0 polystyrene, 5% or better
C11, 14	10n ceramic
C12	470µ electrolytic
C13	47n ceramic
C15	1000µ electrolytic
C16	1µ0 electrolytic

All capacitors are rated 16V or more.

INDUCTORS

L1	TOKO KANK3335R (pink)
L2	TOKO KANK3333R (red)
L3	10µH 5% tolerance (eg TOKO 283AS-100)

SEMICONDUCTORS

IC1, 2	Philips NE602 or NE603A
IC3	78L05 5V 100mA regulator
IC4	TL072 dual op-amp
IC5	Philips TDA7052 audio amp

Varicap diode, TOKO KV1236, dual – one half used

MISCELLANEOUS

Crystal, 4.608MHz
2 silver knobs, 2mm dia approx with pointer
Plastic case
Speaker, between 8 and 30Ω
8 pin DIL sockets for IC1, 2, 4 and 5
4mm antenna (red) and earth (black) sockets
3.5mm chassis-mounting speaker socket
DC power socket (if required)
Tuning knob with pointer, eg 37mm
Printed circuit board

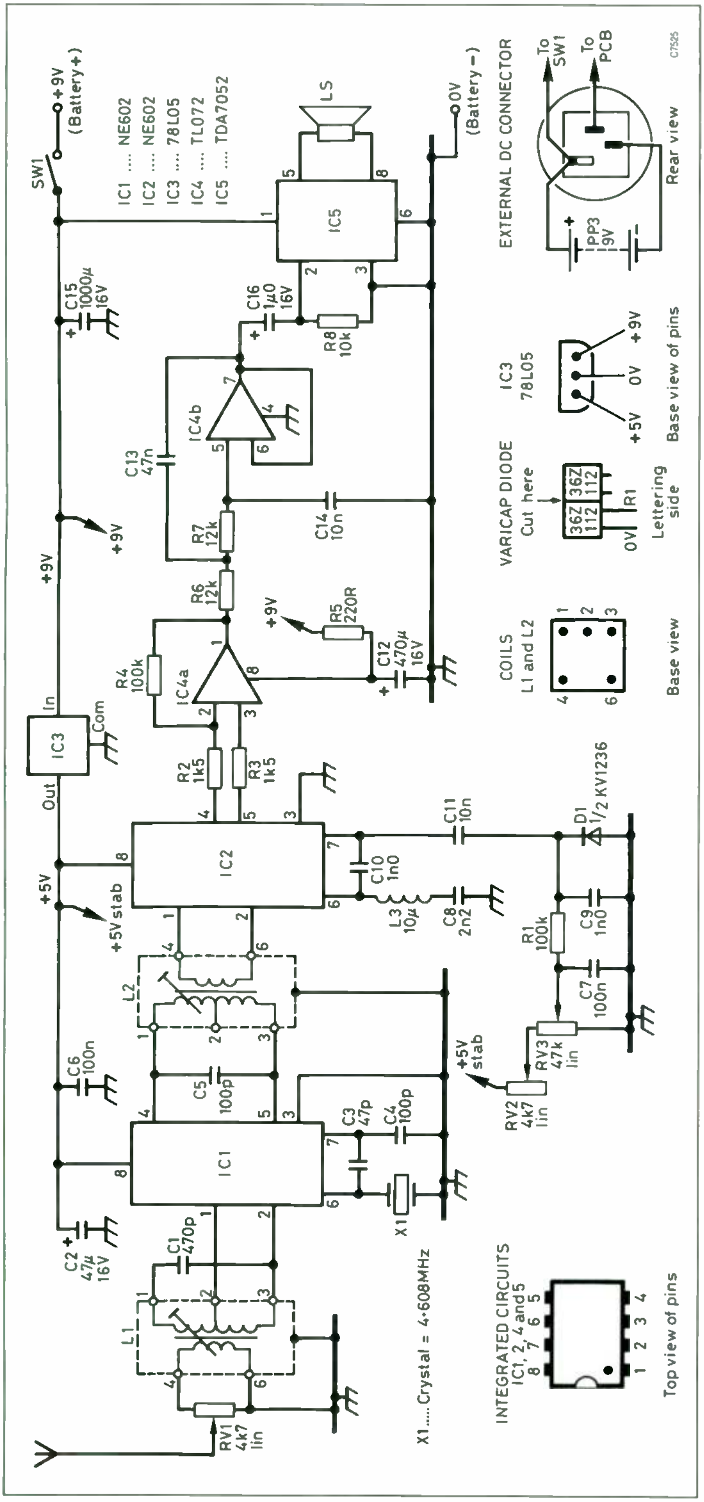


Fig 7.3. The circuit diagram

about 3.0kHz, formed by IC4b. This removes the higher audio frequency signals which are normally caused by adjacent channel stations. It is this filter which gives the DC receiver its selectivity.

IC5 is a low-power AF amplifier which can deliver about 350mW of AF to a loudspeaker.

Construction

A very comprehensive kit of parts for this receiver, including a case and a small loudspeaker in a cabinet, is available from JAB Electronics (address in Appendix 3). In 1996 the cost of the kit is £35.95 but with a little ingenuity the cost can be reduced to just about £15 or even less if the PCB can be produced at home. Alternatively the receiver can be built on prototype board (Veroboard) but considerable work will need to be done on the layout and should only be undertaken if some experience in the use of this type of board has been acquired.

Make a start by marking the PCB fixing holes in the bottom of the box. As always, this job is much easier if done before any components are fitted. Almost any box having dimensions of 120mm × 100mm and 50mm deep or greater will do. The one used for the prototype was a Tandy type 270-232 which was at hand. It is a plastic box with a metal lid, held in position by four self-tapping screws. The three controls are mounted on the lid, while the PCB, power socket and antenna socket are all mounted in the box itself. These details are given here merely to emphasise that any box with similar dimensions can be used.

The foil pattern of the PCB is shown full-size in Fig 7.4 and some useful information about making PCBs can be found in Appendix 2. Again it is worth bearing in mind that a home-made PCB not only makes the unit cost less but gives the additional satisfaction of 'making it all'.

Fig 7.5 shows the layout of the components and must be consulted whenever components are inserted.

1. Fit the three wire links in the positions indicated by a dotted line in Fig 7.5. Off-cuts from resistors are most

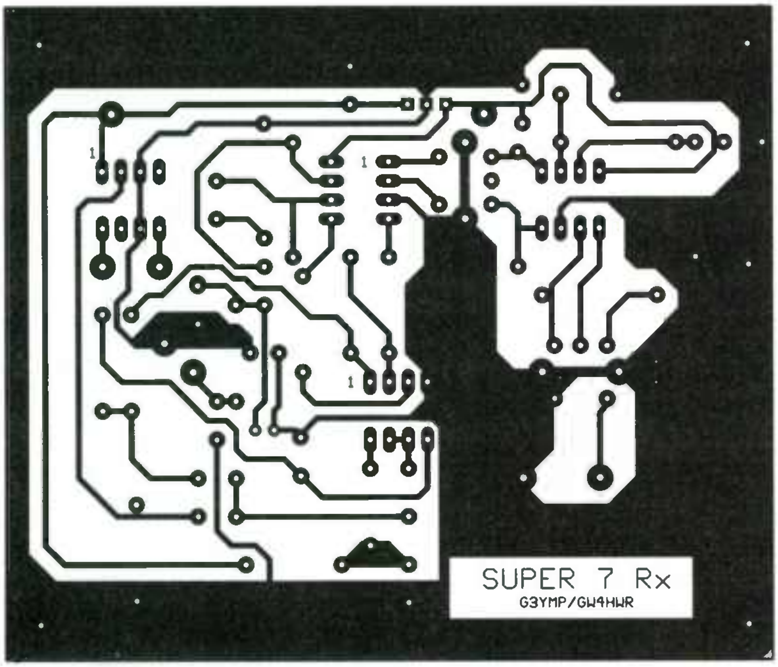


Fig 7.4. The foil pattern of the PCB – full-size

suitable for this. Bend them into the shape of a staple to fit the hole spacing. It is important that the links lie flat on the surface of the PCB.

2. Insert nine panel pins, from the track side of the PCB, in the positions indicated in Fig 7.5 by an 'O'.
3. It is suggested that the larger components are fitted next as it makes it easier to determine the position of the smaller ones later.
4. Fit the three IC holders, ensuring that the notch at one end coincides with that in the layout diagram in Fig 7.5. Do not use too much solder as there is a possibility of a solder bridge being created between adjacent pads on the PCB.
5. L1 and L2 are fitted so that the coil can sits down on the PCB. Note: L1 has a pink border around the core while L2 has a red one. When soldering these (and all components) ensure that the holes in the pads are filled but again be careful to avoid solder bridges.
6. The four electrolytic capacitors C2, C12, C15 and C16 should now be inserted, with care being taken to ensure that the correct polarity is observed. Note the '+' sign on the layout diagram.
7. Follow with the remainder of the capacitors in the most convenient order.
8. The eight resistors are all mounted horizontally with a 12mm pitch which means that the leads should be bent just a little way from the body. Again the most convenient order of fitting can be used.
9. The varicap diode D1 is half of a KV1236. Lay the diode on a hard surface and cut along the grove with a sharp modelling knife. With the lettering upright and facing, the 0V lead is on the left. Refer to the inset in Fig 7.2 if there is any doubt. Fit so that the diode stands about 4mm above the surface of the PCB with the lettering facing R5. The crystal X1 should be fitted with similar clearance from the PCB. Take care with both components – the leads can easily break off!
10. Fit IC3 with about 4mm clearance and double check the orientation with that shown in Fig 7.5.
11. Before proceeding further, check all of the work done, looking especially for solder bridges between tracks and pads. A good magnifying glass is very helpful for this inspection. Check also the values of the components and the polarity of the electrolytic capacitors. Ensure that the diode D1 is the correct way round and that the notches in the IC holders correspond to those in the layout diagram in Fig 7.5.
12. Next connect a red insulated lead to the pin marked '9V' and a black one to the 0V pin. Temporarily connect a 9V supply to these leads and measure the voltages between pin 3 (ground or 0V) and pin 8 on both IC1 and IC2 sockets. There should be 5V in each case. Repeat the test using pin 4 (ground or 0V) and pin 8 of the IC4 socket. There should be 9V. Carefully insert the three ICs in the correct socket with the correct orientation, again referring to Fig 7.5. The pins of the ICs may be splayed outwards and to make them fit the sockets they must be aligned. This is best done by holding the IC with the pins flat against a hard surface (table top) and bending the body gently towards the pins. Repeat with the other side. Very little force is needed – double check the alignment of the pins. The correct orientation is when the dot on the top of the IC is at the same end as the cutout in the holder. When fitted, check that all pins are in their sockets – the magnifying glass is again useful for this operation.

The board is now complete and should be put to one side while the other components are mounted in the box. Three 8mm holes are required in the front of the box for the

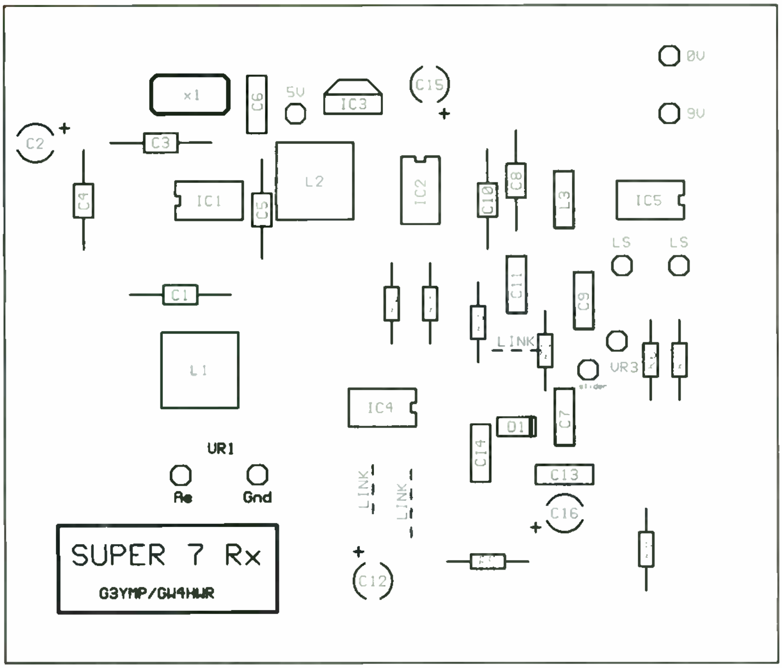


Fig 7.5. The component layout

tuning controls and gain on/off control. They are spaced equally along a line drawn through the centre of the box and should be 50mm apart. It is not critical and can be modified to suit any other box. Two further holes, 8mm diameter, are required in the right-hand side of the box for the antenna and earth connections. They should be about 30mm apart. On the left-hand side two more holes are required for the external power socket (11mm) and the loudspeaker (6.3mm). As the case is plastic all holes can be made using a small drill, say 3mm, and then a taper reamer to open them up to the required size. Check the component often as the reamer is used, to avoid making the holes too big.

The three controls may now be fitted to the lid. Cut the spindles to about 10–12mm from the bush and remove any burrs. Pass each control through the hole from the rear side, and gently twist so that the spigot on one side of the bush makes a mark. Then, with the controls in the approximate position as indicated in Fig 7.7, cross the arc to give a drilling position. 3mm holes should be drilled at these points and enlarged with a round needle file if necessary to allow the spigot on the control to enter and so prevent turning. Ensure that the correct-value controls are in each position, then tighten the nuts. The interconnections can be made using PVC-insulated wire. Leave a fairly long tail where an arrow indicates a connection to the PCB so that the front panel can just lie flat when the PCB is mounted in the box.

Next make the holes for the antenna and earth sockets in the right-hand side of the box and those for the speaker socket and external power supply on the left-hand side. Refer to Fig 7.8 for the suggested positions for these components.

Drill the four 3mm fixing holes for the PCB in the bottom of the box, and fit the panel using 20mm M2.5 screws and spacers so that the board is spaced away from the box.

Complete the wiring by following the instructions in Figs 7.6 and 7.7. The connections to the power socket are shown in greater detail in the insert in Fig 7.3. Note that this socket enables a suitable 9V power supply to be plugged in and automatically disconnects the battery when the plug is pushed into the socket. If there is no intention to use an external supply, the power socket may be omitted and the leads from the switch and the PCB taken directly to the PP3 battery clip.

Testing

This is a very simple operation. Connect a 9V supply and turn RV2 and RV3 to a central position. Connect a

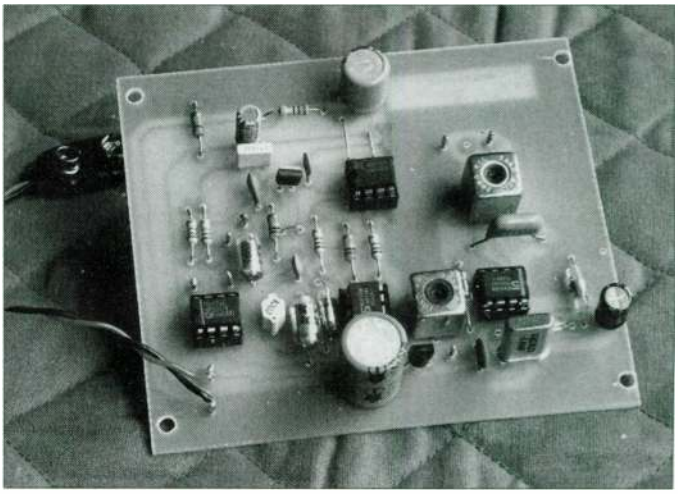


Fig 7.6. The finished PCB

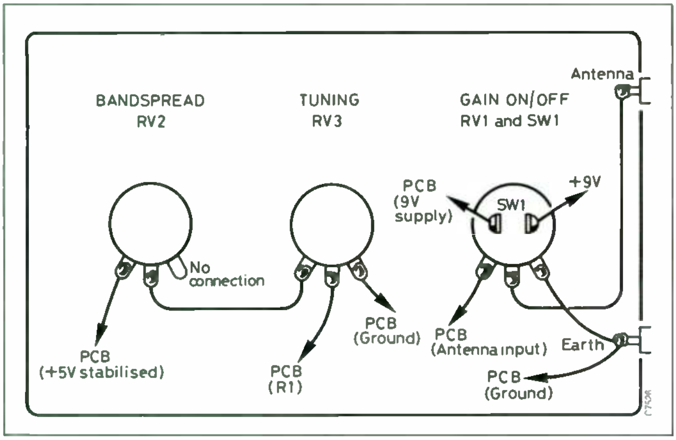


Fig 7.7. Rear view of the controls on the front panel

suitable antenna – anything from 10 to 25m and as high as possible will be fine. The earth connection may be from an earth spike or a metal water pipe but preferably not the earth on the mains plug.

Any loudspeaker having an impedance of between 8Ω and 30Ω will be satisfactory and should be plugged into the speaker socket.

Switch on and advance the gain control RV1 until some background noise is heard. Using the correct trimming tool, adjust the cores of L1 and L2 for maximum noise (or signal if you are lucky enough to hear one). Adjust the main tuning control until a station is heard – SSB will be found at the upper end (tuning control clockwise) and CW at the lower end. The bandspread control will be found most useful in adjusting the signal so that it sounds right when SSB is being received or a pleasant note when it is CW.

Select a signal in the centre of the tuning range and again adjust the cores of T1 and T2 for best results.

If it is found that the band is not completely covered the value of C9 will need to be changed. If the lower end of the band is not reached use a value of 1.2nF instead of the given value of 1nF. On the other hand, if the high end of the band is not reached, use 820pF for C9.

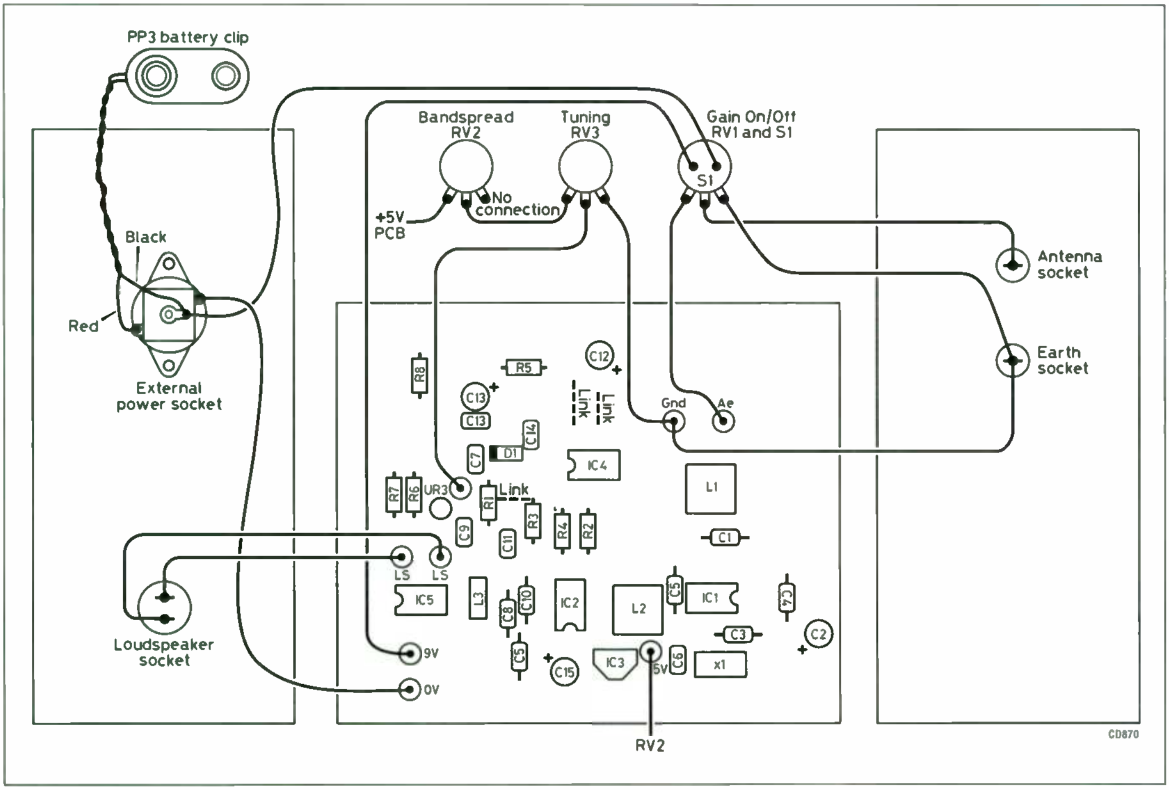


Fig 7.8. The connections to the antenna, earth, PSU and loudspeaker sockets

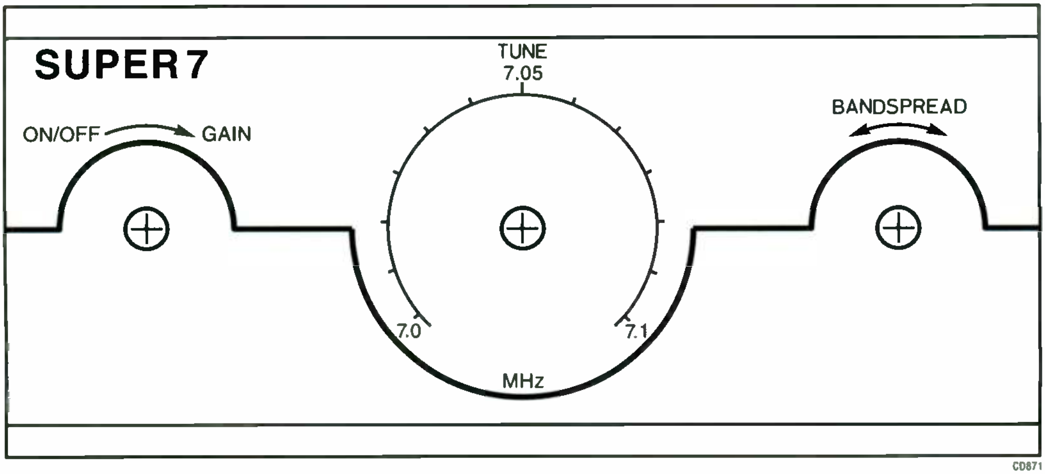


Fig 7.9. A simple front panel

Finish off the receiver by adding a panel such as the simple one shown in Fig 7.9 and fit the control knobs with the skirted one for the main tuning. Refer to Chapter 5 for methods of fixing.

If an antenna tuning unit is available the results can be improved still further. Details of suitable devices can be found in the pages of *D-i-Y Radio* or in the RSGB book *Practical Antennas for Novices*.

Chapter 8

Microwave operating

Although this chapter is entitled 'Microwave operating', it contains all sorts of information which should be useful to anyone about to build and use receivers (and transmitters) for the amateur bands, but in particular the Novice microwave bands. It may seem to be an odd chapter but, hopefully, it will prove useful!

The first part contains information on some of the special characteristics of the microwave bands and the different operating techniques used. The second part gives you some ideas on assembling a station from the transmitters described in reference [1] and the receivers or transceivers described in this book. The last part is a 'data' section entitled 'Odds and ends' which, as its title suggests, is a real mixture of things useful to the newcomer.

Propagation and operating techniques

Microwave operating is often very different to operating on the amateur LF, HF and even VHF/UHF bands. Why should this be so? Because propagation is somewhat different and operating techniques are different to accommodate this. There are other factors, such as antenna gain, receiver noise figures, lower transmitter powers and a host of other differences which also make operating techniques different. Only a brief explanation can be given here. For more detailed information see references [2] and [3].

Propagation

LF and HF ('short-wave') propagation over long distances (worldwide) occurs because of the ionised layers (ionosphere) high above the Earth which bend (refract) and reflect radio waves back to earth way beyond the horizon. These 'short waves' are little affected by the weather or atmosphere, other than some weather conditions, such as electric storms (thunderstorms – see 'Noise' later).

Ionisation is the splitting of molecules of the gases of the upper atmosphere (where the atmospheric density is very low, a partial vacuum) into electrically charged particles (positively charged ions and negatively charged electrons). It is caused by the Sun's radiation, particularly the ultra-violet radiation and, near the Earth's magnetic poles, by the stream of protons and electrons emitted as the 'solar wind' by the Sun. Molecular oxygen and nitrogen are the elements commonest in the atmosphere and these are mainly the elements involved in the ionisation process. Oxygen ions combine together to form ozone, or with nitrogen to form nitrogen oxides, leaving an excess of electrons which collect in the F-layer (see later).

Ultra-violet (UV) radiation from the Sun is largely absorbed in the upper layers of the Earth's atmosphere where the atmospheric density is low. The radiation which is absorbed causes fairly regular daily and seasonal worldwide effects in the ionosphere. Absorption of the UV radiation is mainly responsible for F-layer ionisation at between about 200 and 400km above the Earth's surface, although it is now believed that some other mechanisms are also involved. The height of the F-layer is different by day (when it often splits into two layers, the F1-layer at about 200km and the F2-layer at about 400km) and by night (when only the F1-layer exists). Note that mainly the longer-wave UV radiation reaches the Earth's surface, as most of the short-wave UV radiation is absorbed by the upper atmosphere. By contrast, the somewhat irregular nature of the E-layer, at about 120km above the Earth's surface, is believed to be caused by charged particles from the Sun (protons and electrons) which are emitted as a steady 'solar wind' when the Sun is quiet, or in large numbers from solar flares when it is active. These particles are attracted to the Earth's North and South magnetic poles and spiral in down the magnetic lines of force into the upper atmosphere, where they cause ionisation, often not intense enough to cause radio propagation effects. Solar flares, which release large numbers of charged particles from the Sun, are the main causes of intense E-layer ionisation known as 'aurora'. Aurora is often visible at night and is otherwise known (in the northern hemisphere) as the 'Northern Lights'. Similar effects occur near the South Pole. However, an aurora does not have to be visible to be able to cause E-layer radio propagation: auroras are obviously not visible in daytime because the sky appears brighter than the aurora (due to scattered sunlight). Even at night, when the sky is dark, the aurora does not need to be visible to have effects on radio-wave propagation. Other effects, such as very-high-altitude 'winds', are believed to cause other forms of 'sporadic E' ionisation. The sum total of the Sun's radiation varies over an approximately 11-year cycle, so that there are regular peaks and troughs in radio propagation, according to whether the sunspot cycle is at a maximum or a minimum. F-layer ionisation mainly affects frequencies below about 30MHz, enhancing their propagation, whereas E-layer ionisation tends to enhance propagation above about 30MHz, up as high as 150MHz (and possibly as high as 430MHz, although this is by no means common or even certain). The lowest of all the ionised layers, at about 70km, is the D-layer: this does not normally enhance propagation. On the contrary, strong D-layer ionisation usually causes radio-wave absorption!

At VHF and UHF, propagation via the ionosphere does not occur very often above 50 or 70MHz. When it does, it is usually by auroral reflection, sporadic E and, fairly often at 50MHz, by F-layer reflection and occasionally by a few other, 'rare' modes which you don't need to know about at this stage! Ionospheric propagation can sometimes cause the VHF waves to travel up to 1000 to 2000km at a single hop before returning to earth. VHF and UHF propagation, for most of the time, is dependent upon the atmosphere and weather conditions and transmission is normally limited to 'line-of-sight plus one third'. The 'bending' of VHF and UHF waves is refraction, just as light is 'bent' in moving from a medium of one refractive index to another: for example, a stick appears bent when pushed into clear water at an angle. This is refraction and the angle of 'bend' is related to a property of water known as the 'refractive index'. VHF and UHF waves are bent by changes in the refractive index of air, which is similar.

The amount of bending or refraction of VHF and UHF waves depends upon the 'radio refractive index' (RRI) of the atmosphere, which in turn depends on atmospheric temperature and humidity. Normally the temperature and humidity of the atmosphere decrease steadily with increasing height above the earth. This is known as a 'normal lapse rate'. Under some weather conditions ('anticyclones', when the atmospheric pressure is high and stable), either the temperature or the humidity (or both) may increase quite suddenly with increasing height, thus forming a layer of air with a different RRI which refracts (bends) the waves back towards the earth. Similar conditions can sometimes occur on the boundary between a high-pressure area (anticyclone) and a low-pressure area (cyclone), often known as a 'front', where cool air can enter under a mass of warmer air, with very little mixing, to form conditions vaguely similar to an inversion or 'duct'.

Such a layer, particularly where there is a sharp change in RRI, is known as an 'inversion', or sometimes as a 'tropospheric anomaly' or 'duct'. If a radio wave propagates inside the inversion layer, the layer can act like a pipe or 'waveguide' which allows the radio wave to travel long distances with very low losses. This can enable distances of up to 1000 to 2000km to be covered with very little loss, rather similar to the ionospheric VHF propagation mentioned above. The main difference is that tropospheric propagation can last for several days at a time, whereas VHF ionospheric propagation usually only lasts for a few minutes or a few hours on an 'active day', although the active days tend occur most in the summer months (between May and September) and to come around at 28-day intervals, coincident with the rotation of the Sun and the sunspots on its surface. By contrast, good tropospheric conditions can occur at any time when the weather is 'settled'.

Microwave frequencies *never* propagate via the ionosphere but, like VHF and UHF, are dependent on atmospheric conditions. Under normal conditions propagation is limited to 'line-of-sight plus one third'. However, because of the very short wavelengths, obstructions on a particular path (hills, buildings, trees etc) cause additional path losses. For the same reason, obstructions can sometimes act as reflectors or diffraction (a special form of scattering) around obstructions can occasionally make microwave transmission and reception much stronger than expected!

All the atmospheric effects which can be observed at VHF and UHF occur at microwave frequencies but again, because of the very short wavelengths, the tropospheric anomalies can be on a much smaller scale to have the same effects. Added to these effects, atmospheric irregularities (turbulence), heavy rain, clouds, snow, hail, thunderstorms and aircraft can cause forward, over-the-horizon, scattering. Some of these effects are shown in Fig 8.1. Forward (over-the-horizon) 'troposcatter' occurs if there is any sort of atmospheric irregularity, such as small patches of air of different temperature or humidity (different refractive index) caused by minor turbulence.

You might know, at night, that there is a distant town beyond your local horizon (you can't see it directly) by the fact that light from that town can be seen as a glow in the sky. In the absence of clouds which might reflect the light, you shouldn't be aware of the town's distant lights. However, because of small variations in the atmosphere, there is enough light scattered in your direction for you to know that there is a town somewhere beyond your horizon. The light level may be very low, but it is enough to know with certainty that the town is there.

Similar forward-scatter effects occur at all microwave frequencies, but are most noticeable at 10GHz and above. Forward 'weather' scatter (usually much stronger than

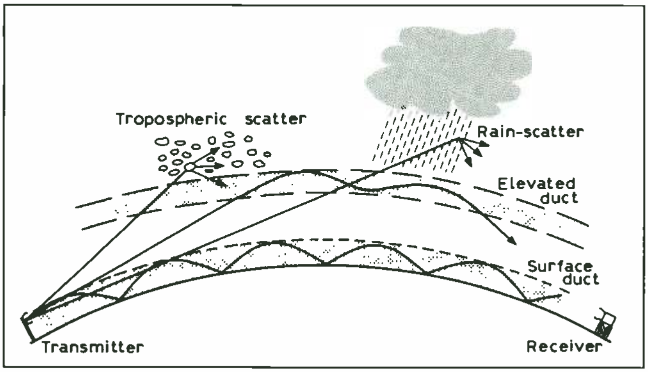


Fig 8.1. Trans-horizon propagation of VHF/UHF and microwaves in the lower atmosphere (troposphere)

troposcatter) also occurs with heavy rain, hail, sleet and snow showers, if these happen to lie in the right direction to be able to scatter the signals in the direction you want to work. If you want to learn more about these modes of microwave propagation, see reference [2].

Noise

Noise is important in any part of a communications system but particularly in receivers where it can limit the ability of the receiver to 'hear' a weak signal. The strength of received signals is commonly measured in 'S-points' indicated on a meter. Each S-point should represent a 6dB (×2, in voltage terms) increase in received signal strength, although many commercial receiver manufacturers seem to have their own ideas on what an S-point is!

It is much more meaningful if the signal strength is referred to the receiver's noise level – measured in 'decibels relative to noise' which you will see written as 'dBn'. Another measurement which is used is 'S + N/N' which is the ratio of signal-plus-noise-to-noise, also measured in decibels. In either case, the higher the ratio, the stronger and more readable the signal.

Noise in communications systems comes from two sources, external and internal. External noise is that which is picked up on the antenna along, of course, with any wanted signal, or sometimes through the mains power supply lines! Internal noise is that generated within the receiver itself. Just to further complicate matters, the noise can be electrical in nature, or thermal in origin!

Electrical noise

Electric storms (thunderstorms) generate electrical noise mainly at low radio frequencies ('static' or 'QRN') which can travel all round the world in exactly the same way as the radio frequency to which your receiver happens to be tuned. Anyone who has listened to short-wave broadcasts will be well aware of the crashes and bangs which take place in stormy weather – they are particularly bad and frequent in tropical areas! These noises are picked up by the antenna to which the receiver is connected in just the same way as the signals to which you want to listen. The lightning discharge which causes the electrical noise may be a few miles away or it may even be on the other side of the world.

You are also probably well aware of 'man-made' noise which may take the form of wide-band noise (again coming from electrical discharges, such as sparking electric motors, car-ignition systems, thermostats, switches and so on) or more selective noise, for instance harmonics of short-wave broadcast stations, the harmonics of TV timebases or computer clock and timing oscillators. Many of these sources of interference, although generated at much lower frequencies, come from 'square-wave' or pulse oscillators (used in digital equipment, such as computers) very rich in harmonics which often extend well into the VHF region: the amateur 50MHz band seems to attract this kind of noise!

These external sources of noise, picked up by the antenna, are so high in level that there is little point in trying to use very-low-noise receivers, since the internal noise level, generated within the amplifying and mixing circuits of the receiver itself (see later, thermal noise) is completely hidden by the noise picked up by the antenna.

Since VHF and UHF signals do not often propagate via the ionosphere, any VHF or UHF frequencies generated by electrical discharge won't travel all round the world in the same way as at LF or HF, although they can travel as far as either the ionospheric or tropospheric propagation allows! Also, since most electrical discharges are at low frequencies, the strength or intensity of the harmonics falling in the VHF or UHF bands will also be weaker and again will travel less far. Occasionally, static charges exist on rain drops, hail or sleet during electric storms and these, too, affect VHF and UHF reception.

In general, then, electrical noise levels picked up by the antenna get less as frequencies get higher. By the time we get to microwave frequencies, the electrical noise levels and man-made noise levels picked up by the antenna have fallen to a small fraction of the levels at LF, HF or VHF.

Thermal noise

The same is not true about 'thermal noise' which exists right across the electromagnetic spectrum. Without going too deeply into theory, all matter is made up from sub-atomic, atomic and molecular particles which are in constant, random motion at normal temperatures. All particle motion ceases at 'absolute zero' (–273 degrees on the Celsius temperature scale, also known as '0 kelvin' or 0K).

If the energy level of the same bit of matter is raised (energy is supplied in the form of, say, heat), then the random movement of the atoms and molecules increases with increasing temperature. This random motion generates random noise, which, if the matter happens to be, say, part of a component in a radio receiver, causes minute fluctuations in current or voltage and can be heard as internally generated electrical receiver noise. Thermal noise can also be detected as electromagnetic radiation, also picked up by the antenna. Any object with a temperature above 0K can radiate electromagnetic energy over a wide band of frequencies, from low radio frequencies, through visible frequencies, right up to X-rays.

To emit thermal noise, the matter does not need to be either 'hot' to human senses or visible like a flame, although the higher the absolute temperature of the matter, the higher the level of thermal noise generated and the wider the range of frequencies it will emit. 'Hot' to the human senses simply means that something is hotter than your body temperature (about 37°C or 310K) and your 'receiver' (nerve endings in your skin) tells you that something is warm or hot. A flame, or the Sun, appear to be hot because they are both at a much higher temperature than the human body and can be sensed by both the skin and the eyes: they are emitting visible and infra-red radiation as well as radio waves. The body senses the infra-red and visible radiation but cannot detect the radio frequencies – a radio receiver is needed for that!

Just because your senses can't detect the radiation doesn't mean that 'thermal radiation' (and hence, thermal 'noise') isn't being generated! Thus we can say that something has a 'noise temperature' of so many kelvin, meaning that it is generating a level of noise related to its absolute temperature. Where the object is not emitting visible electromagnetic radiation (light), the thermal noise is sometimes known as 'black body radiation'.

We have already seen that external natural and man-made electrical noise is much higher at low frequencies than at high frequencies and that electrical noise levels decrease with frequency. We have also seen that 'thermal noise' is present throughout the electromagnetic spectrum. At microwave frequencies external electrical noise is much less, to the point where the external thermal noise (from the Sun, Earth, Moon and other heavenly bodies) is no longer hidden by the external electrical noise. If the level of internally generated thermal noise can be made less than the external thermal noise level, then the level of external thermal noise is the main factor which limits the sensitivity of the receiver. Don't forget, a receiver system includes the antenna, the feeder cable which connects the antenna to the receiver and the receiver itself and each will have its own, distinct 'noise temperature' which will affect the overall receiver performance.

Deep space is obviously cold! Therefore, if you 'look' at the cold sky with a radio telescope (which is nothing more than a quiet, sensitive, UHF or microwave receiver with a high-gain beam antenna), you would expect to receive little noise. If you then pointed your antenna toward a 'hot' object such as a star, the Sun, the Earth, or even the Moon, then you would expect to pick up the thermal noise coming from whichever object your antenna 'sees'.

At one time, the only way in which a UHF or microwave receiver could be made to 'see' thermal noise was by cooling the antenna and the first amplifying stages of the receiver down to as low a temperature as practical in order to make the internally generated noise level as low as possible.

GaAs FETs in modern microwave receivers have inherent noise figures so low, even without cooling, that several decibels of thermal noise from the Moon or Earth can be detected and the Sun noise may be one to two S-points up on the cold-sky noise level. In fact, this is how an experienced microwave operator will decide how good his or her receiver is – by measuring the difference in noise level with the antenna pointed at the cold sky and the 'hot' Moon! Skilled EME operators even use the Moon noise level to 'track' the Moon with the antenna.

Equipment and band characteristics

There are a number of reasons, other than propagation and noise, why microwave operating can be very different to that on LF, HF, VHF or UHF. These relate mainly to equipment characteristics (parameters) and the nature of usage of the bands. They are summarised next:

1. The bands are wider than the lower frequency bands and it is usually not possible to tune across a whole band to find signals. However, wide-band signals can be accommodated in the microwave bands whereas they can't in the lower frequency bands. This means that you must know where to look for what types of signals. The band plans for the two Novice bands were given in reference [1], or you could also find them, in a little less detail, but more up-to-date, in the *RSGB Amateur Radio Callbook*, reference [4].
2. There are fewer microwave operators, so that the bands are seldom crowded or even 'busy'. Interference is not often a problem, unless there happens to be a tropospheric 'opening' or contest in progress. Even then, the bands can hardly be described as crowded!
3. Usually, on the grounds of cost or availability of suitable devices, much lower transmitter powers are used. Because ionospheric propagation is not possible, this usually means that only shorter ranges are covered, typically (as at VHF and UHF) 'line-of-sight plus one third', although longer distances can be

covered when tropospheric conditions allow, and worldwide communication can take place via satellites and moonbounce.

