

# PRACTICAL RADIO CIRCUITS

**RAYMOND HAIGH**



## Part 1: Introduction, Simple Receivers and a Headphone Amp.

*Dispelling the mysteries of radio. This new series features a variety of practical circuits for the set builder and experimenter.*

Towards the end of the 19th century, sending a radio signal a few hundred yards was considered a major achievement. At the close of the 20th, man was communicating with space probes at the outermost edge of the solar system.

No other area of science and technology has affected the lives of people more completely. And because it is so commonplace and affordable, it is accepted without a second thought. The millions who enjoy it, use it, even those whose lives depend upon it, often have little more than a vague notion of how it works.

This series of articles will view the technology in a historical perspective and try to dispel its mysteries. The main purpose, however, is to present a variety of practical circuits for set builders and experimenters. And, with economy in mind, basic components and assemblies are repeated in different receivers.

### MAKING WAVES

Radio uses electromagnetic waves to transport speech, music and data over vast distances at the speed of light.

The electromagnetic waves are generated by making an electric current oscillate at frequencies ranging from 10kHz (ten thousand Hertz) to more than 100GHz (one-hundred thousand million Hertz).

The lowest frequencies are used for submarine communications because of their ability to penetrate water to a considerable depth: the highest mainly for satellite communications. Most radio listeners are served by the portion of the spectrum extending from 150kHz to 110MHz.

Frequency of oscillation is measured in Hertz in honour of Heinrich Rudolf Hertz, the

physicist who first demonstrated the existence of electromagnetic waves in 1886.

Before the valve era, radio frequency oscillations were generated by using an electrical discharge to shock-excite a tuned circuit (H. Hertz and G. Marconi), by the negative resistance of an electric arc

(V. Poulsen), and by mechanical alternators (E. Alexanderson). Semiconductors now play an increasing role, but valves are still used in high-power transmitters.

As their name suggests, the waves comprise an electric and a magnetic field which are aligned at right angles to one another. The electric field is formed by the rapid voltage fluctuations (oscillations) in the aerial. Current fluctuations create the magnetic field.

### HITCHING A RIDE

Electromagnetic waves cannot, by themselves, convey any information. They are essentially **radio frequency carriers**, and arrangements have to be made for the audio frequency speech and music signals to hitch a ride. This is done by modulating the radio frequency carrier with the audio frequency signals.

If the amplitude of the carrier is varied in sympathy with the signal, the process is known as **amplitude modulation** (a.m.), and typical waveforms are depicted in Fig.1.1. Varying the carrier frequency is, of course, known as **frequency modulation** (f.m.).

Marconi's Morse signals were transmitted by simply switching the carrier on and off. It was R. A. Fessenden who, in 1906, used a carbon microphone (said to be water cooled) to directly modulate the radio frequency (50kHz) output of an alternator and be the first to transmit speech and music.

### PROPAGATION

The oscillations produced by the transmitter are fed to an aerial system in order to radiate the electromagnetic energy. The lower the frequency the longer the wavelength and the bigger the aerial.

Aerial designs vary, but the dipole adopted by Hertz in 1886 is still deployed at high, very high

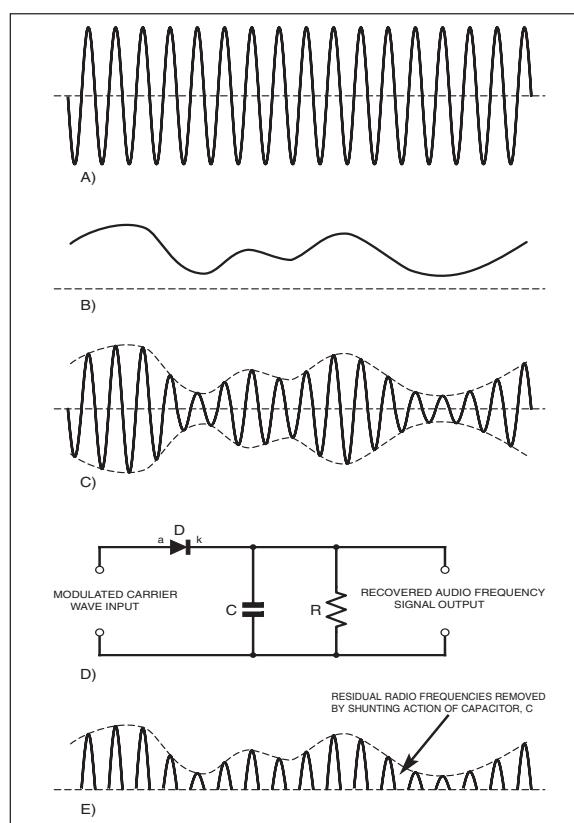


Fig.1.1. Modulation and detection: (A) Radio frequency carrier wave. (B) Audio frequency signal. (C) Carrier wave modulated by audio signal. Average value of imposed audio signal voltage is zero. (D) Diode detector, D, working into load resistor, R, rectifies the modulated carrier wave. Reservoir capacitor, C, removes residual radio frequencies and enables the audio frequency output voltage to approach its peak value. (E) Recovered audio frequency signal.

and ultra high frequencies. The elevated wire and earth arrangement used by Marconi in the 1890's is still used for the radiation of low and medium frequencies.

Transmitter powers range from the miserly one or two watts, radiated by amateurs who specialize in low power communication, to the two-million watts output from some medium wave broadcast transmitters.

Radiation from the transmitter reaches the receiver by either the ground wave (line of sight or diffraction around the earth's curvature), or the sky wave (reflected between the ionosphere and the surface of the earth). Propagation path is frequency dependant: by ground wave up to 500kHz, then gradually shifting to sky wave until, above 30MHz, the waves are no longer reflected back by the ionosphere and escape out into space.

Solar radiation has a profound effect on the charged particles which make up the ionosphere, and propagation conditions vary between night and day, seasonally, and according to the eleven-year sunspot cycle.

## RECEPTION

Reception involves three essential functions: picking up the energy radiated by transmitters, selecting one station from all the rest, and extracting the modulation from the carrier wave in order to make the transmitted speech or music audible to the listener.

### Signal Pick Up

Receiving aerials respond to either the electric or the magnetic field radiated by the transmitter. Sets that use telescopic rod or wire aerials pick up the electric field. Receivers that have loop aerials, i.e., a coil wound on a frame or a ferrite rod, respond to the magnetic field.

Portable receivers usually incorporate both: long and medium waves (150kHz to 1.6MHz) are covered by a loop with a ferrite rod core, and the v.h.f. f.m. band (88MHz to 108MHz) and short-wave bands by a telescopic aerial.

### Station Selection

In order to select one station from the thousands that are spread across the radio frequency spectrum, the receiver has to be tuned to the carrier frequency of the transmitter.

Sir Oliver Lodge was stressing the importance of tuning, a condition he called "syntony", as early as 1889, and he patented his system in 1897. This is one of the most fundamental patents in radio, and his method is still universally adopted.

Lodge's invention exploits the way an inductor (coil) and capacitor combination resonate at a particular frequency. If the capacitor is connected in parallel with the inductor (see Fig.1.2a) the circuit presents a high impedance at its resonant frequency and a lower impedance at all others.

Connecting the capacitor in series with the inductor (Fig.1.2b) results in a low impedance at resonance and a higher impedance at other frequencies. If the inductor or the capacitor (usually the capacitor) is made variable, it is possible to tune the circuit across a range of frequencies.

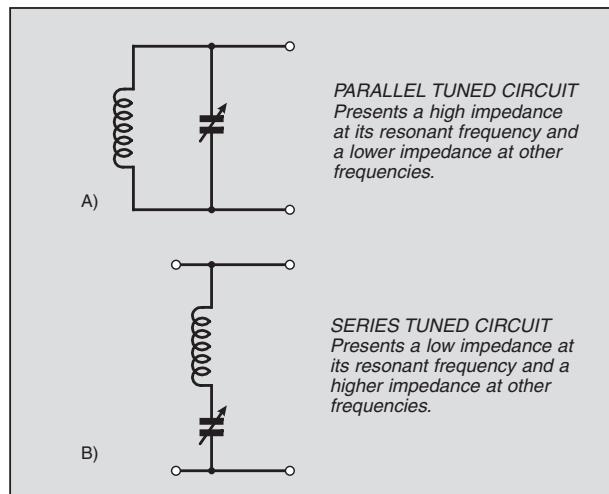


Fig.1.2. Basic tuned circuits. Combining an inductor (coil) and a capacitor produces a circuit which resonates at one particular frequency. The resonant frequency can be varied by changing the amount of inductance or capacitance (usually the latter). The tuning of all radio receivers and transmitters depends upon this phenomenon.

## IMPORTANT EVENTS

**1831**

In published papers and a letter deposited with the Royal Society (opened in 1937), Michael Faraday tentatively proposes electromagnetic wave theory.

**1864**

James Clerk Maxwell's mathematical analysis of Faraday's work published in his paper: *A Dynamical Theory of the Electro-magnetic Field*.

**1888**

Heinrich Rudolf Hertz uses a crude spark transmitter and receiver to demonstrate the existence of electromagnetic waves.

**1889**

Sir Oliver Lodge lectures on the need to tune the transmitter to receiver, a condition he called "syntony".

**1893**

Sir Oliver Lodge uses an invention of Edouard Branley's as a sensitive detector of electromagnetic waves. (The coherer).

**1901**

Guglielmo Marconi transmits radio signals across the Atlantic.

**1904**

Sir John Ambrose Fleming patents the diode valve.

**1906**

Dr Reginald Fessenden modulates a carrier wave and broadcasts speech and music. Dr Lee de Forest makes a patent application for his triode valve, the first electronic amplifying device.

**1913**

Major Edwin Howard Armstrong invents the regenerative receiver.

**1918**

Armstrong invents the superheterodyne receiver.

**1921**

Armstrong invents the super regenerative receiver and W. G. Cady uses quartz crystals to stabilize oscillators.

**1933**

Armstrong demonstrates his system of frequency modulated radio transmission.

**1947**

John Bardeen, Walter Brattain and Dr William Shockley develop the transistor at the Bell Telephone Laboratories.

Sharpness of tuning depends mainly on resistive and other losses in the inductor or coil: the lower these losses the sharper the tuning. Resistive and dielectric losses in the capacitor also affect performance, but, with modern tuning components, these are usually so small they can be ignored.

The ability of the coil to resonate sharply, i.e., be more selective, is known as its "Q" factor: the sharper the resonance the higher the Q.

Resonant tuned circuits magnify signal voltages, a phenomenon that is crucial to radio reception. If a signal of the same frequency as the resonant frequency of the tuned circuit is applied to the coil/capacitor combination, its voltage will be increased in proportion to the Q of the coil. With a Q of 100, a 1mV signal will be magnified to 100mV or 0.1V. We will be returning to this later.

### Demodulation

With amplitude modulated signals (a.m.) the process of recovering the modulation is essentially one of rectification. In Fig.1.1d, diode, D, rectifies the incoming radio frequency carrier wave and capacitor, C, shunts residual radio frequencies to ground (earth) leaving only the audio frequency modulation. Capacitor, C, also exhibits a reservoir action enabling the audio frequency voltage to approach its peak value.

The diode and, indeed, any other a.m. demodulator, is called a *detector*, a hang-over from the earliest days of radio when glass tubes filled with metal filings were used to simply detect the presence of electromagnetic waves.

In 1889, whilst working on the protection of telegraph equipment from lightning, Sir Oliver Lodge noticed that metal surfaces, separated by a minute air gap, would fuse when an electrical discharge occurred close by. He used the phenomenon to detect electromagnetic waves, and called devices of this kind *coherers*.

About this time, Edouard Branley discovered that a spark in the vicinity of a mass of metal particles lowered their resistance. Lodge found this arrangement to be more sensitive and, in 1893, adapted it for use as a detector.

Subsequently, J. A. Fleming's diode valve, patented in 1904, and crude semiconductor devices, were used as rectifiers in order to demodulate signals.

# CRYSTAL SET RADIO

A modern-day "museum piece" receiver

## THE CAT'S WHISKER

The most popular of the semiconductor detectors was the "crystal" or "cat's whisker" which consisted of a short length of springy brass wire touching a crystal of galena (lead sulphide). Adjustment of the point of contact was critical, but these crystal detectors could be more sensitive than Flemming's diode valve. They were much less expensive.

The modern equivalent of the crystal detector is the point contact germanium diode. Here, a gold-plated wire contacts a wafer of germanium, the assembly being enclosed within a glass tube. These diodes are still used to demodulate the signals in most domestic a.m. radios.

## CRYSTAL SET

The simplest receiver, known as a *Crystal Set*, consists of nothing more than a coil, tuning capacitor, diode detector, and a pair of earphones.

A typical circuit diagram for a Crystal Set Radio is given in Fig.1.3, where inductor or coil L1 is tuned by variable capacitor VC1 to the transmitter frequency. Diode D1 demodulates the signal, which is fed straight to the earphones. There is no amplification.

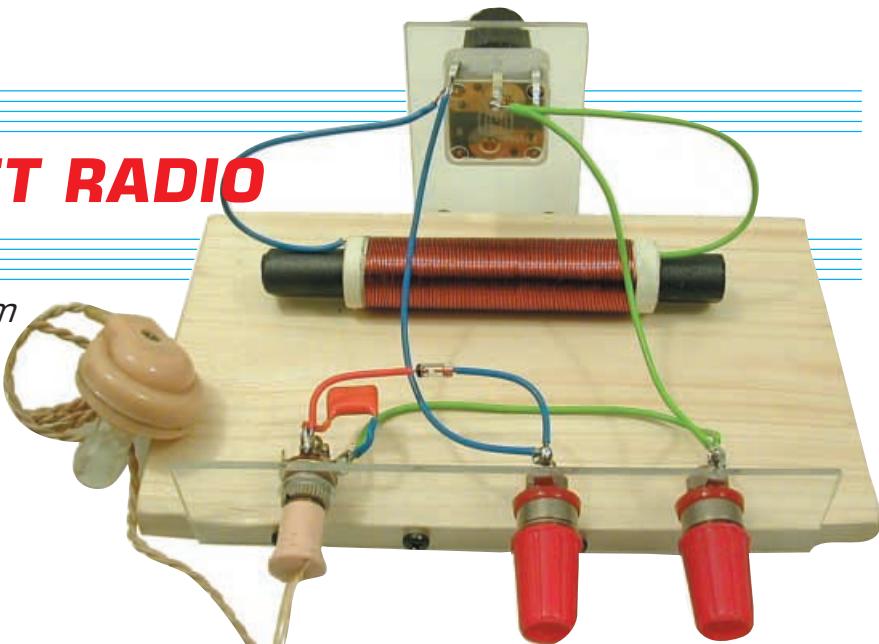
A long (at least 20 metres), high (7 metres or more) aerial and a good earth (a buried biscuit tin or a metre of copper pipe driven into damp ground) are required in order to ensure audible headphone reception. The earphones originally used with these receivers had an impedance of around 4000 ohms and were very sensitive (and heavy and uncomfortable). They are no longer available, but a crystal earpiece, which relies on the piezoelectric effect, will give acceptable results. Low impedance "Walkman" type earphones are *NOT* suitable.