4. To offset lower transmitter powers, highly directional, high-gain antennas are usually used. These concentrate and direct the signals to where they are wanted and improve receiver performance as well as making transmitters 'sound louder'. At the same time it makes searching for signals more difficult – if your antenna is pointing in the wrong direction, the chances are that you might hear nothing!
5. Microwave receivers, because of the lower internal and external noise levels (already discussed), the lower transmitter powers and the weaker long-path signals, are often much more sensitive than receivers for other, lower frequencies. They may need to handle signals from a few fractions of a microvolt (millionths of a volt) to possibly tens or even hundreds of millivolts (thousandths of a volt) without distortion. In order to receive signals without distortion, all stages of a receiver must be as linear as possible – that is, the receiver must be able to produce an exact, undistorted but amplified and demodulated, 'copy' of the input signal at its output, the loudspeaker (audio) or video monitor (video). It is also important that receiver local oscillators are 'clean', ie as free from harmonics and noise as possible, since these can cause spurious signals, distortion and other unwanted effects, as well as degrading the overall noise figure of the receiver.
6. If you know what the equipment performance is (often known as the 'equipment parameters') at both ends of a path, then it is possible to predict, pretty accurately under normal conditions, what sort of results you can expect over a particular path. This is virtually impossible where ionospheric propagation is involved!

Little has been said about receivers, other than discussing noise and the fact that most receivers are expected to handle signals from a few fractions of a microvolt to many tens of millivolts (and possibly much more) without overloading, distorting the wanted signal or interacting with other strong signals to produce unwanted signals, known as 'spurious' signals.

If a receiver stage (or more than one stage) operates in a non-linear mode, then distortion of the signal can be so severe that the output is unintelligible or, in extreme cases, can generate spurious signals from the mixing of two or more strong signals fairly close together in frequency. In other words, signals get 'clipped' by the non-linear stage, so that harmonics are produced, which either distort the wanted signal or give rise to unwanted spurious signals. The same kind of thing can happen in filter stages, mixers and detectors (demodulators) as well as in amplifying stages in the receiver. This type of distortion is often known as 'intermodulation distortion' or IMD.

If the receiver local oscillator is 'dirty', ie it contains harmonics and noise sidebands, then yet another type of spurious receiver response can occur – reciprocal mixing. This is caused by the local oscillator noise sidebands mixing with close-in, unwanted signals to form spurious signals within the receiver passband. To avoid reciprocal mixing, the receiver local oscillator(s) must be free from noise sidebands. Where there are strong harmonics present in the local oscillator signal, this can also cause harmonic mixing which also produces spurious, unwanted signals from signals well away from the wanted signals - in fact, up to the second or third harmonic of the local oscillator frequency plus or minus the IF.

In these respects, 'old-fashioned' valved receivers were often able to handle a much wider dynamic signal range than the early solid-state receivers using bipolar transistors. A good valved receiver might be able to handle signals differing by 80 or 90dB, whereas a poor solid-state receiver might only cope with 20 or 30dB – very poor indeed!

Nowadays, well-designed solid-state receivers using FETs, high-level balanced mixers and clean oscillator sources can cope with dynamic ranges of 100dB or more before serious effects occur.

Fortunately, modern high-quality amateur receivers and transceivers likely to be used in microwave systems are relatively free from these effects. You should be aware that many modern transceivers have both switched, low-gain RF preamplifiers and attenuators at their input. These alternatives are available so that the user can choose either gain or attenuation, whichever suits signal conditions. If IMD effects are found to occur when using a commercial transceiver as the IF for a microwave system, then the 'cure' is usually quite simple: put an attenuator between the microwave converter and the main transceiver to reduce the output of the converter to a level where the receiver of the transceiver can cope without running into IMD problems. A later section gives resistor values to make simple attenuators for just this purpose! It might be worth noting that similar attenuators are usually needed between the main (IF) transceiver transmitter and the microwave transmit converter.

Predicting performance

A typical 'communications link' is shown, together with its various gains and losses, in Fig 8.2. The biggest loss is, of course, the path loss between the transmitting station and the receiving station, although all the other losses can add up to quite a lot, too!

Two types of link exist: terrestrial (Earthbound) and extra-terrestrial (space). Terrestrial links can sometimes

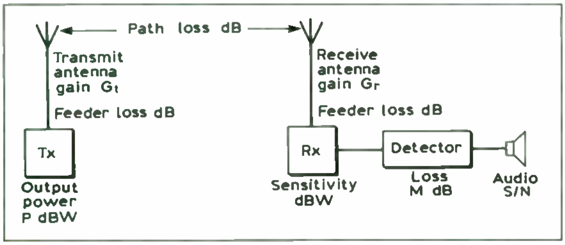


Fig 8.2. Diagram of a communications system, showing losses and gains

be 'line-of-sight' and sometimes anything but line-of-sight, whereas space links are invariably (maybe very long) line-of-sight, ie the Earthbound stations can 'see' the satellite.

In line-of-sight links, the losses are basically those known as 'free-space' losses and are well defined. Non-line-of-sight paths are subject to extra losses caused by obstructions (including the Earth's curvature) and, at some frequencies, losses due to atmospheric absorption by water, water vapour and oxygen. The free-space loss is related to the square of the frequency and the square of the distance. Thus, the higher the frequency and the longer the path, the greater the path loss.

So, the first parameters you need to know are the operating frequency and the path length. If you know the location of each station, then you can not only work out the path length, but you can also get a fair idea of the path profile which will tell you whether the Earth's curvature or obstructions (for example a range of hills) will add to the free-space loss. That is, is it line-of-sight or troposcatter or are there serious obstructions, and so on? There are many microcomputer programs available to help in making such calculations easy and painless!

The other parameters you need to know in order to make such predictions are (for each station):

- Antenna gain
- Feeder loss
- Receiver noise figure, bandwidth and mode
- Transmitter power output

If all the parameters are expressed in decibels (dB), which is a logarithmic scale of power (or voltage) ratios, then it is possible to add together all the known figures and calculate two values: ERS (effective receiver sensitivity) and ERP (effective radiated power of the transmitter). It is usual to refer all decibel values to a common power level, usually 1W (but often by amateurs, 1mW), so that 1W = 0dBW, 2W = 3dBW, 4W = 6dBW, and so on. 100mW (0.1W) = −10dBW, 10mW = −20dBW, and so on. Receiver sensitivity, measured in the same terms, will be a very large negative figure, since most receivers will respond to extremely small signals: fractions of a picowatt (million-millionths of a watt) in power terms, or fractions of a microvolt (millionths of a volt) in voltage terms, at the antenna.

The first of these values, ERS, defines the weakest signal which can be detected by the receiver, while the ERP defines the strength of the signal radiated from the transmitting antenna. ERS will, as already mentioned, be a big, negative value, while ERP will have a positive value.

ERS depends upon several related factors: it is the sum of the minimum detectable signal (MDS), antenna gain, and feeder loss. In turn, the MDS depends on the noise figure of the receiver, its bandwidth, its signal-to-noise ratio (which is the ratio of audio output power to noise power output) and an 'M' (mode) factor. The 'M' factor is a measure of the performance of the receiver detector. If a CW/SSB (product) detector, which is the most sensitive type of detector, has an M factor of 0dB, then an AM envelope detector has 2.6dB loss, a limiting FM detector has 10dB loss and a non-limiting FM detector has 16dB loss. This makes ERS quite a complicated thing to calculate!

It should now start to be obvious why, when working with very weak signals (as amateurs usually do), the modes of operation, in order of preference, should be CW, SSB, AM, NBFM, WBFM. CW and SSB are most effective since they occupy the narrowest bandwidths and employ the most sensitive detector, while FM occupies the widest bandwidths and the least sensitive detectors. This is the reason why, with the exception of ATV, most microwave operators use CW or SSB.

By contrast, ERP is relatively simple to calculate, as it is the sum of transmitter power output, antenna gain and feeder loss. Again, a CW or SSB transmitter will be far more effective than an AM or FM transmitter, since the power is concentrated in much narrower sidebands rather than in a carrier plus wide sidebands.

When the ERS value is subtracted from the ERP value (remember, both are expressed in decibels), then the result is known as the PLC (path loss capability) of the system: if the real path loss is greater than the calculated PLC, then no signals will be heard! If it is less, then signals will be heard. The bigger the difference (in decibels), then the better the signal-to noise ratio of the received signal.

In general, anything which increases the PLC or reduces actual path loss will improve the 'goodness' of a communications system. Increasing the antenna gain at both the transmitter and receiver, decreasing the feeder loss at both the transmitter and receiver, increasing the transmitter power, decreasing the receiver noise figure, bandwidth and frequency of operation all increase the PLC. All these things are within the control of the operators of the two stations trying to make contact.

Reductions in actual path loss are beyond the operator's control since they depend upon either natural weather and tropospheric conditions for terrestrial communications, or the availability of satellites for extra-terrestrial (space) communications. Satellites can be natural passive (Moon) or artificial active amateur satellites (such as the OSCAR or RS series). The most important difference between natural satellites and artificial satellites is that natural ones are passive (they involve reflection losses as well as free-space losses) whereas artificial ones are active, receiving signals, amplifying them and then re-transmitting them in the same or, more usually, a different band. The other significant difference is that artificial satellites are within a few hundred to a few thousand kilometres from the Earth, whereas the one useable natural satellite, the Moon, is about 400,000km from the Earth. This means that the free-space path losses between an Earth-bound station and an artificial satellite are very much less than those between Earth and the Moon.

Obviously this type of calculation is very important for setting up professional communication systems. It can be almost as important for setting up amateur terrestrial links, such as fixed, point-to-point packet or data links where, although the reliability of the links may not need to be as high as for professional links, it still needs to be high by amateur standards.

For the same reasons, it is almost as important that equipment parameters are known (to fractions of a decibel) for amateur space communication as it is for professional space communication! It might be even more important, since active amateur satellites are restricted in size, weight, power and cost, and the Earth-Moon-Earth path (a passive satellite) is very long indeed.

For random contacts over long terrestrial distances, such calculations are less important because weather scatter and tropospheric openings (like ionospheric conditions) are difficult to predict with any certainty, though it is still possible to produce interesting troposcatter predictions which can present an operating challenge! Over short distances the calculations only become important if the path is very obstructed. Calculation of the capability of a communications system sounds very complicated, but these days is quite easy since there are many microcomputer programs available which will do the calculations for you. Some of the simpler programs are listed in reference [2].

Assembling a station

An amateur microwave station is the same as an amateur station using any other part of the radio spectrum, insofar as it consists of an antenna, a feeder, a receiver, a transmitter and some means of changing over from receive to transmit.

Let's look at these various parts of the station equipment in a little more detail. First, the antenna or aerial. Antenna gain is often measured against a theoretical (non-existent) antenna called an 'isotropic radiator'. This is a point source which radiates equally in all directions. You can visualise it as a point in the centre of a hollow sphere. RF power radiated equally in all directions 'illuminates' the entire inner surface of the sphere equally. Now it should be obvious that such an antenna cannot exist, except as a useful concept.

When expressed in this way, the gain of an antenna is quoted in decibels relative to an isotropic radiator (dBi). Instead of theoretical measurements, amateurs often refer to antenna gain relative to a half-wave dipole (dBd), This is a much more practical measurement! In practice, the gain of a dipole is 2.2dB compared with an isotropic radiator.

There is often confusion between these two measurements and commercial antenna manufacturers tend to overestimate their product's gain by claiming so many decibels without referring to a reference antenna. The 2.2dB difference between dBi and dBd can be very important when doing microwave system calculations at very low signal levels where every decibel of real gain counts! In other words, if you are not sure of the facts, assume that the antenna gain is 2.2dB less than the quoted figure to obtain a 'worst-case' result.

On the LF and HF bands, most people are lucky if they can put up a full-sized half-wave dipole, let alone any antenna with more gain than that! A minority of amateurs with plenty of space and tolerant neighbours use a tower and a Yagi (beam) antenna which might give 5 or 6dB gain (one or two 'S' points, depending how the receiver 'S' meter works).

At VHF or UHF, antennas with gain in the region of 6 to 12dB are not too big to use. A VHF or UHF antenna may work very well if mounted as high as possible on a simple, small mast, rather than a tower.

As the gain of an antenna increases, so its beamwidth and bandwidth decrease, although the bandwidth can be increased to some extent by increasing the diameter of the driven element or the numbers of driven elements. In other words, the higher the gain of the antenna, the narrower the 'beam' of radio waves becomes, rather like focussing a torch.

A torch bulb produces a certain amount of light (output) dependent on its power and efficiency. A wide-angle beam from the bulb covers a large area but appears dim. The light from the same bulb, when focussed, covers a very small area but the brightness of the patch of light produced is much greater. There has been 'gain' in brightness by concentrating the available light into a narrow beam. Narrower bandwidth means that the antenna presents a good match to the feeder (low VSWR) over a narrower range of frequencies than an antenna with less gain.

LF and HF antennas with high gain are difficult to use because of their size. VHF and UHF beam antennas are better because, for a given amount of gain, they are much smaller and easier to rotate to direct their radiation in the right direction – that is, towards the station you want to work!

At microwave frequencies, for the same amount of gain as at lower frequencies, antennas are even smaller. A microwave antenna with a gain of 12dBi is a very small antenna – even the open end of waveguide 16 (used at 10GHz) has a gain of about 6dBi! Depending on the microwave band used, antenna gains from 18 to 40dB are not uncommon: for instance an 18in (50cm) dish at 10GHz will have a gain of at least 30dB. This means that the output of a 10mW transmitter fed to such a dish sounds like a 10W transmitter would when fed to a unity-gain antenna, in this case a dipole!

Antennas and feeders

As a general principle, choose and use an antenna with the highest gain you can manage. This means the largest antenna – a long Yagi or several long Yagis on the 1.3GHz (23cm) band or the largest dish antenna you can manage on the 10GHz (3cm) band. Yagi antennas (or to give them their full name, Yagi-Uda parasitic arrays) are multi-element antennas like those used for UHF TV reception. A Yagi antenna consist of a dipole (or 'driven element'), quite often folded to match the feeder impedance to the antenna structure, a slightly longer 'reflector' (or more than one reflector) element behind the dipole and as many as 30 or 40 shorter 'director' elements in front of the dipole. The direction of maximum radiation is along the length of the antenna, from the dipole towards the 'director' elements, the reflectors element(s) stopping much of the radiation in the other direction. A Yagi-Uda antenna is named after its Japanese inventors and the original antenna structures were sometimes known as 'flat-tops' because all the elements are aligned in one flat plane.

Later developments may use loop elements or a combination of loop and 'flat' elements, each type having its own special, claimed advantages. An antenna whose elements are all formed into loops is sometimes known as a loop-Yagi, whereas an antenna whose driven element (and often the reflector) is a loop and the directors are flat elements is known as a 'quagi' (short for quad-loop Yagi). In general, the gain of the antenna is related to the length of the antenna boom expressed in wavelengths at the operating frequency, and this is determined by the total number of elements in the antenna and their spacing from each other. Yagi design is very complicated because the diameter, spacing and length of all the elements and the length and diameter of the mounting boom interact.

Fortunately, there are good microcomputer programs which will design long Yagis and loop-Yagis, as well as horns, slot antennas and various types of dish antennas and feeds (references [5–7]). Other, lower gain, antennas such as the helix, corner reflector and collinear types are sometimes used and occasionally even quarter-wave whips or ground-plane antennas may be used over very short paths where signals are very strong. It has long been known that horizontal polarisation of the antenna (the elements of a Yagi antenna horizontal, or the broad side of a waveguide feed for a dish vertical) is better for over-the-horizon communication than vertical polarisation. This may be because the majority of objects which can absorb RF energy in the path of the radio waves are vertical: tall steel-framed buildings, trees, metal masts and towers, and so on.

The only disadvantage of high-gain antennas is that they are very directional, so you will need to have some means of pointing them quite accurately in the direction you want to work. Rotation can be by hand (on a simple rotatable pole) against a bearing scale, or using a small electric rotator. You may also need to be able to calculate a directional (azimuth) bearing once you know the other station's location. This is easy using a programmable calculator or a computer: once again, there are a number of public domain (free) computer programs available to do this for you. Some of these are listed in reference [3] and most of these, or more sophisticated programs developed from them, are available on disk from several sources (references [5–7]).

Over short paths, antenna gain may be less important and you may not even have to point the antenna particularly accurately in order to receive or transmit strong signals. Even so, you should be aware of the special needs when using high-gain antennas.

A word or two about mounting antennas. As on any other band, as high as possible and in the clear (well away from surrounding objects) for normal terrestrial use. Although outside the scope of this introductory book, moonbounce or amateur satellite antennas mounted almost at ground level may be good enough, provided they have a clear view of the sky in the direction(s) you want to work. If you happen to live on the top of a hill or you are operating portable on a hill-top then, again, antenna height may not be too important.

Feeder losses increase rapidly with frequency, whether the feeder is high-grade, low-loss coaxial cable or waveguide. While waveguide may be much less lossy than coaxial cable, it is expensive and difficult to use because it is large and rigid. Obviously, the higher the antenna, the longer the feeder and the more the feeder loss. To overcome the conflict between the need for high antennas and

Table 8.1. Losses in coaxial feeders

Type	Loss*	Dia. (mm)	Connector	Remarks
URM43	18.1	5.0	BNC	Single core
URM76	22.0	5.0	BNC	Stranded core
RG58C/U	24.0	5.0	BNC	Stranded core
URM67	7.50	10.3	N	Single core
RG213/U	8.00	10.3	N	Stranded core
Westflex 103	1.30	10.3	N	Semi-air spaced
RG174A/U	6.0 @ 400MHz	2.8	min BNC, BNC† SMA/B/C	Stranded core
URM95	19.5 @ 600MHz	2.3	min BNC, BNC† SMA/B/C	Single core
RG178B/U	44.0	1.8	—	Single core PTFE
RG402‡	12.0 (45 @ 10GHz)	3.58	SMA	Semi-rigid precision. Solid copper outer
RG405‡	20.0 (75 @ 10GHz)	2.17	SMA	As RG402
LDF 2-50	3.5 (15 @ 10GHz)	—	Special	Semi-flexible. Foam-filled
LDF 4-50	2.7 (12 @ 10GHz)	12.2	Special	Semi-flexible. Helical membrane, air-spaced
LDF 5-50	1.5	22.2	Special	Semi-flexible. Helical membrane, air-spaced

* Loss in decibels per 100ft (30m) at 1000MHz, unless otherwise shown.
† Two types of BNC connector available for 5mm and 2.5mm cables.
‡ Usable to 18GHz.
5mm cables suitable for SHORT antenna runs at 1.3GHz. 10mm cables suitable for longer antenna runs at 1.3GHz. Smaller cables and semi-rigid cables (known as 'hardline' in the USA) used for VERY SHORT runs inside equipment.

higher feeder losses, most amateurs operating fixed microwave stations mount the microwave transverter (or transmitter and receiver) at, or very close to, the antenna and then use well-screened, low-loss coaxial cable to conduct the intermediate frequency to and from the masthead equipment. Sometimes the same cable can be used to conduct power up to the masthead to operate the equipment. A typical, simple wide-band 10GHz masthead installation is shown in the next chapter, to illustrate the kind of set-up needed. Take a look at a satellite TV receiver installation – this is a good example of the principle of placing the microwave unit at the antenna and using the coaxial feeder to conduct power to the receive converter and intermediate frequency down to the tuneable, programmable 'set-top' receiver/decoder. Exactly the same principles apply to amateur installations. Of course, these problems don't arise in portable working!

Another general rule is to use as few coaxial connectors as possible – each loses some signal – and use only those rated for use at the frequency concerned. Some examples of 50Ω connectors are given below:

- PL259/SO239 DC to 144MHz, poor at UHF
- F-type (satellite TV) DC to 1GHz
- BNC DC to 2GHz
- SMB DC to 4GHz
- TNC DC to 15GHz
- SMC/N-type DC to 10GHz
- SMA DC to 18GHz (some go higher)

Some sources of ready-made antennas are given in references [8–10] and details of how to use the various coaxial connectors is given later in this chapter.

The losses of various types of coaxial feeders at various frequencies is given in Table 8.1.

Change-over systems

With the exception of simple 10GHz microwave transceivers based on in-line doppler modules, which require no switching between transmit and receive (see next chapter), most microwave receivers, transmitters and transverters do need some kind of 'interface' between the microwave unit and the intermediate frequency transceiver as well as transmit and receive switching at the input and output of the microwave unit.

A microwave transverter will usually only require a few milliwatts of intermediate frequency transmitter drive and will deliver a few microvolts of receive signal to the IF receiver. Note that the local oscillator drive will not need switching, since it must be present for both transmit and receive.

It is also very convenient to control the transverter using the PTT ('push to talk') control of the main transceiver. Antenna changeover at the input/output socket of the transverter is also required. Plainly, then, some kind of 'interface' is needed between the transverter and the transceiver.

The interface circuit given in this section was originally developed as a 'universal' interface and transmit/receive sequence switching circuits for microwave and other transverter units. The switching sequencer, in particular, has many other applications. It was developed by G3SEK [43] from a design by N6CA in the *ARRL Handbook*.

The first unit, Fig 8.3, is a low-noise 144MHz IF head

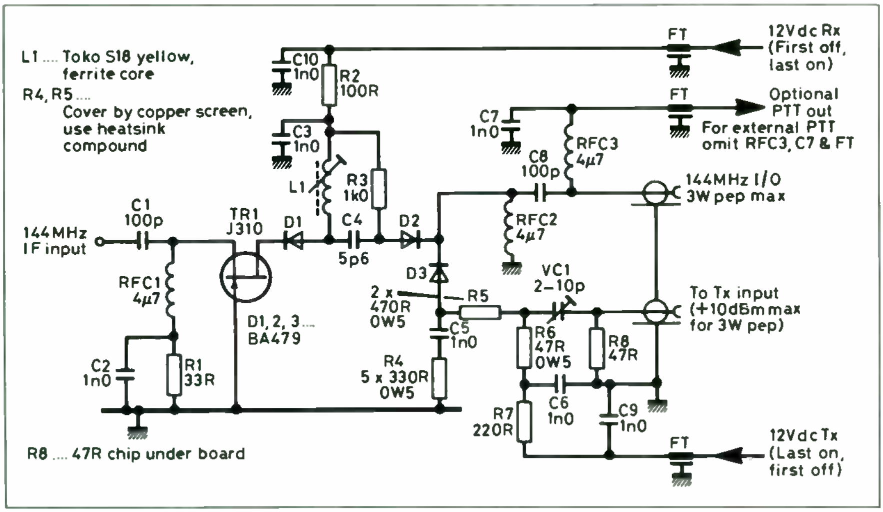


Fig 8.3. Circuit of a transverter interface for use with a low-power 144MHz transceiver, by G3SEK. Component values are given in Table 8.2

preamplifier with good broad-band 50Ω match, together with transmit/receive switching and a power attenuator suitable for 144MHz powers of 1 to 3W. There is also an optional connection for amateur 144MHz transceivers such as the Icom IC202 and Yaesu FT290R, both of which are popular with microwave operators and both of which apply a DC PTT signal through the antenna socket.

The circuit is loosely based around various muTek transverters. The receive gain is about 15dB and the noise figure about 2dB. The maximum RF power output to a transmit mixer is about 20mW for 3W input. This means that a further 13dB of attenuation would be needed to drive most microwave transmit converters, if the power input to the interface is 3W. Component values are given in Table 8.2. The whole unit must be very well screened to prevent leakage of 144MHz signals, either in or out. Input levels much higher than 3W would cause a problem with heat dissipation. For higher-powered transceivers, it would be better to use an external power attenuator which could probably be left in-line on receive as well as transmit, as most microwave transverters could do with a bit less RF gain (see earlier)!

Even with the price of GaAs FETs coming down, transmitter powers are going up, so we need to be very careful about the proper sequencing of transmit/receive changeover to avoid damage to the receiver input amplifier FETs. The correct sequence for switching from receive to transmit is:

1. Receiver power off (but leave the local oscillator running).
2. Energise the coaxial relay and wait for the contacts to settle.
3. Enable the PA and let it reach its quiescent operating point.
4. Enable transmit exciter/driver.

The sequence in going from transmit to receive is exactly the opposite. The sequencer circuit shown in Fig 8.4 is an adaptation of the design by N6CA in the *ARRL Handbook*. TR1 and TR2 provide a PTT interface suitable for relay-switched 0V transmit, 12V transmit or alternatively the DC levels provided by the IC202 or FT290R (see earlier). Switching between receive and transmit causes the voltage across C1 to ramp up or down, taking about 200ms. Comparators IC1a to IC1d have progressively increasing reference voltages, so they will switch over in sequence. The only major change from the N6CA design is to bring the coaxial relay and PA-enable supplies out to separate connections to allow the use of voltages other than 12V. For instance, commonly available SMA microwave relays often operate at 28V. Component values are given in Table 8.2.

Construction

The PCB track layout for the 144MHz interface is given in Fig 8.5 and the component overlay in Fig 8.6. The track layout for the sequencer is given in Fig 8.7 and the component overlay in Fig 8.8. The track layouts are full sized and are 'X-ray' views *from the component side*. The IF interface board has a copper-clad ground plane on the upper side and is designed to fit into a Piper Communications size 2A box for screening, whereas the sequencer board is single sided and should require no special screening. The prototype was mounted on self-adhesive plastic pillars in a convenient corner of the transverter case. All circuit values are given in Table 8.2.

An alternative, single-board interface, designed by Andy Talbot, G4JNT, is available in kit form from the RSGB Microwave Committee Components Service, reference [11].

Microwave PCBs and SMD components

At one time, many microwave circuits were constructed on or in waveguide, particularly for the higher frequencies such as 5.7 and 10GHz. This was because it was

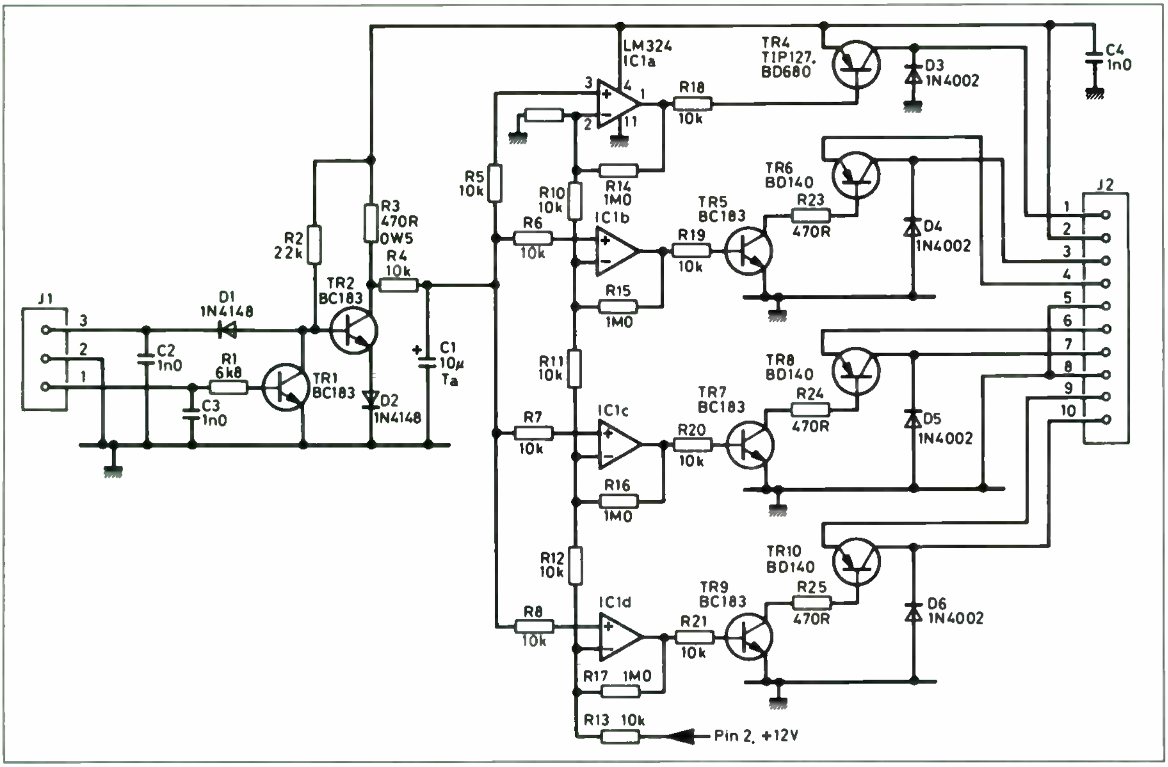


Fig 8.4. Circuit of a switching sequencer suitable for use with almost all microwave transverters and the interface circuit of Fig 8.3. Input connections on J1: (1) +V to transmit (FT290R); (2) ground; (3) 0V to transmit (IC202). Connections on J2: (1) receiver stages, +12V on receive, 0V on transmit; (2) +12V supply (input to all circuits); (3) coaxial relay, 0V on receive, 12 to 28V on transmit; (4) +12 to +28V supply (input to 3); (5) ground; (6) +12 to +28V supply (input to 7) auxiliary control, eg for power amplifier control; (7) auxiliary relay control, 0V on receive, +12 to 28V on transmit; (8) ground; (9) +12V supply (input to 10); (10) transmit stages, +12V on transmit, 0V on receive

Table 8.2. Components lists for 144MHz interface and transmit/receive sequencer

144MHz INTERFACE		**TRANSMIT/RECEIVE SEQUENCER**	
R1	33R	R1	6k8
R2	100R	R2	22k
R3	1k0	R3	47R, 0.5W
R4	66R, 2.5W (5 × 470R, 0.5W)	R4–13	10k
R5	235R, 1W (2 × 470R, 0.5W)	R14–17	1M0
R6	470R, 0.5W	R18–21	10k
R7	220R, 0.5W	R22	(not used)
R8	47R, under board	R23–25	470R*
C1	100p	C1	10µ, tantalum
C2, 3	1n0	C2–4	1n0
C4	5p6	D1, 2	1N4148
C5–7	1n0	D3–6	1N4002
C8	100p	TR1, 2	BC183
C9, 10	1n0	TR3	(not used)
VC1	2–10p, Sky	TR4	TIP127/BD680
L1	Toko S18 yellow (Ferrite core)	TR5, 7, 9	BC183
RFC1–3	4.7µH	TR6, 8, 10	BD140
D1–3	BA479	IC1	LM324
TR1	J310		

* Note: R23 should be 470R, 0.5W. With 12V supplies to pin 4 and/or pin 6 R24 and R25 should be 470R, 0.5W. If using 24–28V supplies, change R24 and/or R25 to 1k5, 0.5W

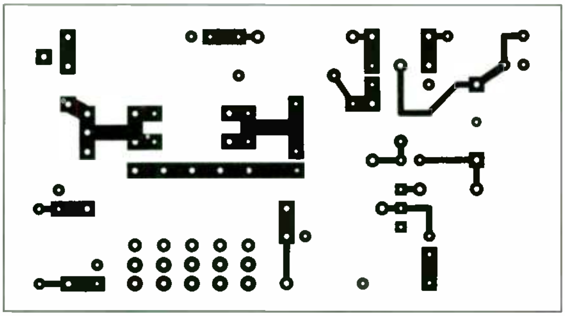


Fig 8.5. PCB track layout for the G3SEK transverter interface

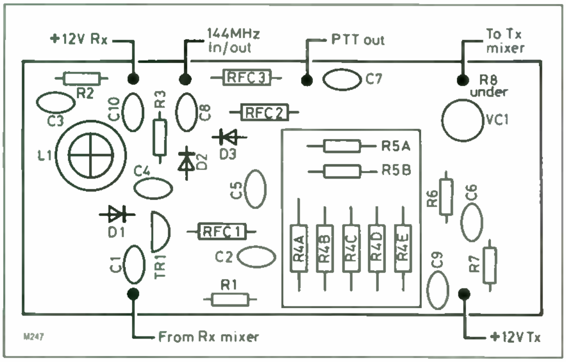


Fig 8.6. Component overlay for the G3SEK transverter interface

more efficient to build conventional components, such as mixer, detector, multiplier or oscillator devices actually *into* the least lossy feeder – waveguide. It is also easy to make filters, cavities (tuned circuits) and matching sections within the same piece of waveguide.

At that time also, printed circuit materials (known as 'substrates') were too lossy and too unpredictable to be reliable at frequencies much above 1 or 2GHz. Improved board materials with closer manufacturing tolerances and microminiature surface-mount devices (SMDs, such as resistors, capacitors and solid-state devices) have made it possible to build efficient microwave circuits on PCBs.

An etched copper line of precise thickness and width, separated from a copper ground plane by a closely defined thickness of a low-loss dielectric (insulator, such as PTFE) will have a well-defined impedance and may, depending on the purpose of the circuit, have a well-defined resonant frequency. It is thus possible to design microwave PCBs which have filters, tuned circuits, impedance matching sections, chokes, splitters and small-value capacitors etched onto them, together with connecting conductors of a defined impedance (such as 50Ω). This method of construction is known as 'microstrip' and is now used at almost all microwave (and UHF) frequencies. All that is needed to turn a microstrip PCB into a

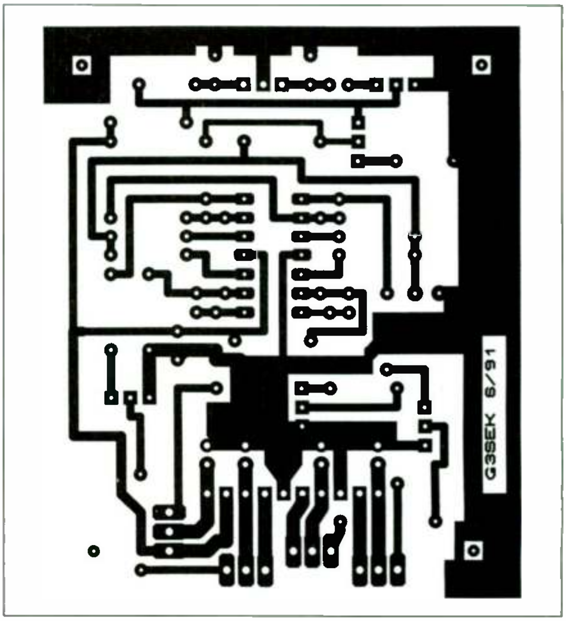


Fig 8.7. PCB track layout for the G3SEK switching sequencer

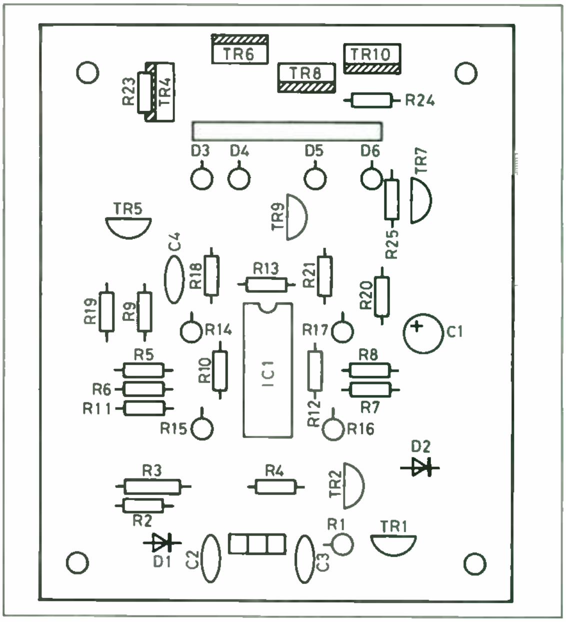


Fig 8.8. Component overlay for the G3SEK switching sequencer

functional circuit is the addition of a few passive components (such as fixed or variable capacitors and resistors) and the active devices (diodes, transistors and integrated circuits).

Microstrip technology offers home constructors the chance to build very efficient microwave equipment with the minimum of effort and with a high degree of success!

The active and passive SMD components mounted on a microstrip PCB are very small and either leadless or nearly so. This makes construction difficult unless strong light and a magnifying glass is used! Equipment for the 1.3GHz band might use a mixture of conventional components (with leads) and microstrip with SMDs and, up to about 3 or 3.5GHz, conventional epoxy/glass-fibre PCB material is used. Beyond this, much thinner, more expensive, rather flexible PTFE/glass-fibre is used. In either case, it is very difficult to produce PCBs of sufficient accuracy at home, so the constructor will normally purchase ready-made, precision PCBs which are ready tinned for easy assembly. Professional PCBs are usually gold-plated. However, ordinary PCB materials and methods of etching can be used for some of the circuits described in the next chapter or the transverter interface described above.

After etching a home-made PCB, it is necessary to clean the copper tracks so they are easy to solder. This is usually done with fine steel wool (Grade 0 or 00), water and detergent or soap. Microwave PCB material doesn't take kindly to such rough treatment! It is better to clean tracks, if this is really necessary, by carefully rubbing the surface to be soldered with a glass-fibre-tipped 'pen' or abrasive 'eraser' made specially for the purpose. These can be found in any good components supplier's catalogue.

Using microminiature SMDs can also be difficult because there is a danger of them 'flipping' over on end while soldering, due to the surface-tension effect of the molten solder. This problem can be solved in one of two ways: either the constructor can make some sort of 'jig' consisting of a spring-loaded needle which is used to hold the component in place while soldering is completed, or the component can be fixed in place before soldering with a *very small* amount of cyanoacrylate glue ('superglue'), then soldered. If you use the latter method, be very careful not to get the glue on your skin, otherwise you may stick your fingers together. Beware, this is not a joke!

Even soldering can be difficult, since many components are easily damaged by too much heat. You should always make sure that your soldering iron is clean and tinned and that the area to be soldered is also clean and tinned. This is usually no problem with SMDs and professionally produced PCBs, but it can be a problem with home-made PCBs. Always use fine, resin-cored solder, 24 or 26 gauge. Silver-loaded low-melting-point (LMP) solder is best as it melts at about 180°C, much lower than normal 60% tin, 40% lead solder. If you have any doubts about your soldering ability, either practice on a few scrap components, or ask for the help of a more experienced constructor.

An alternative to normal soldering is to 'cold solder' the components using silver-epoxy conductive resin: this is very expensive but, used carefully, a little goes a very long way. It will 'cure' (harden) in a few minutes at 100°C or about 24 hours at 25°C to give a joint which is as strong as a soldered joint and also as conductive. Again, this material is listed in the catalogues of many component suppliers. If silver epoxy is used, then there is no need to hold or glue the component in place before the silver-epoxy is applied as it will act as its own 'glue'.

'Boxes' for microwave equipment

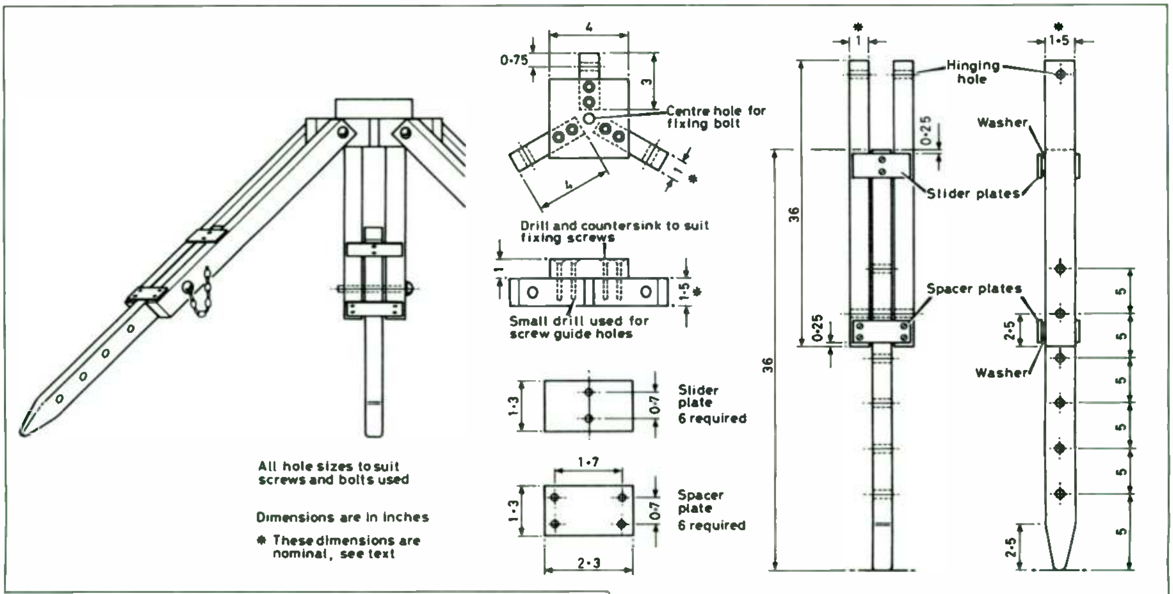
Microwave PCB-based equipment must always be well screened to avoid either stray signal pick-up or stray signal radiation. The box in which the PCB is mounted must always make good contact with the ground plane of the PCB, again in order to prevent stray signals getting where they are not wanted. Another advantage of a good 'box' is that a degree of thermal stability (freedom from the effects of temperature changes) protects the circuit from drift or detuning: this means that oscillators don't drift as far or as rapidly, or tuned circuits go 'off-tune'.

It has already been mentioned that microstrip PCBs are thin and flexible. Flexing of the PCB can cause even larger changes than thermal drift, so it is essential that such PCBs are rigidly mounted. This is best achieved by soldering them into a tin-plate box, taking care to solder all round all the joints between the inside walls of the box and the PCB ground plane. This ensures that the PCB is held rigidly and is well grounded (screened). The ground-plane side of the box can then be used to provide a well-screened and noise/RF-free compartment, so that power and voltage regulator connections can be brought into the earthed box via feedthrough connections. All RF input and output connections should be made with small-diameter coaxial feeder, with or without the use of connectors (see earlier). See reference [1] for more details of suitable methods of connecting coaxial leads to PCBs.

At lower frequencies (eg 1.3GHz), it is still good practice to use such methods, but not so essential. A thick epoxy/glass-fibre PCB which is rigid may be perfectly satisfactory when mounted on grounded nut and bolt fixings in a die-cast box instead of a tin-plate box.

It is also possible to make satisfactory light-weight boxes from pieces of unetched ordinary double-sided copper-clad PCB material, provided that the inside cladding has all its seams properly soldered together and to the PCB ground plane. All coaxial sockets and other screened connections, for instance feedthrough capacitors, must be grounded by connection to both the inside and the outside cladding.

Removeable lids and base-plates can be fixed by means of bolts through holes in the plate which screw into brass nuts soldered to the inside copper cladding of the box.



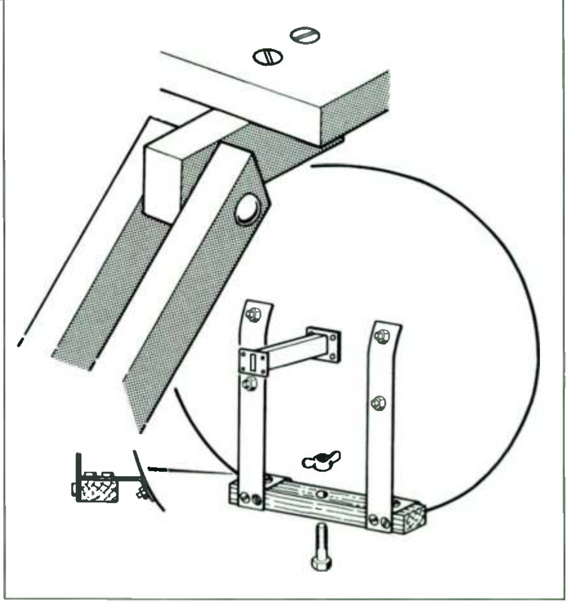


Fig 8.9. Construction details of the home-made tripod for portable use (above), and hinge details and a suggested dish mounting arrangement (right)

Don't just rely on a few bolts for fixing – use one at each corner and several along the length of each side or end of the box where good shielding is needed. A good 'rule of thumb' is that the spacing should be no more than a quarter wavelength apart, ie 57mm at 1.3GHz or 7.5mm at 10GHz, although this is not very critical!

Sometimes it may not be necessary to fit top or bottom plates if the open-topped box is to be mounted with other modules in an outer box. 'Double boxing' like this is a good idea anyway, as it will almost always improve both thermal stability and screening of the PCB.

'Odds and ends'

A home-made tripod for microwave portable use

On the 10GHz band, there is quite a lot of portable operation from hill-tops, and a convenient way of mounting the antenna (horn or small dish) and the transceiver is to use a tripod. The most easily obtainable tripods are of the photographic type, made to mount a camera, video cam-corder or small telescope. These are expensive and not always suitable for amateur radio! Cheap tripods may be too light and flimsy to support the load, or to resist strong winds without blowing over. They may also not have their feet far enough apart to resist winds: the wider apart the feet, the less the chance of blowing over. Photographic tripods are expensive – the tripod described here will cost much less than even the cheapest of photographic tripods.

The design was originally described in reference [12] and is based on wooden tripods such as those used for surveying equipment, but much less expensive! The materials and tools required should be available in most DIY or hardware shops except perhaps for the aluminium sheet used for the leg spacer and the 'slider' plates. Fig 8.9 shows the dimensions of the main parts of the tripod: using wood, none of these dimensions is critical.

The legs are made from 1in × 1.5in (24 × 37mm) softwood. The actual size may be a little less than this because of the way the timber is planed. Such wood is often sold in 6ft 6in lengths (2m) and five such lengths are needed to make the 3ft (0.9m) leg sections and the platform/hingeplate 'fingers'.

The platform/hingeplate is 4in × 4in × 1in (100 × 100 × 25mm), but the size is not critical, so long as the fingers can be fixed securely to it. Board or chipboard can be used and, because of its small size, an 'off-cut' can be used. Polyurethane boat varnish, paint or some wood sealing product will be needed to seal and protect the wood from rain and moisture. You will need the following tools: saw, screwdriver, spanner, drill and drill-bits, sandpaper and a file or Surform™ tool to shape the feet of the tripod.

After cutting all the pieces needed, they can be marked out for drilling. Again, none of the measurements is critical, although the more accurate you can make them, the better the finished job. When marking out the screw holes for the fixed leg plates, make sure the outside sections are spaced far enough apart to allow the sliding leg sections to move freely. Freedom of movement can be improved by later, after weatherproofing the tripod with varnish, rubbing the sliding sections with candle-wax.

Pre-drill the screw holes in the 'fingers' by first marking out and drilling the holes in the platform, then positioning the fingers in their final locations (leaving enough room in the middle to allow the fixing bolt to pass through) and marking the screw-hole positions through the centre of the platform. You can use a similar method to make sure that the holes in the sliding leg sections line up with the 'peg' holes in the outside sections. However, this will need to be left until the legs are assembled.

When you have finished all the cutting, marking and drilling, all the wooden part can be smoothed with sandpaper and then varnished. Two or three light coats of yacht varnish should seal the wood well. Don't try to rush this job: each coat of varnish may take quite a long time to dry, and you should read the manufacturer's instructions well!

When completely dry, the tripod can be assembled, starting with the platform and then the legs. With the legs assembled, but before fitting them to the platform, the holes in the sliding section should be drilled. To allow the sliding sections free movement, washers are used to space the plates away from the legs, and also between the 'fingers' and the outside leg sections. Depending on the thickness of the washers you have available, you may only need to use them on one side of each leg, otherwise one (or possibly more) can be used under each plate and on either side of the 'fingers'.

The fixing pegs, used to adjust the height of the tripod, can be wooden dowelling, aluminium rods, or bolts. Finally, the legs are attached to the platform by bolts through the fingers: these are tightened enough to prevent any sideways movement, but not enough to stop the legs from hinging.

Table 8.3. Parts list for microwave tripod

6 off, 2in (50mm) No 8 countersunk woodscrews
36 off, 0.75in (19mm) No 6 countersunk or roundhead woodscrews
3 off or 6 off, 3in (75mm) by 0.25in (6mm) dia coach bolts (3 used for leg hinges, 3 for leg fixing pegs if required, but see text)
3 off or 6 off, nuts or wing-nuts for above washers, as required, 9 off

The mounting of the equipment or the antenna will, of course, depend on your particular requirements, but a sketch of a typical dish mounting arrangement is given in Fig 8.9. A list of the bits and pieces needed is given in Table 8.3.

Coaxial plug assembly

Standard Belling-Lee 75Ω TV plug

Use below 500MHz and note that they match 75Ω! Referring to Fig 8.10:

1. Cut end of cable even and remove 22.25mm (7/8in) of outer sheath.
2. Remove 15.9mm (5/8in) of dielectric without damaging inner conductor. Lightly tin the end of the conductor.
3. Slide cap and collet clamp over cable and slightly clench the collet in position. Comb out the braid and

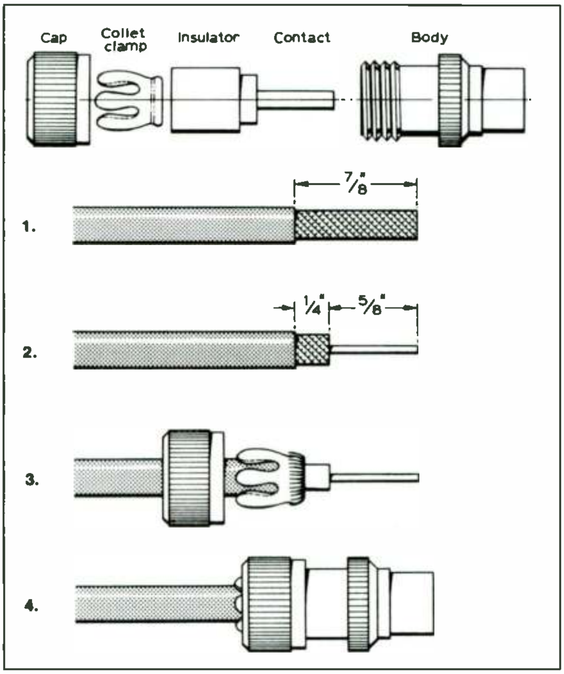


Fig 8.10. Belling-Lee plug assembly

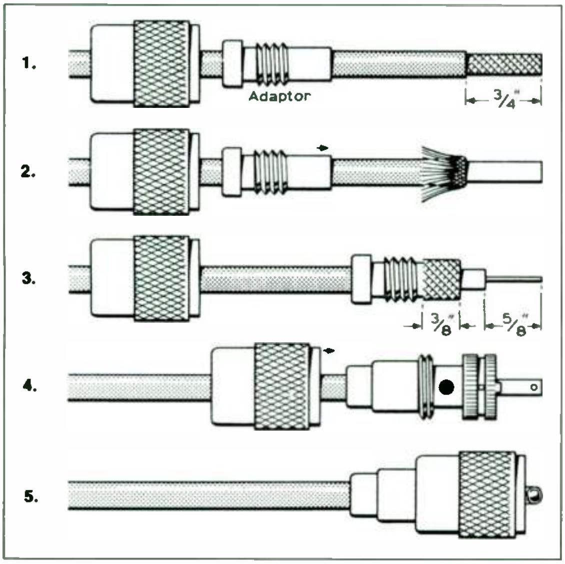


Fig 8.11. PL259 'UHF' type (clamped screen) plug assembly

fan out over collet. Solder cable centre conductor to tip of plug contact. Avoid overheating.

4. Push sub-assembly into the body as far as possible. Gently but firmly screw cap onto the body to complete the assembly.

PL259 'UHF' clamped screen type

Do not use above 144MHz as they are too lossy! Referring to Fig 8.11:

1. Cut end of cable even. Remove 19mm (¾in) of outer sheath. Slide coupling ring and adapter on cable.
2. Fan braid slightly and fold back as shown.
3. Position adapter to dimension shown. Press braid down over body of adapter and trim to 9.5mm (3/8in). Bare 15.9mm (5/8in) of centre conductor. Tin exposed centre conductor.
4. Screw plug sub-assembly on adapter. Solder braid to shell through the solder holes. Use enough heat to create bond of braid to shell. Solder centre conductor to contact.
5. For final assembly, screw coupling ring on plug sub-assembly.

PL259 'UHF' soldered screen type

Do not use above 144MHz as they are too lossy! Referring to Fig 8.12:

1. Cut end of cable even. Remove 28.6mm (1 1/8in) of outer sheath.
2. Bare 15.9mm (5/8in) of centre conductor. Trim braided

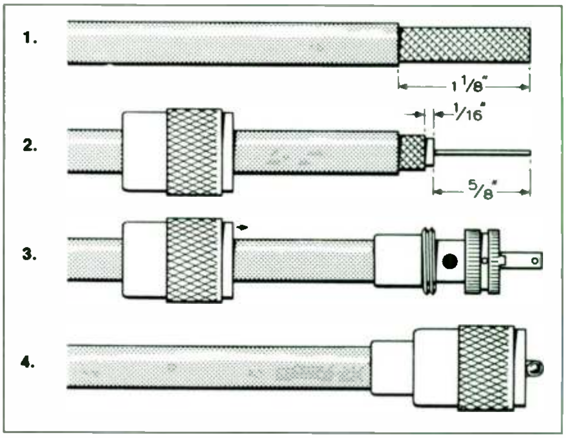


Fig 8.12. PL259 'UHF' type (soldered screen) plug assembly

shield. Slide coupling ring on cable. Tin exposed centre conductor and braid.

3. Screw the plug sub-assembly on cable. Solder assembly to braid through solder holes. Use enough heat to create bond between braid and shell. Solder centre conductor to contact.
4. For final assembly, screw coupling ring on plug sub-assembly.

N type

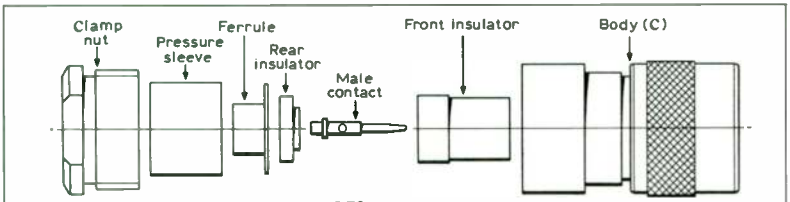
Use up to 10GHz, but they are too big for small equipment! Referring to Fig 8.13:

1. Cut end of cable even and remove 8.7mm (11/32in) of outer sheath.
2. Slide the clamp-nut and pressure sleeve over cable.
3. Fold the braid back. Insert the ferrule between the braid and dielectric. Trim off excess braid. Remove 5.5mm (7/32in) of dielectric without damaging the centre conductor. Tin end of the centre conductor.
4. Slide rear insulator over centre conductor and position against end of dielectric. Slide the contact over the centre conductor until the shoulder of the contact is pressed hard against the rear insulator. Solder the contact to the conductor but avoid overheating.
5. Fit front insulator in body and push sub-assembly into the body as far as possible. Slide pressure sleeve into body and screw in the clamp-nut tightly to clamp the cable.

BNC type, male contact

Use up to 2GHz. Up to 4GHz use TNC type which are very similar but have a screw fitting instead of the 'bayonet' fitting. Referring to Fig 8.14:

1. Cut end of cable even and remove 7.9mm (5/16in) of outer sheath.



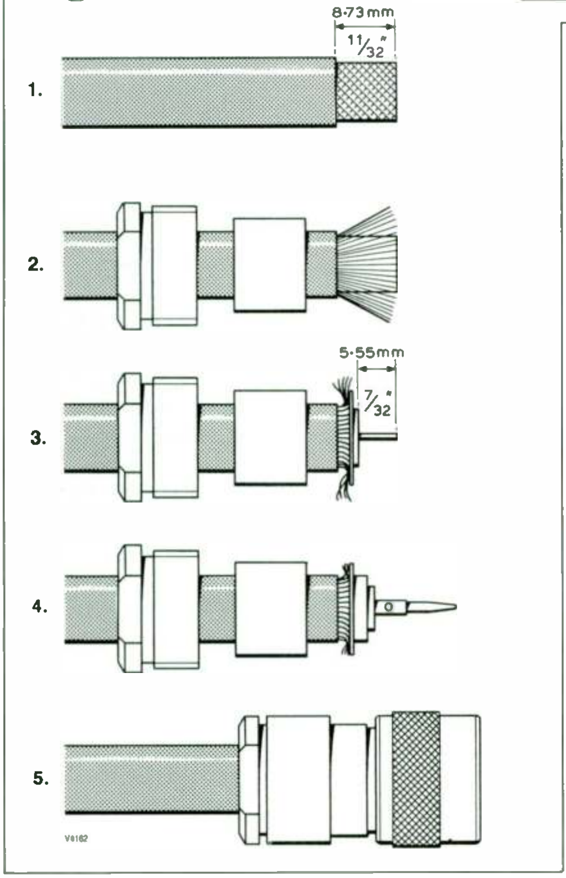


Fig 8.13. N type plug assembly

2. Slid the clamp-nut and pressure sleeve over the cable. Comb out braid.
3. Fold the braid back. Insert the ferrule between the braid and dielectric. Trim off excess braid. Remove 5.2mm (13/64in) of the dielectric without damaging the centre conductor. Tin the end of the conductor.
4. Slide the rear insulator over the centre conductor and locate the shoulder of the insulator inside the recess in the ferrule. Slide the contact over the centre conductor until the shoulder of the contact is pressed hard against the rear insulator. Solder the contact to the conductor but avoid over-heating.
5. Fit front insulator in body and push the sub-assembly into the body as far as possible. Slide the pressure sleeve into the body and screw in the clamp-nut tightly to clamp the cable.

BNC type, female contact

Use up to 2GHz. Up to 4GHz use TNC type which are very similar but have a screw fitting instead of the 'bayonet' fitting. Referring to Fig 8.15:

1. Cut end of cable even and remove 7.9mm (5/16in) of outer sheath.
2. Slide the clamp-nut and pressure sleeve over cable. Comb out braid.
3. Fold the braid back. Insert the ferrule between the braid and dielectric. Trim off excess braid. Remove 5.2mm (13/64in) of the dielectric without damaging the inner conductor. Tin the end of the inner conductor.
4. Slide the rear insulator over the centre conductor and locate the shoulder of insulator inside the recess in the ferrule. Slide the contact over the centre conductor

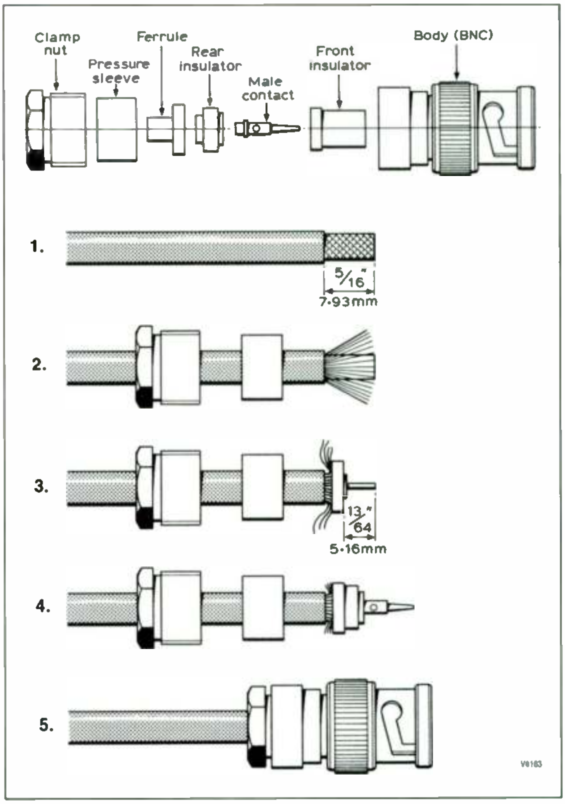


Fig 8.14. BNC (male contact) plug assembly

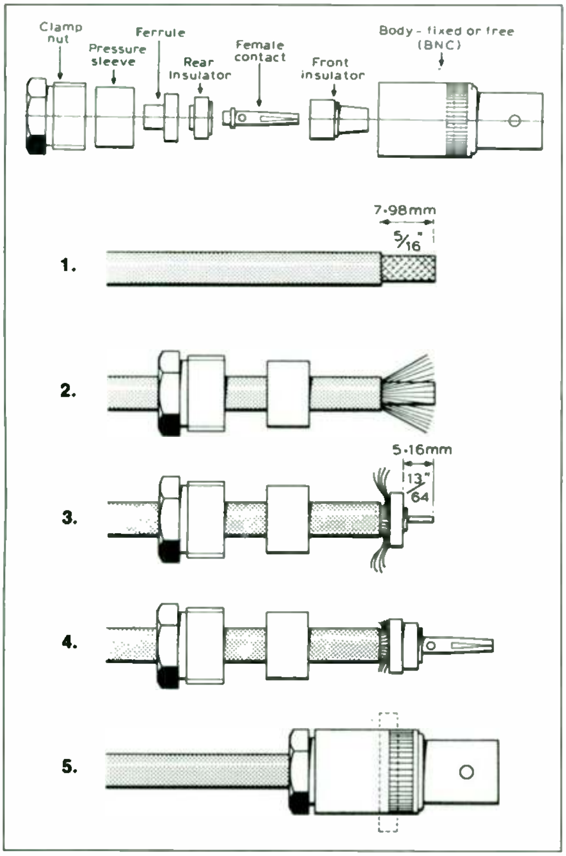


Fig 8.15. BNC (female contact) plug assembly

until the shoulder of the contact is pressed hard against the rear insulator. Solder the contact to the centre conductor but avoid overheating.

5. Fit the front insulator in body and push the sub-assembly into the body as far as possible. Slide pressure sleeve into body and screw in clamp-nut tight to clamp cable.

Making attenuators

Resistive attenuators are very useful for reducing signal levels to prevent circuit overload, eg to reduce the strength of received signals between the output of the receive converter of a transverter and the input of a transceiver used as the IF, or the transmit signal between the output of a transceiver and the input of the transmit converter of a transverter.

Whilst it is possible to make attenuators of exact value (expressed in decibels) using precision resistors, it is often more practical to make attenuators of values close to those needed, by using standard-tolerance resistors, so that is what is given here!

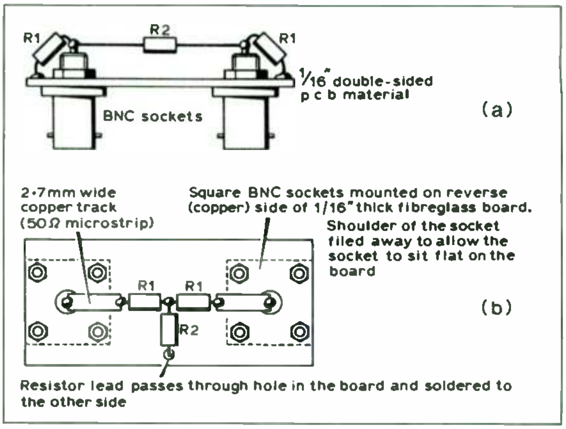


Fig 8.16. (a) Construction of simple attenuator for use below 500MHz. (b) Construction of simple attenuator for use above 500MHz. Note the use of a ground plane and short lengths of microstrip to keep resistors leads as short as possible

The most useful attenuators are those which present 50Ω input and output impedance since nowadays most receivers and transmitters are designed to match 50Ω loads.

Attenuators can take one of two forms: a pi-attenuator or a T-attenuator. When using a single-section attenuator it doesn't really matter which type you use, but when you want to use cascaded attenuators (in series, so that their attenuations add), it is a good idea to use alternate pi-sections and T-sections, as this will often make construction easier.

Attenuators made from standard resistors can be used with reasonable accuracy from DC to 1 or 2GHz. However, if you try to make a single-section attenuator with too high attenuation, the accuracy will suffer because of leakage round the attenuator from input to output. This effect increases with frequency, so that if you want to make a reasonably accurate high-value attenuator for use at VHF or UHF, then several stages of lower attenuation, each screened from one another, should be connected in series. Generally, though, the beginner may only need to put a simple single-stage attenuator between a low-power transmitter and a transverter or a transverter and a receiver.

Fig 8.16(a) and (b) show two ways of making simple, single-stage attenuators: the double-sided PCB material could be used as the lid of a small die-cast box or could be mounted in the lid of a small tin-plate box, either of which will provide excellent screening.

Fig 8.17 shows the circuit diagram of a switched five-stage 50Ω attenuator illustrating the principle of cascaded, low-attenuation stages to produce a very useful piece of test gear. The switches are shown in the 'on' position, so that the total attenuation is 31dB. By using a

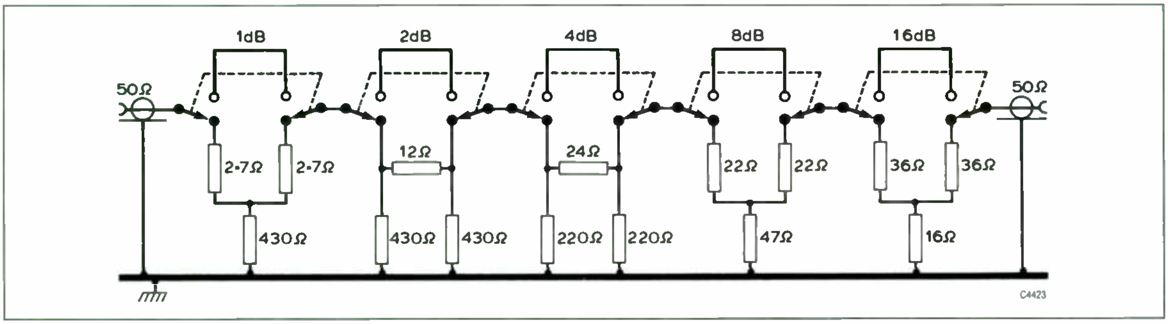


Fig 8.17. A switched-step resistive attenuator for use in 50Ω systems. The attenuator can be switched in steps of 1dB from 0 to 31dB. Any individual section, either pi- or T-type, can of course be used on its own (see text)

combination of the switches, it is possible to increase the attenuation in 1dB steps between 0dB and 31dB.

Fig 8.18 is a photograph of a three-stage switched attenuator, showing the type of construction needed for screening between stages: note that the resistors are mounted directly on the switch terminals using the shortest possible leads with the input and output connected to BNC coaxial sockets. The switches are mounted on the lid of a small die-cast box and the screens between stages are made from thin copper sheet.

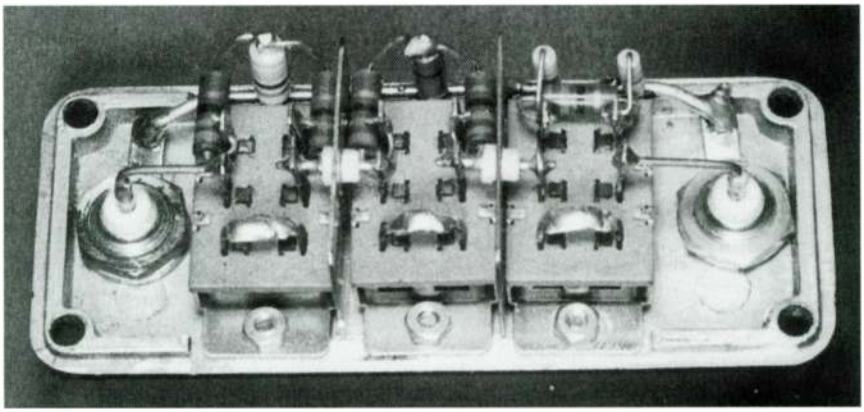


Fig 8.18. Photo of a three-stage switched attenuator to show the form of construction (see text)

For simple attenuators, you could simply select one or more sections of either the pi-sections or T-sections shown and use these on their own without the need for switching. For instance, you might need 8dB attenuation: select the T-section comprising two 22Ω resistors and one 47Ω resistor. Other choices should be obvious! Fit the resistors in circuit with short leads within the transverter box, close to the input or output socket where the attenuator is needed.

Apart from keeping leads as short as possible, the only precaution to take is to ensure that the *input* resistor of a transmit attenuator is rated to safely dissipate at least 90% (and preferably *all*) of the power applied to it. This of course does not matter for a receiver attenuator where the power levels are so small that power dissipation is not important.

An example of a power attenuator is to be seen in Fig 8.3, where resistors R4, R5 and R6 form a pi-attenuator: note that the input resistor R4 consists of no less than five 330Ω 0.5W resistors in parallel to give enough power rating to withstand 2.5W dissipation, the remaining 0.5W being dissipated in R5 and R6.

References

[1] *Practical Transmitters for Novices*, John Case, GW4HWR, RSGB, 1995.

[2] 'System analysis and propagation', Barry Chambers, G8AGN, in *Microwave Handbook*, Vol 1, ed Mike Dixon, G3PFR, RSGB, 1989.

[3] 'Operating techniques', Mike Dixon, G3PFR, and Julian Gannaway, G3YGF, in *Microwave Handbook*, Vol 1, ed Mike Dixon, G3PFR, RSGB, 1989.

[4] *RSGB Amateur Radio Call Book*, RSGB, 1995 (or later editions).

[5] Public Domain and Shareware Library (PDSL), Winscombe House, Beacon Road, Crowborough, E Sussex, TN6 1UL. (Tel: 01892 663298).

[6] Venus Electronics, 26 Pevensey Way, Frimley Green, Camberly, Surrey, GU16 5YJ. (Tel: 01252 837860).

[7] Programs written by members of the RSGB Microwave Committee: D J Butler, Yew Tree Cottage, Lower Maescoed, Hereford, HR2 0HP.
[8] 1.3GHz loop-Yagi antennas: Mike Walters, G3JVL, 26 Fernhurst Close, Hayling Is, Hants PO11 0DT.
[9] 1.2/1.3GHz Yagis and trough reflectors: Severnside Television Group, c/o 18 Linnet Close, Patchway, Bristol, BS12 5RN.
[10] Satellite TV dish antennas: any satellite TV shop or antenna installer.
[11] Microwave Committee Components Service, c/o Mrs Petra Suckling, G4KGC, 314A Newton Road, Rushden, Northants, NN10 0SY.
[12] 'A home-made tripod for microwave operation', C H Ousby, G0CHO, *Radio Communication* November 1985, pp867–868.

Chapter 9

Receivers for the Novice microwave bands

Microwave receivers (or indeed receivers for any other frequency) are usually harder to make than transmitters because they handle much lower signal levels and are more difficult to align. Any RF amplifiers in them have to generate as little noise as possible in order to amplify much smaller signals, nearer to the noise level, than those in transmitters.

Oscillators are just as important in receivers as they are in transmitters. An oscillator source used to drive the mixer in a receiver or receive converter must not only be frequency stable but also as 'clean' as possible – that is, free from noise and harmonics. Oscillator noise adds to the overall receiver noise figure, especially with a low intermediate frequency (IF) and unwanted harmonics can cause spurious (unwanted) mixing products as well as degrading the noise performance. 'Dirty' oscillators are just as bad news in receivers as they are in transmitters! In general, an oscillator source which is clean enough to be connected to an antenna and used as a transmitter will be good enough as the local oscillator source in a receiver. A low-power microwave transmitter such as those described in *Practical Transmitters for Novices* (reference [1]) can be used either as a signal source (signal generator) for aligning a receiver or, more important, it can be used as a receiver local oscillator. If you've had a go at building and tuning-up a low-power microwave transmitter, then you'll find receiver construction and alignment much easier – and you might also have built a few pieces of test gear, described in that book, which can help in getting a receiver going too!

Matching at the input of the receiver has to be very good in order to make best use of the small signals coming from the antenna. Mixer and local oscillator circuits have to generate as little noise as possible, otherwise the receiver will not 'hear' signals which may be near to the noise level.

On the LF and HF bands, most of the noise in the receiver comes from the antenna as 'man-made' or natural noise, so that there is little point in trying to use very low-noise amplifiers at the front end of an LF/HF receiver. 'Man-made' noise is usually broad-band and comes from many sources – electric motors, car ignition, thermostats, computers, TV timebase harmonics, electrical wiring, 'leaky' insulators on high-voltage overhead power lines, and many others, in fact anything which acts like an old-fashioned 'spark' transmitter!

Natural noise in the LF and HF bands comes mainly from atmospheric 'static', such as thunderstorms (often at the other side of the world!), noise 'storms' generated by the Sun or other bodies in, or beyond, the solar system. The planet Jupiter, for instance, is quite a strong radio transmitter!

At one time in the UHF bands (at least, above about 400MHz) the noise picked up from the antenna was often less than the thermal and electrical noise generated by the RF amplifier(s), mixer and local oscillator stages of the receiver itself. With the newest gallium arsenide field effect transistors (GaAs FETs), noise figures are so low, especially at microwave frequencies, that amateur receivers can easily hear thermal ('hot-body') noise from natural sources such as the Earth, the Sun, the Moon and certain types of star or galaxy (so-called 'cosmic noise'). 'Man-made' noise and harmonics at these frequencies was very low, although now it is steadily increasing as more use is made of the microwave frequencies.

As well as having to introduce as little noise as possible, a receiver also has to be able to handle signals with a range from a few fractions of a microvolt (one millionth of a volt) to possibly hundreds of millivolts, without causing distortion, cross-modulation and overload effects. All these things make receivers (particularly microwave receivers) much harder to make than transmitters, but fortunately there are now some easy ways to overcome many of these problems!

The two most popular amateur microwave bands are the 1.3GHz ('23cm') and 10GHz ('3cm') bands. These are allocated for use by Novices, hence the title of this chapter. They are, of course, suitable for beginners who hold Class B or Class A licences too!

The 10GHz Novice amateur microwave band is close to the 11/12GHz (Ku) band used for DBS television ('DBS' stands for 'direct broadcasting by satellite'). The

1.3GHz Novice amateur microwave band lies in the intermediate frequency band used for DBS receivers.

This means that inexpensive, second-hand DBS (or new but out-of-date) receivers can be easily adapted for either of the bands. Modified DBS receivers may not always be suitable for very-weak-signal, narrow-band (DX) work, but they are certainly excellent for your first steps into wide-band microwaves! Much of this chapter describes how you might be able to use such 'surplus' receivers. There will also be descriptions of home-built 1.3 and 10GHz narrow-band receivers.

Most microwave receivers use a fixed-tuned down-converter to some lower, intermediate frequency (IF) receiver. This is a tuneable receiver which contains the selectivity filters and detectors or demodulators and gives output at audio and/or video frequencies. The front-end down-converter design, sometimes known as a 'low-noise block converter' or 'LNB', is usually much simpler than the tuneable IF which has to provide selectivity filters and multimode demodulators! The DBS receiver systems, mentioned above, operate on this principle.

If you are fortunate enough to own or have access to a really good wide-range, multimode receiver (manually tuned, programmable or 'scanning'), then your tuneable receiver (IF) problems are already solved, at least as far as narrow-band and some types of wide-band operation are concerned! The author uses an AOR3000A: this particular multimode receiver covers the range 100kHz to just over 2GHz and is used as a 'tuneable IF' for many microwave projects, as well as for monitoring all the amateur bands up to (and including) the 1.3GHz amateur band. However, not many beginners are likely to have access to such a comprehensive receiver. Almost any other wide range or scanning receiver, preferably covering up to the 1.3GHz band, could be used as a narrow-band tuneable IF: however, many provide only AM and NBFM reception, neither mode being much used in the microwave bands. Some of the simpler scanning receivers can be adapted to receive CW and SSB by, for example, fitting a BFO. One advantage of the microwave bands is that they are seldom as crowded as the HF bands and therefore very narrow IF filters are not needed to help avoid adjacent channel interference.

Most of the activity in both the 1.3GHz and 10GHz bands is CW, SSB or ATV (very-wide-band FM), rather than AM or channelised NBFM which are hardly used at all. For CW and SSB, any good non-channelised (tuneable) 144–146MHz multimode receiver will give excellent performance. For wide-band FM and ATV the tuneable IF can be much simpler, especially if you are not particularly interested in DX. If you're interested in ATV, then you'd be wise to join the British Amateur Television Club (BATC), reference [2], as the BATC quarterly journal *CQ-TV* contains information and circuits of

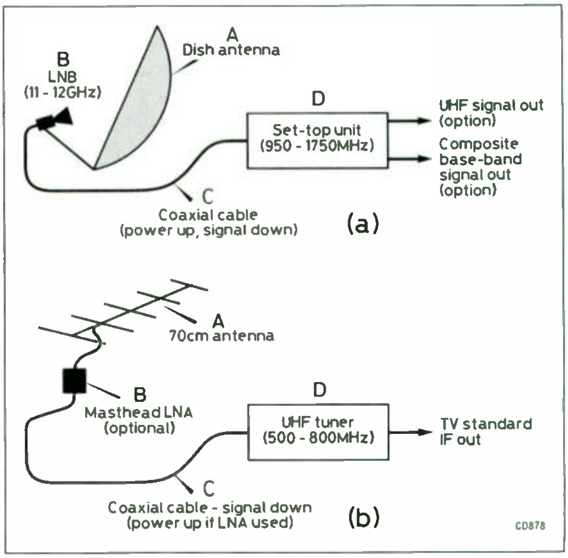


Fig 9.1. (a) Block digram of a typical DBS receiver set-up. (b) Block diagram of a typical 70cm ATV set-up

interest and their Members' Services (address at end of this chapter) can supply PCBs and others parts for many simple ATV projects (to members only). There is also a Publications Service, reference [3], which can supply handbooks, back numbers of *CQ-TV*, photocopies and anything else related to BATC publications.