## DRAWBACKS

Quite apart from the absence of amplification, two factors seriously limit the performance of crystal receivers.

Germanium diodes become increasingly reluctant to conduct as the applied voltage falls below 0.2V, and this makes the receiver insensitive to weak signals. Silicon diodes have a threshold of around 0.6V, and are, therefore, unsuitable for circuits of this kind.

The earphone loading imposes heavy damping on the tuned circuit, reducing its *Q* and, hence, its selectivity, i.e. its ability to separate signals. With such low selectivity insensitivity can be a blessing, and crystal sets are normally only capable of receiving a single, strong transmission on the long and medium wavebands. (They will sometimes receive more than one if a shortwave coil is fitted).



The author's Crystal Set "knock-up" on a wooden baseboard. This uses two screw terminals for the Aerial and Earth wire connections instead of croc. clips.

The aerial and diode can be connected to tappings on the tuning coil in order to reduce damping, but the improvement in selectivity is usually at the expense of audio output.

When valves cost a week's wages and had to be powered by large dry batteries and lead/acid accumulators, the construction of simple receivers of this kind could be justified. With high performance transistors now costing only a few pence or cents, crystal sets are now regarded as "nostalgic pieces".

Some readers may, however, wish to build one out of curiosity, or for the novelty of having a receiver that does not require a power supply. Moreover, the components required are all used in more complex receivers to be described later.

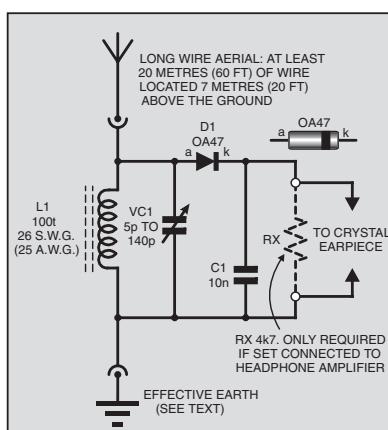


Fig.1.3. This simplest of radio receivers uses a germanium diode as the "cat's whisker" crystal detector.

## CIRCUIT DETAILS

Ferrite loop aerial L1 and polythene dielectric variable capacitor VC1 form the tuned circuit. Point contact germanium diode D1 demodulates the signal; capacitor C1 bypasses residual r.f. (radio frequencies) to earth and also exhibits a reservoir action, enabling the a.f. (audio frequency) output to approach its peak value. The

recovered audio signal is fed directly to a crystal earpiece.

Signal voltages induced in the ferrite loop aerial by the radiated magnetic field are much too weak to produce an output from the detector, and the component is used here simply as a tuning coil. The ferrite core does, however, reduce the number of turns required for the coil winding, thereby reducing its resistance and increasing its *Q* factor.

## COMPONENTS

### CRYSTAL SET

#### Resistor

RX 4k7 0.25W 5% (only required if set is connected to amplifier)

#### Capacitors

C1 10n disc ceramic.  
VC1 5p to 140p (minimum) polythene dielectric variable capacitor (see text)

#### Semiconductors

D1 OA47 germanium diode

#### Miscellaneous

L1 ferrite rod, 100mm (4in.) x 9mm/10mm (3/8in.) dia., with coil (see text)

Crystal earpiece and jack socket to suit.; plastic control knob; plastic insulated flexible cable for aerial wire, down-lead and earth connection, 30 metres (100 ft) minimum; buried biscuit tin or 1 metre (3ft) of copper pipe for earth system; 50gm (2oz) reel of 26s.w.g. (25a.w.g.) enamelled copper wire, for tuning coil; card and glue for coil former; multistrand connecting wire; crocodile clips or terminals (2 off), for aerial and earth lead connection; solder etc.

Approx. Cost  
Guidance Only

£4  
excl. earpiece & wire

## CONSTRUCTION

The circuit is simple enough to be assembled on the work bench, and a printed circuit board layout is not given. The components and the various interwiring connections are illustrated in Fig.1.4.

### COIL DETAILS

Full construction and winding details for the ferrite tuning/aerial coil L1 are shown in Fig.1.5. The coil is made from 26s.w.g. (25a.w.g.) enamelled copper wire, close wound on a cardboard former. This same ferrite tuning coil forms the loop aerial in the following TRF Receiver.

The r.f. bypass capacitor C1 can, in practice, be omitted with no noticeable reduction

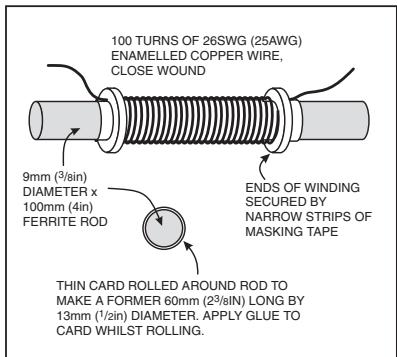


Fig.1.5. Construction and winding details for the ferrite rod tuning/aerial coil L1. This loop aerial is also used in the TRF Receiver.

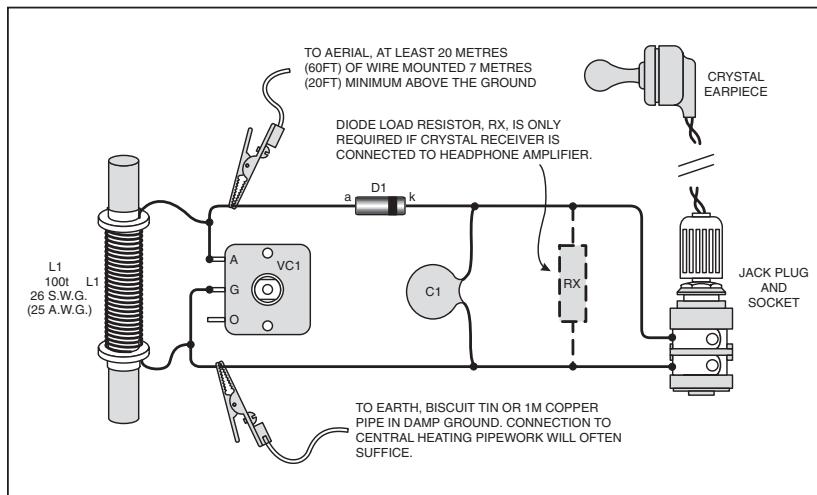


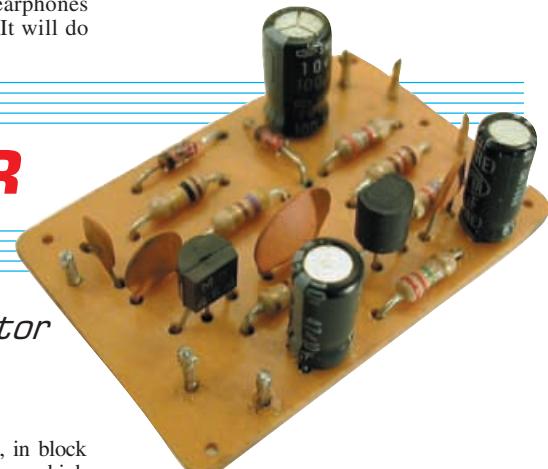
Fig.1.4. The components and various interwiring connections for the simple crystal set. This circuit is easily "lashed-up" on the workbench and no circuit board layout is given. The author's demonstration set is shown in the heading photograph.

in performance. However, if the set is to be connected to either the headphone amplifier (Fig.1.10) or speaker amplifier described next month, this component, together with diode load resistor, RX, must be included.

### AMPLIFICATION

Audio frequency amplification *after* the diode detector will permit the use of low impedance Walkman type earphones or even loudspeaker operation. It will do

nothing, however, to overcome the diode's insensitivity to weak signals. For this we must have radio frequency amplification of the signals picked up by the aerial *before* they reach the detector. (The standard circuit for a transistor portable receiver has three stages of radio frequency amplification ahead of the diode).



## MK484 TRF RECEIVER

*Uses a single i.c. radio chip and a transistor*

### TRF RECEIVER

Receivers with tuned circuits and amplification, at signal frequency, ahead of the detector stage were known, during the valve era, as tuned radio frequency, or t.r.f., receivers.

This arrangement was adopted by Ferranti when they designed their popular ZN414 radio i.c. Introduced in 1972, the chip relied upon a then new manufacturing technique developed by Bell Laboratories and known as collector diffusion isolation.

No bigger than a single transistor, and requiring a power supply of only 1.5V, the device enabled truly miniature receivers to be built, one of which was featured on the BBC TV science programme, *Tomorrow's World*. The chip is still produced, but in a plastic package instead of the original metal case and with the type number **MK484**.

### INTERNAL ARRANGEMENT

The chip's internal architecture, in block form, is depicted in Fig.1.6. The very high impedance input stage minimizes damping on the tuned circuit, enabling it to maintain a high *Q* factor and, consequently, reasonable selectivity. This is followed by three stages of radio frequency amplification ahead of a two transistor detector or demodulator.

Chip characteristics and pinout details are also listed with the block diagram Fig.1.6. Internal capacitors impose the low frequency operating limit, and the performance of the transistors determines the tail-off at high frequencies.

MK484 Specification . . .	
Supply Voltage (via external load resistor)	1.1V to 1.8V
Current Drain (affected by signal level)	0.3mA to 0.5mA
Frequency range (peaks at 1MHz)	150kHz to 3MHz
Input Impedance	1.5 megohms
Output Impedance	500 ohms
Sensitivity	better than 100 $\mu$ V
Power Gain	70dB
Internal Component Count:	10 Transistors 15 Resistors 4 Capacitors

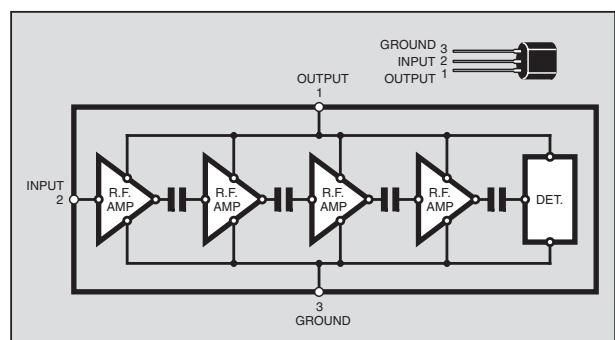


Fig.1.6. Block diagram showing the internal arrangement of the MK484 radio i.c.

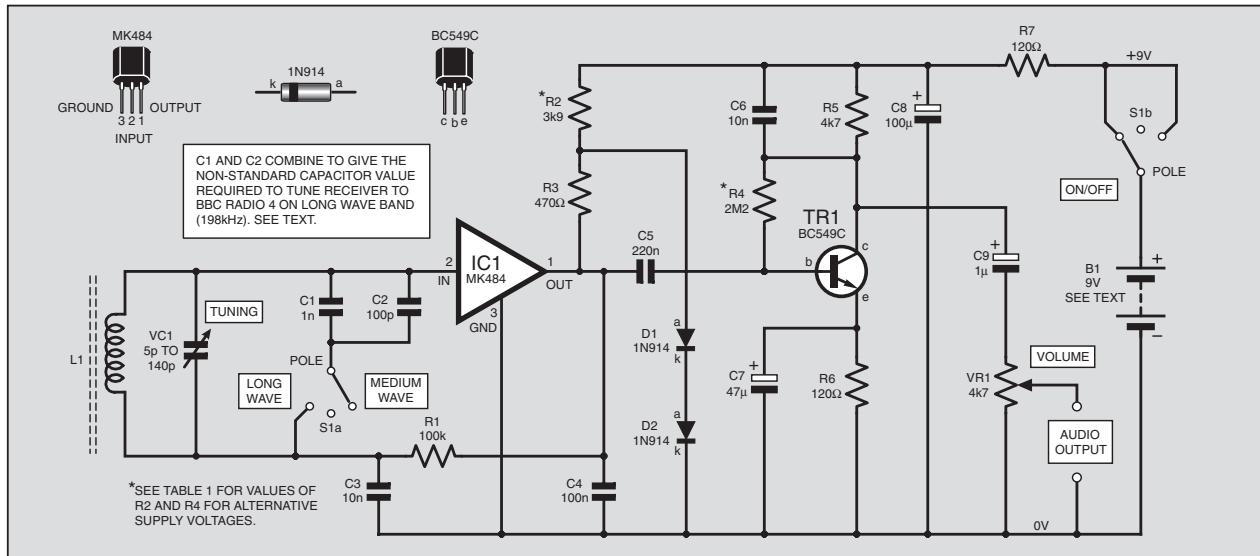


Fig.1.7. Complete circuit diagram for the MK484 TRF Receiver.

## TRF CIRCUIT

The circuit diagram for a simple TRF Receiver using the MK484 i.c. is given in Fig.1.7. Inductor or coil L1 is "tuned" by variable capacitor VC1, from roughly 550kHz to 1.7MHz, i.e., over the medium wave band.

Provision is made for toggle switch S1a to connect an additional capacitor across L1 to tune it to a lower frequency long wave station. For *BBC Radio 4* on 198kHz, a non-standard component is required, and this is made up from capacitors C1 and C2.