Wide-band receivers for 1.3GHz and 10GHz amateur television (ATV)

Since domestic DBS equipment became common and cheap, amateurs have been able to adapt and modify DBS receivers, available as 'surplus' from many sources. Older, or second-hand, equipment is very suitable for modification and is very cheap to buy. This general introduction explains why this is so.

Fig 9.1(a) is a block diagram of a typical DBS receiver system. The satellite signals are broadcast in 'Ku' band, using wide-band FM at approximately 11 to 12GHz and are received on a dish antenna (A), typically 50 to 80cm diameter with a gain of 30dB or more. The dish feed may be at the centre of the dish or may be 'offset' and, being a broad-band antenna and feed, is not very frequency conscious. This means that the antenna is suitable for signals in the 10GHz amateur band (10GHz to 10.5GHz) without modification, losing only a few decibels of gain and perhaps not having quite as good a 'beam pattern' in the amateur band as in the DBS band.

The LNB (low-noise block converter, B) usually consists of a couple of stages of low-noise, broad-band, RF preamplification, a mixer, a local oscillator whose frequency is controlled by a device known as a 'dielectric resonator' (DR), and a post-mixer low-noise, broad-band amplifier covering the intermediate frequency (IF) range, 950 to 1750MHz. The LNB is always mounted at or very close to the focus of the dish in order to minimise the losses between the dish and the LNB. Power for the LNB is fed up the coaxial feeder (C) and the IF is fed down the same feeder to the set-top tuner (D).

The set-top tuner consists of a voltage-tuned converter covering the IF range and a decoder which 'unscrambles' (decodes) the 'scrambled' (coded) TV signals. This is not needed for amateur TV and can be bypassed. Then there is an FM demodulator giving standard 'composite base-band' output and/or UHF (Channel 22) output suitable for feeding into a standard domestic video recorder/TV receiver. There are several things to note about this simple description. First, the LNB is broad-band and, although covering approximately 11 to 12GHz, can be retuned to the amateur 10GHz band simply by retuning its local oscillator. In most cases this means getting into the LNB and changing the DR from one of about 10.1GHz to one of about 9.0GHz. This is quite easy because the DR is a small ceramic disc (known as a 'puck'), about 5mm diameter and 2mm high, which is glued to the LNB printed circuit board, close to the oscillator lines and easily identified. Such DRs may be hard to find but ready-modified LNBs can be obtained from Bob Platts, G8OZP (address at end of chapter). In some LNBs, there is a printed IF filter in circuit which may need to be bypassed if the gain of the modified LNB seems low.

Next, the set-top tuner IF range covers the other Novice microwave band (1.3GHz or '23/24cm' band) directly. All you need to do to use it for 1.3GHz ATV is to make it continuously voltage tuned rather than microprocessor-tuned to preset channels. Since it is designed to take amplified output from a Ku-band LNB (which has a typical gain of at least 30dB, and often nearer to 50dB), you will need to replace the LNB with a low-noise preamplifier (LNA) at the antenna, using the same feed arrangements to send DC up, and signal down, the low-loss feeder. This arrangement may not be needed if the receiver is to be used only for short-distance work. Modifications to a typical 'surplus' unit are given later. Obviously these will differ slightly from type to type (make to make), but there should be enough detail to enable you to have a fair idea of what is needed. If in doubt, ask another nearby amateur already active on ATV to help you!

Finally, it should be mentioned that some ATV activity still takes place in the 70cm amateur band, although this uses amplitude-modulated (AM) TV signals in a form of SSB known as 'vestigial sideband, reduced carrier' because the band is now too narrow to accommodate FM signals without causing in-band interference with other users. It is possible to retune almost all TV UHF tuners to cover the 70cm band (430 to 440MHz) although this will not be discussed here, since most ATV activity nowadays is concentrated in the 1.3GHz and 10GHz amateur bands. However, a block diagram of a typical 70cm ATV setup is shown in Fig 9.1(b) and reference [4] gives some ideas on the use of modified UHF tuners and a suitable FM video demodulator circuit, as well as an intercarrier sound demodulator.

The reason for the popularity of the two microwave bands for ATV is, first, that there is more bandwidth available and, second, there are many more almost 'ready-made' DBS receivers available!

A 'bare-bones' 1.3GHz ATV monitor receiver

Satellite set-top tuners (Ferguson-BSB), types SAT-5006, SAT-5600 and SAT-5601, are available at low cost from Mainline Electronics (address in Appendix 3) and can be used to build a 'bare-bones' (basic) ATV monitor receiver. The BSB dish, feed and LNB is also available on the surplus market and can be retuned as a 10GHz LNB (see elsewhere).

The tuner consists of a PCB enclosed in a tin-plate box about 3.25in (83mm) long, 2.0in (51mm) wide and 0.5in (13mm) high. Circuit connections are brought out to 10 pins on one edge of the box. There may be a piece of PCB material with eight edge-connector pads, fixed on the tuner, which can be used for soldered connections. Pins which are shown in Fig 9.2 as connected together are connected by tracks on this small PCB. Not all tuner modules are fitted with this PCB and there may be other small differences, such as the type of semiconductors fitted. The older type of tuner (5006) appears to have many more components mounted on the 'top' side of the main PCB: in fact, the newer 5600/5601 types use more surface mount devices (SMDs) on the 'bottom' (screened) side of the board. However, the connections are the same for these different models. Decoupling capacitor leads, where needed, must be kept very short and, in the type of tuner without the PCB, can be grounded directly to the tin-plate box of the module.

Fig 9.2 shows the pin layout from the 'top' (unscreened) side of the tuner and Fig 9.3 shows them from the side, with the tuner seen from the side. Pin 1 is the signal (RF) input pin. The sensitivity and noise figure of the unit is typical of all satellite tuner modules which are always used following a high-gain, low-noise first converter (LNB, see elsewhere). Thus, a preamplifier will be needed, preferably with a gain of not less than 13dB, together with a noise figure of 1.5dB or better. A suitable, high-performance preamplifier is described later, together with other, general-purpose wide-band amplifiers.

Pins 2 and 5 must be grounded (the negative of the various supply voltages is also grounded). Pins 3 and 7 require connection to a stabilised +12 to +15V supply

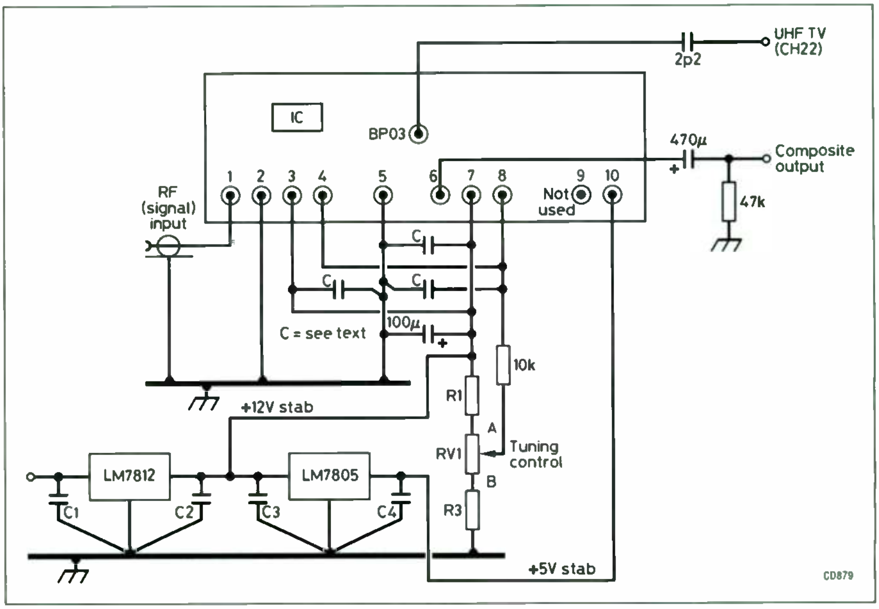


Fig 9.2. Top view diagram of a voltage-tuned DBS TV intermediate frequency tuner (converter) unit, complete with typical voltage regulator circuits for the supplies and tuning voltages used in the converter

(+12V is most convenient), with small decoupling capacitors (120pF, but not critical) connected as close to the pins as possible. Pins 4 and 8 need connection to a variable tuning voltage derived from the +12V stabilised supply.

Pin 9 is not used in this application (it was originally intended for output to a frequency divider for digital PLL control), whilst pin 10 requires a +5V stabilised supply, also derived from the +12V stabilised line. Again, all pins must be decoupled, as close as possible to the pin, with small decoupling capacitors (120pF, but not critical). Pin 6 is the 'baseband' composite video output which must be connected to the following demodulator circuit (or TV receiver) through a series capacitor and parallel resistor, as shown in the block diagram. Fig 9.2 also shows the IC voltage regulator circuits for the supplies, and the decoupling and tuning arrangements. No PCB layout is given because this is not critical and may not even be needed!

Alternatively, UHF output can be taken from the point BP03 (shown in Fig 9.2) direct to a TV receiver for 'slope detection'. This is not particularly effective, however, and the constructor choosing to use UHF output should consider feeding the UHF output into a UHF TV tuner and then into a receiver back-end consisting of a video amplifier, video FM demodulator and inter-carrier sound demodulator. A suitable circuit and layout, using an NE592 video amplifier, TDA1035 intercarrier sound demodulator and LM386 audio output chip was described in reference [5].

Information on how to convert Amstrad SRX100/200 set-top tuners to ATV was given in reference [6].

Preamplifiers (LNAs) for 1.3GHz

Bipolar transistor preamplifiers

Inexpensive bipolar transistors such as the MRF901, BFR90/91 and BFR34a are capable of giving adequate performance for many purposes. Preamplifiers using transistors of this type can be used on their own, and will certainly improve the performance of most converters by a considerable amount. In receivers where preamplifiers

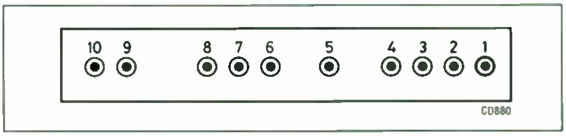


Fig 9.3. Side view of the connections to the DBS tuner

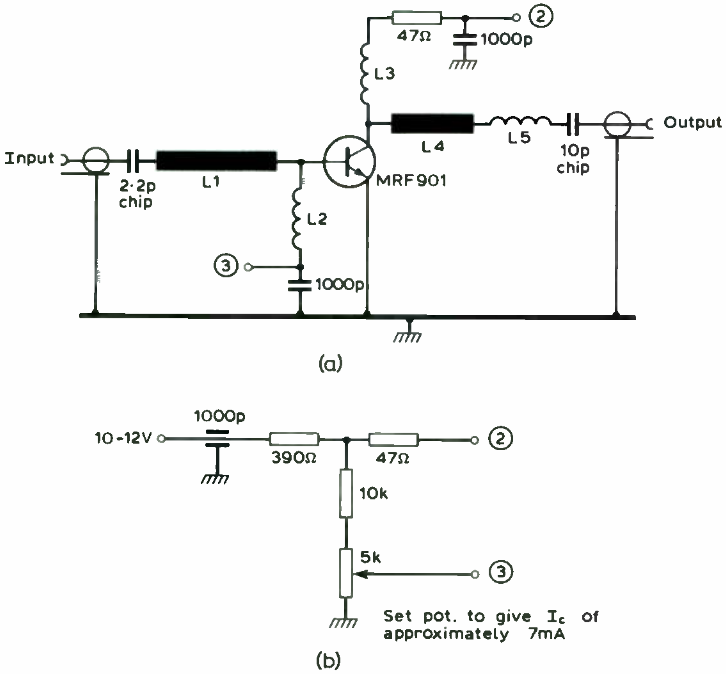
with higher performance are used, bipolar amplifiers can be used to follow the first low-noise stage as this will probably not have sufficient gain to overcome the converters' noise figure alone.

The circuit of the preamplifier is shown in Fig 9.4. The input circuit uses a series capacitor and a length of 50Ω microstrip to provide the required impedance transformation. A simple output matching network is used to provide a low output VSWR, so that subsequent stages can operate at optimum performance. The gain is approximately 10dB across the band, with a noise figure of about 2dB.

The preamplifier is constructed on 1.6mm thick glass-fibre double copper-clad printed circuit board. The layout is given in Fig 9.5.

Alignment

The only adjustment needed is to apply power and set the collector current to the required value (5–10mA) using RV1. Provided that the preamplifier has been carefully constructed, it should then function correctly.



L1: 16.5mm by 2.5mm wide microstrip line
L2: 6t, 2mm diameter (0.25mm copper wire)
L3: 5t, 2mm diameter (0.25mm copper wire)
L4: 4mm long x 2.5mm wide microstrip line
L5: 6.5mm long wire flat on board (0.5mm enamelled copper)

(c)

Frequency (MHz)	Gain	NF (dB)
1240	10.7	2.9
1260	10.4	2.7
1280	10.6	2.7
1300	10.5	2.7
1320	10.0	2.8

(d)

Fig 9.4. (a) Circuit of a microstrip preamplifier using MRF901. (b) Bias circuit. (c) Inductor values. (d) Performance

A high-performance GaAs FET preamplifier

Gallium arsenide field effect transistors (GaAs FETs) can produce very low noise figures at 1.3GHz and preamplifiers using these transistors can give excellent performance. Noise from the earth can be the major factor limiting receiver performance when GaAs FET preamplifiers are used. In order to use the full potential of these devices it is essential that the input circuit of a preamplifier has a very low loss, or the added noise may degrade the performance. Also, any practical design must allow for the fact that these devices are potentially unstable at 1.3GHz and steps should be taken to ensure stability. The preamplifier to be described was designed to take these features into account but is quite difficult to construct if you are a beginner.

The circuit diagram of the preamplifier is shown in Fig 9.6. The low-loss input circuit consists of L1, C1 and C2. Source bias is used so that the preamplifier can be run off a single positive supply. The two source decoupling capacitors are lead-less types, to ensure that the source of the GaAs FET is well grounded at RF. The output circuit is untuned and consists of R2 and C5. This configuration ensures that the amplifier is stable and has a low output VSWR. The value of C5 was chosen so that the capacitor is series resonant, ie it has a very low series impedance at 1.3GHz. A three-terminal voltage regulator is included within the preamplifier housing. This not only provides the 5V supply required, but also affords some degree of protection from voltage spikes on the power supply line, which could otherwise damage the GaAs FET.

Construction

Constructional details of the preamplifier are shown in Figs 9.7 and 9.8. First cut out a sheet of copper for the main box, mark out the positions for the holes, and make scribe lines for the corners and to indicate the position of the centre screen. Cut out the corner pieces (preferably by sawing) and drill all holes with the exception of holes E, and tap hole D. Clean the sheet using a printed circuit eraser or Brasso, taking care to remove any residue of the cleaning agent at the end. Bend up all four walls and adjust the corners using pliers to ensure that the walls touch. The centre screen should be fabricated next. It is best to make this piece slightly oversize initially and then to file it to be a tight fit in the main box. The screen should be cleaned after drilling and de-burring the hole. The leadless capacitors are then soldered to the screen, in the positions shown in Fig 9.8(b). The soldering is best done by clamping the sheet in a horizontal plane and applying a small flame from underneath. Tin each capacitor on one side using a soldering iron and small amount of solder and tin the screen in three places, again using only a small amount of solder. Place the capacitors on the

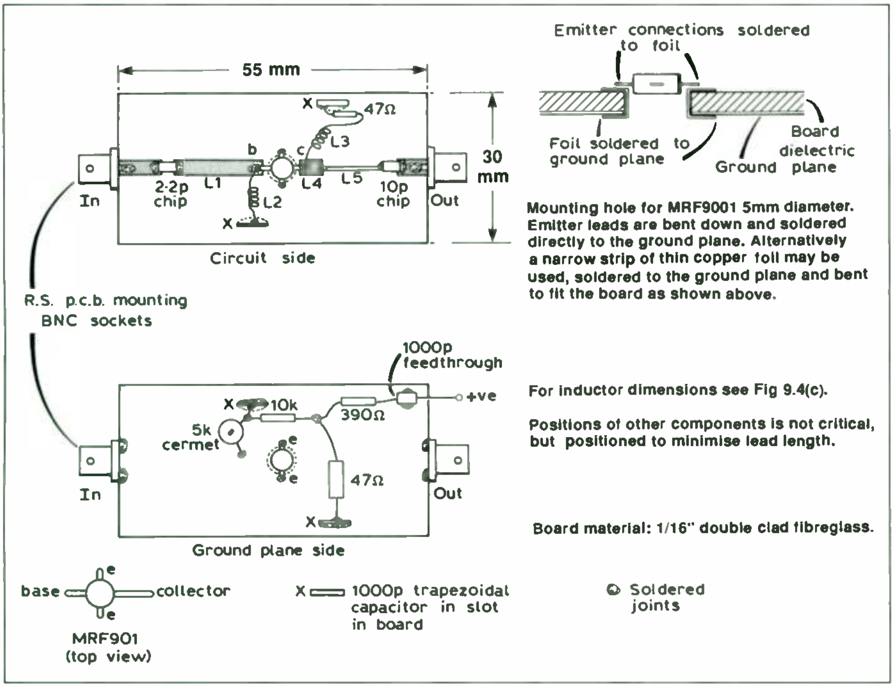


Fig 9.5. Layout of the simple bipolar transistor 1.3GHz preamplifier

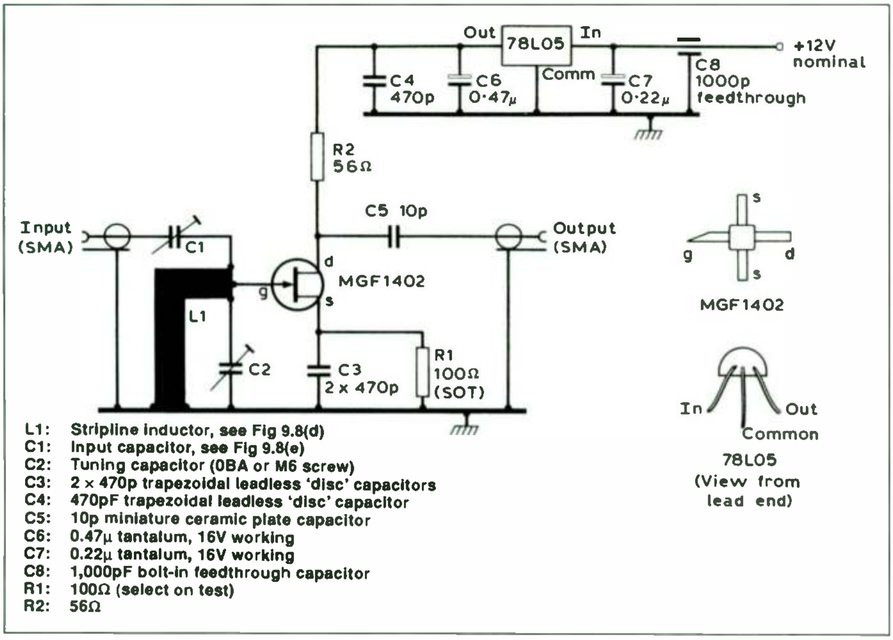


Fig 9.6. High-performance GaAs FET 1.3GHz low-noise amplifier (LNA), designed by G3WDG

screen, tinned sides down, and reheat the screen under each capacitor in turn. As soon as the solder melts, press down on the capacitor until it is flat on the screen. Using an ohm-meter, check that the capacitors are not shorted to the screen. Remove the excess solder by filing if shorts are found. Fabricate the retaining plate as shown in Fig 9.8(c) and place it on to the screen so that the bumps align with the capacitors. Fix it in position using an M2 screw and nut.

Locate the screen in the box using the scribe marks as a guide to correct alignment. Measure the distance between the screen and the inside of the end wall of the larger compartment and check that this agrees with the dimension given in Fig 9.7. Move the screen if necessary. Clamp the screen in position using a toolmaker's clamp applied to the sidewalls of the main box around the screen. Jig a clean brass nut in position at hole D using a stainless steel or rusty screw to hold it in place. Tighten the nut slightly against the wall of the box.

Mount the box in a vice so that the junctions of the sidewalls are horizontal and solder along the junctions using a small flame from underneath each corner in turn, re-positioning the box each time. It is easiest to preheat the corner using the flame and to make the joints with a soldering iron. This reduces the chance of re-melting the joints already made. The screen should be soldered next (along all three sides) using the

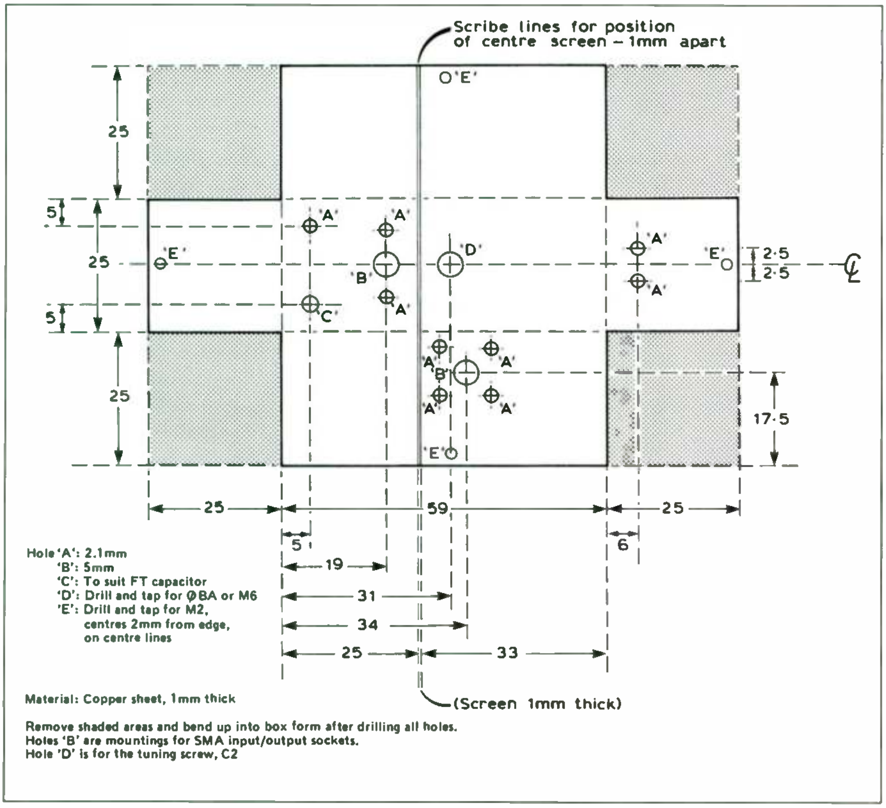


Fig 9.7. Details of the main box of the GaAs FET amplifier

using vernier calipers before proceeding. The line can then be fitted into the box, using M2 fixings.

Measure the distance between the top surface of the line and the bottom of the box at the fixing end. This should be 4mm. If necessary, remove the line and file the holes in the box so that this dimension can be achieved. Similarly, measure the height of the input end and bend the line up or down as necessary. The input tab is made next and should be bent so that when located on the input connector, the sides and top of the tab align with the tab on the input line. The tab can then be soldered to the input connector, leaving a 0.5 to 1mm gap between the tabs. The assembly is completed by fitting the components. The layout is shown in Fig 9.8(f).

same technique, with the box mounted so that the open side is uppermost. Finally, invert the box and solder the nut in position.

When the assembly is cool, remove the jigging screw and run a tap through the nut and sidewall. Remove the tap and check that the tuning screw runs freely in and out. If necessary, file away any excess solder around the nut so that the output connector fits into position correctly. Drill the fixing holes for the input and output connectors. The lid is made next. Cut out the material for the lid and place the box symmetrically on the lid. Scribe around the outside of the box on the lid, cut out the corners and bend the lid over the box to form a tight fit. Using a 1.6mm bit, drill through the sidewalls of the lid and box (holes E). Tap the holes in the box and open out the holes in the lid to 2.1mm.

The next stage in the construction is to make the input line, details of which are given in Fig 9.8(d). The line should be cleaned before bending up the tabs. The overall length of the line is quite critical and, since errors can occur during bending, it is best to make the line slightly longer initially and then file off excess material at the input end of the line. Recheck all dimensions of the line

After mounting the grounding tag, solder R1 into position. When making the joint to the source decoupling capacitor, do not allow solder to run along the capacitor or it will be difficult to mount the GaAs FET correctly. Cut the leads of C5 to 2mm length and solder one end to the output connector. Bend the leads of C5 so that the free lead is in line with the hole in the screen.

Mount the feedthrough capacitor and connect up the voltage regulator circuitry. Apply power and check that +5V is available at the output of the regulator (connect a 1kΩ resistor between the output of the regulator and ground during this measurement). Cut the source leads of the GaAs FET to 2.5mm length. Using tweezers, twist the drain lead through 90° and, holding the end of the drain lead, mount the GaAs FET into position, with its source leads touching the bypass capacitors. Unplug the soldering iron and solder the drain lead to the free end of C5. Check that the gate lead passes centrally through the hole in the screen and adjust the position of the device by careful bending if necessary. The source leads of the GaAs FET are soldered next: again, unplug the iron just before making the joints. Soldering the gate lead requires some care.

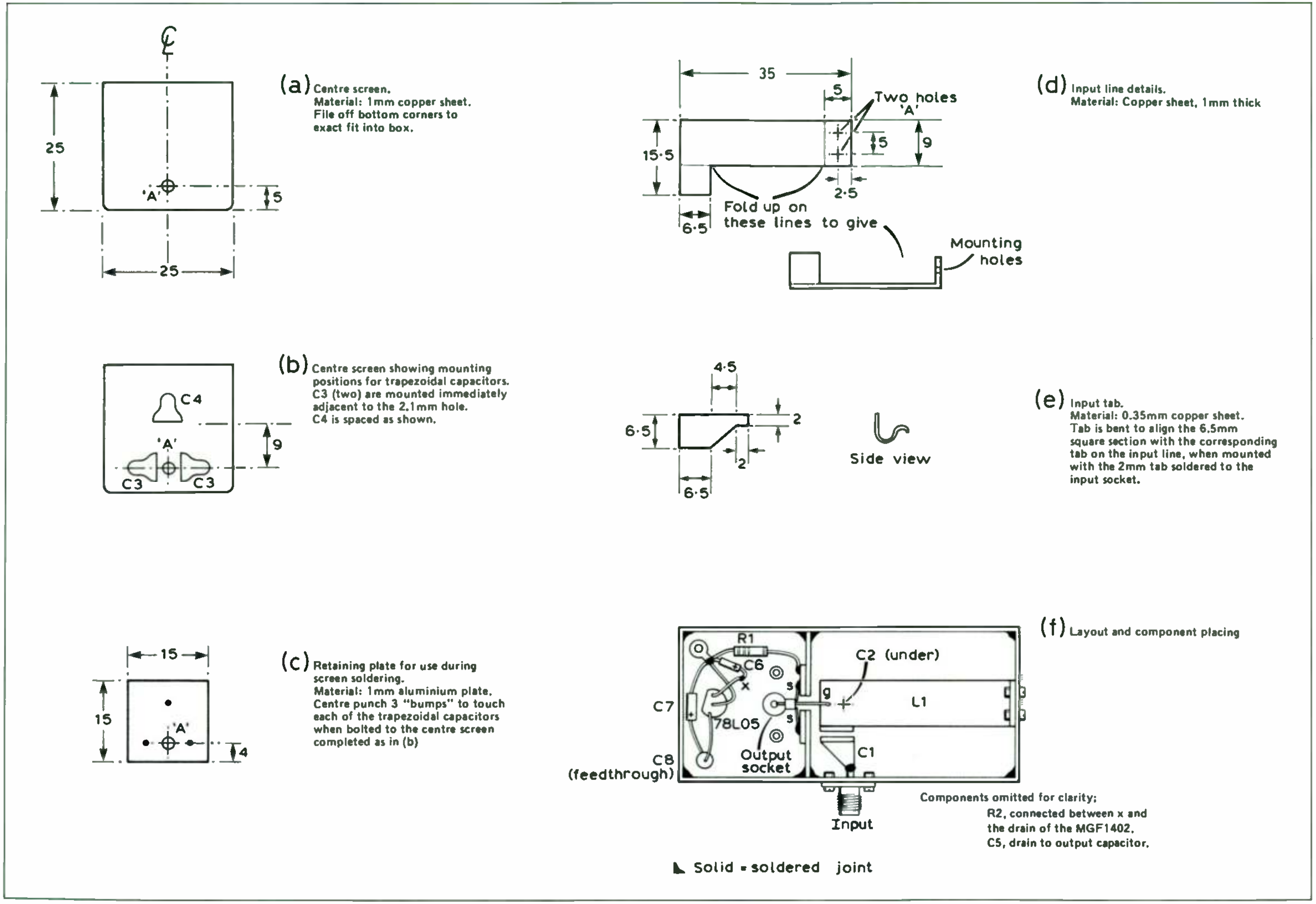


Fig 9.8. (a) Centre screen. (b) Centre screen showing mounting positions for trapezoidal capacitors. (c) Retaining plate for use during screen soldering. (d) Input line details. (e) Input tab: material 0.35mm copper sheet. (f) Layout and component placing

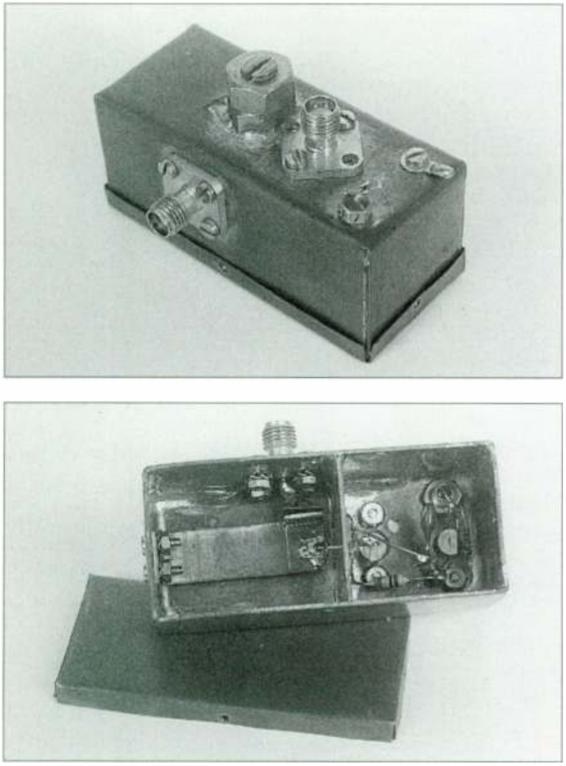


Fig 9.9. The completed 1.3GHz LNA

First, slightly loosen the fixings of the input line, but not enough to allow the line to move. Using a minimum of a 45W iron, heat the end of the line at its edge until the solder flows. The body of the iron should be connected via a flying lead to the box during this operation. Move the iron to the centre of the line next to the gate lead. Then solder the gate lead to the line. Re-tighten the fixings of the input line. The final operation is to fit R2. Cut one lead to 2mm length and tin. With the iron unplugged, solder the other end of R2 to C4 such that the free end is touching the drain lead of the GaAs FET about 1mm from the package. Then solder R2 to the drain of the GaAs FET.

Adjustment

With the preamplifier connected in circuit, apply power and check the current drawn. This should lie somewhere between 10 and 15mA. If not, the value of R1 will need to be altered. Next, fit the tuning screw and adjust for maximum noise. Tune in a weak signal and adjust the position of the input tab and the tuning screw for optimum signal-to-noise ratio.

The performance of the preamplifier is shown in Table 9.1.

Table 9.1. GaAs FET preamplifier performance

Frequency (MHz)	Gain (dB)	Noise figure (dB)
1235	15.6	1.04
1245	16.4	0.90
1255	16.6	0.76
1265	16.4	0.65
1275	16.1	0.58
1285	15.6	0.56
1295	14.8	0.55
1305	13.9	0.56
1315	12.9	0.58
1325	12.2	0.62

Microwave monolithic integrated circuit (MMIC) amplifiers

These general-purpose broad-band amplifiers use two or four MMICs to provide a total of well over 50dB of gain over the band from low frequency to about 2GHz. They were first described by Bob Platts, G8OZP, in reference [4], where they were used as mast-head amplifiers to boost ATV signals in the range 450 to 850MHz produced from 10GHz by a low-gain microwave 'head' of the type used before the introduction of modern LNBs or by a Gunn oscillator/mixer without any RF preamplification. Whilst such high gain is not needed behind modern LNBs, such amplifiers are still useful in the shack for many purposes – for instance, as an amplifier at the input to a frequency counter or in other test equipment. They can also be used to boost the output of very-low-power crystal harmonic frequency markers. MMICs are easy to use and most of them are unconditionally stable, ie they are relatively uncritical as to input and output circuit matching and do not usually need much, if any, screening. They have one input connection, one output connection and two grounded pins, arranged on a simple cross-shape. They need a bias resistor (and sometimes a small RF choke) in the +DC feed to set their standing current to optimum and DC blocking capacitors in the input and output circuits. They are very-broad-band devices which give useable gain up to about 2GHz in this particular application, although MMICs are now available for use at 10GHz and higher. Not only do they provide wide-band amplification but they can also provide considerable power output, enabling them to be used in oscillator and low-power transmitter stages: power output can be as high as +20dBm (100mW) with some types, although it is usually around +10dBm (10mW) before the gain starts to compress. It's worth getting to know a bit about these devices as you gain experience and maybe you should try to get hold of some manufacturer's data sheets to get further ideas on how useful they can be! There is much useful information on MMICs in reference [7].

The amplifier is built on two separate two-stage PCBs, the idea being that with such high gain, the two amplifiers

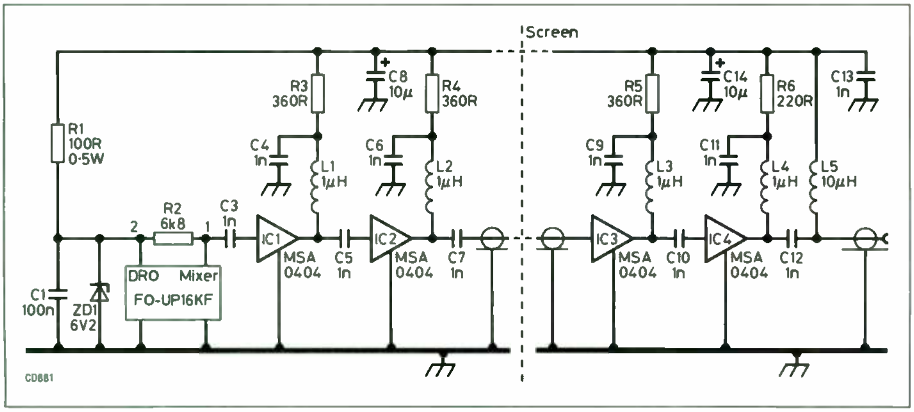


Fig 9.10. Original circuit of the BATC (G8OZP) wide-band MMIC general-purpose amplifiers

can be separated by screening, with one immediately at the mixer output and the other elsewhere. Alternatively they can be used separately. The first two-stage amplifier is designed to take its power from the second two-stage amplifier. The second two-stage amplifier is designed to take its power up the feeder cable which also takes the amplified signal down to the shack. With minor modifications, either can be used on its own. PCBs for both amplifiers are available to BATC members from their Member's Services.

The circuit of the original amplifiers is shown in Fig 9.10. It should be noted that R1, C1 and ZD1 provide a Zener-stabilised supply for the dielectric resonator oscillator (DRO) in the original design which used a Mitsubishi FO-UP16KF oscillator-mixer module. R2 supplied bias to the Schottky-barrier diode mixer to improve its sensitivity. None of these components is needed when the first amplifier is used with a conventional Gunn oscillator-mixer, and can be omitted. Instead, the mixer diode can be connected directly to the 'mixer' pad on the PCB, with the resistor, which is usually permanently connected across the mixer terminal to earth, left in place. Similarly, when used for other purposes, the input should be connected between the 'mixer' pad and the ground plane.

The PCB track patterns (to scale) are shown in Fig 9.11 and the PCB layouts of both amplifiers' components, not to scale, are shown in Fig 9.12. Note that many of the components are very small, leadless, 'surface-mount' devices (SMDs). You should not try to substitute normal components for these, otherwise the amplifiers will probably not work properly! Suitable SMDs are available from several of the component suppliers given at the end of the chapter.

The two amplifiers were intended to be used in cascade with the DC power fed up the coaxial feeder and amplified signal down the same feeder. In the 'second amplifier', C12 provides DC isolation, allowing the DC voltage to reach the +12V line via RF choke L5 (10μH). The amplifier output from IC4 is prevented from getting through the DC line to ground because the RF choke provides RF (signal) isolation. Figs 9.13 and Fig 9.14

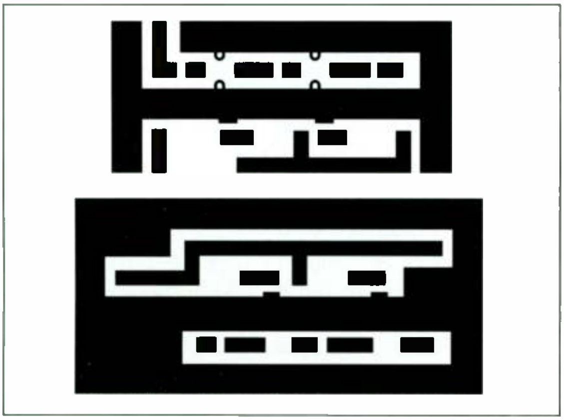


Fig 9.11. PCB layouts for the MMIC amplifiers. Top: board 1; bottom: board 2. PCBs are available from BATC

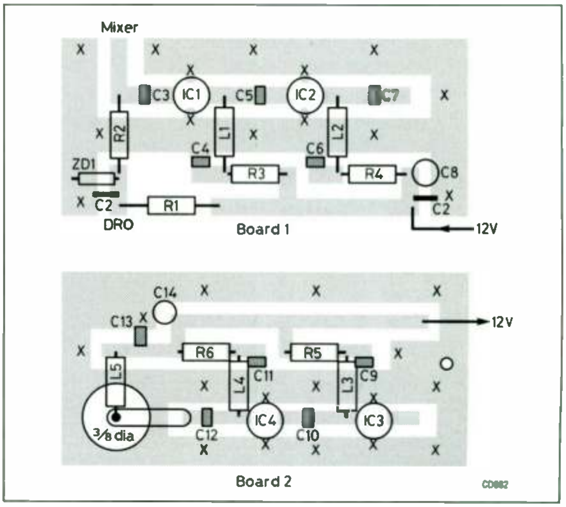


Fig 9.12. Component layout on PCBs, for MMIC amplifiers. Components are soldered to the track side of the board

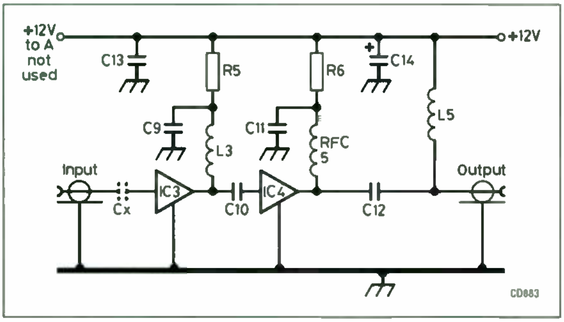


Fig 9.13. Modifications to the second amplifier to allow it to be used on its own

show simple modifications which allow either amplifier to be used on its own. If the second amplifier is to be used on its own, then an additional capacitor, shown dotted as Cx, should be added between the input connector and IC3.

If the 'first amplifier' (which has a lower noise figure than the second amplifier) is to be used on its own, then RFC3 (10µH, shown dotted) should be added and the DC feed taken up the coaxial feeder, rather than be connected from the +12V DC line in the second amplifier. DC isolation is provided by C7 and signal isolation by RFC3. Additional decoupling is provided by C9.

If the amplifiers are to be used as originally intended, then do not fit Cx, C9 or RFC3: you would also not need to fit the output socket of the first amplifier or the input socket of the second amplifier, simply connecting the two together by means of small-diameter coaxial cable of convenient length. When used together, the two amplifiers must not be allowed to 'see' each other, ie they must be screened from one another, to prevent the possibility of feedback oscillation because the overall gain is so high.

The MMICs originally recommended for IC1, 2 and 3 were Avantek type MSA0404. IC4 was specified as

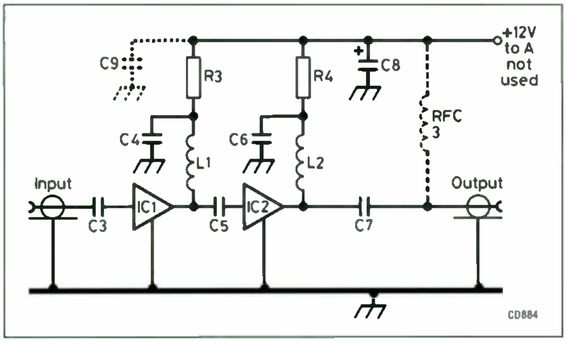


Fig 9.14. Modifications to the first amplifier to allow it to be used on its own

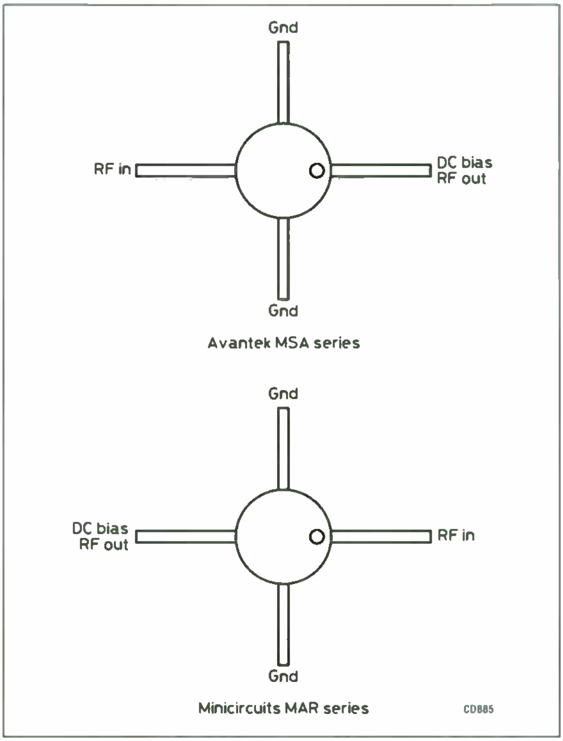


Fig 9.15. Note carefully that two well-known makes of very similar and interchangeable MMICs are definitely not interchangeable as far as connections are concerned!

Avantek MSA0304. There are now more and better types available, and either Avantek MSA0685 or Minicircuits MAR-6 could be used for ICs 1, 2 and 3 (lower noise and similar gain) and Avantek MSA0485 or Minicircuits MAR-4 (higher power output without saturation) for IC4. Note, however, that the identifying dot on the body of Avantek devices indicates the *output* pin, whereas it indicates the *input* pin of the Minicircuits devices (see Fig 9.15), otherwise they are interchangeable!

Receivers for 1.3GHz narrow-band use

A basic 1.3GHz receiver, with an intermediate frequency (IF) in the 144 to 146MHz amateur band, was described as part of a transverter (combined transmit and receive converter) in the companion book *Practical Transmitters for Novices*, reference [1]. Both the transmit and receive mixers were driven by a local oscillator source, designed by G4DDK, which could also be used as a simple low-power 1.3GHz transmitter. Both transmit and receive amplifiers used microwave monolithic integrated circuits (MMICs).

The combined receive and transmit converter printed circuit board (PCB) was designed by Rick Campbell, KK7B, and is available from several sources given in the above book. The circuit is 'no-tune' – in other words, it needs no tuning or test equipment to get it working. There are many other, better, designs available, but this one is particularly recommended for beginners. No other narrow-band designs are described here for this reason. The performance of this receive converter can be greatly improved by the use of a low-noise pre-amplifier (LNA), such as that described earlier.

An alternative, much more compact, design by G4JNT is available in kit form from the Microwave Committee Component Service (see 'Component/kit suppliers' list at the end of this chapter).

Receivers for 10GHz wide-band FM

A simple 10GHz WBFM receiver head

Reference [1] described a simple 10GHz WBFM transmitter consisting of a Gunn oscillator/in-line mixer assembly (doppler intruder alarm head) and a Gunn power supply unit/modulator. In the transmitter design, the in-line mixer was used as a power detector to monitor the Gunn transmitter output.

Instead of using it just for this purpose, you could also use the diode as a mixer and feed the IF signal output from the mixer into, say, a scanning receiver as a tuneable IF, as suggested earlier. In theory, almost any intermediate frequency can be chosen. In practice, most in-line mixer diodes are too well decoupled to allow this, since their original purpose was to produce an output in the audio range (doppler shift). Thus, the decoupling is such as to bypass most of the higher radio frequencies very effectively. Many in-line mixers therefore work better with a low IF such as 10.7MHz or sometimes 28 to 30MHz. The advantage of a wide-range scanning receiver is that you can choose whatever IF appears to work best with the particular doppler unit you choose to use! Using the transmitter oscillator as the local oscillator for a simple receiver mixer in this way lets you turn your Gunn/mixer unit into a transceiver which needs no antenna or other switching for changeover. Indeed, you can receive and transmit simultaneously if you want to do so – full duplex, like a telephone! Fig 9.16 shows you how this works.

Two input circuits which enable the mixer output to be coupled into a tuneable IF receiver and still allow you to monitor the Gunn output are given in Fig 9.17. The simple input circuit of Fig 9.17(a) is suitable when the microwave head is very close to the tuneable IF receiver, such as it would be in a portable station, where the microwave head is close to both the antenna and the tuneable receiver, or mounted very close to a remote oscillator/mixer as shown in Fig 9.18. The alternative circuit, shown in Fig 9.17(b), uses a broad-band matching transformer (wound

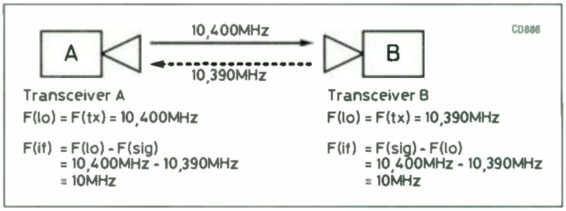


Fig 9.16. A simple explanation of full duplex working using two microwave transceivers whose transmit and receive frequencies are separated by the common IF

on a ferrite bead) and is better suited to use with a transceiver circuit such as that given in the next section.

If you intend to use the microwave head remotely from the tuneable IF receiver – which is the usual way to set up a receiver at home (Fig 9.18) – then you will need to use a low-noise IF preamplifier (LNA) very close to the mixer, so that the coaxial cable does not cause serious loss of signal. General purpose wide-band MMIC amplifiers

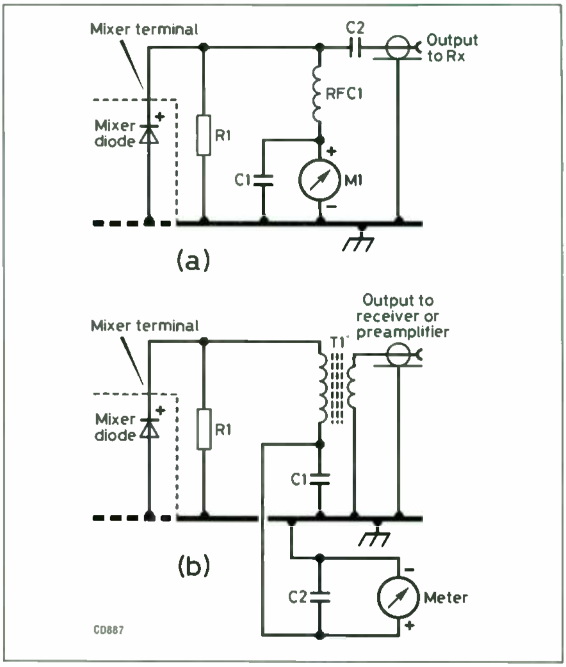


Fig 9.17. (a) A simple 10GHz diode mixer/receiver matching circuit which allows you to monitor the mixer current. This tells you that the local oscillator is working properly. R1, as fitted to doppler unit, typically 33–47kΩ. RFC1, 10μH axial lead choke, C1/C2, not critical, typically 1nF (1000pF) disc ceramic. Meter, typically 1mA FSD – this may need to be a more sensitive miniature meter with a suitable shunt resistor. If the mixer diode is connected the other way round, then the meter connections also need reversing. (b) An input circuit using a broad-band ferrite 4:1 impedance matching transformer. This type of circuit is used in the complete transceiver circuit described elsewhere in the chapter. Values as in (a)

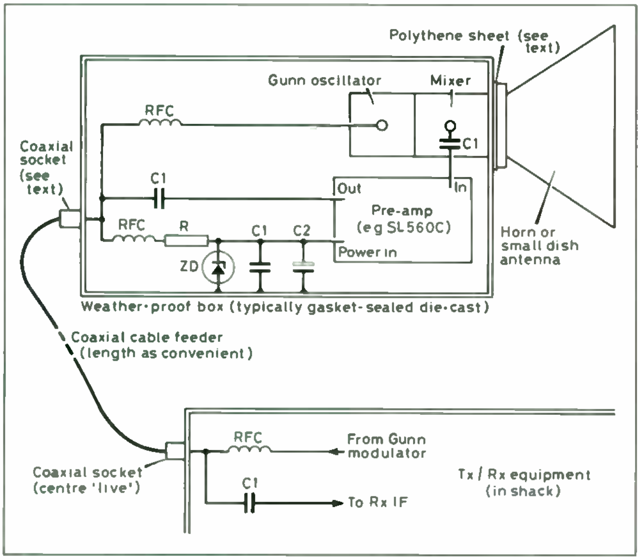


Fig 9.18. Remote mounting of a 10GHz microwave oscillator/mixer unit, using a single coaxial cable to feed DC voltage up the cable and amplified intermediate frequency down the same cable

have already been described earlier in this chapter. The design which follows is an alternative and uses an older type of IC with a similar internal circuit to a MMIC but which was designed, in an 8-pin plastic DIL package, as a wide-band amplifier in the range 10 to 300MHz. The LNA design which follows uses the Plessey SL560c (or RS560c). This IC is very versatile. It has a gain of up to (maximum) 40dB and a noise figure less than 2dB (when matched into an input source impedance of 200Ω). Its bandwidth is 10 to 100MHz at high gain or, with slightly less gain, to 300MHz. It can be used with an operating voltage in the range of 2 to 15V, depending on how the IC is used.

Table 9.2. SL560c amplifier characteristics: input in common-emitter mode

Impedance (Ω)	Rb (kΩ)	1st stage current (mA)	Approx gain high (dB)	Approx gain low (dB)	Noise figure (dB)
50	10	4.5	40	30	3.4
100	3.9	2.25	35	25	
150	2.7	1.5	30	20	
200	2.2	1.125	27	17	1.8
300	1.8	0.75	24	14	

For an input impedance of 50Ω, the amplifier performance at a supply voltage of 9V (at pin 4 of the IC) is:

Frequency (MHz)	Gain (dB)
10–60	approx 36 (flat)
100	approx 32
144	28
200	24
300	18

Output impedance: 50Ω, noise figure: 3.4dB. The above gain figures can be reduced by 10dB by connecting pin 5 to pin 4.

The input stage can be used in either common-base or common-emitter mode. Common-emitter mode gives highest input impedance and lowest noise. Common-base mode gives slightly lower gain but lower input impedance which can be adjusted to match 50Ω or less. The gain range is 'programmable'. If pin 5 is left open-circuit, you will get highest gain – if pin 5 is connected to pin 4, the gain is reduced by 10dB.

Full application notes are available from the device supplier, although the main characteristics are given in Table 9.2. The IC has low-impedance voltage output. At high frequencies (above about 200MHz) the IC may be unstable. A series resistor of 300Ω in the output circuit ensures stable operation over the whole of the frequency range, although this loses a little of the available gain.

The available gain depends on the current drawn by the first (input) stage of the IC and this current is set by the value of R_B. The gain is higher with a low input impedance than with a high one. The noise figure is also dependent upon the input impedance, being at a minimum of 1.8dB with an input impedance of 200Ω, rising to 3.4dB at 50Ω.

The impedance of an in-line mixer is in the order of 200–300Ω, so that the best noise figure and signal transfer is realised when the LNA is connected as close as possible to the mixer without the need for any special input matching circuit.

The circuit of this amplifier is given in Fig 9.19. The circuit may be built on a PCB, the layout of which is given in Fig 9.20, or using the 'ugly' or 'dead-bug' layout of Fig 9.21. Either layout is satisfactory. There is no alignment – just choose your supply voltage and the gain you need, fit the completed amplifier near the mixer, power it up and use it! You don't even have to take any particular precautions in construction (other than keeping component lead lengths as short as possible), as the IC is remarkably robust.

A complete 10GHz wide-band FM (voice/MCW) transceiver

About 15 years ago, low-power, wide-band FM voice transmission (WBFM) was becoming very popular as it was a simple, easy and inexpensive way for amateurs to experiment and communicate: it was also an ideal way of learning microwave techniques. Many of the amateurs who learned microwave techniques this way have since

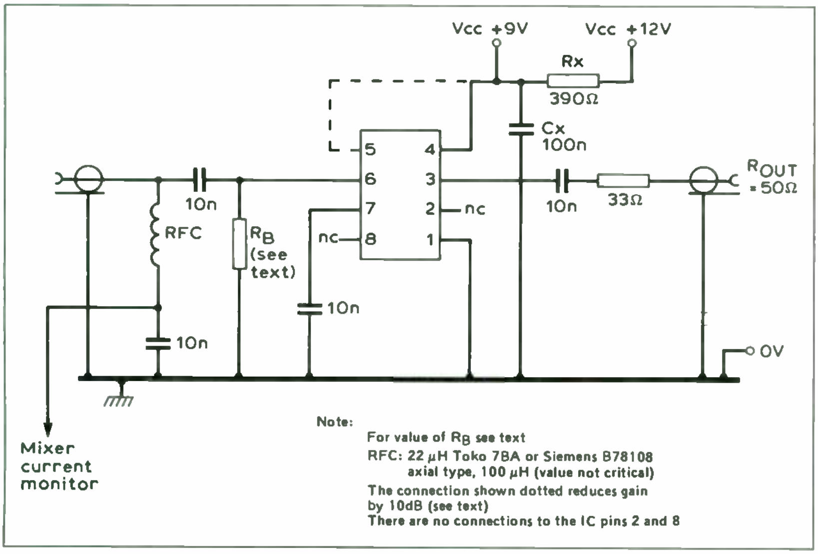


Fig 9.19. SL560c amplifier circuit

pioneered the much more technically demanding narrow-band techniques and, using much higher powers and extremely sensitive receivers (mostly home-built), are now exploring long-distance communications by troposcatter or via moon reflection.

At the time when WBFM was popular, 10GHz low-powered Gunn oscillators (used as local oscillators in receivers and as transmitters) and some in-line waveguide oscillator-mixers were just becoming available on the surplus market in the form of doppler radar 'intruder alarms'. Until then, the only available 10GHz oscillators used klystron valves (tubes), typically the ex-USAF 2K32 tube (used in the 'forties) which needed a stabilised heater supply and a stabilised +300V HT supply, as well as a stabilised −150V supply in order to develop much the same level of power output (a few tens of milliwatts) as a Gunn oscillator using a single, low-voltage supply.

Gunn devices need a single supply of about +6 to +8V stabilised and a few other simple circuits, making them ideal for portable use! A typical low-power WBFM transceiver consisted of a doppler Gunn oscillator and in-line mixer module, plus a stabilised, modulated power supply unit (PSU) with built-in IF signal processing circuit, demodulator and audio output device. Around 10 years ago, 10GHz wide-band receivers and transmitters were similar except that multi-function integrated circuits (ICs) and other components, and the circuits into which they were built, improved the performance of simple microwave equipment. The circuit to be described here was originally designed and manufactured by muTek Ltd

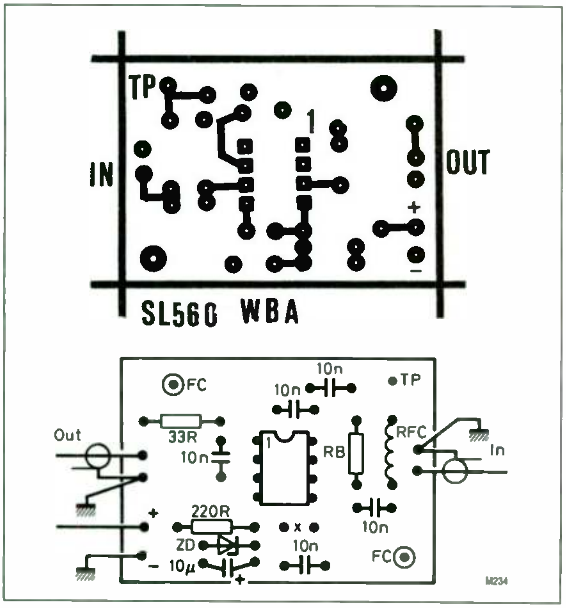


Fig 9.20. SL560c amplifier PCB and component layout. Note that the isolated pads are earth points, linked to the ground plane with wire or circuit pins and soldered on both sides of the board. Pin 1 is soldered to ground on the top ground plane. Pins 2/8 not used. Points 'x' are open-circuit for maximum gain or linked for 10dB reduction in gain. Performance at different frequencies is given in Table 9.2

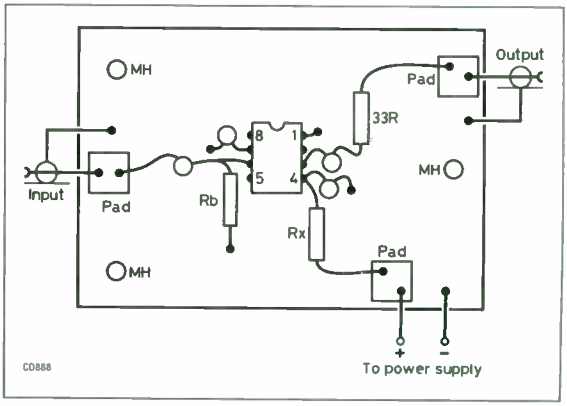


Fig 9.21. 'Dead bug' layout of SL560c amplifier (not to scale)

(headed by Chris Bartram, G4DGU, and later by Mike Dorsett, G6GEJ). This was sold as the 'GDIF 107ub' and, although quite an old design which uses some integrated circuits which may soon be superseded, is still a very effective circuit which is easy to build and align with a minimum of test gear.

By muTek's kind permission, full details of the design are given here. What follows is quoted more-or-less directly from their description of the circuit, with some additional notes.

The GDIF 107ub circuit has all that is needed to make a complete transceiver when used with a suitable 'microwave head'. This will consist of a Gunn diode oscillator and a diode mixer. Gunn diodes are negative-resistance devices which produce microwave output: put a Gunn diode across a suitable microwave tuned circuit, such as a waveguide cavity, and, when supplied with the right voltage, it will oscillate at a frequency determined mainly by the dimensions of the tuned circuit.

Other effects also determine the final frequency. The load into which the oscillator works affects the frequency and can alter it by several megahertz for a change from a matched load to, say, a load with a 3:1 VSWR. This is known as frequency 'pulling'. The other effect, which is used to advantage in the GDIF 107ub, is known as 'pushing'. By varying the supply voltage applied to the Gunn diode, the frequency of oscillation will vary as a more-or-less linear function of the applied voltage over a range which depends on the diode in use and the loaded Q of the tuned circuit (cavity). Fig 9.22 shows the voltage/frequency characteristics of two types of Gunn oscillator.

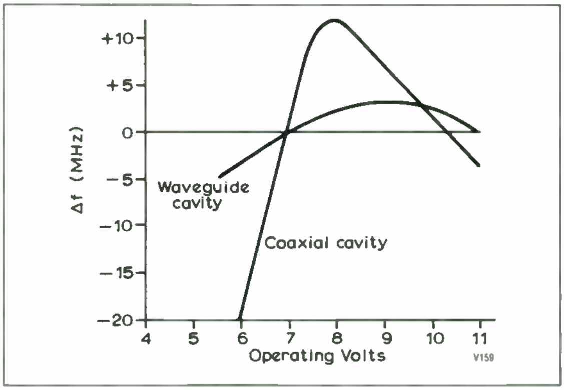


Fig 9.22. Gunn voltage/frequency characteristics

If you are interested in the physics of how a Gunn device works, reference [8] will tell you all you need to know. Oscillator pushing is used to tune the oscillator over the limited range normally needed for communication and to apply both modulation (FM speech or tone-modulated FM/CW) and automatic frequency control (AFC).

For many years the WBFM part of the band has been 10,370MHz to 10,400MHz, close to the narrow-band section (10,368 to 10,370MHz). The wide-band section can easily be covered, using oscillator pushing, so that there is no need to tune the oscillator by any other means, such as tuning screws, although the tuning screw present in all ex-doppler units is used as a 'band-set' control to set the lowest operating frequency required. A block diagram of the transceiver is given in Fig 9.23, the full circuit is given in Fig 9.24, and the component values in Table 9.3.

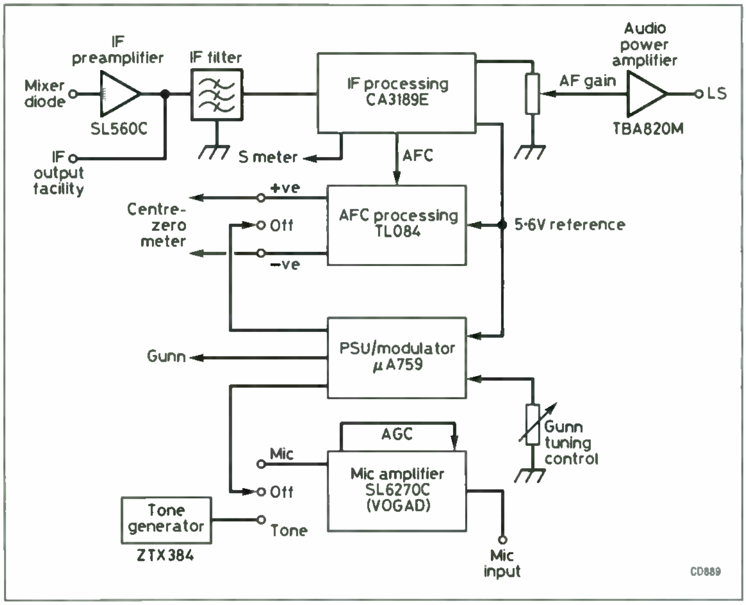


Fig 9.23. Block diagram of GDIF 107ub transceiver

The various circuits, including the Gunn power supply circuit (PSU), use the internal +5.6V reference built into the CA3189E integrated circuit, IC2, which is the main IF signal processing circuit. A single section of a quad operational amplifier (op-amp) chip (IC5) is used as a simple voltage regulator, the output voltage being set by R33. Should the maximum output voltage be too low for the Gunn oscillator in use, it can be increased by putting another resistor of suitable value in parallel with R32. This will probably be in the range 100 to 500kΩ: the smaller the resistor, the higher the maximum output will be. The output of this voltage regulator drives a potential

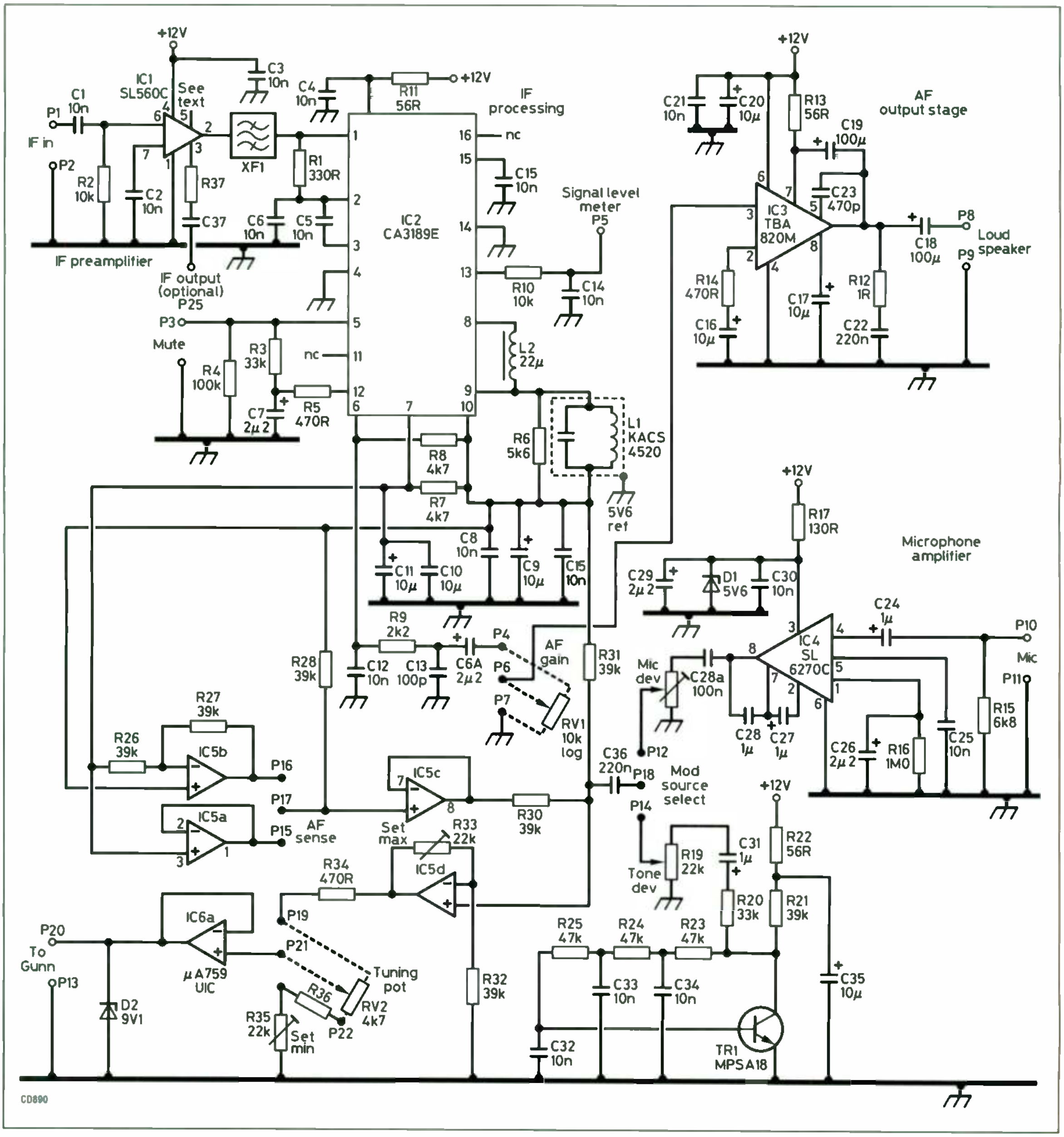


Fig 9.24. Circuit diagram of GDIF 107ub transceiver

divider consisting of the tuning potentiometer and the 'set minimum' preset potentiometer, R35. A unity gain, non-inverting power op-amp buffer (IC6a) provides sufficient output current capability to drive the Gunn diode and also contains internal short-circuit protection. Over-voltage protection for the Gunn diode is provided by a Zener diode with a breakdown voltage chosen to be a little higher than the normal maximum Gunn operating voltage.

Automatic frequency control (AFC) and modulation are also applied to the power supply by modulating the reference line. The AFC output of the CA3189E is buffered by op-amps operating in both the inverting and non-inverting unity gain modes. This is to allow AFC

Table 9.3. Components list for the muTek GDIF-107ub 10GHz wide-band FM transceiver circuit

RESISTORS

R1	330R
R2, 10	10k
R3	33k
R4	100k
R5, 14, 34	470R
R6	5k6
R7, 8	4k7
R9	2k2
R11, 13, 22	56R
R12	1R0
R15	6k8
R16	1M0
R17	180R
R18	22k lin min horiz preset cermet or carbon (set speech level)
R19	22k lin min horiz preset cermet or carbon (set tone level)
R20	330k
R21, 26–28, 30–32	39k
R23–25	47k
R33	22k lin min horiz preset cermet or carbon (set Gunn volts max)
R35	22k lin min horiz preset cermet or carbon (set Gunn volts min)
R36	22k
R37	1k0

Resistors are all 0.25W miniature carbon film or metal film, unless otherwise stated.

RV1	10k log panel mounting, with/without double-pole on/off switch (volume control)
RV2	4k7 log, 10-turn, with turns counting dial (Gunn tuning control)

CAPACITORS

C1–6, 8, 10, 12, 14, 15, 21, 25, 30, 32–34, 37	10n ceramic disk or equiv
C6A, 7, 26, 29	2µ2 elec or tantalum bead
C9, 11, 16, 17, 20, 35	10µ elec or tantalum bead
C13	100p ceramic disk or equiv
C18, 19	100µ elec or tantalum bead
C22, 36	220n ceramic disk or equiv
C23	470p ceramic disk or equiv
C24, 27, 28, 31	1µ0 elec or tantalum bead
C28A	100n ceramic disk or equiv

Capacitors are all 16V working.

SEMICONDUCTORS

D1	5V6 zener
D2	9V1 zener
IC1	SL560C/RS560C
IC2	CA3189E
IC3	TBA820M
IC4	SL6270
IC5	LF347N
IC6a	µA759A
TR1	MPSA18

INDUCTORS

L1	Toko KACS4520
L2	22µH

FILTER

XF1	SFA 10.7MF (Red Spot), eg Maplin HX99H (280kHz) or Maplin UF71N (50kHz)

MISCELLANEOUS – (o) = optional

1mm circuit pins, 25 off (Vero or similar)
Protective diode 1N4001/4002 (o)
Power input plug/socket, non-reversible (2 or 3-pin)
Speaker or headphones, 8Ω. Speaker may be mounted within the transceiver box. If plug-in headphones (or an external loudspeaker) are used, then the jack socket used to connect the headphones (or speaker) should be wired to connect an 8Ω resistor (0.5W) between the output of IC3 and ground when neither headphones or external speaker are connected
Closed circuit key jack (o): any convenient size, for morse key
200µA centre-zero (tuning) meter (o): could be a more sensitive meter, such as miniature edgewise 75µA type, with shunt and series resistors to give approximately 2-0-2V scale
200µA 'S-meter' (o): Similar to tuning meter, this could be switched to read battery voltage (for portable use) and/or mixer current to monitor the output of the Gunn oscillator.
Power on/off DPST min toggle switch or part of volume control
Mic/tone switch, SPCO, centre off, min toggle
AFC switch, SPCO, centre off, min toggle
Mute switch (o), SPST, on/off
Power on indicator (o): Min Red LED, series resistor 1k0 for 12V supply

operation with the Gunn oscillator frequency on either side of the incoming (received) frequency. The AFC sense is selected by means of a centre-off toggle switch – in the centre position, the AFC is off, allowing normal operation. The tuning range does vary slightly with the different AFC modes, but this is not really a problem. Once used, the AFC becomes addictive! Once a signal – even one quite near to the noise – is captured, it will usually stay within the receiver pass-band quite happily for hours on end, unless the system is disturbed. By connecting a centre-zero meter in series with a suitable resistor across the two AFC outputs, a tuning meter may be added.

A centre-off switch also selects the modulation source: both tone and speech modes are available. The tone source is a simple transistor (TR1) phase-shift oscillator operating at around 1kHz to provide a tuning signal or for CW, whilst the microphone amplifier is a dedicated IC (IC4, known as a 'VOGAD' or voltage operated gain-adjusting device) which includes automatic gain control (AGC). The use of AGC ensures that it is very difficult indeed to over-modulate, even when standing on a hilltop in the middle of a gale, operating portable! Separate deviation adjustments are provided for each source.

The receiver IF is 10.7MHz. This has been chosen for several reasons, although it does, perhaps, have some disadvantages. The major reason for using 10.7MHz is to eliminate the need to mechanically retune the oscillator if a higher IF is used. The alternative is to use a separate transmitter if a higher IF is used, although this is not always desirable or possible. Thus, the choice of 10.7MHz is a compromise which offers simplicity, ease of obtaining good performance at reasonable cost, inter-unit compatibility for full-duplex operation (see Fig 9.16) and low losses from long cable runs if the unit is operated with the microwave head remotely mounted (see Fig 9.18).

The major disadvantage to the use of such a low IF is concerned with the generation of noise sidebands in the Gunn local oscillator. All oscillators generate noise around (above and below) the carrier frequency: the amount is a function of the active device and the circuit in which it works. The noise sidebands generated have two related origins: those due to amplitude modulation of the oscillator (by noise generated within the device and external to it) and those due to phase modulation which happens whenever an oscillator is amplitude modulated. In simple microwave systems such as this, the problem comes from the amplitude noise component, as the phase component is mainly cancelled out in the mixer. With modern Gunn oscillators, particularly those designed for doppler intruder alarm use, the problems are not particularly serious and may, certainly for many purposes, be disregarded. This is particularly true for short links, or even some long line-of-sight links, where signals are strong.

A low-noise RF amplifier IC (IC1 – SL560c or RS560c) is used as the 'head' amplifier, immediately after the mixer. This IC requires a source impedance of around 70Ω for best performance. As typical microwave mixer diodes have an IF impedance of around 200 to 400Ω, some sort of impedance matching is required for best performance, although the simple circuit given in Fig 9.17 could be used. Alternatively, an LC tuned circuit such as a pi-network could also be used. However, a broad-band transformer, wound on a two-hole ferrite bead, was chosen for this design as being simple and needing no alignment.

Following the head amplifier, and before the passband-defining filter, an IF output is provided from the board (from pins 4A and 25), allowing use to be made of the amplified output from the mixer before filtering, limiting and demodulation by the main IF signal-processing IC (IC2). This output could, for instance, be used as input to a scanning receiver as described earlier. The main IF signal-processing IC and all the other functions of the transceiver are still available, so that it is possible to use the transceiver normally while using a scanning receiver as an independently tuned 'second' receiver. The filter fitted is a standard 240kHz bandwidth ceramic filter. It is possible to fit similar three-terminal filters of narrower bandwidth, if the constructor so desires: 180kHz and 50kHz low-cost filters, centred at 10.7MHz, with identical pin-out and similar impedance and loss characteristics are available at very low cost. It may be worthwhile experimenting with the 50kHz type particularly, as these ought to offer improved receiver noise performance due to the narrower bandwidth of the filter and lower deviation. The CA3189E also provides a signal level (S-meter) output which will drive a 200μA meter directly and also facilitates the use of a similar centre-zero tuning meter as an aid to accurate receiver tuning.

The audio output stage (IC3) is a TBA820M. This produces sufficient audio power for most applications without the 'latch-up' problems which can sometimes arise from running other AF output ICs on low voltages. This IC is quite old and might sometime need to be replaced by a more modern equivalent: however, it is still freely available and should be used in preference to a more modern replacement which would need a different track layout on the PCB.

Making your PCB

First, get or make your PCB! The original muTek Mark 1 PCB layout (by G4DGU) used a very-high-quality, double-sided, 'through-hole plated' tinned PCB. The track side (underside) of the board was fairly ordinary but the opposite side, where all the components are mounted, was a continuous 'ground plane' to which all ground (earth) connections were made. Both sides were tin-plated to ensure easy soldering and, where connections were needed between the track side of the board and the ground plane, these were already made by means of the through-hole plating. This required extremely accurate PCB methods which would have been impossible to use at home. The layout was subsequently modified and simplified by G6GEJ to avoid the need for through-hole plating and accurate double-sided etching. This not only made the PCB production easier for a professional company, but also much easier for home constructors!

A suitable, modified (Mark 3) PCB layout by G6GEJ is given in Fig 9.25 (artwork for the track side of the PCB) and Fig 9.26 (ground-plane side of the PCB, showing where insulated holes are needed).

The ground-plane side of the board should be completely protected during etching. Where you need insulated connections through the board, remove the copper cladding of the ground plane, as shown in Fig 9.26, by using a small drill-bit (rotated in the fingers) to remove a little circle of copper round the holes.