Tuning coil L1 is wound on a ferrite rod in order to form a loop aerial which, as we have seen, responds to the magnetic fields radiated by transmitters. The high permeability ferrite material concentrates the lines of magnetic force, and the signal developed across the coil is equal to that picked up by an air-cored loop of around 200mm (8in.) diameter. The threshold sensitivity of IC1 is better than 100µV, and this is sufficient for the reception of strong signals via the loop.

## SELECTIVITY

Current drawn by IC1 increases as signal strength increases, and the gain of the MK484 is supply voltage dependant. Connecting all of the stages to the supply via the audio load resistor R3 produces a measure of automatic gain control (a.g.c.). (Increased current demand at high signal levels increases the voltage drop across the load resistor thereby reducing the gain of the chip.) IC1 input pin 2 is biased via resistor R1, and r.f. bypass capacitors C3 and C4 ensure stability.

The value of the audio load resistor (sometimes called the a.g.c. resistor) R3 can range from 470 ohms to 1000 ohms. Selectivity is better when the value is kept low: gain is greater when the value is high. Most readers will need all the selectivity they can get and a 470 ohm resistor is used in this circuit.

Optimum supply voltage with a 470 ohm load is around 1.2V: more than this can cause instability problems, less will reduce gain. The voltage delivered by a fresh dry cell can be as high as 1.7V and the chain of silicon diodes, D1 and D2,

each of which begins to conduct at a 0.6V threshold, holds the supply at the correct potential.

Some readers will no doubt wish to use the circuit with different supply voltages, and the value of dropping resistor R2 should be altered to avoid excessive current drain. Table 1.1 gives suitable values for this resistor for various battery voltages.

## AUDIO OUTPUT

The output from IC1 pin 1 is low, so the audio amplifier stage, TR1, is included to increase it to a useable level. The signal from IC1 pin 1 is applied to TR1 base (b) via d.c. blocking capacitor C5, and the output is developed across collector (c) load resistor R5.

Emitter (e) bias is provided by resistor R6 which is bypassed by capacitor C7. Base bias is derived via resistor R4. Connecting

**Table 1.1: MK484 TRF Receiver**  
(Values of resistors R2 and R4 for different supply voltages)

Voltage	R2	R4
1.5V	100Ω	180k
3V	1k	1M
4.5V	1k8	2M2
6V	2k2	2M2
9V	3k9	2M2

this resistor to the collector rather than the supply rail provides a measure of negative feedback, stabilizing the stage against temperature and transistor gain variations. The value of this resistor has to be optimized for different supply voltages, and appropriate values are given in Table 1.1.

## COMPONENTS

Approx. Cost  
Guidance Only  
£10  
excl. case, earpiece, wire & batt.

### TRF RECEIVER

#### Resistors

R1	100k
R2	3k9 see Table 1.1
R3	470Ω
R4	2M2 see Table 1.1
R5	4k7
R6, R7	120Ω (2 off)
All	0.25W 5% carbon film

#### Potentiometers

VR1	4k7 rotary carbon, log.
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#### Capacitors

C1	1n polystyrene (see text)
C2	100p polystyrene or "low k" ceramic (see text)
C3, C6,	10n disc ceramic (2 off)
C4	100n disc ceramic
C5	220n disc ceramic
C7	47µ radial elect. 16V
C8	100µ radial elect. 16V
C9	1µ radial elect. 16V
VC1	5p to 140p (minimum) polythene dielectric variable capacitor

#### Semiconductors

D1, D2	1N914 silicon signal diodes (2 off)
TR1	BC549C npn small signal transistor
IC1	MK484 radio i.c.

#### Miscellaneous

S1	d.p.d.t. centre-off toggle switch
L1	ferrite loop aerial: 100mm (4in.) × 9mm/10mm (3/8in.) dia. ferrite rod with coil (see text)

Printed circuit board available from the EPE PCB Service, code 392; plastic case, size and type to choice; plastic control knob (2 off); 50gm (2oz) reel of 26s.w.g. (25a.w.g.) enamelled copper wire, for tuning coil; card and glue for coil former; crystal earpiece and jack socket to suit; multistrand connecting wire; 9V battery, clips and holder; p.c.b. stand-off pillars; mounting nuts and bolts; solder pins; solder etc.

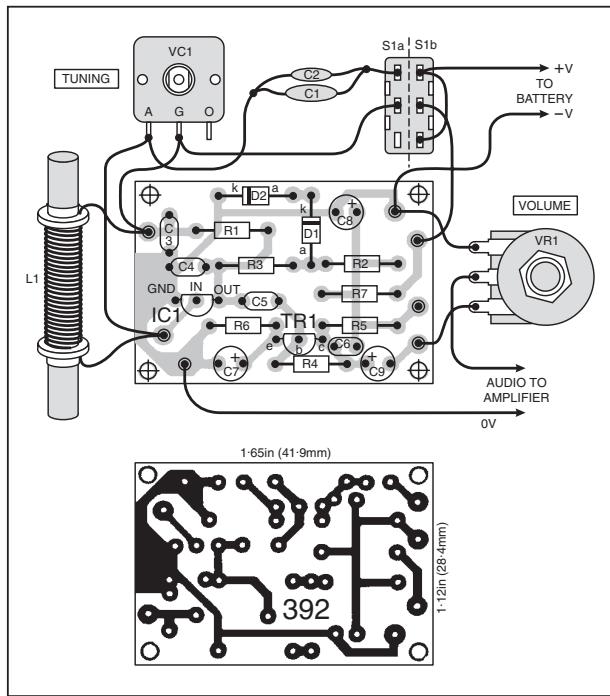


Fig. 1.8. Printed circuit board component layout, interwiring to off-board components and full-size underside board copper track master.

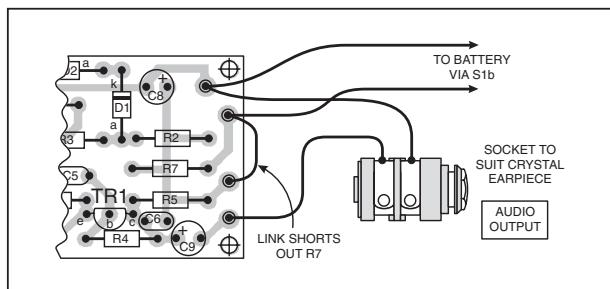


Fig. 1.9. Connecting a crystal earpiece, via socket, directly to the p.c.b. in place of the Volume control. Note the "shorting" link wire.

Headphone and loudspeaker amplifiers will, in most cases, be connected across the same battery power supply, and resistor R7 and capacitor C8 decouple the tuner circuit in order to prevent instability. Bypass capacitor C6 connected across collector load R5 is also included to avoid instability. Audio output is taken from the collector of transistor TR1 and connected to the Volume control VR1, via d.c. blocking capacitor C9.

A crystal earpiece can be connected in place of the volume control but the output, especially when weaker signals are being received, will be barely adequate. With this arrangement there is no need for resistor R7, and provision is made, on the printed circuit board, for it to be shorted out (see Fig.1.9).

## CONSTRUCTION

If you have not already made up the "tuning coil" for the Crystal Set, construction of the TRF Receiver should commence with the winding of the ferrite loop aerial as detailed earlier in Fig.5 and as follows. Wind thin card (a postcard is ideal) around a 100mm (4in.) length of 9mm (3/8in.) diameter ferrite rod until an

overall diameter of 13mm (1/2in.) is achieved. Apply adhesive as the card is wound on.

Coil L1 consists of 100 turns of 26s.w.g. (25a.w.g.) enamelled copper wire close wound, i.e. with turns touching. Secure the start and finish of the winding with thin strips of masking tape wound tightly around the former. The task of producing a neat coil can be eased by slightly spacing the turns as they are wound on and repeatedly pushing them together with the thumb as the winding proceeds.

The inductance of this loop winding is higher than normal in order to ensure full Medium Wave coverage with the specified tuning capacitor (medium wave loops usually comprise about sixty turns on a 9mm (3/8in.) dia. rod). Longer rods, which will increase signal pick-up, may be used if a larger receiver can be tolerated.

Use rubber bands, strips of card or wood or plastic blocks to secure ferrite loop aerials. Do not use metal mounts as these can form a shorted turn and dramatically reduce efficiency.

## VARIABLE CAPACITORS

(Polythene dielectric type)

Some retailers supply extenders for the stubby spindle. If an extender has to be fabricated, use a 6mm diameter tubular stand-off bolted to the central hole in the spindle (bolt is usually 2mm). Grip the capacitor spindle when tightening bolt. **Do not tighten against internal end stop.**

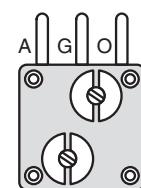
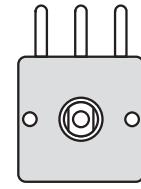
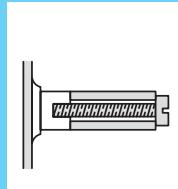
Secure capacitors to bracket or front panel with two bolts driven into threaded holes in its front plate. **Bolts (usually 2mm) must not extend through the thickness of the front plate.**

Twin-gang capacitor lead-outs are usually thin metal strips. Moving vanes (the strip often marked 'G') should be connected to ground or the OV rail. Strips for the fixed vanes, normally used to tune the aerial and oscillator circuits in a superhet receiver, are often marked "A" and "O". One or both should be connected to the "hot" end of the simple receiver's tuning coil.

Internal trimmers should be set to minimum capacitance when a variable is used with simple receivers. Twin-gang polyvars have two trimmers. Four-gang units have four trimmers.

For complete coverage of the medium wave band with this ferrite loop aerial, the variable capacitor should have a 5pF minimum capacitance and a maximum capacitance of at least 140pF. The aerial tuning section of most polythene dielectric variables, as used in transistor portables, should be suitable.

If necessary, both sections (aerial and oscillator) can be connected in parallel to ensure the necessary maximum capacitance. This will, however, double the minimum capacitance and slightly curtail coverage at the high frequency end of the band.



## RECEIVER BOARD

Most of the TRF Receiver components are assembled on a small printed circuit board (p.c.b.). The topside component layout, off-board interwiring and a full-size underside copper foil master are shown in Fig.1.8. This board is available from the EPE PCB Service, code 392. How to connect an earpiece directly to the Receiver p.c.b. is illustrated in Fig.1.9.

Insert and solder in position the resistors and capacitors first and the semiconductors last. The 3-pin MK484 radio i.c. must be mounted close to the board to prevent instability: leave just sufficient lead length for the application of a miniature crocodile clip as a heat shunt whilst soldering.

Take care to remove all traces of the enamel from the ends of the coil winding in order to ensure a good connection. Solder pins, inserted at the lead-out points, will simplify the task of off-board wiring.

# HEADPHONE AMPLIFIER

Add-on amplifier for personal listening

The single transistor Headphone Amplifier circuit illustrated in Fig.1.10, will ensure an acceptable output via Walkman type 'phones. The audio input signal is coupled to the base of transistor TR1 via d.c. blocking capacitor C1. Base bias resistors R1 and R2, fix the standing collector current at around 4mA. Emitter bias is provided by R3, which is bypassed by C3.

Walkman type 'phones form transistor TR1's collector load, both earpieces being wired in series to produce an impedance of 64 ohms. Bypass capacitor C2 acts as a high frequency shunt across the 'phone leads. This measure avoids instability problems and is particularly necessary when the amplifier is used with some of the more sensitive receivers to be described later in the series.

Bypass capacitor C4 ensures stability when tuner and amplifier stages are powered by the same battery, particularly when battery impedance rises as it becomes exhausted. On/off control, S1b, is one half of a two-pole, centre-off, toggle switch.

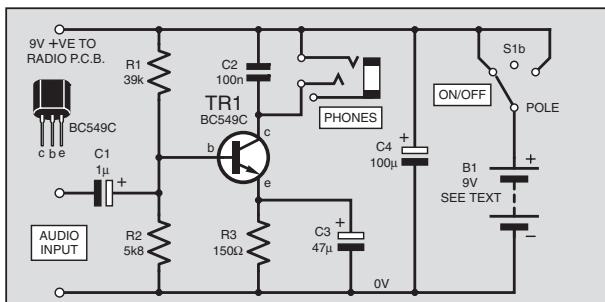


Fig.1.10. Circuit diagram for a single transistor Headphone Amplifier.

## CONSTRUCTION.

All parts, except the 'phone socket and battery, are assembled on a small p.c.b. and the component layout, off-board wiring and full-size copper foil master are given in Fig.1.11. This board is available from the EPE PCB Service, code 393.

Follow the assembly sequence suggested for the TRF radio board. Again, solder pins at the lead-out points will ease the task of off-board wiring.

Wiring the output to the tip and centre ring on the jack socket will result in the series connection of the earpieces and produce a nominal 64 ohm load for transistor TR1.

## SPOT CHECKS

Check the two p.c.b.s for poor soldered joints and bridged tracks. Check the orientation of electrolytic capacitors and semiconductors.

Make sure the off-board wiring has been correctly routed and, if all is in order, connect the battery power supply. Current consumption of the tuner/amp with a 9V supply and resistors R2 and R4 as specified in Table 1.1 should be approximately 2.5mA.

Readers who are keen to minimize battery drain could reduce bias resistor, R2, in Fig.1.10, to 4.7kΩ or less. This

will lower the standing current drawn by the Headphone Amplifier at the expense of maximum undistorted output.

The add-on amplifier stage will permit low-impedance Walkman type 'phones to be used with the Crystal Set (Fig.3). A Volume control is unnecessary: simply connect a 4700 ohm resistor (RX) to act as a diode load in place of the 'phones, and link receiver to amplifier via d.c. blocking capacitor, C1.

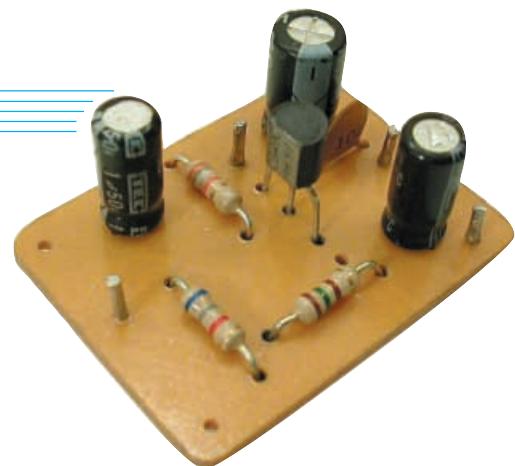
## PERFORMANCE

Performance of the MK484 TRF Receiver and Headphone Amplifier combination is far superior to the simple Crystal Set. The MK484 is, moreover, sufficiently sensitive to operate from a ferrite-cored loop and an external wire aerial and earth are not required.

Selectivity is barely adequate, and very powerful signals tend to spread across the dial. Rotating the ferrite loop aerial to null out the offending station will, however, usually effect a cure. (Loop aerials are directional and signal pick-up falls to a minimum when the axis of the coil is pointing towards the transmitter).

Although the circuit will permit the clear reception of a number of stations, sensitivity is not sufficient for the reception of weak signals. A simple add-on circuit, which will transform the performance of the receiver and make it as selective and sensitive as a commercial superhet, will be described next month.

Next month's article will also include an amplifier for readers who want loudspeaker operation, and a design for another simple, but high performance, medium and long wave receiver using individual transistors.



## COMPONENTS

### HEADPHONE AMPLIFIER

#### Resistors

R1	39k	See SHOP (see text)
R2	5k8	
R3	150Ω	TALK page

#### Capacitors

C1	1μ radial elect. 16V
C2	100n disc ceramic
C3	47μ radial elect. 16V
C4	100μ radial elect. 16V

#### Semiconductors

TR1	BC549C npn small signal transistor
-----	------------------------------------

#### Miscellaneous

S1	d.p.d.t. centre-off toggle switch (see text)
----	--

Printed circuit board available from the EPE PCB Service, code 393; jack socket to suit 'phones; multistrand connecting wire; 9V battery, clips and holder; p.c.b. stand-off pillars; solder pins; solder etc.

Approx. Cost  
Guidance Only

£6

excl. 'phones

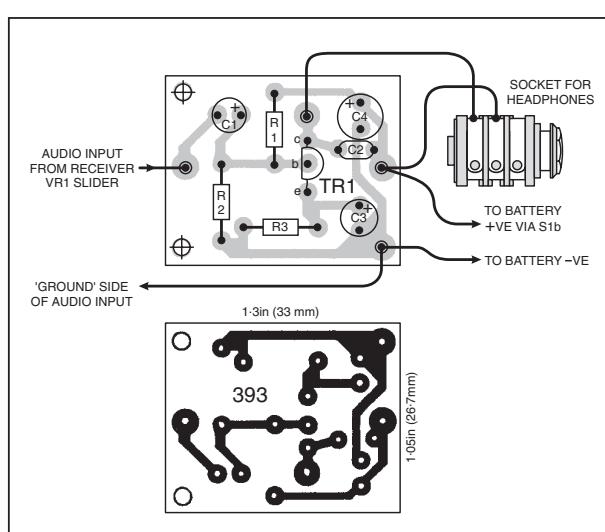


Fig.1.11. Headphone Amplifier printed circuit board component layout, wiring details and full-size copper foil master.

# PRACTICAL RADIO CIRCUITS

**RAYMOND HAIGH**



## Part 2: Regeneration, Q-Multiplier, Reflex Radio and a Speaker Amp.

*Dispelling the mysteries of Radio. Features a variety of practical circuits for the set builder and experimenter.*

In Part One, last month, we looked at the fundamental principles and early history of radio, and detailed the construction of a TRF (tuned radio frequency) receiver. Its selectivity and sensitivity are barely adequate and, this month, a simple add-on unit that will transform its performance is described.

Also included is an alternative circuit for a simple medium wave portable radio. But first, some historical background.

### AUDION

The invention of the triode valve, by Lee de Forest, in 1906, made available, for the first time, a means of amplifying radio frequency signals.

These early valves were only partially evacuated (soft), hand made, and extremely expensive. Their operation was not completely understood, and they were used, initially, as detectors and audio frequency amplifiers.

Lee de Forest called his invention the Audion. It was only later that Eccles, of flip-flop fame, described the device as a *triode*.

### SERENDIPITY

In 1913, whilst experimenting with a triode detector, Edwin Howard Armstrong realized that radio frequencies were present at the anode (plate in the USA) or output port of the valve. He connected a second tuning coil in the output circuit and noticed a dramatic rise in receiver sensitivity when he brought it closer to the grid tuning coil. When the coils were very close, the circuit began to oscillate.

He had, almost by accident, discovered the regenerative detector and valve oscillator. He patented the circuit in October 1913, two months before his twenty-third birthday.

Lee de Forest, Alexander Meissner, Irving Langmuir, C. S. Franklin and others made similar discoveries, and there was much patent litigation. In 1921, the Columbia Court of Appeals gave judgement to Lee de Forest on the basis of a legal technicality. It is widely accepted,

however, that the credit, at least for the regenerative receiver, is Armstrong's.

### BREAKTHROUGH

Armstrong's discoveries made reliable, long distance radio communication a possibility. The valve oscillator eventually formed the basis of powerful transmitters capable of operating at higher frequencies than those attained hitherto.

His regenerative circuit provided a simple and inexpensive means of greatly increasing receiver sensitivity and selectivity. It remained the most popular receiving system until the superhet (another invention of Armstrong's) achieved dominance during the 1930s.

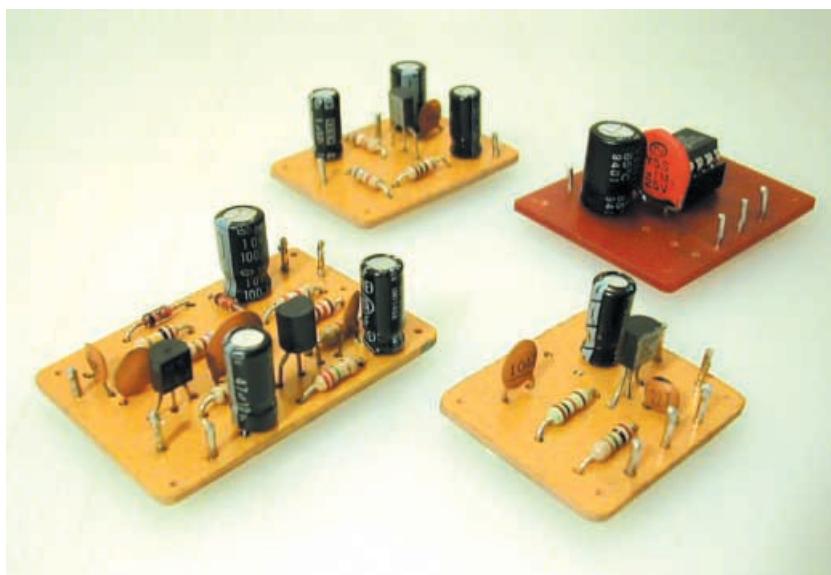
### MAGNIFICATION

In Part One we touched on the signal magnifying effect of a resonant tuned

circuit formed by combining an inductor (coil) and a capacitor. It will be recalled that magnification is limited mainly by resistive and other losses in the coil.

If losses are kept low, the coil is said to have a high *Q* factor. With careful design and construction, *Q* factors in excess of 100 are not difficult to achieve. However, when the coil is connected into circuit, the loading or damping effect of valves, transistors and other components reduces its *Q* significantly.

If a signal at the resonant frequency is applied to the coil and capacitor combination, its voltage will be increased in proportion to the *Q* factor. Thus, with a *Q* of 100, a 1mV signal will be magnified to 100mV or 0.1V. Off-resonance signals are not magnified in this way, and the greater the *Q* the more selective the tuned circuit.



Completed circuit boards for the following (left to right, clockwise): MK484 TRF Receiver (Pt 1 – June '03), Headphone Amplifier (Pt 1 – June '03), Speaker Amplifier (this issue) and Q-Multiplier (this issue).

## REGENERATION

By progressively feeding back energy to the tuned circuit in phase with the incoming signal, i.e. *positive feedback*, the resistive and other losses in the coil are gradually overcome and very high *Q* factors can be achieved. As the positive feedback is increased beyond the point where the losses are eliminated, the circuit begins to oscillate.

Armstrong found that feedback, or *regeneration* as it came to be known, increases the strength of weak signals by a factor of 1000 or more and, because the increase is due wholly to the dramatic rise in tuned circuit *Q*, there is also a big improvement in selectivity.

Regeneration enhances weak signals more than strong ones, and the system exhibits an a.g.c. (automatic gain control) action. In practice, however, the effect is not pronounced, and there is a much greater range of output levels than is the case with a superhet receiver with conventional a.g.c. circuitry.

## DRAWBACKS

Regenerative receivers are easily swamped by powerful signals (the tuning tends to lock onto strong carriers), and their sharply peaked selectivity curve attenuates the higher audio frequencies. Overloading by strong signals can, however, be avoided by fitting a simple input attenuator, and some top cutting is not too

high a price to pay for a big improvement in selectivity.

Skill is required of the operator if high performance is to be achieved. The regeneration control has to be carefully set to bring up weak signals, and the input level adjusted to prevent overload. This, more than anything else, brought about the gradual demise of the system after Armstrong invented the superhet, with its more user-friendly controls, in 1918.

Like the author, readers will no doubt be keen to get high performance at the lowest possible cost, and a regenerative receiver is as close as it comes in the field of radio and electronics to getting something for nothing. A number of modern examples of the technique will, therefore, be included in the series.

## SIMPLE Q-MULTIPLIER

*Improve the performance of last month's MK484 TRF Receiver*

### Q-MULTIPLIER

By applying regeneration, or *Q* multiplication, to its ferrite loop aerial, the performance of the MK484 TRF Receiver described last month can be dramatically improved. Levels of sensitivity and selectivity approaching those of a domestic superhet can be achieved. Because of the small voltages developed across the loop aerial, swamping by strong signals is not normally a problem, especially if the ferrite rod is rotated for minimum pick-up, as described last month.

The circuit diagram of the simple add-on Q-Multiplier unit is given in Fig.2.1 where L1 is the receiver's ferrite loop aerial, and field effect transistor, TR1, provides the radio frequency amplification needed for the multiplying process.

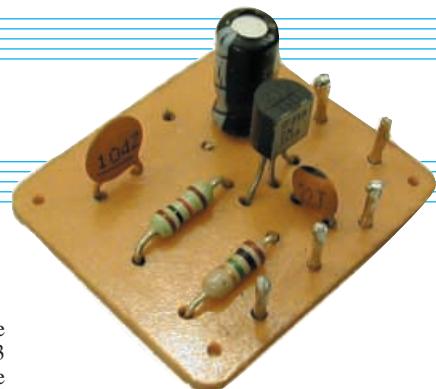
Amplification, and hence the level of feedback, is controlled by potentiometer VR1, which varies the voltage on the drain (d) of transistor TR1. Bypass capacitor C1 eliminates potentiometer noise.

The received signal is taken from the tuned circuit via d.c. blocking capacitor C3 (biasing puts a positive voltage on the input pin of the MK484 radio i.c.), and R2 is TR1's gate (g) bias resistor. Source (s) bias is developed across resistor R1, which is bypassed, at radio frequencies, by capacitor C2.

The circuit is configured as a Hartley oscillator with feedback from the source of TR1 being coupled to the tuned circuit by coil L2. This is two turns of plastic insulated hook-up wire wound over the "earthy" end of tuning coil L1. If the feedback coil L2 is wound in the same direction as the tuning coil, the correct connections for Q-enhancing positive feedback are as shown in Fig.2.2.

### CONSTRUCTION

With the exception of the Regeneration control, VR1, all of the components are mounted on the small printed circuit board as illustrated in Fig.2.2. A full-size



copper track master is also included. This board is available from the EPE PCB Service, code 397.

Commence construction by mounting the resistors and capacitors on the board first and the transistor TR1 last. It is good practice to clip a miniature crocodile clip onto the leads of field effect devices to act as a heat shunt whilst they are being soldered into position.

Terminal pins, inserted at the board lead-out points, will simplify the task of off-board wiring, details of which are also given in Fig.2.2. Locate the multiplier p.c.b. close to the receiver's ferrite loop aerial in order to keep the leads to coil L2 reasonably short; no more than two or three inches (50mm to 75mm).

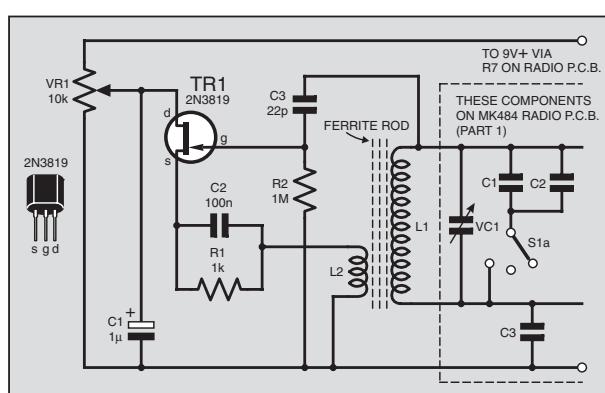
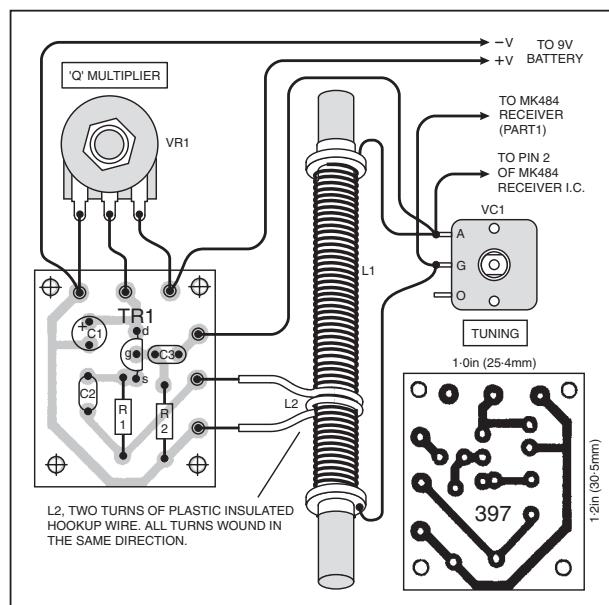


Fig.2.1 (above). Circuit diagram for the simple add-on Q-Multiplier for the MK484 TRF Receiver. (Tuning coil L1 was covered last month.)