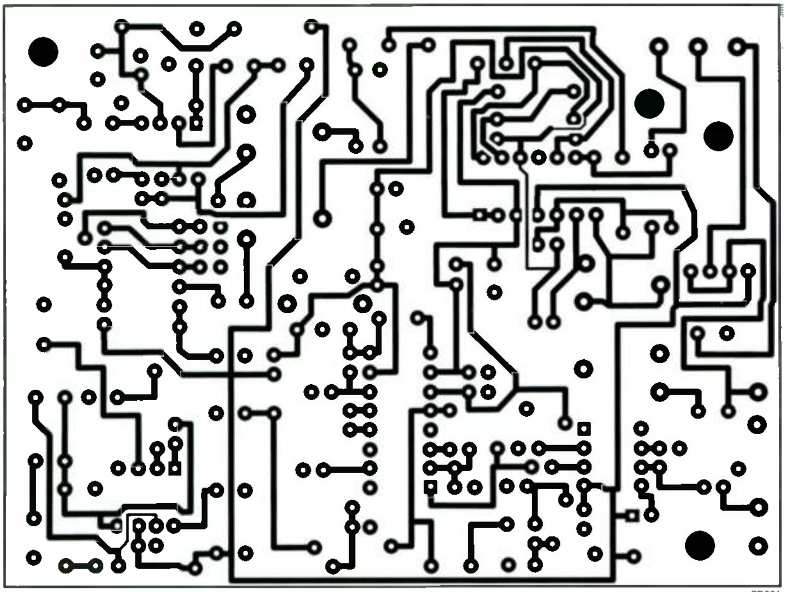


Fig 9.25. Artwork for the track side of the GDIF 107ub transceiver PCB. Note: this is an 'X-ray view' from the *top* of the board. Large square pads indicate pin 1 of ICs; the large black circles are mounting holes for the board and for IC6a. Isolated pads indicate portions of component leads grounded on the ground-plane side (top) of the board *or* no connection

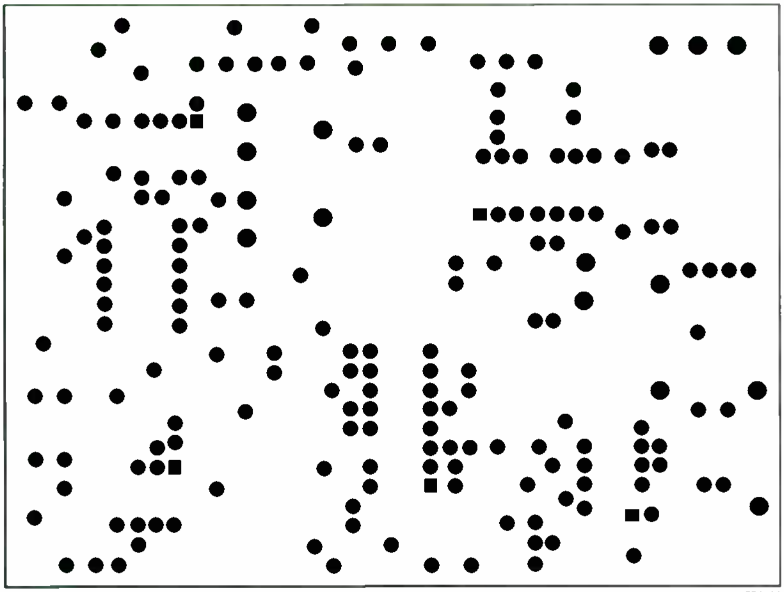


Fig 9.26. Clearance holes on the upper (ground-plane) surface of the GDIF 107ub PCB

Once you have made or got a PCB, construction can really begin! First of all, before soldering anything in place, make a paper drilling template for the three 3mm mounting holes in the PCB. It is very difficult to drill accurate holes in the box which is to hold your transceiver if you can't lay the PCB absolutely flat in the bottom of the box (see later)! Next, fit all the PCB connector pins by inserting them from the track side, pressing them firmly into place using the hot soldering bit whilst supporting the board close to the pin. Then solder them in place, including those used for external connections and ground connections. Those used to make ground connections should be soldered on both sides of the PCB.

Following this, solder in all the resistors and capacitors. Be careful to get the right components in the right places, the right way round (electrolytic and tantalum capacitors) and make sure that, where connections are made to both the PCB tracks and the ground plane, these are properly soldered – it is sometimes difficult to make the solder flow properly – see Fig 9.27. Finally, solder in all the ICs, transistor and diodes, again making sure that each device is put in the right way round. Don't try to test the board yet!

Building a system using the board

Integrating the GDIF 107ub with the rest of the 10GHz system is not difficult. However, if you spend a little time thinking about what you want to do, before you do it, it will make the task easier still! Most people will want to use their board with a surplus doppler intruder alarm as the microwave 'head' to operate over short paths from home, although some may want to use the transceiver to work much longer line-of-sight paths from a portable (hilltop) site.

The only type of doppler unit which is really suitable is the in-line mixer type. The other 'side-by-side' or 'piggyback' types are not really suitable because the offset between the transmit and receive 'ports' won't allow both to be at

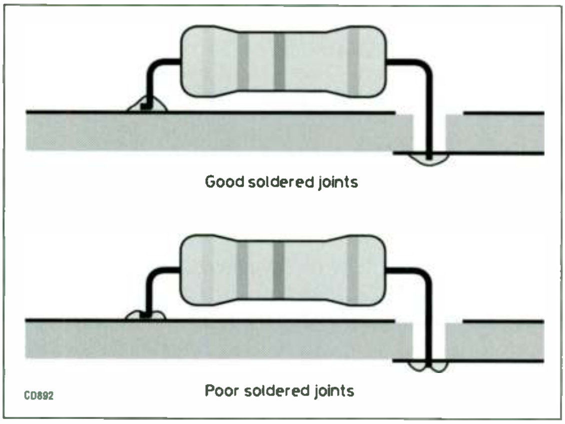


Fig 9.27. Good and bad soldered joints on a PCB

the focus of a dish antenna at the same time, and it is really necessary to use a dish antenna to give the strongest possible signals on both receive and transmit: a dish antenna 'concentrates' or focuses the signals to give a lot of gain in both the receive and transmit modes. For example, an 18in dish, used properly, will give a gain of more than 30dB, making a 10mW transmitter sound like a 10W signal!

However, if you only want to cover short distances, up to perhaps 10km line-of-sight, it is possible to use the low-gain horn antennas (typically 10 or 12dB) often attached to surplus units, or even use the 'side-by-side' or 'piggyback' units mentioned above. Over a few kilometres, even the open end of the waveguide may give enough gain – the open end of a waveguide (for instance waveguide 16, WG16, often used at 10GHz) has a gain of about 6dB!

Putting it in a box

The connections to the board needed to get your system running are given in Fig 9.28. The signal-strength and tuning meters are optional and can be omitted if not required. Likewise, the 'mute' (which cuts out the audio

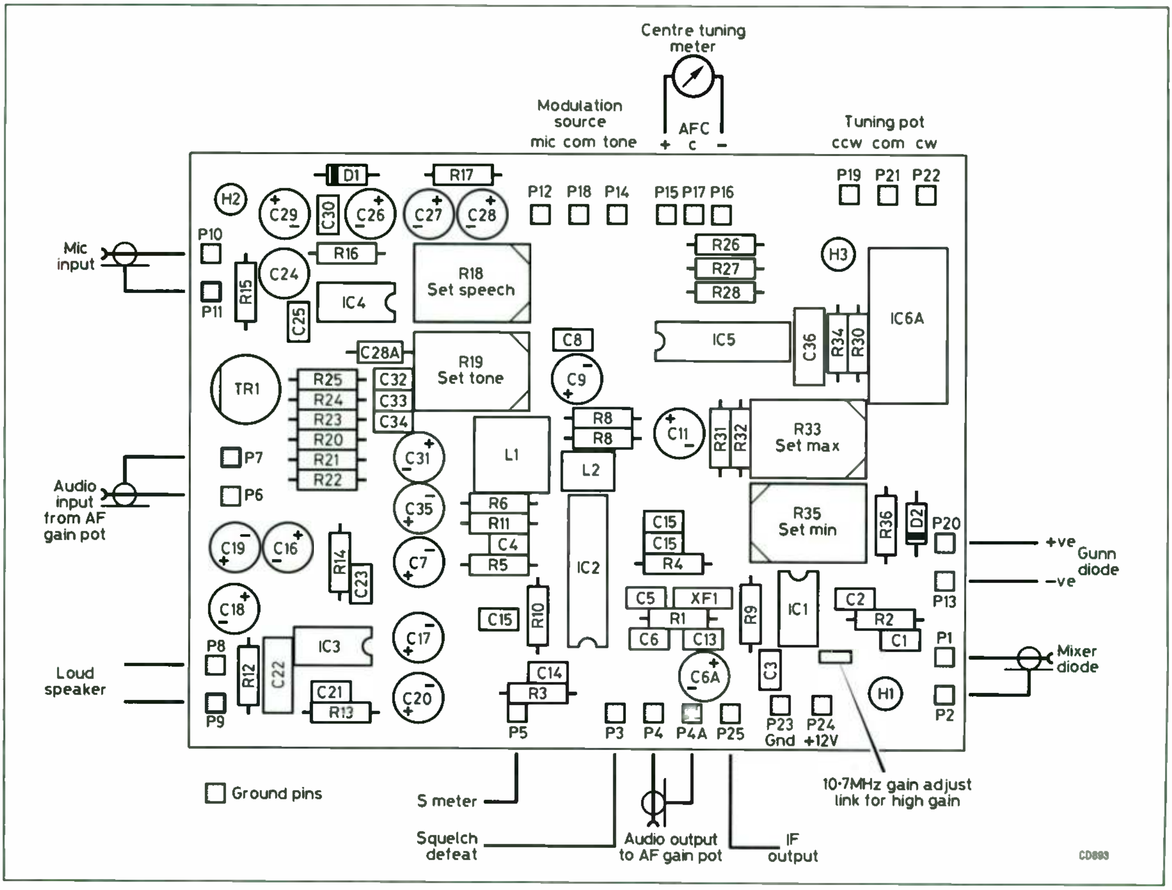


Fig 9.28. Component overlay and connections to off-board components of the GDIF 107ub transceiver PCB

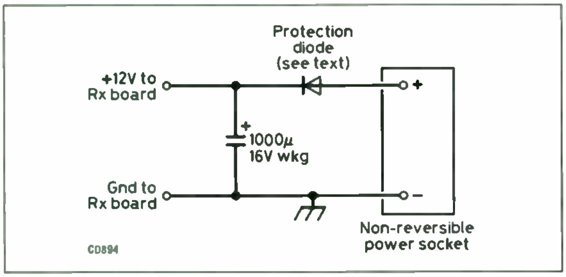


Fig 9.29. Reverse polarity protective diode is simply fitted in the positive supply lead to the transceiver

noise when there is no received signal) can be disabled by shorting the 'mute' terminal pin to ground. The AFC and modulation select switches are miniature centre-off change-over toggle switches, although they could be replaced by small rotary switches.

The main tuning control should preferably be a 10-turn 5kΩ linear-law potentiometer with a turns counter. If this is not available, then an ordinary 270° pot with a slow-motion drive could be used. A 10kΩ log pot is suitable as the audio frequency (AF) gain control: if you use a control fitted with an integral on/off switch, then this can be used for power on/off switching.

Note that no 'reverse polarity protection' is fitted on the board. This is best fitted on the power input socket and can be simply a suitable diode (such as a 1N4001 or 1N4002) fitted into the positive supply lead, as shown in Fig 9.29.

As the output impedance of a typical microwave diode mixer is of the order of 200 to 400Ω and the source impedance required for best noise performance by the IF preamplifier IC is around 70Ω, some matching is needed. A 4:1 broad-band impedance transformer is used and details of its construction are given in Fig 9.30. Decoupling the 'cold' end of the transformer primary winding, as shown in Fig 9.17, will allow you to monitor the mixer diode current to prove that both the Gunn and mixer diodes are functioning normally. The microphone amplifier is intended for use with a low-impedance (600Ω) dynamic microphone. Note that it is possible to 'blow' the audio output IC if its output is accidentally short-circuited.

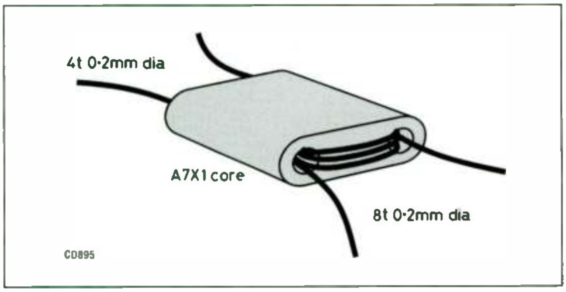


Fig 9.30. Construction details of the broad-band ferrite impedance matching transformer used between the diode mixer of a Gunn doppler unit and the input to the GDIF 107ub transceiver PCB

It is a good idea to mount the board and the microwave head in a good, rigid box, such as a die-cast box, to prevent any IF breakthrough and to provide some thermal (heat) insulation for the head: Gunn oscillators will drift rapidly over tens of megahertz if exposed to extremes of heat or cold, and a die-cast box (and perhaps some expanded polystyrene 'lagging' around the head itself, inside the box) will help to keep this drift within acceptable limits. Obviously you must cut the mounting holes needed in the box for all the switches, controls, meters, the transceiver board and the microwave head, before you can start to put the system together! Once you've done all this 'engineering' work, you can mount the board in the box and make all the connections to the other hardware, such as meters, switches, power supply socket, loudspeaker, microphone and key jack.

Setting up the Gunn oscillator

The setting up procedure breaks down into two phases: getting the oscillator onto frequency and then setting up the tuning range and deviation controls. Before connecting the Gunn, turn the AFC and modulation switches to their 'off' positions and connect a voltmeter between the PCB pins 13 (ground, negative) and 20 (positive). Turn the tuning pot fully clockwise and adjust R33 for a reading of +8.5V on the meter. Now turn the tuning pot fully anti- (counter-) clockwise and adjust R35 for a reading of +6V on the meter. If these adjustments are not straightforward, you have probably connected the tuning pot the wrong way round! Once the power supply is set up, rotation of the tuning pot should vary the output voltage smoothly from +6V to +8.5V. Set the voltage to about +7V using the tuning pot, leave it there, switch off and disconnect the power source.

Most doppler Gunn oscillators have been designed for negative ground, positive supply, but there are occasional ones whose polarity is reversed. You can check by looking at the way the Gunn device is inserted in its mounting. Fig 9.31 shows the polarity of the usual type of Gunn package. If the Gunn device is the 'wrong' way round, you'll have to carefully remove it, turn it round and remount it, taking care not to drop it. The author has lost more Gunns by dropping and losing them than by blowing them up by excess voltage or current!

One word of warning: the positive connection of the Gunn is also the heatsink end. Ideally, the positive of the supply should be grounded so that the heatsink end of the Gunn can be connected to the ground of the cavity which acts as a very large heatsink. With the normal

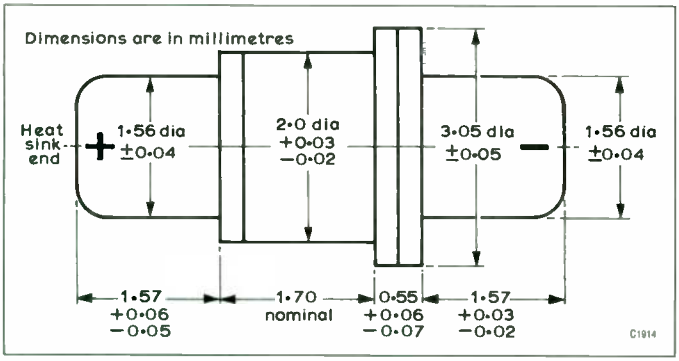


Fig 9.31. Gunn device outline showing polarity and heatsinking arrangement

low-power Gunn device which generates about 5 to 30mW for a current of 120 to 150mA, heatsinking is not too critical and the mounting pillar will act as a sufficient heatsink. If you attempt to use a high-power Gunn (surplus types generating 200 or 300mW and taking a current of 1.5A) in this way, however, the heatsinking provided by the mounting pillar will definitely not be good enough and a 'blown' Gunn will certainly result – don't try it!

Having checked your doppler module for polarity, make sure the power supply to the board is disconnected and connect the Gunn oscillator in place of the test meter. Connect the voltmeter across the mixer diode, reconnect the power supply and switch on the power supply again. You should see a reading, possibly several hundred millivolts, on the meter, indicating that the Gunn is oscillating.

Now is the time to ask someone for help if you haven't got a wavemeter! Slightly slacken the lock-nut on the Gunn cavity tuning screw: this will usually be a screw somewhere near to the middle of the cavity, rather than the one near the iris plate between the Gunn cavity and the mixer. Slowly screw the screw into the cavity until the frequency is set at about 10,385MHz, the middle of the wide-band section, then tighten up the lock-nut.

Next set the tuning control fully clockwise to give maximum voltage output and carefully adjust R33 for the highest frequency possible. The voltage tuning characteristic is usually beginning to flatten out quite severely at this point: the maximum voltage should be fixed at a point just before this flattening-out occurs.

Once the maximum frequency has been set, turn the tuning pot fully anti- (counter-) clockwise and adjust R35 to the point where the power output of the Gunn is starting to fall off rapidly. This is the lowest frequency and voltage at which the Gunn will start and operate reliably: set the lowest voltage just above the point where rapid drop-off occurs.

Now measure the total voltage tuning range and, if necessary, readjust the tuning screw to set the frequency at the middle of the voltage range to the middle of the range you want to tune. Once the tuning range has been properly set, it should remain reasonably stable unless the load into which the oscillator works changes significantly (for instance if you change an antenna). Only then might you need to reset the frequency by means of the tuning screw. You can make a note of the readings on the tuning pot turns-counting scale or slow-motion drive and construct a graph of reading against frequency which will allow you to reset the oscillator frequency with reasonable accuracy. Switch the power supply on and off several times to check that the oscillator restarts reliably each time power is applied, especially when the Gunn voltage is near minimum. Once you are certain that the Gunn is working reliably, you can disconnect the meter and reconnect the mixer to the board.

Setting up the receiver demodulator and transmitter deviation

One problem with some 10GHz WBFM full-duplex contacts is a mis-match of the 10.7MHz IFs. This mismatch can be caused either by differences in the centre frequencies of the IF ceramic filter or simply by inaccurate adjustment of the CA3189E quadrature detector (demodulator) tuning (T1). Assuming that the centre frequencies of the pass-band ceramic filters in the two systems are within about ±30kHz of each other, then best performance will be obtained by carefully adjusting the quadrature detector tuning. Correct adjustment requires an unmodulated signal at 10GHz (or 10.7MHz) with the receiver AFC switched off. Using such a signal correctly tuned-in, adjust the quadrature coil T1 slowly until exactly +5.6V is produced at pin 7 of the CA3189E. The adjustment is quite critical but can at a pinch be made on noise alone in the absence of a suitable test signal.

The simplest way to set the deviation controls is to get a report from another station. However, if another unmodulated 10GHz source is available (for example the narrow-band transmitter described in reference [1]), then the facility exists to set these controls using the receiver circuitry already on the board. Tune in the source and monitor the audio output of the GDIF 107ub: then simply adjust the tone and speech levels until they sound right. Headphones are recommended for this job, otherwise you might get audio feedback which will either cause 'ringing' oscillation or cause so much distortion that you'll not be able to tell what the quality of the signal really is. When you are sure that the signal sounds right, then the setting up of the transceiver is complete.

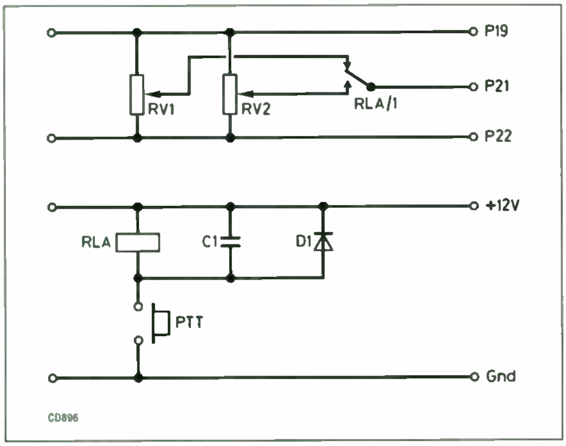


Fig 9.32. Using the GDIF 107ub as a single-frequency transceiver by switching pre-set voltages to the Gunn oscillator. RV1, used for tuning the receiver, can be the original tuning control. RV2 is a second, preset, variable control connected in parallel and used to tune the transmit frequency. The contacts RLA/1 (single-pole changeover) are used to change from receive (normally closed contact) to transmit (normally open contact), activated by means of a 'PTT' switch which energises the switching relay, RLA. C1 and D1 are used to suppress the transient switching voltages caused on making and breaking the relay coil current. C1, 1000pF, D1 IN914, RYA, 12V subminiature relay with single pole c/o contacts. A miniature panel-mounted toggle switch could be used

Other uses for the GDIF 107ub

As described, the GDIF 107ub circuit and its microwave head is very suitable for full duplex operation (Fig 9.16). You may want to use it as a single-frequency transceiver – in other words, to transmit and receive on the same frequency. Suppose you want to work on a single frequency of 10,380MHz: to transmit on this frequency, the Gunn voltage would need to be set so that the oscillator is on this frequency. On receive, the Gunn voltage would need to be set so that the oscillator frequency is offset by ±10.7MHz, ie 10,390.7MHz or 10,369.3MHz.

To avoid the inconvenience of having to retune the oscillator between transmit and receive, it is possible to pre-set either the transmit or the receive frequency (or both) by using the simple relay-switched circuit given in Fig 9.32. If two potentiometers are connected in parallel between the external connection pins 19, 21 and 22, then it is possible to make the transmit and receive frequencies independently variable. For instance, RV1 can be the existing multi-turn tuning control which is used to tune the receiver, whilst RV2 can be a preset control which is used to preset the transmitter frequency: the selection between transmit and receive can be made using a front-panel 'transmit-receive' or 'PTT' (press-to-talk) switch, with the oscillator control voltage selected by a small relay, or maybe directly with a front-panel switch.

One other application which should be mentioned, although the technique has been superseded since the development of 10GHz frequency sources, such as the G4DDK/G3WDG001, described in reference [1], or the receive converter design which follows which is also based upon the G4DDK crystal-controlled source and the G3WDG multiplier/amplifier technique. This application is the locking of a 10GHz Gunn oscillator to a low-power, crystal-controlled 10GHz source. The basic arrangement for this is shown in Fig 9.33, just for interest.

A very-high-quality 10GHz receive converter

This design by G3WDG (reference [9]) is a well-known receive converter design which, when used with a good

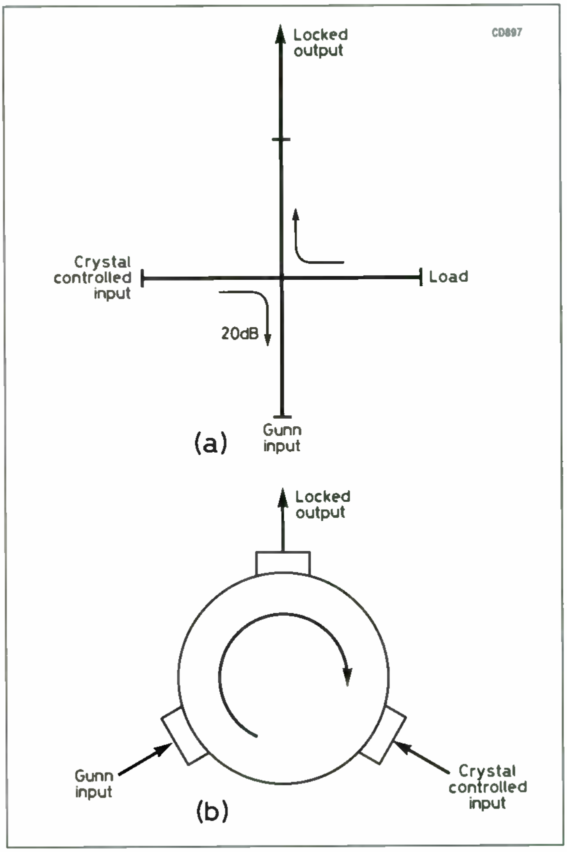


Fig 9.33. Two methods of frequency locking a Gunn oscillator to a crystal-controlled 10GHz source, using (a) a 20dB cross-coupler or (b) a circulator. Both methods are now outdated since crystal-controlled 10GHz sources with outputs higher than a Gunn oscillator are now easy to make and use, for example the G4DDK-004/G3WDG-001 design (reference [1])

144–146MHz tuneable, multimode receiver, will give very high performance. Many UK and overseas amateurs use this design, so it is well proved.

Although it is not easy for beginners to make as the components are very small, it is included here as an example of the sort of project you might be able to tackle if given help by another, more experienced, constructor. 'Minikits' containing PCBs, all of the hard-to-get, special components and a detailed construction booklet are available from the RSGB Microwave Committee Components Service (address at end of chapter). The design originally used surplus Plessey GaAs FETs, but these are no longer available. Suitable Mitsubishi MGF-series GaAs FETs are also available from the RSGB Microwave Committee Components Service. Beginners are advised to get some practical experience by building and operating a simple microwave transceiver before tackling this design, unless considerable help is available from an experienced constructor and operator.

The converter consists of two main units: the first unit is the G4DDK-004 crystal controlled local oscillator (LO), described in reference [1] as part of a 10GHz narrow-band transmitter, the G3WDG-001 design. This same LO, crystalled to give output at 2556MHz, is needed to drive the ×4 multiplier of the converter to 10,224MHz for the receiver mixer local oscillator drive. The second unit is the G3WDG-002 10GHz to 144MHz receive converter. This consists of two stages of low-noise pre-amplification before a dual diode mixer and a low-noise post-mixer (IF) amplifier. The front-end noise figure is less than 3dB. This can be improved (to around 1dB, or less) by using an external preamplifier (LNA). This kind of extremely low-noise amplifier is almost certainly too difficult for a beginner to construct without serious risk of damage to an expensive, special type of GaAs FET known as a high electron mobility transistor (HEMT). Again, minikits for such amplifiers are available from the RSGB Microwave Committee Components Service once you have enough experience and skills in construction! It is unlikely that beginners will need such high performance until they have gained considerable operating experience.

Circuit description and operation

The circuit is shown in Fig 9.34, the layout of the board and components in Fig 9.35 and their values in Table 9.3.

Referring to the circuit diagram, Fig 9.34, the 2556MHz LO input signal by a G4DDK-004 oscillator source, described in reference [1]) is fed to F1 which acts as a ×4 frequency multiplier producing a few milliwatts at 10,224MHz. The multiplier circuit is identical to that used in the G3WDG-001 module. The input signal is fed to the gate of the FET via a lumped element matching network L1/L2. The cold end of L2 is decoupled via C2 and negative gate bias is applied via L2. The output of the FET is matched to 50Ω via microstrip elements, and drain bias is fed via a quarter-wave line L4 which is decoupled at 10GHz by a low-impedance quarter-wave stub L3 and the chamfered element (a microstrip shunt capacitor) which form a series-resonant circuit at the input frequency (2556MHz) to improve the efficiency of the multiplier. Wide-band stability is provided by decoupling elements R1, C3 and C4. A number of harmonics are present in the output from the FET.

The wanted fourth harmonic is selected by the cavity filter FL1 and passed to the LO port of the hybrid ring

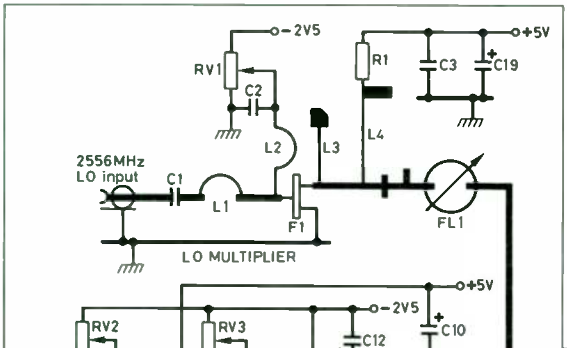
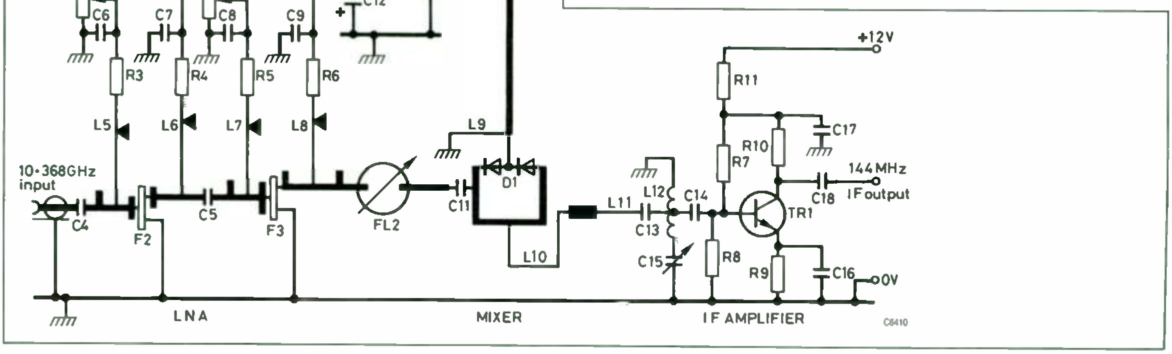



Fig 9.34. Circuit of the G3WDG-002 10GHz to 144MHz receive converter. Component values are given in Table 9.3

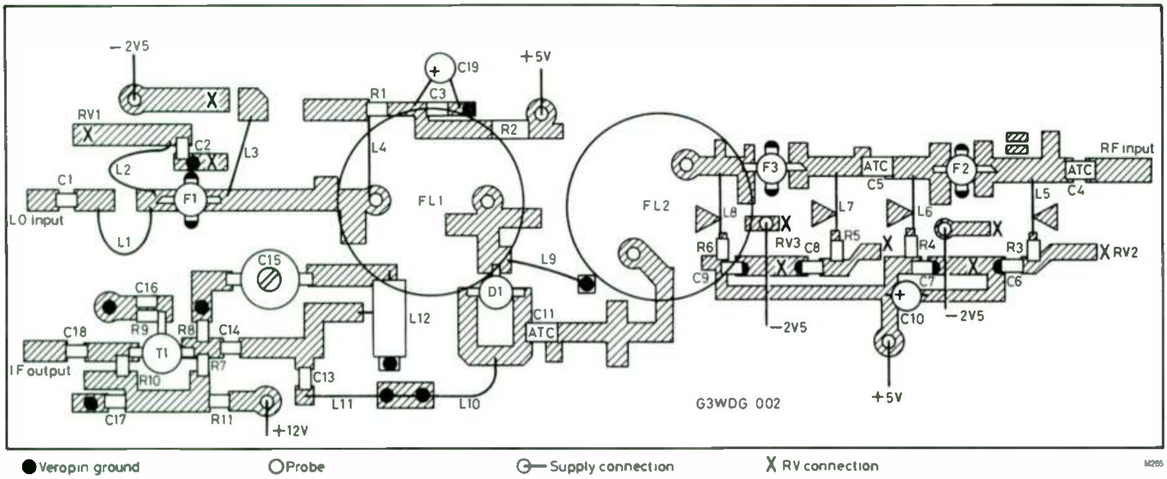


Fig 9.35. Layout of the G3WDG-002 circuit

mixer via a microstrip matching network. The mixer uses a series diode pair D1, connected between the ends of a folded three-quarter wave line. This configuration gives good rejection of the LO signal at the RF port and vice versa. L9 is a shorted quarter-wave line to provide the required low-impedance IF return path, while having no effect at the LO frequency. The conversion loss of the mixer including the matching networks is about 6–7dB.

Table 9.3. Components list for the G3WDG-002 10GHz to 144MHz receive converter

RESISTORS

R1, 3–5	47R SMD, 0805 size 6
R2	220R SMD, 1206 size, (or ¼W leaded)
R7	18k SMD, 0805 size
R8	4k7 SMD, 0805 size
R9	270R SMD, 0805 size
R10	100R SMD, 0805 size
R11	560R SMD, 0805 size
RV1–3	2k2 horizontal preset, eg Allen-Bradley 90H, Bournes VA05H or Philips OCP10H etc

CAPACITORS

C1, 2, 3, 6	220p SMD, 0805 size 7, 8, 9
C13, 14, 16	1000p SMD, 0805 size 17, 18
C4, 5, 11	2p2 ATC chip capacitor, 100 or 130 series
C12	22 to 47µ tantalum bead, 10V
C10, 19	2µ2 to 10µ tantalum bead, 10V
C15	30p trimmer, 5mm diameter, eg Murata TZ03Z300 (Green)

INDUCTORS

L1	16mm length of 0.315mm diameter ECW, formed into a hairpin. 1mm each end to be tinned and soldered to tracks as shown in layout
L2	As L1, but 19.5mm long
L3	Straight length of 0.315mm diameter ECW, tinned 1mm each end, as above. The wire should be soldered to the edge of the stub and as close to the drain connection of F1 as possible
L4	Straight length of 0.315mm diameter ECW, tinned 1mm each end, as above. Solder between the stub edge and the probe connection to FL1
L5–8	Straight length of 0.2mm diameter (not too critical) tinned or silver-plated copper wire. Solder between the track, stub point and terminal pad as shown in layout
L9	10mm length of 0.2mm diameter wire, as L5. Bend to fit between earth pin and mixer connection
L10 + 11	Single 20mm length of 0.2mm tinned or silver plated copper wire, as L5. Solder between mixer centre, stub and C13, as shown in layout
L12	4 turns of 0.6mm diameter tinned or silver-plated copper wire. Wound to 5mm inside diameter, turns spaced ½ wire diameter. Centre-tapped. Mount 1mm above the board

SEMICONDUCTORS

F1, 3	P35-1108 GaAs FET (Birkett Black Spot)
F2	P35-1145 GaAs FET (Birkett Red Spot) or P35-1108 GaAs FET (Birkett Black Spot) – see text
D1	Alpha series dual diode (DMF 3909-99)
TR1	BFR90/91

MISCELLANEOUS

FL1, 2 Cavity resonators as for G3WDG-001. See text and diagrams for details

PCB pins, approx 33 off, 1mm dia, 1.5mm head dia (approx), RS Components 433-864

SMA sockets, 3 off

Tin-plate box type 7754 (37 × 111 × 30mm) from Piper Communications

Feedthrough capacitors, solder-in, 1nF to 10nF, or Filtercons

Positive and negative regulated supplies, eg positive from 7805 IC, negative from ICL7660 voltage converter, see Figs 9.36 and 9.37

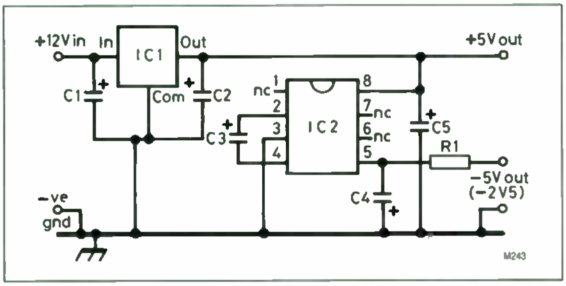


Fig 9.36. Circuit of the G4FRE-023 regulator. Component values: IC1: µA7805; IC2, ICL7660PCA; R1, 680R ¼W metal film; C1, 1µF tantalum bead, 16V wkg; C2, 0.1µF tantalum bead, 10V wkg; C3, C4, 22µF tantalum bead, 10V wkg; C5, 10µF tantalum bead, 10V wkg; PCB, G4FRE-023

A two-stage, low-noise RF amplifier (LNA) is provided to reduce the noise figure of the unit to a more acceptable level (less than 3dB). The amplifier is of conventional design and the original circuit used surplus Plessey FETs, which have recently been replaced with Mitsubishi MGF-series GaAs FETs. It is very similar to the power amplifier used in the G3WDG-001 design, except that a low-noise FET can be used in the input stage as an option. F2 can be either a red or black-spot surplus GaAs FET according to the level of performance required. Overall noise figures of 2.6dB to 3.2dB are typical, but see the comments on stability later. The input circuit of F2 has an 'optional' stub which in some cases when connected can reduce the noise figure by a small amount. It is usually not required. The overall gain of the LNA is about 19 to 20dB and its own inherent noise figure in the region of 1.9 to 2.5dB.

The output from the LNA goes to the RF port of the mixer via a microstrip matching network and a high-pass filter (C11) after passing through filter FL2 which provides about 20dB of image rejection (with a 144MHz IF). Note that FL2 can easily be tuned to the wrong image (10,080MHz), so care should be taken when tuning up (see later). The IF output from the mixer is fed to a low-noise amplifier via a low-pass filter consisting of L10, a quarter-wave line, and L11, to prevent 10GHz energy from reaching the IF amplifier. The IF amplifier is a well-proven design from another application, constructed in surface-mount form to save space.

The negative bias generator used to supply the gate bias for the FETs uses the same PCB as that used in the G3WDG-001 module (G4FRE-023). Two modifications have been made for this application – the use of a 7805 regulator and the omission of the zener diode. The circuit is shown in Fig 9.36 and the board layout in Fig 9.37. Note that C12, the negative rail decoupling capacitor, is not shown as it is fitted on the reverse side of the board. It can been seen in Fig 9.38, which shows how the power supply board is fitted.

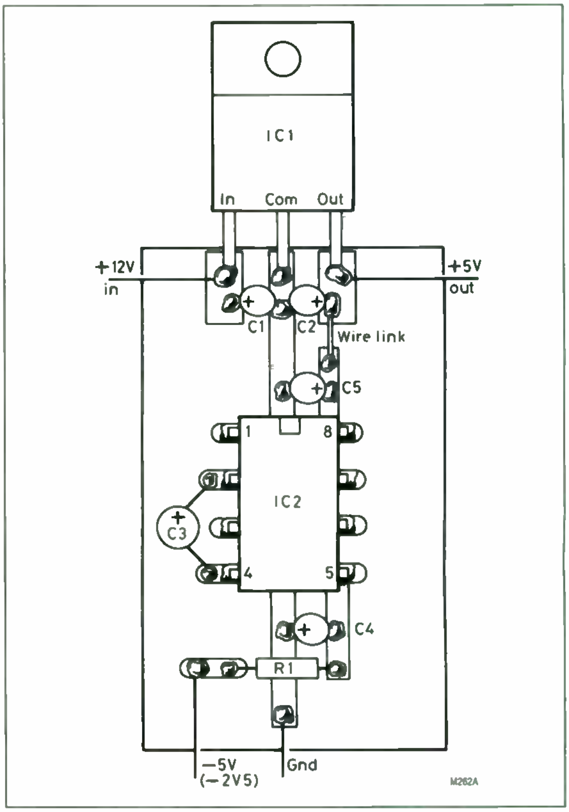


Fig 9.37. Layout of the G4FRE-023 regulator. Note that all the components are mounted on the track side of the PCB

Construction of the G3WDG-002 receive converter

This module uses the same methods of construction detailed for the G3WDG-001 module and it is strongly

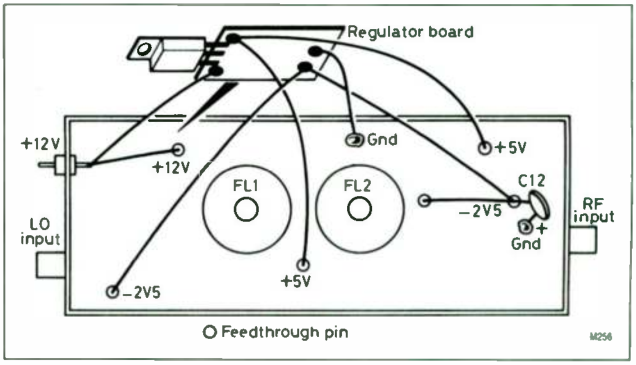


Fig 9.38. Positioning the regulator circuit within the converter

recommended that the procedures described are used as follows:

1. Fit grounding PCB pins and filter locating pins and solder in place. Lightly tin around the edge of the ground plane.
2. Solder both filters into position. Leave the tuning screws and lock nuts in position to avoid unwanted debris accidentally falling into the cavities.
3. Locate the PCB into its box and trim to a neat fit if needed, particularly in the corners of the box where there are joints. The PCB material will cut quite easily with a sharp scalpel blade and straight-edge. Locate the ground plane 17mm from the top of the open box and mark its position. Locate and mark the SMA socket centre-pin clearance holes. Drill the holes and de-burr. Locate, drill and de-burr holes for any feedthrough components needed for power supplies. Tack-solder the corner seams of the box and make sure that the lids are a neat fit. Adjust as necessary. Check also that the board will fit neatly. When satisfied, solder the corner seams fully. Solder the SMA connectors and the feedthroughs in position.
4. Relocate the PCB so that the input and output tracks touch their respective socket spills, tack-solder the PCB in place and, when satisfied that it is correctly located, solder all round the ground plane and solder the SMA socket spills to their respective tracks. This completes the mechanical construction of the module.
5. Fit inductors L1–11, as specified in the components list (Table 9.3), into position, ensuring that the wires lie flat to the board.
6. Fit all chip components using the mounting techniques described earlier.
7. Fit all components which have leads, ensuring that static-sensitive devices (ICs, FETs etc) are put on the board last of all to minimise the risk of damage to the devices.