Fig.2.2 (right). Printed circuit board component layout, wiring and full-size copper foil master for the Q-Multiplier.





# MW REFLEX RADIO

A 60's style, low-cost, easy-build medium wave portable

## REFLEXING

The high cost of valves in the early days of radio led designers to contrive ways of using them twice, first as radio frequency amplifiers and then, after the signal had been demodulated, as amplifiers of the recovered audio frequency signal.

This technique, known as **reflexing**, was adopted again when transistors were first introduced in the 1950s. At that time, devices with a modest specification cost the present day equivalent of £10 (\$15) or more, and there was the same incentive to use them twice.

Although the cost of transistors has plummeted, some of the reflex designs developed during the 1960s combined simplicity with good performance, and they are well worth a second look.

In 1964, Sir Douglas Hall published the first transistor reflex circuit in which impedances along the signal path were roughly matched. It was subsequently reworked by G. W. Short and others, including the author, and the version given here uses current production transistors and components. It also incorporates a smooth and effective regeneration control and an optional circuit for preventing strong-signal overload.

## REFLEX RECEIVER

The circuit diagram for the MW Reflex Radio is given in Fig.2.5. Coil L1 is a ferite loop aerial tuned by variable capacitor VC1. If desired, an additional capacitor,

made up of C1 and C2, can be switched across the coil by S1a to tune it to *Radio 4* on the Long Wave band. This arrangement works well in areas where the transmission can be received at reasonable strength.

Coupling winding L2 matches the low impedance presented by the base (b) of transistor TR1 to the tuned circuit. Potentiometer VR1 controls the gain of the circuit at radio frequencies and acts as the Q-Multiplier or regeneration control.

Transistor TR1 functions as a grounded emitter stage at both radio and audio frequencies, with the amplified signals being developed across collector (c) load resistor R1.

Transistor TR2 is configured as an emitter follower buffer at radio frequencies, the output being developed across radio frequency (r.f.) choke L5. The relatively high impedance at the base of TR2, in this mode, optimizes signal transfer from the collector of TR1, whilst the low emitter impedance is a reasonable match for detector diode D1.

The demodulated signal is fed back to the base of TR1, via coupling coil L2, for further amplification at audio frequency. Residual radio frequencies are removed by capacitor C4.

Output from the collector (c) of TR1 is directly coupled to the base (b) of TR2, which functions as a common



emitter amplifier at audio frequencies. Emitter bias is provided by resistor R3 which is bypassed by capacitor C8.

Audio output is developed across collector load resistor R2 and is coupled to the Volume control by d.c. blocking capacitor C10. Radio frequencies are removed from the audio signal path by the shunting action of capacitor C9.

Power is connected to the circuit via switch S1b, and a low current l.e.d., D2, with its dropping resistor R5, act as an optional On indicator. Readers may wish to connect the tuner and a power amplifier to the same battery, and the necessary supply line decoupling is provided by resistor R4 and capacitor C11.

## FEEDBACK

Connecting the collector of TR1 to the "hot" end of the tuning coil L1, via capacitors C5 and C6, provides the positive feedback needed for the *Q* multiplying process. In order to keep the feedback at the correct level, the capacitors must have a very low value, and C5 comprises about 6mm ( $\frac{1}{4}$ in.) lengths of plastic covered hook-up wire twisted together.

Low value ceramic capacitor C6 is placed in series with C5 so that the twisted wires can have a reasonable length. Shunt capacitor C7 improves the action of VR1, the Regeneration or Q-Multiplier control.

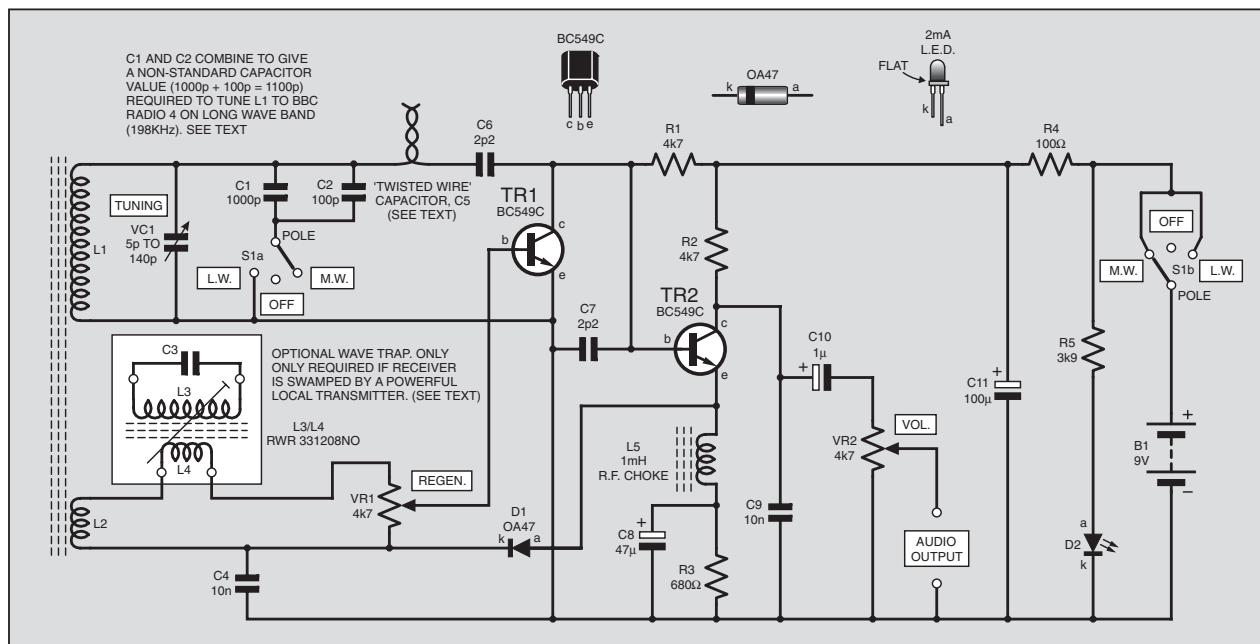


Fig.2.5. Circuit diagram for the MW Reflex Radio. Provision is provided for one preset longwave station – BBC Radio 4.

**Table 2.1: Wave Wrap Tuning Ranges with Standard Value Capacitors**

Capacitor Value pF	Frequency (kHz) (core fully In)	Frequency (kHz) (core fully Out)
33	1300	1700
47	1100	1400
68	900	1200
82	820	1100
100	740	1000
120	680	900
150	600	800
180	550	700
220	500	650

#### Notes:

- (1) The above tuning ranges are obtained with a Toko type RWR331208 tuning coil
- (2) Use polystyrene or "low k" ceramic capacitors

## SWAMPING

Since the 1960s, often powerful local stations have proliferated on the medium wave band and they tend to swamp these simple receivers. (The author lives almost in the shadow of a transmitter mast, and the radiated energy is strong enough to badly overload domestic superhets.)

Other readers may be affected in this way, and the simple tuned circuit formed by L3 and C3 is included to attenuate the offending signal. The device is known as a *Wave Trap*.

The tuned circuit takes more than one form and the principles are discussed later. The value of trap tuning capacitor C3 must be selected so that the adjustable core of the coil can be set to the frequency of the offending station. Table 2.1 gives a range of values for the medium wave band.

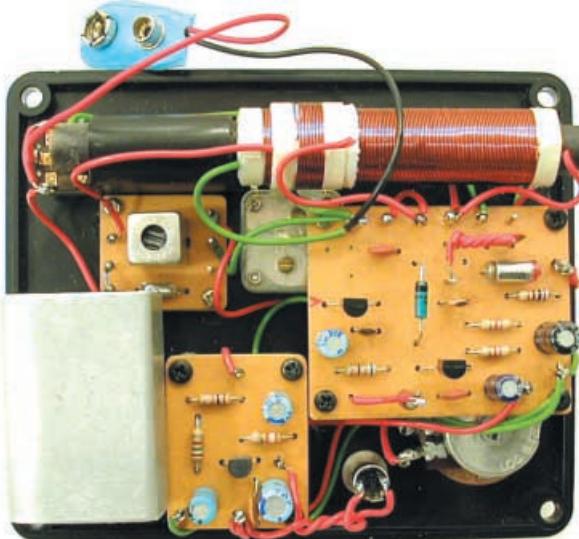
Coupling winding L4 matches the high impedance trap to the low impedance circuit formed by L2, VR1 and the base/emitter junction of TR1.

## CONSTRUCTION

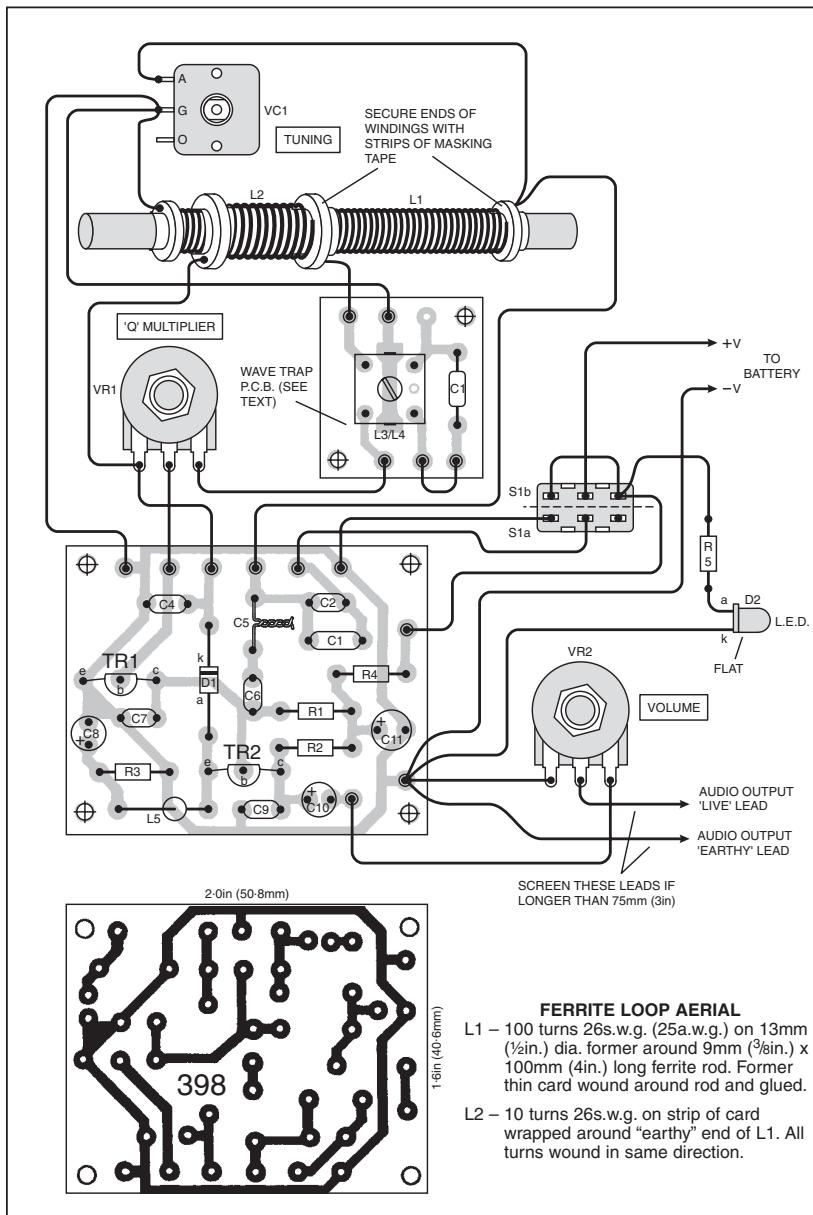
Most of the components for the MW Reflex Radio are mounted on a small printed circuit board. The component side of the board and the off-board wiring together with a full-size copper track master are illustrated in Fig.2.6. The board is available from the *EPE PCB Service*, code 398.

Solder the resistors and r.f. choke L5 in place first, then the capacitors and, finally, the semiconductors. Germanium diodes can be damaged by excessive heat during soldering, and the leads of diode D1 should, therefore, be long enough to permit the attachment of a miniature crocodile clip to act as a heat shunt. The dropping resistor for the optional on/off indicator l.e.d., D2, is *not* mounted on the p.c.b.

With very compact receivers, it is possible for radio frequency choke L5 to interact with the ferrite loop, L1, and produce unwanted feedback (some designs use this as a means of providing preset regeneration). Assuming that the p.c.b. will be mounted in the same plane as the loop aerial (it invariably is), the choke should be mounted vertically on the board to avoid this problem. Miniature radio frequency chokes look like, and are colour coded in the same way as, resistors, the code giving the value in microhenries ( $1000\mu\text{H} = 1\text{mH}$ ).



*Interior of the headphone version of the MW Reflex Radio showing the wave trap, receiver and headphone amp p.c.b.s.*



*Fig.2.6. Printed circuit board component layout, interwiring and full-size copper foil master for the MW Reflex Radio. Ferrite loop aerial construction was covered in Part 1. The Wave Trap is only needed where a local transmitter swamps the receiver. Connect VR1 directly across L2 when the trap is not wanted.*



Author's head-  
phone version of  
the MW Reflex  
Radio.



Completed speaker version of the MW Reflex Radio.

## COMPONENTS

### REFLEX RADIO

#### Resistors

R1, R2,	4k7 (2 off)	<b>See SHOP TALK page</b>
R3	680Ω	
R4	100Ω	
R5	3k9Ω	

All 0.25W 5% carbon film

#### Potentiometers

VR1	4k7 rotary carbon, lin.
VR2	4k7 rotary carbon, log.

#### Capacitors

C1	1000p polystyrene (see text)
C2	100p polystyrene (see text)
C3	see Table 2.1, only required if using Wave Trap
C4, C9	10n disc ceramic(2 off)
C5	twisted wires (see text)
C6, C7	2p2 disc ceramic (2 off)
C8	47μ radial elect. 16V
C10	1μ radial elect. 16V
C11	100μ radial elect 16V
VC1	5p to 140p (minimum), polythene dielectric variable capacitor

#### Semiconductors

D1	OA47 germanium diode
D2	low current (2mA) i.e.d.
TR1, TR2	BC549C npn small signal transistors (2 off)

#### Miscellaneous

L1/L2	ferrite loop aerial: 100mm (4in.) x 9mm/10mm 3/8in. dia. ferrite rod with coil (see text)
L3/L4	tuning coil, Toko RWR 331208 (only required if Wave Trap fitted)
S1	d.p.d.t. centre-off toggle switch (see text)

Printed circuit board available from the EPE PCB Service, code 398; plastic case, size and type to choice plastic control knob (3 off); 50g (2oz) reel of 26s.w.g. (25a.w.g.) enamelled copper wire, for tuning coil; card and glue for coil former; i.e.d. holder; connecting wire; 9V battery and clip; stand-off pillars; solder pins; solder etc.

**Approx. Cost  
Guidance Only** £12  
**excl. case, wire & batt.**

Again, solder pins inserted at the lead-out points will simplify off-board wiring. Readers who do not require the Wave Trap should, of course, connect coupling coil L2 directly to the "hot" end of VR1.

### LOOP AERIAL

The loop aerial is the same as the one used in the MK484 TRF Receiver described last month, but with the addition of a ten turn base coupling winding, L2.

A strip of card or masking tape, wound over the "earthy" or start end of L1, will make it easier to add the coupling coil. The base winding of L2 must be connected in the correct sense to ensure positive feedback, and full details are given in Fig.2.6.

### SETTING UP

Check the completed p.c.b. for poor soldered joints and bridged tracks, check the orientation of the semiconductors and electrolytic capacitors, and make sure the off-board wiring has been correctly routed.

If all is in order, connect the board to a 9V battery. Current consumption, without i.e.d. D2, should be around 3mA.

Connect the Reflex Radio p.c.b. to the Headphone Amplifier described last month or the Speaker Amplifier described later. Switch on and tune in a weak signal at the low frequency end of the medium wave band and advance Regen. control VR1.

Signal strength should increase dramatically. If it does not, reverse the connections to L2. The circuit should begin to oscillate (a hiss in the speaker) when VR1 is close to its maximum setting. If the Q-Multiplier action is too fierce, untwist capacitor C5 a little.

If the Wave Trap (L3/L4 and C3) option has been fitted, tune the receiver to the offending station, then, with a plastic trimming tool, adjust the core of L3/L4 until its perceived strength has been reduced as much as possible.

If provision has been made for reception of BBC Radio 4 on long waves, switch in capacitors C1 and C2 and peak the signal with tuning capacitor VC1.

### WAVE TRAPS

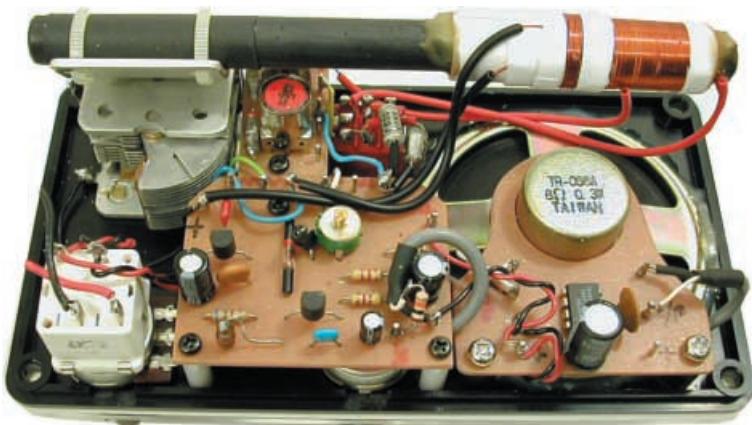
Simple receivers are swamped by powerful signals, which can also degrade the performance of complex communications equipment. An old, but effective, solution is to attenuate the offending signal before it gets into the receiver. If this is not practicable (e.g., sets with loop aerials), then it should be attenuated *before* it reaches the amplifier stages.

This single-frequency attenuator is called a Wave Trap. It is no more than a tuned circuit resonant at the frequency of the signal to be blocked out or shunted to ground.

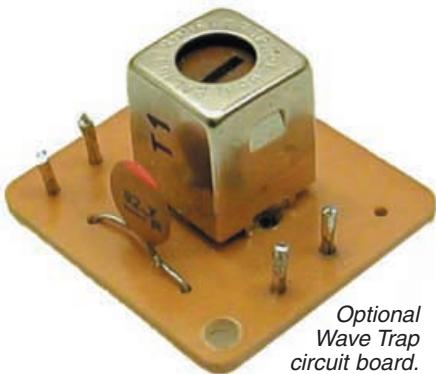
### Rejection

The most common arrangement is shown in Fig.2.7a. Here the parallel tuned circuit, connected in the aerial lead, presents a high impedance to the unwanted signal and heavily attenuates it. This arrangement is very effective when the input impedance of the receiver is less than 1000 ohms (most are either 50 ohms or around 600 ohms).

A parallel tuned trap can be inserted in a loop aerial coupling circuit if an impedance matching winding is provided. This



Interior layout of the Reflex Radio built by a friend (Dr. P. O'Horan) of the author. Note the air-spaced tuning capacitor, trimmer capacitor in place of twisted wires, and mods. to amplifier p.c.b. This set worked "first time" and is claimed to be as good as many small superhet sets.



Optional Wave Trap circuit board.

has already been described in connection with the MW Reflex Receiver project, and the basic circuit is repeated in Fig.2.7b. Without the matching winding, L2, the low impedance presented by the loop coupling circuitry would appear directly across L1 and reduce its  $Q$  to a useless level.

### Acceptance

It will be recalled (see Part 1 – June '03) that a capacitor and inductor in series present a low impedance at resonance and a much higher impedance at other frequencies. The circuit is shown in Fig.2.7c.

In the past, this type of trap was often connected between the aerial and earth terminals of receivers with a high input impedance where it exhibited a shunting effect at the unwanted frequency. (Some valve era receivers had aerial coupling windings that were self-resonant within the medium wave band, and this resulted in the high input impedance). It is occasionally encountered in superhet receivers designed around integrated circuits, where it is used to shunt the intermediate frequency.

### TRAP COMPONENTS

The trap tuning inductor should, preferably, be screened to prevent re-radiation of the unwanted signal within the receiver. A modern Toko coil is suitable, and details of suppliers are given in the *Shoptalk* column.

Capacitors should, preferably, have a polystyrene dielectric but “low  $k$ ” ceramic plate components can be used. Different frequency ranges, within the medium wave band, for various standard capacitor values, are given in Table 2.1.

### TRAP CONSTRUCTION

A universal printed circuit board, which can accommodate any of the trap configurations described here, is illustrated alongside Figs.2.7a to 2.7c. The copper track side master of the board is also included. This board is available from the EPE PCB Service, code 399.

Mount the board as close as possible to the “trapping point” to keep connecting leads as short as possible. Aerial traps should be located inside any metal chassis, alongside the aerial terminal.

### ADJUSTMENT

Tune in the offending station and, using a plastic trimming tool, adjust the “trap” tuning coil core until maximum attenuation is achieved.

Traps of this kind work well on the long and medium wave bands where swamping problems are usually encountered. As frequency increases, trap bandwidth widens, and the circuit is no longer capable of single-signal attenuation.

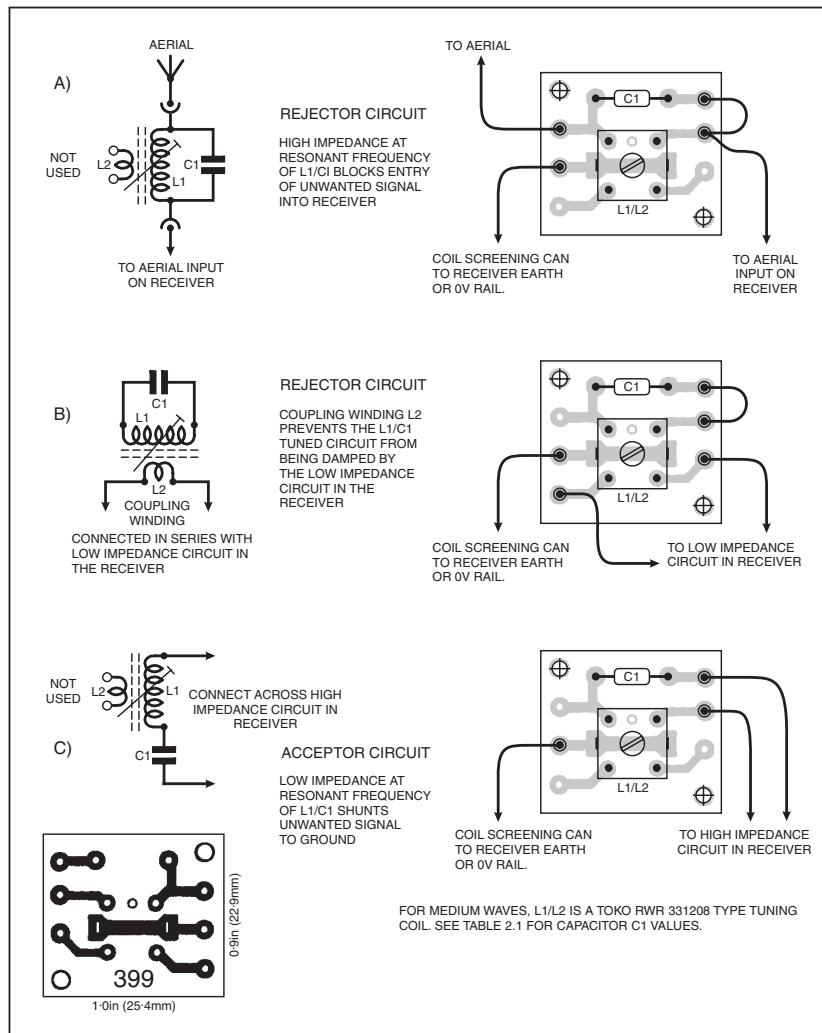
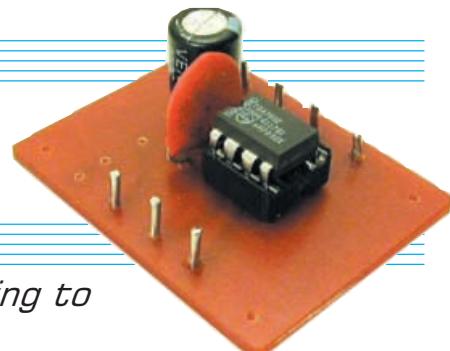


Fig.2.7. Various Wave Trap circuit arrangements to prevent “swamping” of receivers by powerful, usually local, signals. Wiring details and a full-size printed circuit board are also illustrated.

## SPEAKER AMPLIFIER

Add loudspeaker listening to your receivers



Many readers will require a loudspeaker output from the various receivers described in the series. A suitable power amplifier can be built using the Philips TDA7052 integrated circuit.

The designers of the i.c. adopted an internal bridge configuration for the output stage, and the device will deliver reasonable power at low supply voltages (450mW with a 4.5V, and 1W with a 9V, supply into an 8 ohm speaker). It also eliminates the need for a speaker coupling capacitor. The external component count is minimal; just two capacitors.

The circuit diagram for a simple TDA7052 Speaker Amplifier is shown in Fig.2.8, where bypass capacitors C1 and

C2 ensure stability at radio and audio frequencies. The input pin (IC1 pin 2) is connected to the signal source via a potentiometer (Volume control) and a d.c. blocking capacitor. These components are included with the radio receiver circuits, but are shown again here in the interests of clarity. This input arrangement must also be adopted if the amplifier circuit is to be used with other equipment.

### CONSTRUCTION

The printed circuit board component layout, wiring and full-size copper track master for the Speaker Amplifier is illustrated in Fig.2.9. This board is also available from the EPE PCB Service, code 400.

# COMPONENTS

Approx. Cost  
Guidance Only £7  
excl. speaker

## SPEAKER AMPLIFIER

### Capacitors

C1 100n disc ceramic  
C2 220 $\mu$  radial elect. 16V

### Semiconductors

IC1 TDA7052 (Philips) power amp

### Miscellaneous

LS1 8 ohm miniature loudspeaker (see text)

See  
SHOP  
TALK  
page

Printed circuit board available from the EPE PCB Service, code 400; 8-pin d.i.l. socket; multistrand connecting wire; twin-core screened audio cable, if leads to Volume control will be longer than 75mm (3in.); solder pins; solder etc.

An 8-pin d.i.l. socket is recommended for IC1 as this makes substitution checking easy. Again, solder pins at the lead out points are a help when carrying out the off-board wiring.

On completion, check the board for bridged tracks and poor soldered joints, and check the orientation of the i.c. and the electrolytic capacitor.

If all is in order, connect an 8 ohm speaker, the volume control potentiometer, and a 9V battery. With the volume control turned to minimum, current consumption should be approximately 5mA. With a good output from the speaker, current drain will increase to approximately 100mA.

## PERFORMANCE

The noise level of the amplifier is extremely low and its output is free from audible distortion up to the power levels quoted earlier. With a sensitivity of 40mV r.m.s., it can easily be driven to full output by any of the receivers in this series (other than last month's Crystal Set).

Output short circuit protection is built into the chip, which shuts down when dissipation becomes excessive. It will not, however, withstand prolonged abuse, especially with higher supply voltages.