Note: it is best to apply the supply voltage to the board *before* fitting the FETs, to check that both the +5V and –2.5V voltages are present and correct on the respective tracks/pins. On completion of this test, disconnect power and solder in the devices only if everything checks out correctly.

Individual 'build' techniques are exactly as described for the G3WDG-001 module and need not be described further. In this design there are two 'pill-box' filters to fit – note that the lengths of the filter probe-pins are significantly different for the LO and signal filters: make sure you fit the right pins in the right places!

Alignment with simple test gear

As before, once completed, the PCB should be carefully examined for poor joints, accidental solder bridges and

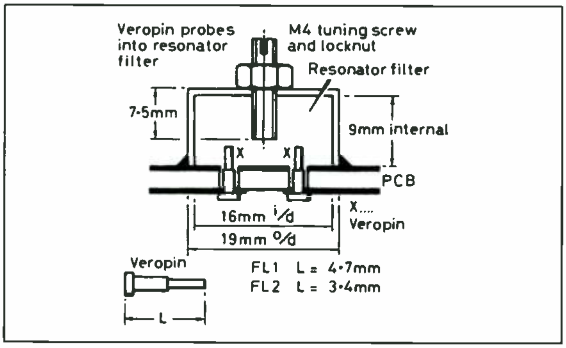


Fig 9.39. Filter coupling probes etc

other forms of short-circuit. Once satisfied that all is well, the alignment procedure may begin. You should already have checked before mounting the FETs and other semiconductors that the correct supply voltages will appear on the positive and negative supply rails when a +12V supply is connected to the input feedthrough capacitor.

1. Preset the FL1 and FL2 tuning screws as shown in Fig 9.39. Note that the 7.5mm dimension shown is the length of screw protruding from the locknut.
2. Turn the bias potentiometers RV1, RV2 and RV3 so that full negative bias will be applied to the gates of the three GaAs FETs when power is applied.
3. Insert a multimeter in series with the +5V supply between the regulator output and the +5V rail and set initially to, say, 500mA full-scale deflection.
4. Connect some form of matched load to the 10,368MHz input socket, such as a 10GHz termination, attenuator or SMA-to-waveguide transition with a horn or similar well-matched (low-VSWR) antenna connected.
5. With no oscillator drive applied, apply +12V to the power input feedthrough. The indicated current should be no more than a few microamps. Switch the range of the multimeter as necessary. If considerably more current is measured look for short-circuits or misconnected components.
6. Adjust RV1 to give an indicated current of about 1mA on the meter.
7. Apply the LO signal (approximately 10mW at 2556MHz). The indicated current should rise to approximately 7mA. The absolute value is not critical. If this order of value is not reached, the input drive may be too low, in which case retune the LO drive source and/or change the lead length between the LO source and the module.
8. Connect a 144MHz SSB receiver to the IF output socket and tune C15 for a noise peak. This should be quite a significant peak if the IF amplifier is working correctly.

9. Carefully adjust the FL1 tuning screw a turn or so either side of the preset position. A clear drop in the 144MHz noise level should be heard at the correct tuning point. Lock the tuning screw in this position.
10. Adjust RV2 to cause the indicated current to rise by approximately 12mA, and RV3 to cause a further increase of 15mA. The total current shown should now be in the order of 35mA. The LNA is now powered up at approximately the optimum bias currents for the two FETs.
11. Preliminary alignment is completed by tuning FL2 for a peak in the noise level. Careful tuning will show that two peaks can be heard. The correct one is with the tuning screw at the smaller penetration, ie further out of the filter cavity. Lock the screw in this position.
12. If a signal source is available (maybe a G3WDG-001 personal beacon?), check that this can be heard satisfactorily. It is worth reconfirming that FL2 is set to the correct image by tuning it for maximum signal. If no such signal source is available, try listening for other local signals on the band, perhaps harmonics from lower-frequency equipment.
13. Remove the test meter and make good the connection.
14. Final alignment can be done using a noise-figure meter or weak signal to optimise the performance. Adjust RV1, RV2, RV3, FL1, FL2 and C15 for best results. If a noise-figure meter has been used, recheck with a signal source or generator that FL2 is on the correct frequency, as the meter will not tell you if you are tuned to the wrong image!

After alignment, the converter should have a noise figure below 3.5dB. Prototypes have varied from 2.4dB to 3.3dB. The overall gain should be in the region of 27–30dB.

Stability

During the initial tuning-up phase, the module should be operated with both top and bottom lids off. Under these conditions the module should be perfectly stable with either a surplus red or black-spot FET in the front end, or the recommended Mitsubishi alternative. However, problems with stability were encountered with some of the prototypes when the lid was put onto the component/microstrip side of the box. Note that the module works perfectly well without a lid and can be operated like this with no problems, unless mounted close to another metal surface. In one of the prototypes, the impedance connected to the RF input socket had an effect too. Quality of construction, particularly how well the ground plane side of the board is soldered to the box, may also have an effect. Prototypes using black-spot FETs seemed to be more stable then those using red-spot FETs, although the problem should not occur when using the recommended Mitsubishi alternatives. A common cure for lid-induced oscillations (often used in commercial LNBs) is to mount a piece of lossy material in the lid above the LNA section of the unit. The choice of material is quite important and a lossy rubber, the same as that used professionally in many microwave applications, should be used. This is known as 'RAM' (radar absorptive material). Black anti-static IC foam was tried initially, but was not nearly as effective as the proper material. The rubber sheet should be glued on the inside surface of the lid, as flat as possible, above the two-stage amplifier. Note that the lossy material on the lid does not degrade the performance: indeed the designer has often seen an improvement of up to 0.2dB with the lid in place!

Other applications

As described above, the application is for narrow-band use at 10,368MHz. However, the design has been made sufficiently wide-band so that the unit can be used anywhere in the 10,000–10,500MHz band with virtually the same performance. All that has to be done is to choose the appropriate LO frequency and tune FL1 and FL2 to the desired LO and RF frequencies respectively.

Two particular applications might be in the 10,450–10,500MHz band for receiving future amateur satellites, and, lower down in the band, for ATV.

A large amount of flexibility also exists with the choice of the IF, limited only by the tuning range of the '144MHz' tuned circuit. However, IFs below 144MHz are not recommended for high-performance applications as the image rejection will be insufficient and the noise performance will suffer. (You will not see this on a noise-figure meter, though, so beware!) Higher IFs should be possible by modifying the IF amplifier, although this has not been tried by the authors. However, the mixer on its own has good performance with IFs up to at least 1.3GHz. For ATV use, it should be possible to accommodate a standard amateur FM TV signal within the FL2 bandwidth, but the IF bandwidth might be too narrow. A damping resistor across L12 should increase the bandwidth, but this has not been tried. A better solution would be to use a higher IF, eg 480, 612 or 1240MHz with a modified IF amplifier to suit. If a higher IF is used, the bandwidth of FL2 could be increased by using longer probes.

References

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[2] British Amateur Television Club, Membership Secretary: Dave Lawton, G0ANO, 'Grenehurst', Pinewood Road, High Wycombe, Bucks, HP12 4DD. Tel: 01494 528899.

[3] BATC Publications, c/o Ian Pawson, G8IQU, 14 Lilac Avenue, Leicester, LE5 1FN. Tel: 0116 2769425.

[4] *The ATV Compendium*, Mike Wooding, G6IQM, The British Amateur Television Club, 1989.
[5] *CQ-TV*, No 135, 1986, John Wood, G3YQC (BATC).
[6] 'Getting started on microwave ATV', Dave McQue, G4NJU, *Radio Communication* October 1994, pp13–15, and November 1994, pp68–69.
[7] *The ARRL UHF/Microwave Experimenter's Handbook*, American Radio Relay League, 1990.
[8] 'Microwave semiconductors and valves', *Microwave Handbook*, Vol 1, ed Mike Dixon, G3PFR, RSGB, 1989, pp6.22–6.28.
[9] Charles Suckling, G3WDG. Design and construction booklet (part of kit), Microwave Committee Components Service, c/o Mrs Petra Suckling, G4KGC, 314A Newton Road, Rushden, Northants NN10 0SY. Re-published with the author's permission in the *Microwave Handbook*, Vol 3, ed Mike Dixon, G3PFR, RSGB, 1992.

Component/kit suppliers

- BATC Member's Services, c/o Peter Delaney, G8KZG, 6 East View Close, Wargrave, Berks, RG10 8BJ. Tel: 01734 403121.
- Mainline Electronics, PO Box 235, Leicester LE2 9SH. Tel: 0116 2777648.
- Bob Platts, G8OZP, 220 Rolleston Road, Burton-upon-Trent, Staffs, DE13 0AY. Tel: 01283 531443 (weekdays only, 7–9pm). (Converted LNBs, kits of parts for tuneable ATV converters for 750–1700MHz, Gunn oscillator ATV modulators, Gunn oscillators.)
- RSGB Microwave Committee Components Service, c/o Mrs Petra Suckling, G4KGC, 314A Newton Road, Rushden, Northants, NN10 0SY. Tel: 01933 411446.

Appendix 1

Tools and how to use them

Choosing tools

If you do not have many tools you will need to beg or buy some. Unfortunately they can be rather expensive. This section is intended to help you get as much as possible for your money.

It is not always best to look for the lowest price as many cheap tools do not perform well, even when new. The tools are described in the order which, in the opinion of the author, indicates their importance to a beginner in home construction, but other people may well have other ideas of the priority.

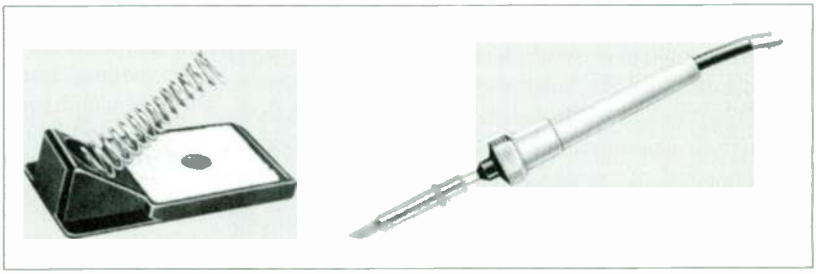

Fig A1.1. A simple soldering iron and stand

Soldering iron

There are many small types available at a price of about £7 to £8. Look for the power, which should be in the range 15 to 25W. The higher power would probably be best for those who have not soldered before. Choose one which has interchangeable bits and a range of these available for the iron you select.

The bits have points with a width ranging from about 1mm up to 6mm. You will not need all of them at first and one 1 to 2mm and a second 5mm would be fine. When you buy the iron check that a suitable stand is also on offer. There are some kits that include an iron, a stand, some solder and a booklet giving very useful hints on soldering. The iron in the photograph (Fig A1.1) is one of the Antex range.

If there is any spare money, a thermostatically controlled soldering iron is a worthwhile investment because in use it is always at the correct temperature, the 'bits' are interchangeable for different sizes and, because they cannot overheat, last a long time. Unfortunately, a solder station (iron, stand and control system) will cost about £95. A small butane-gas-powered soldering iron is very useful for working outside or away from supply mains (very useful on antennas). Both of these items can sometimes be found in radio rallies.

Wire cutters

These most important tools are used almost continuously during construction work. Again there are many types on offer, at prices ranging from £1 to £20! Sometimes the very cheap ones are satisfactory, but always test them – or ask for them to be tested by cutting the wire ends of a resistor and a transistor (the lead-out wires of transistors are usually steel). They must cut right through the wire with a snap, not squeeze it very thin or, even worse, twist the wire sideways. Sometimes cutters will work on iron wire and not on copper – this is why two components were suggested for the test.

The better cutters and some types of pliers often have a joint similar to that shown in the photograph (Fig A1.2). These are called 'box joints'; they cost about £10 to £20 but are excellent and will last forever if treated carefully – do not try to cut very thick copper wire or iron more than about 1mm. Do look out for this type in the second-hand shops etc – you might be lucky and find a second-hand pair of cutters made by Lindstrom.

Fig A1.2. Wire cutters

A good but much cheaper cutter looks like one shown in Fig A1.3. This has what is known as a 'lap joint'. Many of this type have a safety clip which holds the end of the

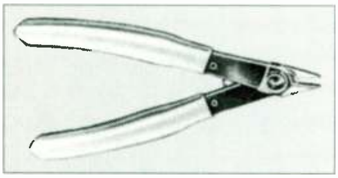

Fig A1.3. A lower-priced type of wire cutter

cut wire and stops it flying. The cutter shown in the photograph is one made by Cooper Tools and costs about £4.50. Again there are many types and sizes but the larger side cutters used by electricians are not really suitable.

Screwdrivers

Most households have a screwdriver of some sort. You will need a thin one, about 2–3mm across the end of the blade, something like the one in Fig A1.4. This is called a 'terminal screwdriver' and costs about 20p. It can be used for many jobs, including tightening the grub screws in control knobs and in terminal blocks. A medium-size driver will also be useful, about 5mm across the blade.

One other driver is worth looking for at this stage – the 'cross point' – sometimes called 'Phillips' (Fig A1.5). The fixing screws of small plastic boxes are of this type. Choose a small one so that it will fit the small screws used.

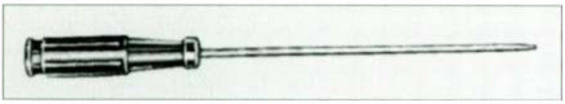

Fig A1.4. A terminal screwdriver

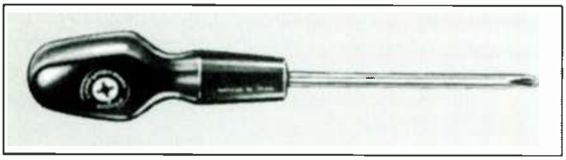

Fig A1.5. A Phillips screwdriver

Hand drill

Holes will need to be made quite early on during construction projects. For the beginner, a hand drill similar to the one in Fig A1.6 is probably best. The drill bit (twist drill) is more likely to do what is wanted than it would if a power drill was used. In any case cost is important and even a small hand drill can cost £10. It might be worthwhile paying another visit to the market stall or second-hand tool shop – perhaps a car boot sale! First make sure that the gears run smoothly with no grinding or slipping. Then check the chuck. This is the part which holds the bits. There are three little pieces of metal that open up and close as the outside is turned. Make sure they do! Try to hold a thin nail about twice as thick as a dressmaking pin. If the

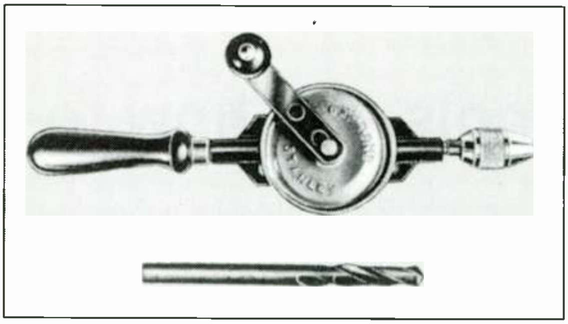

Fig A1.6. A hand drill and bit

nail falls out, don't buy it. Finally, open the jaws (the three pieces of metal inside the chuck) by turning the outside of the chuck. If the pieces flop about or fall back into the chuck – don't buy it. The general rule is: the lower the asking price, the closer you must examine it.

Now hopefully you have managed to get a drill so you will need some twist drills ('bits'). Again these can be rather expensive. Unless you know something about drills it would be advisable to buy new ones, so give the second-hand shop a miss. However, there is a way to avoid too much outlay – start with just three bits: one each of 6mm or ¼in (probably the biggest that the drill will accept), 3mm or 1/8in and 1.5mm or 1/16in. They should cost between £1 and £2 for the three.

Taper reamer

One of these is worth a box of bits. There are two sizes generally available and the picture (Fig A1.7) shows what they look like. They allow a small hole in sheet metal or plastic to be made larger. At the same time they ensure that the final hole will be round! It often surprises the inexperienced constructor to find that larger drills tend to make holes in thin sheets which are almost triangular.

The smaller reamer will enter a hole of 3mm or more and by gentle turning will enlarge it up to 12mm if necessary. If kept for use on aluminium and plastic, it will last for a long time but less if used on steel. It costs about £4 which may seem a lot but if you try to buy one 12mm twist drill you will probably have to pay £2 and in any case your hand drill would not accept one. The

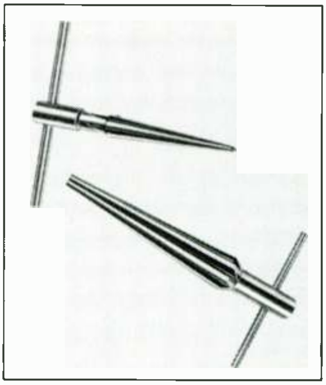

Fig A1.7. Taper reamers

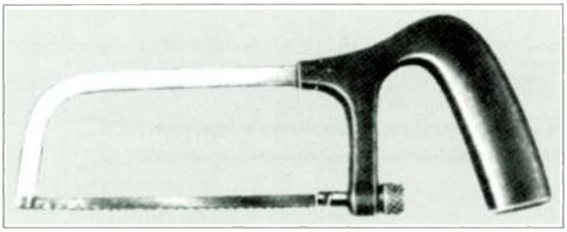

Fig A1.8. A junior hacksaw

larger reamer needs a hole of 6mm and will enlarge up to 25mm. Start with the smaller one, obtainable from Cirkit or Bonex (see Appendix 3).

Hacksaw

See Fig A1.8. If a full-size hacksaw frame is available, all you need is one or two fine blades – 24 teeth per inch should be satisfactory for most jobs. Be sure to put the blade in the frame so that the arrow on the blade points in the direction in which the saw is pushed. In other words, the saw must cut as you push it away from you.

If you are not so lucky and have to buy there are a number of advantages in the 'junior' hacksaw.

The saw and replacement blades are much cheaper and it is easier to handle than its 'big brother' because it is smaller and lighter. Some very cheap ones are available and are quite useful, but if possible get one with a blade tension screw as in the illustration. Usually with this type of junior hacksaw it is possible to turn the blade through 90° so that long strips of metal or copper laminate can be cut.

In addition this type will enable a sawing wire to be used in the place of a blade. It is a long, thin round file and enables the saw to move in any direction so that rectangular (or any other shape) holes can be cut in sheet material. The sawing wire cannot be fitted to a frame which does not have a tension screw, so it may worthwhile paying a little more so that the extra facility will be available if required in the future. Sawing wires or 'Abrafile' are obtainable for full-size frames but they are much dearer and they break easily!

Fretsaw

A fretsaw with a metal cutting blade will enable any odd-shaped hole to be cut in up to 1.5mm mild steel, 3.0mm aluminium alloy and copper laminate. Being very thin, it not only wastes less metal but also takes less energy to use it.

Modelling knife

A small one is very useful in preparing the ends of insulated wires, cutting Veroboard and copper laminate, and in fact a whole host of jobs – you probably have one already.

Needle files

These are very small files and can be bought in sets or singly. The most useful is a round one. It is about 3mm across the thickest part, tapering down to a sharp point. It can be used to correct the position of a hole that has been drilled just a little to one side of the correct place. It is surprising how often that happens! Alternatively it can be used to make a hole in a PCB or Veroboard just a little bigger. Take care when using needle files – the name is very 'pointed'! Also, the point breaks very easily. All files should be fitted with a handle to protect the palm of the hand. Cheap handles for needle files can be made from 50mm × 12–15mm dowelling, rounded at one end and with a hole drilled at the other end to accept the file.

There are many other tools you may need but aim to build up your kit gradually. There is one tool which can be added to your kit which can be made at very little cost. It is a piece of test equipment.

A diode probe

If you have a digital voltmeter (DVM), an RF probe will enable you to measure small radio frequency voltages. It may work with an analogue meter but it depends on the sensitivity. If your meter has a sensitivity of 20,000Ω per volt or higher and a DC voltage range of 3V or less it will work quite well. The probe is a simple rectifying device which converts the RF into DC, which is then measured by the DVM set to a low-voltage DC range. You may quite correctly enquire why the meter is not set to an AC range. The answer is that the losses at RF (due to the capacitance of the leads and instrument) is high and little or none of the voltage under test will reach the DVM. The RF can 'pass through' a capacitor or any circuit which has capacitance. The probe overcomes this by rectifying the RF literally at the tip of the probe and so the losses are almost nil.

The circuit shown in Fig A1.9 is very simple, consisting of two RF diodes which form a voltage-doubling rectifier circuit and two capacitors. C2 removes most of the RF and presents a DC voltage to the DVM.

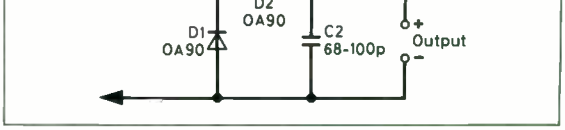

Fig A1.9. The circuit of the RF probe

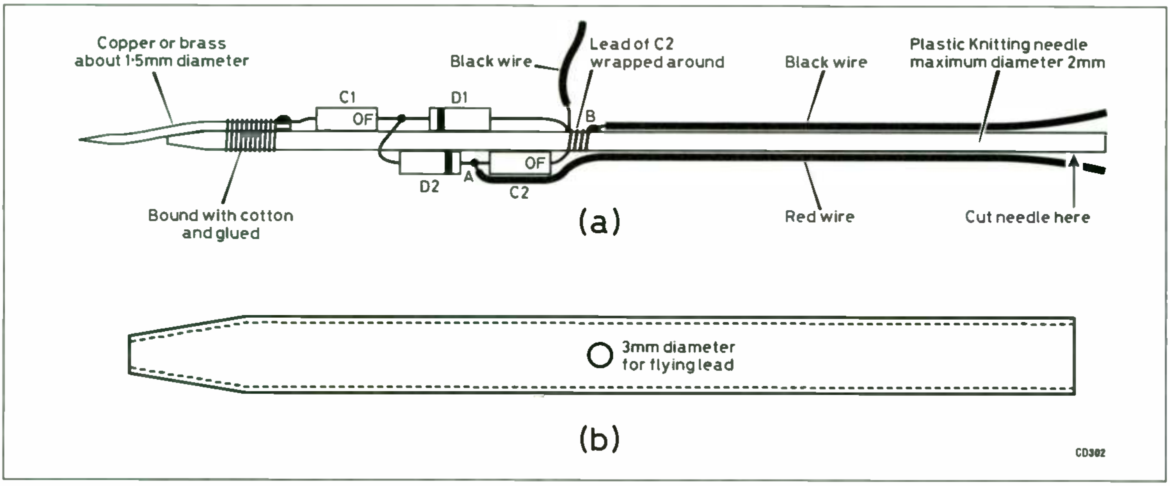

Fig A1.10. (a) The position of the components on the needle. (b) The pen body

Construction

This is a variation on the 'ugly' method. Although it is not essential, the device is more convenient to use if it is fitted into a thin hollow tube. The prototype was built on a plastic knitting needle, about 2mm in diameter. Anything thicker will make it very difficult to fit the assembly into a pen body, which is the container used in the probe to be described. A components list is given in Table A1.1.

1. The point of the probe can be made from a piece of brass or copper wire about 1.5mm in diameter and 35mm long. Bend it into the form of a very shallow 'Z', bind it to the end of the needle and then glue it. The bend (offset) should be arranged so that the point and the needle are in approximate alignment to make it easier to fit the whole assembly into a pen barrel.
2. The components are arranged in two lines along the needle as shown in Fig A1.10. The polarity of the two diodes is most important. Refer to the diagram. The cathode marks (a band) *must* be as shown. If the capacitors have a band or the letters 'OF' (standing for outside foil) they should also be connected as shown, although the device will still work correctly if these are reversed.
3. Push the needle, complete with components, into the body of a disused ball-point pen (the fatter variety) so that the tip of the wire protrudes by about 4mm. Figs A1.10 and A1.11 should make this clear. If the components listed have been used it should be possible to do this successfully. Try to keep the leads of the components short but remember that germanium point-contact diodes can be damaged by too much heat, so make your joints quickly.
4. When everything fits into the body of the pen, carefully remove it, hold the assembly against the pen

Table A1.1. RF probe components list

C1, 2	68pF polystyrene
D1, 2	OA90 germanium point-contact diode
Plastic knitting needle, 2.0mm diameter	
Brass or copper rod, 1.5mm diameter, 35mm long	
Disused plastic pen barrel	
Banana plugs to suit meter; one red, one black	
Red and black PVC-coated wire	

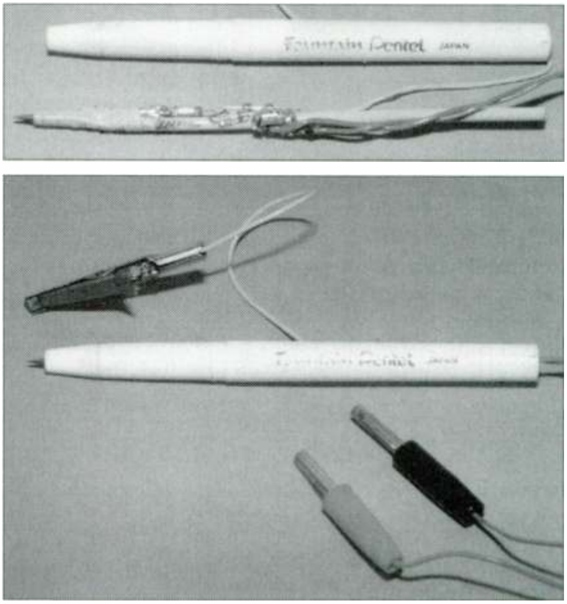

Fig A1.11. The probe removed from the pen body (top) and the completed RF probe (bottom)

body and mark the position of the earth band of wire produced by wrapping the lead of C2 around the needle.

5. Make a 3mm hole in the plastic pen body at the position marked, pass a piece of PVC-insulated wire through the hole so that it comes out of the big end of the pen, and solder the wire to the earth band. Refer to Fig A1.10.
6. Solder the lead-out wires, red to point A and black to point B (the earth band). These wires can be twisted together or a piece of screened wire could be used.
7. Again hold the assembly up to the pen and mark the needle at the end of the pen barrel. Cut the needle at this point. If you are sure that all is in order you can apply a tiny drop of superglue to the side of the four components to hold everything in position.
8. Gently push the complete assembly into the pen while carefully pulling the lead coming out of the hole to take up the slack.
9. Finish off by fitting a red 4mm plug (or whatever size fits the sockets on your meter) to the red lead and a black one to the black lead.
10. Finally solder a small crocodile clip to the flying lead coming from the middle of the body.

The probe can be used in 'chassis' form provided that the components are not touched. The pen will make it easier to use and make it look good.

Using the probe

When using this test device, it must be remembered that it is almost unaffected by the frequency of the RF and simply indicates that there is an RF voltage present. If there is more than one signal present the probe can give no indication of this; the output voltage will simply be a function of all input signals. As the probe uses a voltage doubler and because the meter connected to the output draws almost no current, the voltage at the output will be almost equal to the peak-to-peak voltage of the RF input, ie twice the peak voltage and approximately three times the RMS value.

In use the crocodile clip is normally connected to the 'earthy' end (usually zero volts) and the point of the probe to the part of the circuit to be tested.

Cutting copper laminate

This can be done using a hacksaw if the width or length of the required piece is not too great. Turning the hacksaw blade through 90° will help if thin strips are needed but care is needed to stop the material sliding about as it is cut. A broken blade is often the result unless the board is held securely. The edges will not be perfectly straight after sawing and will need to be cleaned up by means of a fine file. Altogether the operation is rather time consuming and often frustrating.

An alternative method (normally used by the author) is similar to glass cutting. Use a sharp modelling knife and a steel rule to score the material so that the copper coating is cut completely through to the laminate. Mark the position of the cut on the reverse side and score on the plain side or the other copper side if double-sided board is being used. As with glass cutting the next step requires courage. Hold the board in the jaws of a vice or a work bench such as a Workmate™ so that the score marks are in line with the edge of the vice. Apply pressure to the surface over as much area as possible, bending the board against the edge of the clamp. If all is well it will break (with a tearing sound) along the lines scribed. The process works better when glass-fibre board is being 'cut' but is generally successful with all types of 'substrates' (the material which supports the copper). The edges still need a little cleaning up but at least they are straight. Practice using some scrap board before proceeding to cut a working piece. If you are preparing a printed circuit board, cut the board to size before etching and drilling. The tracks and the holes tend to dictate the position of the break if it is attempted after the board is almost complete. This can be quite traumatic after a great deal of work. *It is most important that a sharp knife with a pointed blade is used and that the copper is cut completely.*

Cutting aluminium sheet

This is much more difficult and is often the major reason for constructors opting for a ready-made box. However, it need not be too difficult – there are a number of ways in which the problem can be overcome.

Some suppliers, such as Badger Boards, may be prepared to supply aluminium sheets cut to your specified size and gauge but you must remember that this service, together with post and packing, may well bring the cost near to that of a commercial box.

If you live in or near a town (even a small one), it is worth looking through Yellow Pages for small engineering firms. Many of these, if involved with aluminium sheet, often have off-cuts from which your pieces could be cut and sometimes they will be prepared to cut your pieces in the guillotine. You must be careful to give the exact sizes – remember the most important saying – "Measure twice, mark once and cut once". Ask the cost first and then decide if the exercise is economic.

18 gauge aluminium can be cut by means of tin snips but it is hard on the hands and the finished article is not very flat. For small pieces some success can be had if the following method is adopted. Mark the piece to be cut, then cut it out by using the tin snips about 3mm from the line, so that the piece is a little too large. Now carefully follow the line using the tin snips so that the part of the metal you want lies flat along the lower of the blades. In this way the curl from the first cut will be removed and

the resulting piece will be almost flat. Like many operations, a little practice is worth many hundreds of words.

Finally, consider sawing. The hacksaw can be used but the size is limited by the presence of the frame. Turning the blade through 90° sometimes helps but the width of the piece is now limited to the depth of the frame. If you are lucky enough to possess a jig saw, your main problem is following your lines. Then there will be considerable work with a file to get the edges smooth and straight.

Making holes

The choice of a hand drill has already been discussed so probably it seems a bit superfluous to spend time stating the obvious. However, drilling holes is not always as simple as it sounds. There are a number of ways in which the hole will not turn out quite as expected:

1. It may end up in the wrong place – just a little out of position – but if a row of holes are to be drilled in a straight line for panel controls or something similar; even half a millimetre causes the controls to look very wrong. It is therefore most important to provide a well defined 'dent' in the exact position.
2. The hole may not be round but almost triangular!
3. Worst of all, the drill bit cuts part of the way into the material and then seizes – sometimes so badly that the bit can't be removed from the work.

Drilling is not quite the same for both thick and thin materials but in every case the drill bit must be sharp and when the position of the hole has been accurately determined it must be centre 'popped'. This is the engineer's name for the 'dent' mentioned above. It should be made with a centre punch. This may be either manual or automatic; the first is a rod of steel ground to a sharp point which requires the assistance of a hammer while the other contains its own spring-loaded 'hammer'. The process is basically the same for both tools. It is important to rest the work on a solid surface – this is not always easy if the holes are to be made in a box but a little ingenuity will allow the material to be 'backed up' by means of a lump of metal which can be held in the hand or better, in a vice. Many workshop jobs seem to require three hands! Hold the punch at an angle of about 45° so that the point can be accurately located on the marked position. Apply firm pressure to maintain the position and bring the punch vertical. If a manual punch is in use give the end a sharp tap with the hammer – just once! A second blow will probably make a second dent because the tool bounced from the first blow. In the case of an automatic punch, simply press down and the spring inside will be compressed until the release point is reached, then the 'hammer' inside delivers the blow.

If the hole to be drilled is a small one, the drill bit can be located in the 'pop mark' and the hole drilled. The seizing action can be prevented by the use of a simple lubricant but this is only necessary when the material to be drilled is either aluminium or steel. Brass or printed circuit material does not require it. A suitable lubricant is penetrating oil or one of the general-purpose sprays such as WD40. If drilling a PCB the 'pop' is normally provided by the tiny 'hole' in the centre of the pads.

When large holes are to be drilled always start with a small hole (called a 'pilot') – about 3mm is usually satisfactory – then follow with the larger bit. If the material is thick, that is 3mm or more, there should be no trouble provided that a lubricant is used in the case of steel or aluminium. When the holes are to be made in thin sheet a new problem may occur. Because the material is so thin the point of the bit cuts through to the other side of the material before the full diameter of the bit has cut into the top and the bit starts to wander, resulting in a hole which is basically triangular. There are two ways of avoiding this – the first is to ignore the shape but make the hole too small, then finish it with a taper reamer to open it up to the required size. The second method requires that the sheet is firmly clamped to a piece of hard wood so that when the hole is drilled the hardwood holds the point of the drill and the bit can't wander.

Use of a taper reamer not only enables the hole to be adjusted to the correct size, it ensures a round hole and leaves the surface of the panel almost smooth. A drilled hole will leave the face of the material slightly raised and at the back there will be a very jagged edge. There are a number of special tools intended to clean up the edges but they are rather expensive. A cheap alternative is yet another drill bit. Choose one which is considerably larger than the hole and, using fingers rather than a hand or power drill, turn the bit gently so as to remove the sharp, jagged edges. Don't use too much pressure – a spinning action is best. Do not continue after the burr has been removed, especially if the hole is being made for a semiconductor device which needs a heatsink – any 'countersinking' will reduce the area of contact between the semiconductor and the heatsink.

Finally, do not reverse the direction of rotation when using a hand drill to release a jam – it will spoil both the hole and the drill bit. The best solution is to avoid the jam by means of lubricant. Stop drilling when the hole is made – the hole will be oversize if the rotation of the bit is continued.

Nuts and screws

A little knowledge will enable the correct choice to be made when using these. Fig A1.12 summarises some of the more important points. You should be aware of the fact that there are two basic systems in use in the UK. The Imperial system uses a measurement known as 'BA'

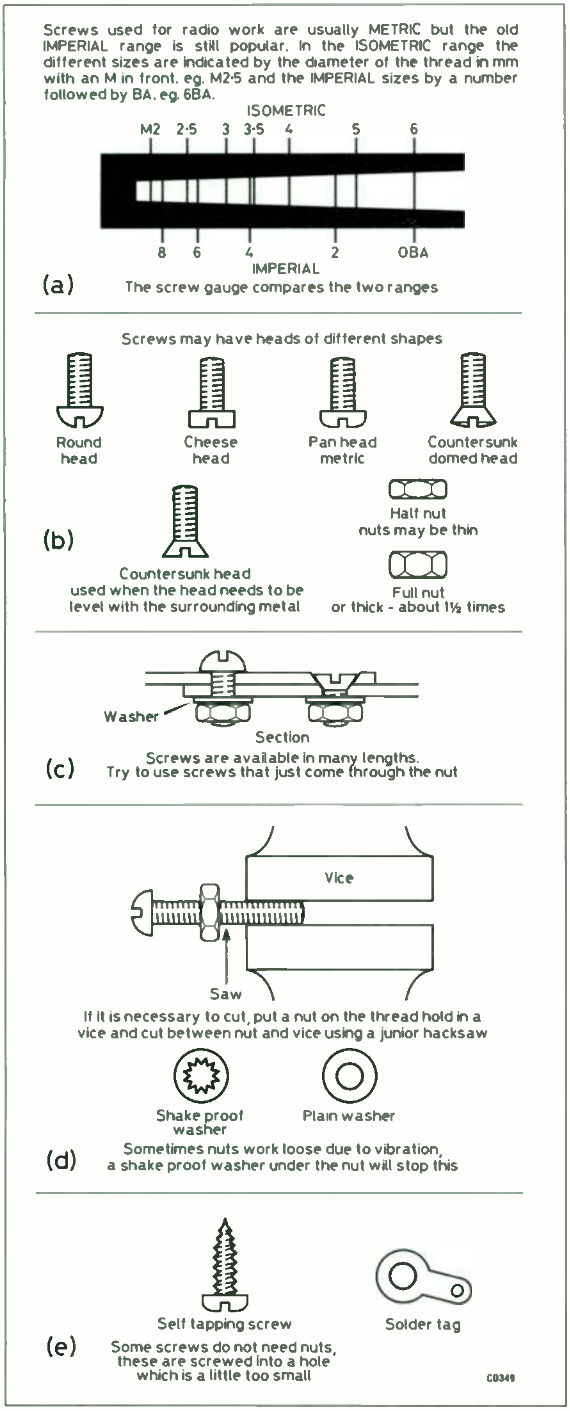

Fig A1.12. Nuts and screws and things. (a) Comparison of Imperial and Isometric sizes. (b) Various types of screw heads. (c) Using screws and bolts. (d) How to cut screws, plus an introduction to washers. (e) Self-tapping screws

(British Association). The screws and nuts are normally obtainable in sizes from 0BA (about a quarter of an inch) to 8BA, about one-sixteenth of an inch. Normally only the even number sizes are used but all are available. The other system is 'Isometric' where the outside diameter of the screw is quoted in millimetres with an 'M' proceeding the number. For example, M2.5 is a screw (or nut) with an outside diameter of 2.5mm. The gauge in Fig A1.12(a) compares the diameters of the screws in the two systems. Some of the screws and nuts seem to be almost identical in the two systems but they are not and mixing Imperial screws with metric nuts will result in a jam or stripped threads.

It is important that the screws used be of the correct length. When assembled the screw should just extend beyond the edge of the nut as shown in Fig A1.12(c). In some applications a screw which is too long will cause fault conditions. An example is the fixing screws used with a miniature tuning capacitor of the type used in the project described in Chapter 5. If these are fixed by means of screws which are too long, the plates of the capacitor will be shorted and probably mechanically damaged.