Current consumption for a given power output, although acceptable, is almost twice that of other i.c.s which have more complex external circuitry; e.g., the

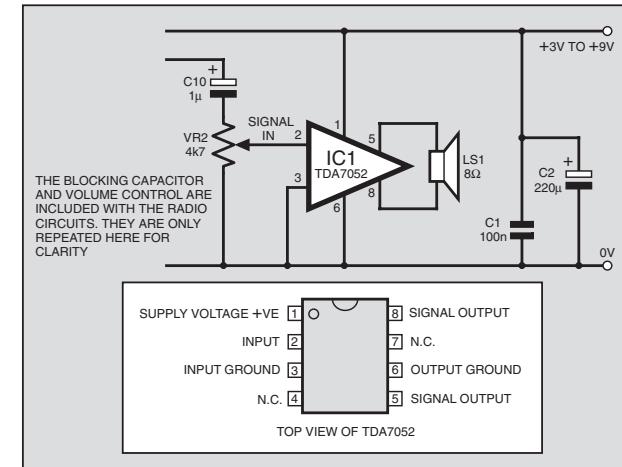


Fig.2.8. Circuit diagram for the Speaker Amplifier.

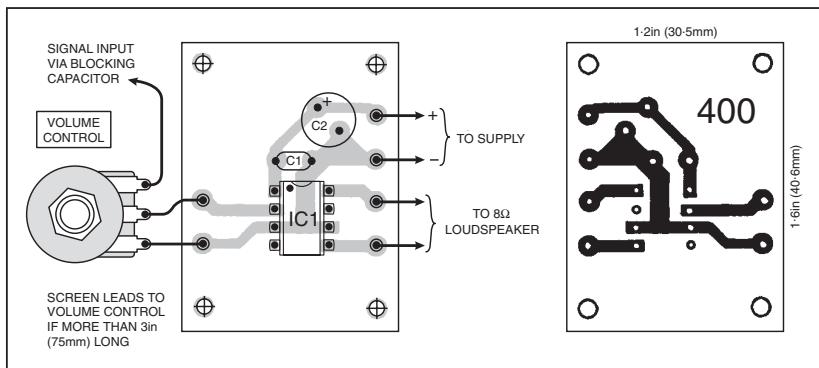


Fig.2.9. Speaker Amplifier printed circuit board component layout, wiring and full-size copper foil master. Note the Volume control pot. is included in the radio circuits.

LM386N-1 and the TBA820M. (The May 2002 edition of EPE contained full circuit details of these and other amplifiers).

## COMPONENTS

Most of the components for the circuits in Part Two are widely available and no difficulty should be encountered in obtaining them. The semiconductors are not particularly critical. Most *n*-channel junction f.e.t.s should work in the add-on Q-Multiplier.

Similarly, most high gain ( $h_{fe}$  at least 400) small signal *npn* transistors should be suitable for the Reflex Radio. The BC239C,

BC547, 2N2926 and 2N3711 have been tried and found acceptable. A germanium point contact signal diode must be used (small signal silicon diodes are not suitable), but the actual type is not critical and an OA90 or OA91 could be substituted.

Semiconductor base connections vary and must be checked.

Next month's article will describe high performance regenerative receivers for both general coverage (150kHz to 30MHz) and the amateur bands. We also hope, space permitting, to take a close look at coils, variable capacitors and tuning systems.



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# PRACTICAL RADIO CIRCUITS

**RAYMOND HAIGH**



## Part 3: Regenerative Receivers – A modern-day version of Armstrong's 1913 circuit.

*Dispelling the mysteries of Radio. Circuits for the set builder and experimenter.*

In Part Two we reviewed the history and theory of regeneration and used the technique to improve the performance of two, portable, radio receivers. This month a regenerative receiver designed for serious listening on the long, medium and short wave bands will be described.

### BASICS

For a regenerative receiver to perform well, three basic requirements have to be met. (1) Its regeneration control must be smooth, completely free from backlash, and have a minimal effect on tuning.

(2) The tuned circuit to which the *Q* enhancing positive feedback is applied must be isolated from the aerial: failure to do this will result in reaction dead spots on frequencies (or harmonics) at which the aerial is resonant.

(3) Provision must be made, at the receiver input, for the attenuation of powerful signals, otherwise the regenerative circuit will lock onto strong carriers and it will not be possible to receive weak transmissions on adjacent channels.

### ARMSTRONG UPDATED

A modern, transistor version of Armstrong's circuit, patented in 1913, is shown in Fig.3.1. In the original, the feedback coil (tickler coil in the USA), L3, was connected in place of the radio frequency choke, L4, and regeneration controlled by adjusting its proximity to tuning coil L2. This was eventually superceded by the variable capacitor system shown here, where increasing the capacitance of VC1 increases feedback through L3.

Choke L4, in the drain (d) circuit of TR1, acts as a load for the radio frequency component of the amplified signal, controlled amounts of which are fed back through L3 to overcome losses in the tuned circuit (L2/VC2) and increase its efficiency or *Q* factor.

Armstrong discovered that the technique permits the amplification of weak signals by a factor of more than 1000.

Further, because tuned circuit *Q* is raised, there is also a dramatic improvement in selectivity.

Source bias is developed across resistor R3, which is bypassed by capacitor C2, and signal detection occurs by way of rectification at the gate/source junction of transistor TR1. (In the original valve versions, diode rectification between grid and cathode resulted in detection or demodulation). Low value blocking capacitor C1 prevents the audio voltage developed across gate resistor, R1, being shorted by the tuning coil.

### AUDIO SIGNAL

The amplified audio signal is developed across drain load resistor R2 and coupled to the audio amplifier stages via d.c. blocking capacitor C3. Residual radio frequencies are bypassed by capacitor C4.

In some versions of the circuit, a transistor type audio transformer (e.g., an LT44) is substituted for the resistive load in order to maximize signal transfer. However, even with this arrangement, the audio output is very low, and at least one additional stage of pre-amplification will be required ahead

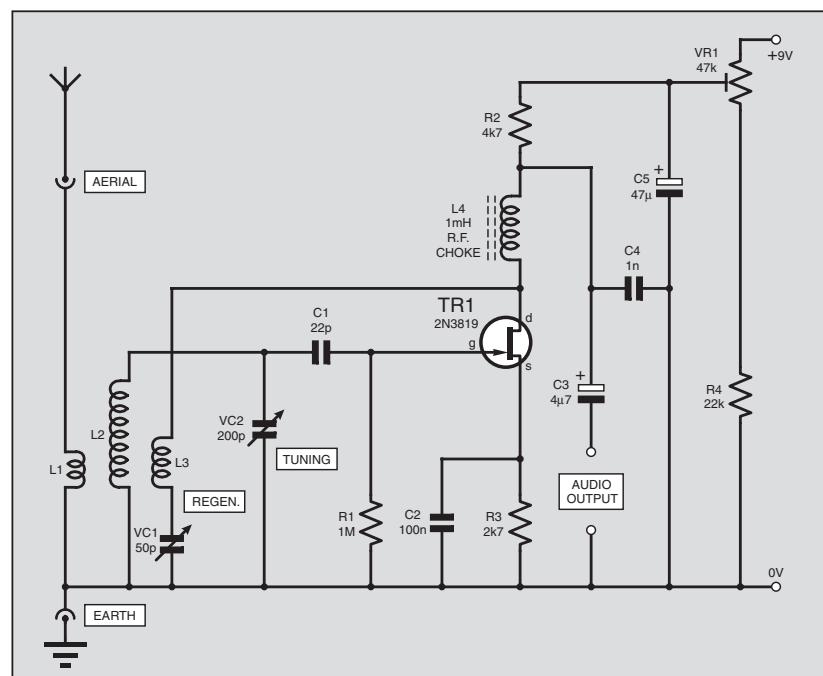


Fig.3.1. Circuit diagram for a modern transistor version of Armstrong's Regenerative Detector. In Armstrong's circuit, patented in 1913, feedback coil L3 is connected in place of r.f. choke L4 and its proximity to L2 is adjusted to control regeneration. VR1 presets regeneration control range.

of the headphone or speaker amplifiers described in Parts 1 and 2.

The gain of TR1, and hence its willingness to regenerate, is determined by preset potentiometer VR1, which adjusts the drain voltage. By this means the circuit can be optimized for different transistors and coil feedback winding ratios.

## POPULARITY

Using gradually improving versions of Lee de Forest's triode valve as the amplifying device, Armstrong's circuit, followed by a one or two valve audio amplifier, remained popular as a domestic receiver until the end of the 1920s in the USA and well into the 1930s in the UK. Regenerative receivers were still being manufactured by Ever-Ready (their Model H) as late as the 1950s, and they were constructed by amateurs up to the close of the valve era.

It is not easy to use low impedance, current amplifying bi-polar transistors in this circuit. However, it saw something of a revival in amateur circles following the introduction of the field effect transistor (f.e.t.), with its more valve-like characteristics, in the late 1960s.

## IMPROVED CIRCUITS

Smooth regeneration can be obtained more readily, and with simpler coils, by configuring the *Q* multiplier, or regenerative detector, as a Hartley oscillator. A typical circuit is given in Fig.3.2, where feedback from the source(s) of the dual-gate MOSFET, TR1, is connected to a tapping on the tuning coil L2.

The level of feedback is controlled by VR1, which varies the gain of the transistor by adjusting the voltage on its gate g2. Preset potentiometer VR2 (wired as a variable resistor) determines the source bias and optimizes the action of the regeneration control for individual tuning coils and transistors.

Audio output is developed across drain load resistor R3. The stage is decoupled from the supply rail by resistor R2 and capacitor C5, and the filter network formed by C4, R4 and C6 removes radio frequencies from the output.

## SEPARATION

During the valve era, the functions of signal detection and *Q* multiplication or regeneration were invariably carried out by a single device. This combining of functions can make it more difficult to obtain the smooth, backlash-free control of regeneration which is crucial to the efficient operation of a receiver of this kind. Best modern practice uses separate transistors.

The dual-gate MOSFET circuit illustrated in Fig.3.2 can be used just as a *Q*-multiplier by increasing the value of capacitor C4 to 100nF. Filter components, R4, C6 and coupling capacitor C7, can be omitted when the stage is configured in this way.

The "hot" end of the tuned circuit must, of course, be connected to gate g1 of the transistor, and resistor R1 is best retained to hold gate g1 at 0V during coil changing.

## DETECTORS

A field effect transistor (f.e.t.), biased into the non-linear region of its

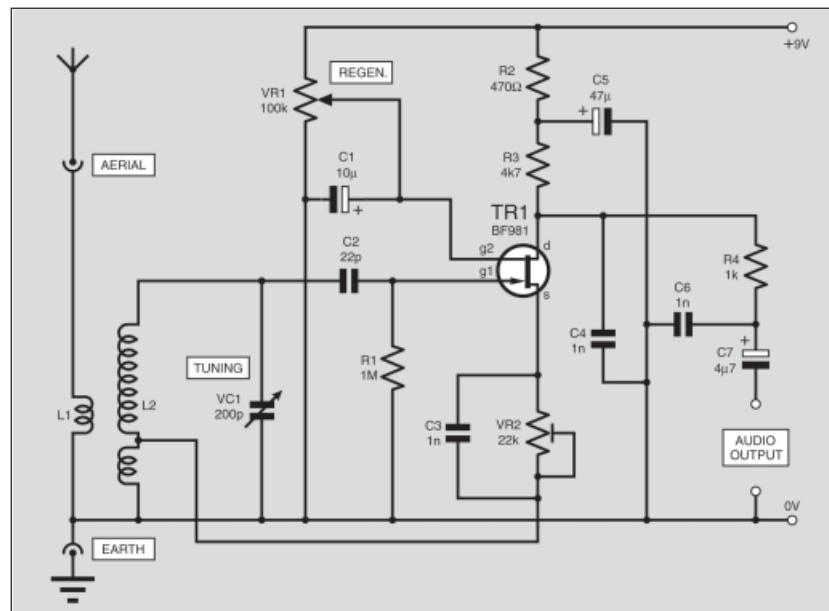


Fig.3.2. Circuit diagram for an improved Regenerative Detector based on a Hartley oscillator. VR2 presets regeneration control range. This circuit forms an excellent *Q*-Multiplier for use with a separate detector, in which case increase capacitor C4 value to 100nF and delete C6, C7 and R4.

characteristic curve, forms an excellent detector stage. The "drain bend" version (the transistor equivalent of the valve "anode bend" detector) is included as TR3 in the Regenerative Receiver design illustrated in Fig.3.4. This arrangement is discussed later.

Alternatively, the audio output can be taken from the source of the f.e.t. We then have the transistor equivalent of the valve "infinite impedance" detector. The modified circuit, using the component numbering of Fig.3.4 for ease of comparison, is shown in Fig.3.3.

High-value source bias resistor R9 is bypassed only at radio frequencies by capacitor C10 (C9 is omitted), and C13 is increased to 47 $\mu$ F to decouple the stage which is now in the common drain mode. The r.f. filter components, R8 and C15, and the original decouplers, R6 and C11, are not required.

There is little to choose between the two detectors: both work well, imposing very little damping on the tuned circuit. In theory there is some gain with the drain bend version whilst the gain of the source follower is slightly less than unity.

In practice, the need to ensure non-linearity over a range of f.e.t. characteristics results in the drain bend circuit providing very little gain. If the value of r.f. bypass capacitor C10 in Fig.3.3 is reduced, the source-follower detector may become unstable when the regeneration control is critically set.

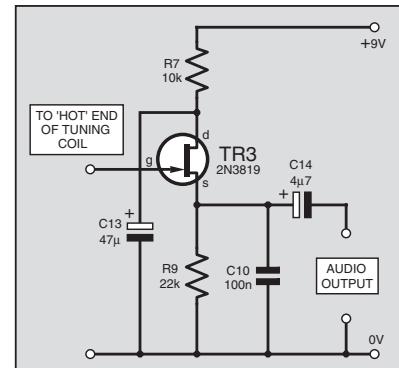
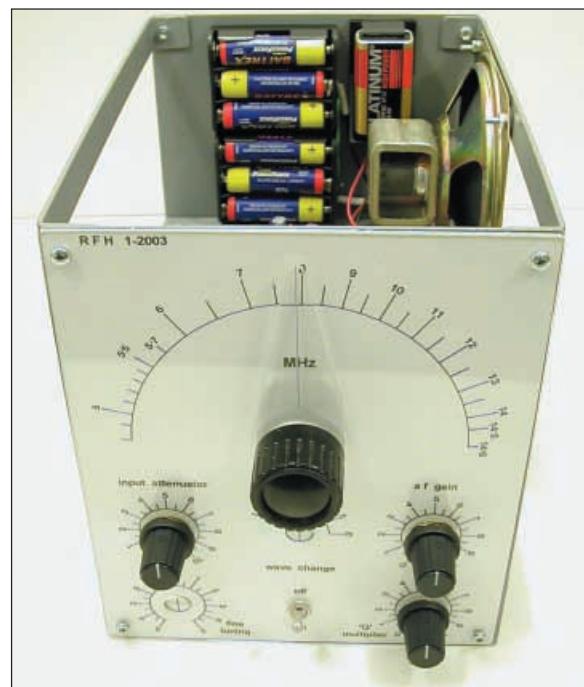


Fig.3.3. Source-follower detector circuit. Transistor equivalent of the valve "anode-bend" detector.