It is easy to cut a screw – a large pair of wire cutters will do the job but it will be impossible to get the nut to screw on afterwards. The best technique is illustrated in Fig A1.12(d). A nut is threaded on to the screw and the piece to be cut off is held in the jaws of a vice. Any damage to the thread will not matter as the part held is to be cut off. Use a fine blade in the hacksaw (a junior hacksaw is most suitable) to cut the screw between the nut and the vice. Hold both nut and screw in the vice to allow the cut end to be smoothed, using a fine file which is used at about 45° and moved away from the head of the screw. Remove from the vice and separate nut and screw – any roughness on the cut end will be removed by the nut as it comes off the end of the screw.

Note the various types of screw head available shown in Fig A.12(b) – round head and countersunk head are probably most commonly used.

Self-tapping screws are very useful when it is difficult or impossible to get to the other side of the work to put on a nut. When using these, try a few test holes in a scrap piece of material to be used. If the hole is too big the screw will tear the material and fail to hold, while if it is too small it will be difficult to drive the screw in. It is possible to find the drill size from tables but it is generally easier and quicker to do a test drilling.

Both nuts and screws are expensive to buy and constructors are advised to save any from equipment which is being stripped for components – the screws are often neglected and thrown away with the debris.

If a screw is to be passed through a hole which is in an almost inaccessible position, the following tip may help. Push a small piece of wax (eg from a candle) on to the

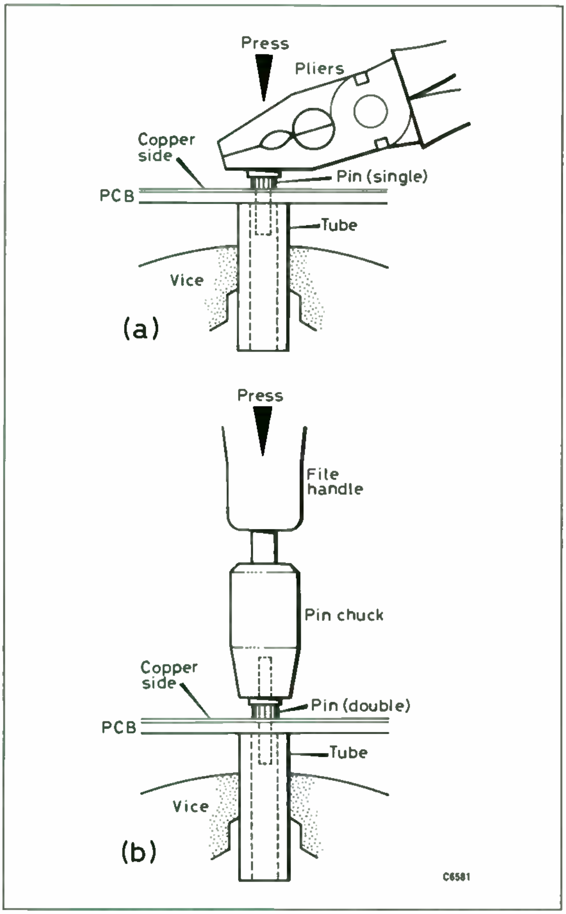

Fig A1.13. A simple jig makes pin insertion much easier

head of the screw and then 'stick' it to the blade of the screwdriver. The screw can now be carefully inserted through the hole.

Terminal pins

Many constructional articles contain the statement "First insert the terminal pins" but very few give any help in carrying out this fiddly and sometimes very difficult task.

Certainly it is important that the pins be inserted before any components are fitted to the PCB but the technique described will allow a pin to be fitted at any stage in the construction if one has been overlooked earlier. Pins are available in two types, both having a nominal diameter of 1mm with a splined section of about 1.5mm just below the head. Single-ended pins are more commonly used and provide a pin on the component side of the PCB. Double-ended pins have a 1mm section on both sides of the head. Both pins must be inserted so that the head is on the copper side of the board.

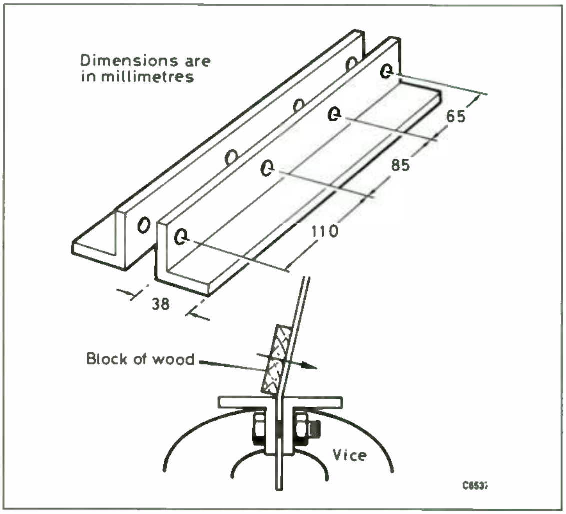

Fig A1.14. Bending bars which will last a lifetime

The plain section of the pin will pass easily into the hole, it is the splined section which requires considerable pressure to seat the head against the copper pad. A short piece of copper or steel tube about 6mm outside diameter held in the jaws of a vice makes a very good support for the PCB while the pin is pressed in. Fig A1.13(a) should make the operation clear.

A double-sided pin is a little more difficult and some form of holder makes the job much easier. A pin pusher can be any piece of metal rod with a 1mm holed drilled in the end and fitted with a suitable handle. It sounds easy but, unless there is access to a lathe, almost impossible. A convenient pusher can be made from a small pin chuck which is pushed into a small file handle. Again reference to Fig A1.13(b) should make everything clear.

Making boxes

Ready-made boxes are expensive and a little hard work can save pounds. Almost always an aluminium box will be satisfactory but large projects and power supplies may require steel. Do not attempt to bend steel which is thicker than 19 gauge (or 18 gauge aluminium). A pair of bending bars will make the process easier and will last forever. Two pieces of angle iron 1.25 to 1.5in (30 to 40mm) and 12in long are required. Try to obtain pieces with smooth outside faces and rather sharp 90° corners. The bars need to have ¼in (6mm) holes drilled at intervals so that ¼in or 0BA bolts can be passed through to hold them together. It is most important that the holes in the two pieces should match and it would be advisable to get the help of an engineer to get these holes drilled. The spacing of the holes shown in Fig A1.14 will provide a range of six bolt intervals, allowing material of any width from a few millimetres to 250mm be held with the bolts fairly close to the edges of the metal.

Clamp the metal to be bent between the bars with the fixing bolts as close as possible. The bending line should be in line with the edge of the bars. Hold the assembly in a vice or Workmate™-type bench. Use a block of wood or large file to bend the metal towards the bending line. Fig A1.14 shows the method of use.

The secret of a good bend is to keep the file or block of wood as close as possible to the point where the metal emerges from the bending bars. Much more force will be needed but avoid moving further away from the bars; it will be much easier but a rounded bend will result. A block of hard wood held against the bend will allow the bend to be completed by means of a few hammer blows while the wood prevents any damage to the aluminium.

When making a box required for a variety of projects two portions need to be formed. The cover is a simple square 'U' while the base needs to be a 'U' with a 12mm flange on the bottom edges. Bending the long edges of both the base and the cover should present no difficulty but the 12mm flange on the sides of the base is quite difficult. A simple solution is arrived at by the use of two pieces of 12mm (½in) aluminium angle bolted to the base to act as the flange.

The angle will need to be drilled (3mm holes) at each end and the holes marked through onto the base. The edge of the angle must be flush with the edge of the base. Bolt them to the base using 6BA or M2.5 screws and nuts. The heads of the screws must be on the underside of the base. There is no need to use countersunk head screws if rubber feet are to be used – these will give enough clearance for the heads. The position of the holes in the side of the angle for the cover fixing screws should be marked after the cover has been made and drilled.

The cost of the home-made box is only a fraction of that of the ready-made one if you can get hold of cheap aluminium sheet.

Appendix 2

Making printed circuit boards

"The PCB foil pattern is shown for those who wish to make their own". Perhaps many home constructors 'wish' to make their own but do not do so because they are not sure how it should be done. It is not a difficult job and can save a lot of money once the initial bits and pieces have been obtained. It is also quite fascinating to see the board gradually taking up its final form.

There are many ways of producing a PCB but most are not suitable for the fairly complex circuits with a high component density which are used with the projects described earlier in this book. Although there appear to be a number of big problems, the best method is the photographic process. The copper laminate to form the final PCB is coated with a material which is sensitive to ultraviolet light. A transparency is made from the foil pattern, laid onto the sensitised PCB material and exposed to ultra-violet light. The light passes through the clear parts of the transparency and changes the state of the sensitive coating so that it can be dissolved by the developer, leaving the unexposed areas still covered. These areas will not be attacked by the etching solution and will form the PCB pattern after etching is complete.

The process just described can be carried out in practice by executing the following steps.

1. Make a transparency from the printed foil pattern. Although there are others, only two methods are recommended.
   (a) Find a small printer with an orthographic camera and see if they will make a transparent copy of the foil pattern in the book or magazine. Stress that it must be a one-to-one copy – no increase or decrease in size. Take the original, not a photocopy, as this will be degraded and may be slightly different in size. The cost is not likely to be high but a co-operative printer must be found.
   (b) A photocopy made on transparent paper which is not the shiny acetate type but one which has a matt surface will normally be dense enough to resist the UV (ultra-violet) light. If blue drafting film can be obtained it will make an even better copy. The copy machine must be modern – some of the older ones do not produce dense black copy. If neither of these methods is possible, make two copies (at the same time and on the same machine) on transparent material, then carefully register them and hold in position with sticky tape. The process is a bit fiddly but does make a good image.
2. Obtain or cut a piece of coated copper laminate a little larger than the foil pattern. Remove the protective skin. This can be done in ordinary light as long as direct sunlight is avoided. Ensure that the transparency is the correct way round – there is normally some legend on the foil pattern which will help in this. If not, the correct orientation is found when the pattern is the same as shown in the diagram. This last is most important as a PCB which is a mirror image of the one required will be useless. When sure that the image is correct, place in contact with the laminate and lay on the glass surface of an ultra-violet light box so that the transparency is against the glass and the sensitive side of the PCB material against the transparency. Close the lid and switch on the light. The exposure time depends on the light source but is normally between 5 and 10 minutes. If this has not been ascertained carry out a test on a small off-cut of material first. It will be necessary to find someone with a light box that can be borrowed or alternatively one can be made. Instructions for this will be found at the end of this section. Like other photographic processes, there will be no apparent image on the material when it is removed from the light box.
3. Develop the image. This is a very simple exercise but care is necessary to avoid damage to persons and clothes etc. The developer is a dilute solution of sodium hydroxide (caustic soda). This can be bought at most chemists in crystal form – it is often used for cleaning drains and it is possible that already there is some in the house. Treat with great care, wear protective gloves and avoid splashing as the mixture is made

up. The correct strength is one teaspoonful in a pint of cold, boiled water. This not necessary if the water supply is very soft. Use a glass, stainless steel or plastic dish and a stirring rod of glass or wood. *Do not use aluminium equipment.* Add the crystals to the water a little at a time. *Never add water to sodium hydroxide crystals* – the first drops of water may boil and throw the mixture over everything! After the solution is made up, screw the cap of the container of the crystals very tightly and store the bottle in a safe place, preferably in a cupboard high enough to be out of reach of children. Alternatively, the developer can be purchased already made up from Maplin or Cirkit but it is rather more expensive – about £4 for 250ml, compared with £1.50 for 500g of crystal which will make up many litres of solution.

When the exposure is complete, remove the PCB from the light box and immerse in the solution, pattern-side up, and gently move the piece with the stirring rod. As the exposed material is dissolved, a coloured stain will leave the board and bright copper will be left in its place. The unexposed areas will remain covered with the steel grey material, this is the 'etch resist' which will prevent the 'circuit' being removed in the next step. Wash the board in cold water. Don't throw the solution away yet.

4. Etch the board. In this process the bare copper areas are removed to leave the required 'printed' circuit. Ferric chloride solution is the most commonly used chemical for the purpose. It can be purchased in the form of either crystal or made-up solution. The same precautions must be observed as previously detailed in paragraph 3. Comparative prices in 1996 are: made-up solution £5 for 250ml compared with £3.50 for 500g of crystals which will make up 1.2 litres of working solution. If making up, dissolve the crystals in warm water – there is no advantage in making-up part of a pack of crystals as the solution keeps very well, probably better than crystals. Store in a glass or plastic bottle. Waterproof gloves, an apron and glass or plastic containers are imperative. Use plenty of water to wash off any spills or splashes from the skin immediately and from bench or clothes within a reasonable time. Never wear light clothes – the ferric chloride stains won't come out.

A deep dish is best (it must not be metal) for the etching process and use plenty of solution (generally all of it), even for a small board. The solution can be used many times, in fact until it nears exhaustion

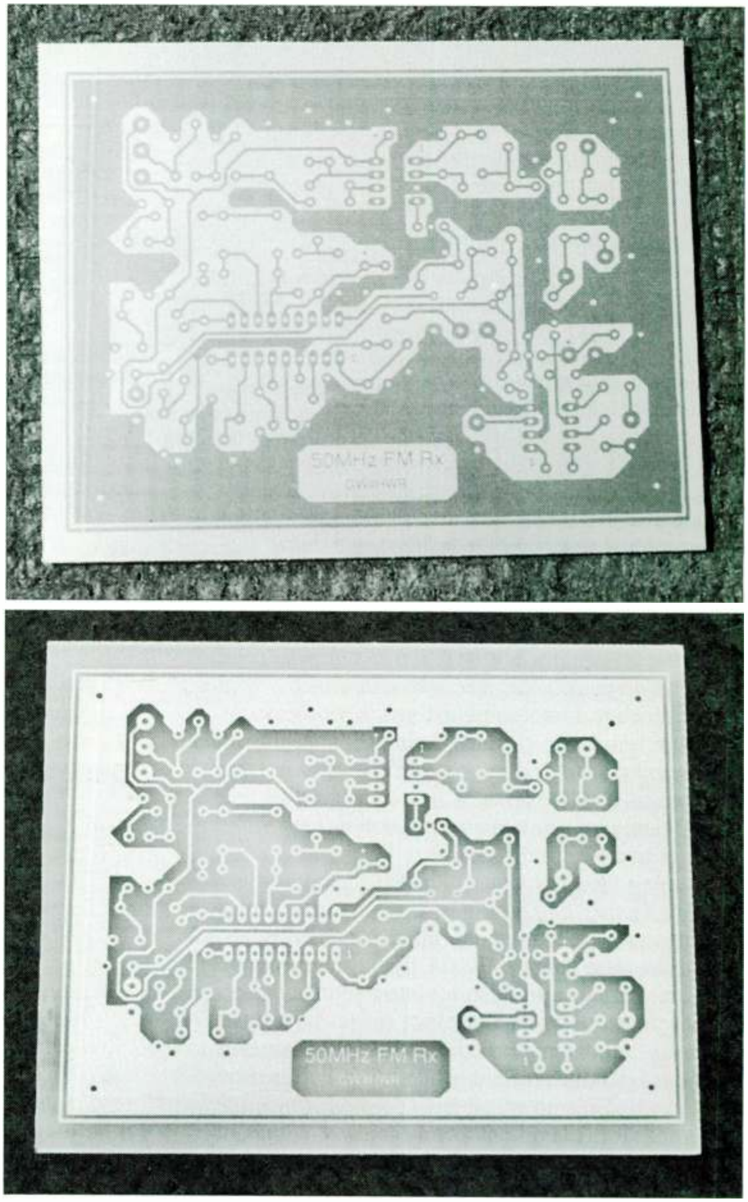

Fig A2.1. PCB before etching (top) and after etching (bottom)

which is indicated by very slow etching. Drill a small hole in one corner of the board and thread a piece of PVC-insulated wire through it so that the board can be removed from the solution without soiling the fingers. Lower the board into the bath and try to keep it moving. The time taken depends on the temperature of the solution and the degree of agitation. It also depends on the amount of copper to be removed, but 20 minutes or less is normal. Inspect often and do not continue with the etch bath once all the bare copper has been removed. Return the solution to the container and seal carefully, washing the outside of the bottle. Clearly label the bottle and store in a safe place as mentioned for the developer solution. Wash thoroughly and dry the board. Inspect carefully to ensure that no areas of bare copper remain. If there are the board must be returned to the etch bath.

Fig A2.2. The light box surrounded by typical accessories

5. Remove the etch resist. There are a number of solvents which can be used but the author favours the following method. Place the dry board, circuit side down, once again in the UV light box and expose for 5 to 10 minutes. Return to the sodium hydroxide solution and agitate until all resist has be washed away. Wash and dry. Unless there is another board to be treated the developer solution should be disposed of by pouring down the drain together with plenty of water.
6. Drilling the holes. A 1mm drill is required for this – it can be held in an ordinary hand drill but great care is needed to avoid drill breakage. A mini drill is much safer and easier to use, and is even better if a drill stand is also available. Don't use too much pressure and use a piece of soft wood under the board. Most foil patterns show a well-defined drilling point and the drill will tend to centre itself into the middle of pads etc. When drilling is complete there will be some signs of an eruption around each hole. Remove this by using a sharp drill bit (about 3mm) held in the fingers and rotated once or twice. Do not overdo this as it will remove too much of the solder pads. A light rub with fine wire wool will finally prepare the board for use.

Double-sided PCBs

Although there are no projects in this book requiring patterns on both sides of the board, the section would not be complete without some mention of the method. There are no problems (except patience) when the UV process is used. Take a strip of PCB material a little longer then the foil pattern and about 10mm wide. Use small pieces of Sellotape™ or similar to attach one transparency to the strip so that it is just outside the pattern area. Hold the second overlay to the other side of the strip and adjust the position until the correct holes coincide, then fix to the strip. Remove the protective coating from both sides of the PCB and slide it in between the two transparencies. Again fix with tape and expose both sides to the UV light in turn. Develop and etch as already described and then turn the board to ensure that both sides are being processed.

The light box

This is a very simple device requiring very little skill other than the ability to make a wooden box. The dimensions given are not very critical and may be modified to accommodate a larger choke than the one quoted (or two 8W chokes). The window area should not be made any bigger, as it would then be possible to put boards and film in a position of reduced illumination. In the original

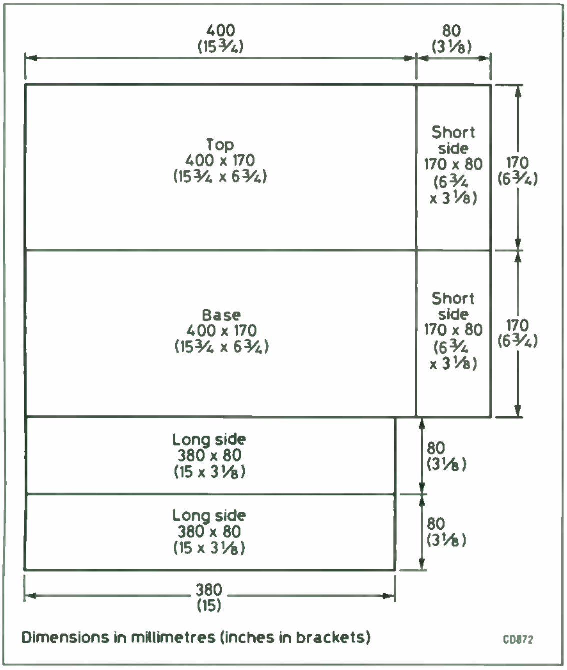

Fig A2.3. Cutting plan. Note the dimensions are only correct if material is 10mm (3/8in) thick

article, which appeared in the March 1988 issue of *Radio Communication*, the dimensions were all given in inches. They have now been converted to millimetres with the imperial size in brackets. If you can happily slip from one system to the other and back it is suggested that for this project one system be used at all times.

Many would-be cabinet makers avoid making boxes because of the difficulty of making the top fit the bottom. This problem can be avoided and a top produced that will fit, even if the box itself is rather mis-shapen. Top and bottom are made up in one piece, then the top is sawn off. The cutting plan for the pieces is shown in Fig A2.3. If you are lucky you may be able to convince your DIY supplier (especially if he is a builder's merchant) to cut the six pieces for you. If not: a piece of 10mm (3/8in) actual dimension ply about 540 × 500mm (21 × 20in) will be required.

Cut the pieces as accurately as possible and clean up the edges with a plane. Mark the top edge of all four side pieces and then draw a line exactly 12mm (½in) below the top edge. Also draw a line on the outer surface of the top and bottom, 10mm (3/8in) from each edge which will act as a guide for the nails. Use a good woodworking glue and 20mm (¾in) panel pins. Note: 25mm

Table A2.1. List of parts for the light box

Two 12in 8W UV tubes. Those used in insect traps are suitable.
Two starter lamps
Four tube lamp holders. If batten types are used then Terry clips are not required
Two starter lamp holders
One 13W choke. 20W is acceptable but the box will have to be enlarged.
Four Terry clips, 12mm (½in)
A piece of book cloth about 1 × 1.5m (optional)
A piece of 20mm (¾in) foam 750 × 300mm (8 × 18in)
A piece of 10mm (3/8in) plywood
20mm (¾in) panel pins
A pair of hinges
A pair of catches
Woodworking glue

(1in) pins are too long and will foul the saw when the top is sawn off later. Starting with the top, drive pins (in the centre of the 10mm (3/8in) strips) through the long and short edges so that they just emerge on the other side. A spacing of 75mm (3in) is about right. Do the same with the bottom. Note: the lower part of one short side must not be glued (see Fig A2.4) as this piece must be removable to allow access to the tubes and starters etc.

Coat the top of one short side with glue, align the top with the side and drive in the nails. Before the heads disappear check the alignment and, if not correct, withdraw the nail with pincers or pliers and repeat, moving the nail a little to one side of the first position. When satisfied that all is correct, hammer the nails right in.

Next coat the top edge of one long side, bring the top and short side into position, making sure that there is no gap between long and short sides, and drive the nails in. Now coat the top edge of the second short side, and top 12mm (½in) only of the two long sides and nail. Do not drive the nails in the lower part of the short side all the way. Leave 3mm (1/8in) protruding so that they can be removed later. If you have not already done so, nail the other corners but do not put nails closer than 6mm (¼in) of the line drawn 12mm (½in) from the top.

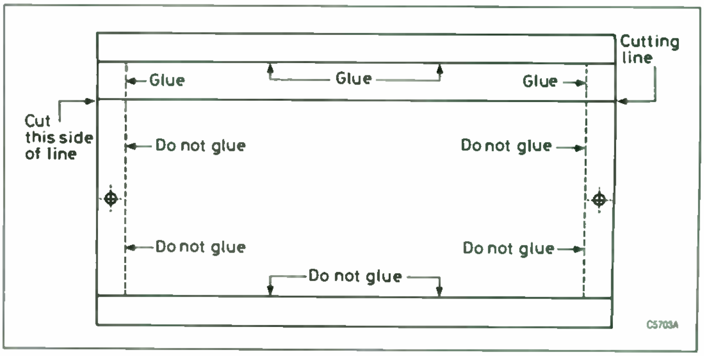

Fig A2.4. Showing the non-glued edges

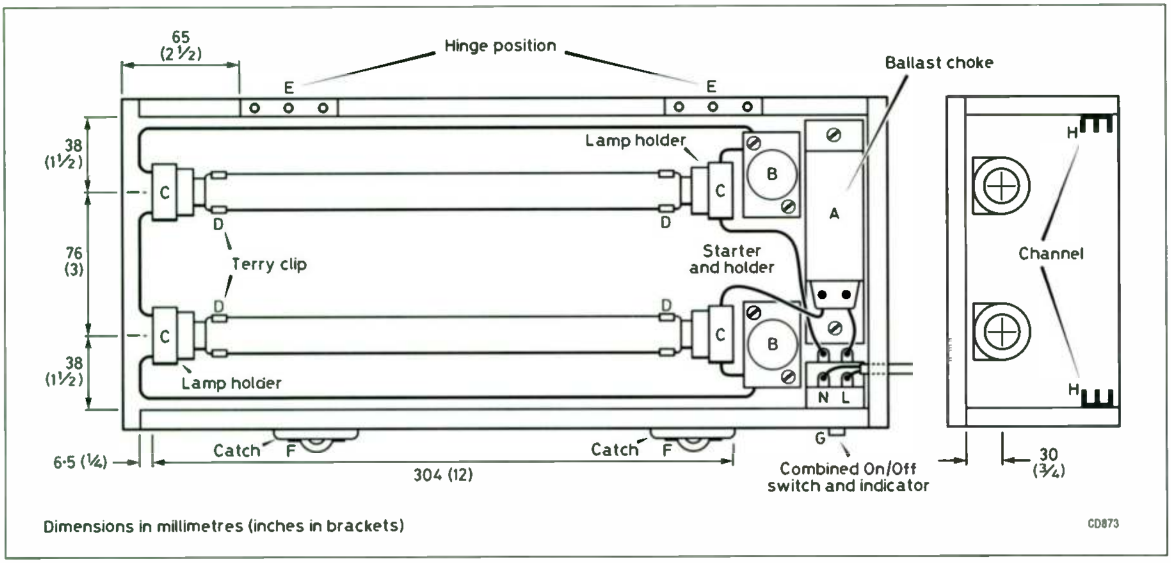

Fig A2.5. Layout of components and critical position of tubes

Now glue and nail the bottom. Once again leave the nails in the unglued short side protruding. Wipe off any excess glue with a damp cloth. The next job is probably the hardest part. Leave the glue to set: at least overnight! When dry, tidy up the edges with the plane or rasp and sandpaper. Now cut off the top. Hold the box as securely as possible. If you have a Workmate™-type bench it should be no problem, or perhaps you could borrow one for this task. If not, hold the box as tightly as possible. Starting at the short end which is not glued at the bottom, saw just to one side of the line drawn 6mm (¼in) from the top edge. It is now 21.5mm (⅞in) from the top because of the top board. Try to keep the line just visible and saw very slightly below it so that the inside depth of the top is a full 12mm (½in) deep. Turn the box as necessary and continue sawing. If it is necessary to clamp across the depth of the box, make sure that the gap already sawn is not squeezed together. Put in pieces of card or PCB to keep the gap open and so prevent the saw jamming. Take special care when the cut is almost complete, and hold the top so that as the last bit is sawn it does not break away. Clean up all the edges with plane, rasp or sander. You should now have a box with a fitting lid. Using a small drill (2mm or No 44), drill holes in the centre edges of the unglued short end right into the sides. See Fig A2.4. Remove the nails that are sticking out and gently tap the side piece out.

The hinges are let into both top and bottom so that there is almost no gap when the lid is closed. The recess can be cut with a coarse file. Drill a 6mm (¼in) hole in the right-hand short side about 25mm (1in) from front and bottom for the mains lead. The mains switch should now be fitted about 37mm (1½in) from the right hand edge and 25mm (1in) from the top edge. The exact position and size of hole will depend on the type of switch chosen. Make sure that it is a mains type, preferably double pole, and, if possible, with a built-in neon indicator to show when the light is on. Alternatively a separate indicator could be used.

The choke, starter lamp holders and lamp holders (or Terry clips) can now be fitted in accordance with the dimensions given in Fig A2.5. If Terry clips are to be used to hold the tubes rather than batten-type tube holders, the centre of the tubes should be about 20mm (¾in) above the floor of the box. If less than this, use spacers under the Terry clips. In the prototype 0BA full nuts were used for this purpose. Check that the tubes, together with their end connectors, will fit and then remove all parts from the box. Cut a piece of kitchen foil the same size as the bottom of the box. Try to keep it free from creases and, using dilute glue or wallpaper paste, glue the foil to the bottom of the box with the shiny side facing up. Smooth out as far as possible and press the foil over the component fixing holes with a finger to locate the screws later. While the glue is drying, locate the components in their approximate positions and wire up as shown in Fig A2.6. It is much easier to connect up this way as space inside the box is rather limited. Use mains-grade insulated wire – the inners of mains flexible cable would be in order. When the glue is dry, re-fix the components in the box, keeping the wires in the corners as far as possible. Fix the on/off switch and connect a 1.5m length of two-core mains lead. Connect the output side of the switch to the choke etc. Use a small cable clamp to prevent strain on the switch when

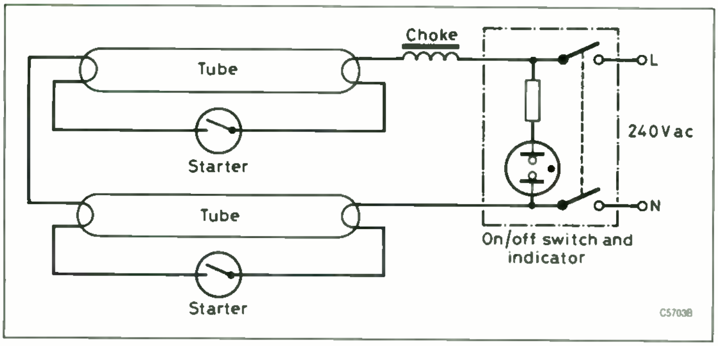

Fig A2.6. Showing how two tubes are connected to a common ballast

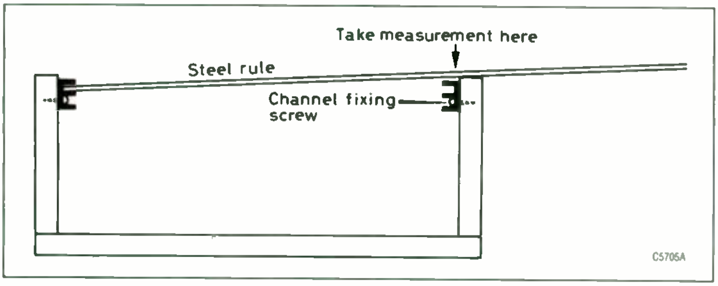

Fig A2.7. Measuring the required width of glass

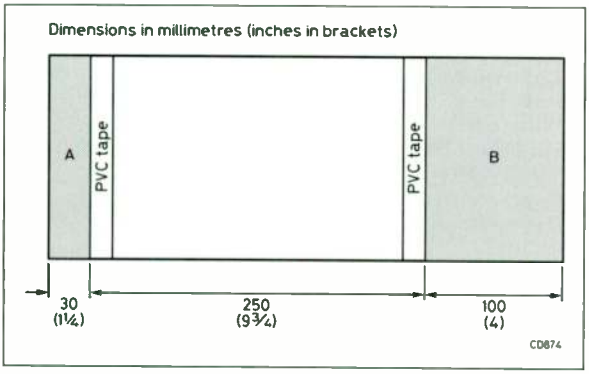

Fig A2.8. Masking the glass and area to be painted

the cord is pulled. A 13A plug top fitted with a 3A fuse completes the electrical installation which may now be tested. Note: the output from the 8W tubes is relatively harmless but do not leave switched on without the top in position and do not look closely at the lamps for more than a few seconds.

To get a professional finish the box could be covered. A local bookbinder can usually supply thin book cloth which is ideal. Use carpenter's glue and allow 25mm (1in) to turn in at the edges. Enlarge the two holes in the small free end to accommodate 20mm (¾in) self-tapping screws. Fit the hinges and small catches so that there are no undue gaps between top and bottom. Cut two pieces of plastic sliding door channel to fit inside the long edge of the box. Screw and glue the channels so that they are almost level with the top. The 10mm (3/8in) screws should be in the lower slot.

Use a steel rule to measure the distance between the bottoms of opposite pieces of channel. Check at both ends and in the centre and use the smallest measurement. Measure the length between the short ends and obtain a piece of 3mm or 4mm glass with these dimensions. Measure very carefully and reduce the width by about 1mm to make sure that it will slide into the top grove of the channel. Mask the glass as shown in Fig A2.8 and paint areas A and B using black paint. When dry, remove the tape. Slide the glass, painted side down, into the top slot of the channel and fix the loose end of the box into position.

Finally cut a piece of soft 20mm (¾in) foam to fit inside the lid and hold in position with a few spots of glue. The foam acts as a pressure pad to hold the transparencies and film/PCB together. The box is now complete.

Appendix 3

Suppliers of components

Almost all of the suppliers listed will provide a catalogue, many of them free of charge. You should try to get as many as possible as they often give valuable data about components in addition to giving their availability and cost.

At the time of writing this book, UHF and microwave components were not easy to get from the usual amateur suppliers. It was also often difficult to get suitable components in small quantities from some of the larger suppliers. Some components are available from 'surplus' sources and these are given *where they are known to be reliable*.

Other components, such as surplus waveguide components, can often be obtained from rallies, although there will usually be no guarantee that such components will work properly. The chances are that waveguide 'hardware', unless obviously damaged, *will* work properly. Things like attenuators and wavemeters may need recalibrating although, in the authors' experience, even this is unlikely unless you want to carry out very precise measurements.

The list of suppliers that follows was current at the time of going to press (1996). The list is not complete and there are many more suppliers. Those in the list are known to supply in small quantities or to supply PCBs for the various projects described. Other suppliers, not included in this list, may be prepared to supply on these terms – *ask them!*

Badger Boards,
87 Blackberry Lane,
Four Oaks,
Sutton Coldfield B74 4JF.
Tel: 0121-353 9326.
(PCBs for various designs.)

J Birkett,
25 The Strait,
Lincoln,
Lincs LN2 1JF.
Tel: 01522 520767.
(Surplus GaAs FETs, Gunn diodes and oscillators, microwave mixer diodes.)

Bonex,
12 Elder Way,
Langley Business Park,
Slough,
Berks SL3 6EP.
Tel: 01753 549502.
(Toko inductors and trimmer capacitors, some chip components, Avantek MMICS and GaAs FETs, general miniature components.)

British Amateur Television Club,
Membership Secretary David Lawton (G0ANO),
'Grenehurst',
Pinewood Road,
High Wycombe,
Bucks HP12 4DD.
Tel: 01494 28899.
(Members' services include CQ-TV quarterly journal, other publications, book library and reprints, PCBs, camera spares, operating contests and awards, video library, technical advice.)

Cirkit Distribution Ltd,
Park Lane,
Broxbourne,
Herts EN10 7NQ.
Tel: 01992 441306.
(Catalogue from W H Smith. Wide range of general miniature components, some UHF transistors and Gunn modules, RF connectors.)

Electromail,
PO Box 33,
Corby,
Northants NN17 9EL.
Tel: 01536 204555.
(Very large catalogue, identical to RS Components. Wide range of general components. SMDs and silver-loaded solder.)

Electrovalue Ltd,
28 St Judes Road,
Englefield Green,
Egham, Surrey TW20 0YB.
Tel: 01784 433603.
(Components and ferrites.)

European Microwave Components Ltd,
7 Freebournes Court,
Newland Street,
Witham, Essex CM8 2BL.
Tel: 01376 515200.
(Wide range of microwave components: solid-state devices, connectors and adaptors, coaxial/waveguide transitions.)

Farnell Electronic Components,
Canal Road,
Leeds LS12 2TU.
Tel: 0113 2636311.
(Very large catalogue. Wide range of general components, range of microwave connectors/semi-rigid coaxial cable.)

Golledge Electronics Ltd,
Merriott,
Somerset TA16 5NS.
Tel: 01460 73718.
(Crystals.)

C M Howes Communications,
Eydon, Daventry,
Northamptonshire NN11 6PT.
Tel: 01327 60178.
(Receiver and transmitter kits for beginners.)

JAB Electronic Components
1180 Aldridge Road,
Great Barr,
Birmingham B44 8PB.
Tel: 021-366 6928.
(Kits and components.)

Kanga Products,
Sea View House,
Crete Road East,
Folkestone,
Kent CT18 7EG.
Tel: 01303 891106.
(Kits and components.)

LMW Electronics Ltd,
12, Bidford Road,
Braunstone,
Leicester LE3 3AE.
Tel: 0116 2630038.
(Microwave converter and transverter kits, semiconductors and other UHF/microwave components.)

Mainline Electronics,
P O Box 235,
Leicester LE2 9SH.
Tel: 0116 2777648.
(Semiconductors, components. 'No-tune' transverter PCBs.)

Maplin Electronics,
PO Box 3,
Rayleigh,
Essex SS9 8LR.
Tel: 01702 552911.
(Catalogue from W H Smith. Wide range of general miniature components.)

McKnight Crystals Ltd,
Hadley Industrial Estate,
Hythe,
Southampton SO4 6ZY.
Tel: 01703 848961.
(Crystals made to order.)

Piper Communications,
4 Severn Road,
Chilton,
Didcot,
Oxon OX11 0PW.
Tel: 01234 834328.
(Range of UHF and microwave semiconductors, range of UHF and microwave components, tinplate project boxes for many of the designs described here.)

Quartslab Marketing Ltd,
P O Box 19,
Erith,
Kent DA8 1LH.
Tel: 01322 330830.
(Crystals made to order.)

P G Sergent, G4ONF,
6 Gurney Close,
Costessey,
Norwich,
Norfolk NR5 0NB
Tel: 01603 747782.
(Wide-range wavemeter (144MHz to 2500MHz), cavity block for self-calibrating 10GHz wavemeter.)

RSGB Microwave Committee Components Service,
314A Newton Road,
Rushden,
Northants NN10 0SY.
Tel: 01933 411446.
(PCBs and special components for designs described here, in other RSGB books or by the designers, G3WDG, G4DDK and G4JNT. Discount prices for RSGB members.)

Index

Some other RSGB publications . . .

- ❑ **AMATEUR RADIO OPERATING MANUAL**
  Covers the essential operating techniques required for most aspects of amateur radio including DX, contests and mobile operation, and features a comprehensive set of operating aids.

- ❑ **MICROWAVE HANDBOOK**
  A major publication in three volumes. Volume 1 covers operating techniques, system analysis and propagation, antennas, transmission lines and components, semiconductors and valves. Volume 2 continues with construction techniques, common equipment, beacons and repeaters, test equipment, safety, filters and data. Volume 3 concludes with practical equipment designs for each band.

- ❑ **PRACTICAL ANTENNAS FOR NOVICES**
  This guide is written especially for newly qualified holders of the UK Novice Licence, and describes in detail how to build simple but effective antennas for each of the Novice bands up to 434MHz.

- ❑ **PRACTICAL TRANSMITTERS FOR NOVICES**
  Contains a selection of 'easy-to-build' transmitter designs suitable for the UK Novice bands (including microwaves), together with simple test equipment. The theory and practice of transmitting techniques is also outlined to help with understanding the circuits presented. Although primarily aimed at Novices, it will be of interest to any amateur who is building transmitters for the first time or who is considering moving up to microwaves.

- ❑ **RADIO COMMUNICATION HANDBOOK**
  First published in 1938 and a favourite ever since, this large and comprehensive guide to the theory and practice of amateur radio takes the reader from first principles right through to such specialised fields as packet radio, slow-scan television and amateur satellite communication.

- ❑ **TEST EQUIPMENT FOR THE RADIO AMATEUR**
  Explains the principles of measurement techniques, and gives constructional details of many items of up-to-date equipment of interest not only to the radio amateur but also to the electronics enthusiast.

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