## HIGH PERFORMANCE

# REGENERATIVE RADIO

*A modern-day update of a 1913 circuit*

The full circuit diagram for a High Performance Regenerative Radio incorporating the essential features described here is given in Fig.3.4. It is easy to set up and performs well.

Grounded base stage, TR1, isolates the tuned circuit L2/VC1 from the aerial and TR2 functions as the *Q*-Multiplier. Field effect transistor TR3 is a drain bend detector and transistor TR4 an audio preamplifier.

Although excellent *Q* multipliers can be designed around dual-gate MOSFETs (metal-oxide semiconductor field effect transistors), devices of this kind are becoming more difficult to obtain. For this reason a j.f.e.t. (junction field effect transistor) is used in the *Q* multiplier stage.

Performance is not compromised and these simpler devices are widely available. The circuit in Fig.3.2 should assist any readers who might wish to experiment with dual-gate MOSFETs as an alternative.

### INPUT CIRCUIT

Some readers may be plagued by a medium wave transmission which is powerful enough to swamp the receiver, and L1 and C1 act as a Wave Trap, blocking out the offending signal. Wave trap circuits were discussed in Part 2 last month, and component values and a printed circuit board design were also given.

Potentiometer VR1 connected as the emitter resistor for transistor TR1, controls signal input, and resistors R2 and R3 fix the base bias. The base of TR1 is "grounded" at radio frequencies by capacitor C5; and R1, C3 and C4 decouple the stage from the supply. Blocking capacitor, C2, prevents the grounding of TR1 emitter when aerials are connected to the receiver via a balun transformer and coaxial cable.

The grounded base configuration results in a low input impedance and a high output impedance, and the stage can be coupled directly to the tuned circuit without imposing excessive damping. Because TR1 is a *pnp* transistor, its collector (c) can be connected to the 0V rail via coil L2, eliminating the need for a coupling winding.

### STABILITY MATTERS

Stability is ensured by stopper resistor R4 and by maintaining a low level of base bias on TR1. Constructors may wish to try reducing the value of resistor R3 (not less than 47 kilohms) to improve performance when low gain transistors are used in the aerial input circuit.

However, if this is overdone the stage will no longer be unconditionally stable,

and control of regeneration will become erratic, especially when tuning capacitor VC1 is set at a low value.

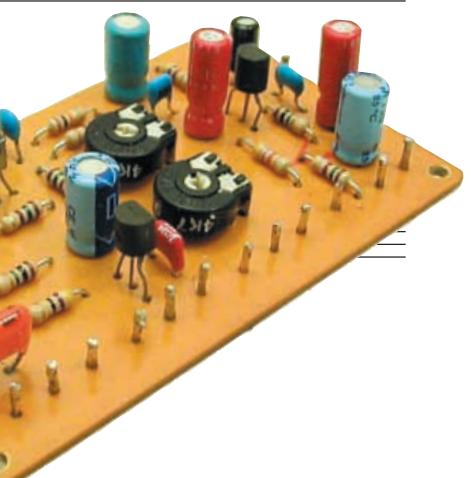
It could be argued that using a field effect transistor, with its near square law characteristics, in the TR1 position, would reduce the receiver's susceptibility to cross-modulation.

Cross-modulation occurs when a powerful signal drives the input stage into non-linearity. If then begins to function as a modulator, imposing the strong signal on adjacent weaker signals and spreading it across the dial.

The regenerative circuit of Fig.3.4 will lock onto a powerful signal long before it is strong enough to make TR1 non-linear. The measures taken to avoid this (wave trap and input attenuator) will, therefore, also prevent cross-modulation. Moreover, *p*-channel field effect transistors are not so widely available, and this militates against their use.

### TUNING

The simplest possible tuning arrangement is depicted in Fig.3.4, and the hand-

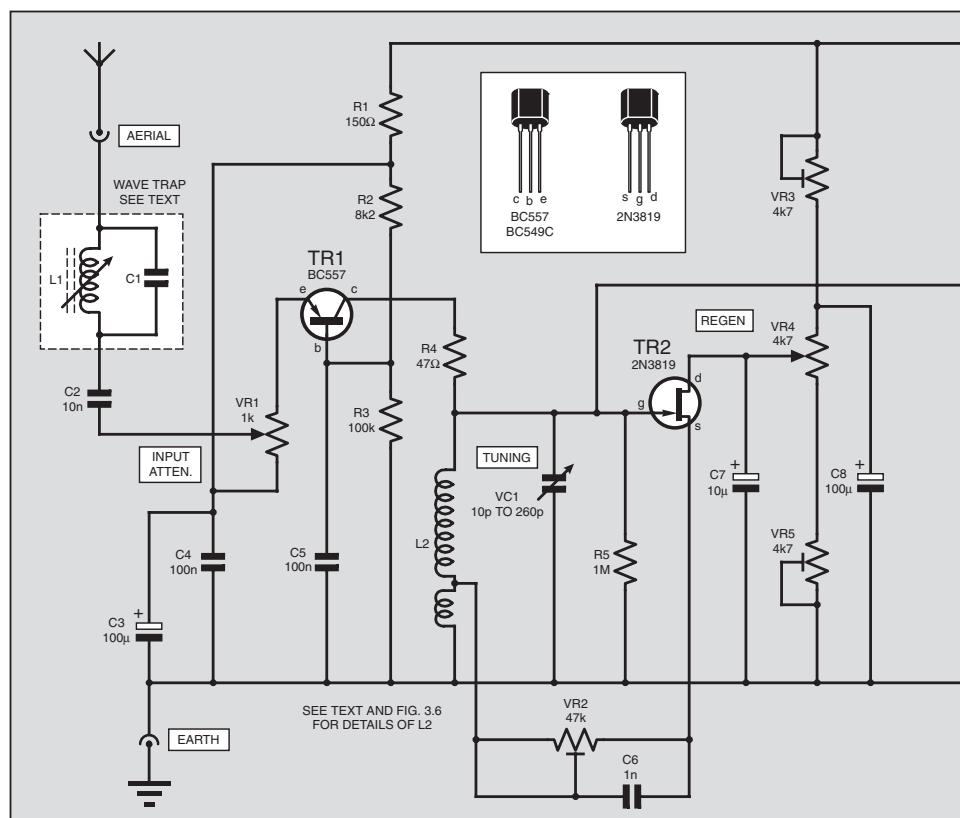


wound, short wave coil L2 is illustrated in Fig.3.6.

The tuning capacitor VC1 is a 10pF to 260pF unit formed by connecting both a.m. gangs of a polyvaricon (polythene dielectric) capacitor in parallel. Typical connection details are shown in Fig.3.7, and the copper track side of a printed circuit board suitable for mounting most screw or tag fixed variable capacitors of this kind is also shown.

### REGENERATION

Regeneration, or *Q* multiplication, is provided by TR2, a field effect transistor configured as a Hartley oscillator. Feedback is taken from TR2 source (s) to a tapping on coil L2 via preset potentiometer VR2 and its bypass capacitor C6. This arrangement enables the control of regeneration to be optimized for different coil and transistor combinations.



## REGENERATIVE RADIO

### Resistors

R1, R6, R11	150Ω (3 off)
R2	8k2
R3	100k
R4	47Ω
R5, R10	1M (2 off)
R7	10k
R8, R13	470Ω (2 off)
R9	22k
R12	4k7
All 0.25W 5% carbon film	

See  
SHOP  
TALK  
page

### Potentiometers

VR1	1k rotary carbon, lin.
VR2	47k carbon preset, horizontal
VR3, VR5	4k7 carbon preset, horizontal (2 off)
VR4	4k7 rotary carbon, lin.
VR6	4k7 rotary carbon, log.

### Capacitors

C1	only required if Wave Trap fitted (see Part 1)
C2	10n disc ceramic
C3, C8, C11, C12	100μ radial elect. 25V (4 off)
C4, C5, C10	100n disc ceramic (3 off)

C6	1n polyester
C7, C9	10μ radial elect. (2 off)
C13, C15	1n polyester or ceramic – see text and Table 3.1 (2 off)
C14, C17	4μ7 radial elect. – see text and Table 3.1 (2 off)
C16	47μ radial elect. – see text and Table 3.1
C18	10n polyester or ceramic – see text and Table 3.1
VC1	10p to 260p polythene dielectric variable capacitor

### Semiconductors

TR1	BC557 pnp small signal transistor
TR2, TR3	2N3819 n-channel field effect transistor (2 off)
TR4	BC549C npn silicon transistor

### Miscellaneous

L1	only required if Wave Trap fitted (see Part 1)
L2	tuning coil, hand-wound (see Fig.3.6)
S1	d.p.s.t. toggle switch

Printed circuit boards available from the EPE PCB Service, codes 405 (Regen) and 406 (T/Cap); diecast or aluminium box for chassis, at least 200mm x 150mm x 75mm (8in. x 6in. x 3in.), or aluminium sheet to fabricate a base and front panel; aerial and earth screw terminals; one large and three small plastic control knobs; audio type screened leads; 50g (2oz) reel of 24s.w.g. (23a.w.g.) enamelled copper wire for tuning coil; plastic tube, 20mm (3/4in.) outside diameter (o/d) for coil former; 9V battery (PP3) and clip; connecting wire; nuts, bolts and washers; solder pins; solder etc.

## DETECTOR PREAMPLIFIER

Drain bend detector, TR3, is biased into non-linearity by resistor R9, which is bypassed at audio and radio frequencies by capacitors C9 and C10. Audio output is developed across drain load resistor R7, and R6 and C11 decouple the stage from

Table 3.1. Capacitor Values for a Wide or Narrow Audio Frequency Response

Part No.	Wide Response	Narrow Response
C13	1n	10n
C14	4μ7	100n
C15	1n	10n
C16	47μ	4μ7
C17	4μ7	100n
C18	10n	330n

the supply rail. Residual radio frequencies are filtered out by R8, C13 and C15, and the signal is coupled to transistor TR4 through d.c. blocking capacitor C14.

Audio preamplifier stage, TR4, is necessary in order to boost the weakest signals. Emitter bias is provided by resistor R13, which is bypassed by C16; R10 is the base bias resistor, and R12 is TR4's collector load.

Supply rail decoupling is effected by R11 and C12. The output signal is taken from TR4 collector, via blocking capacitor C17, and the audio output level is set by Volume control VR6.

### AUDIO RESPONSE

Speech signals, especially when they are overlaid by noise, can be greatly clarified by reducing the response of the system to low and high audio frequencies. Telephone companies throughout the world operate on this principle, and heavily attenuate frequencies below 300Hz and above 3000Hz (3kHz). Narrowing the response leaves speech intelligible while removing parts of the spectrum that carry a good deal of the noise.

The values of the capacitors in the receiver's audio signal path, i.e. from the collector of TR3 onwards, can be chosen to tailor the

Feedback is adjusted by regeneration control VR4, which varies the voltage on the drain (d) of TR2 thereby altering its gain. The range of adjustment is fixed by presets VR3 and VR5, and the action of the regeneration control can be made very gentle and smooth when the swing of VC1 is not too great. Potentiometer noise is eliminated by capacitor C7.

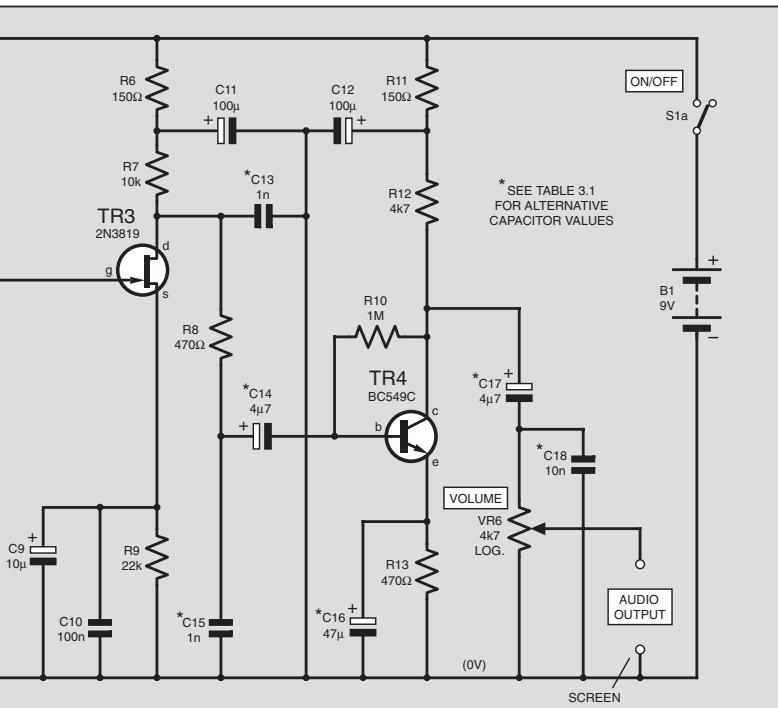


Fig.3.4. Complete circuit diagram for the High Performance Regenerative Radio. See Table 3.1 for alternative capacitor values. Note the Wave Trap is optional – see text and Part 2 (July '03).

audio response. Increasing the value of shunt capacitors C13, C15 and C18, will reduce response to high frequencies.

Reducing the value of coupling capacitors, C14 and C17, will attenuate low frequencies. Reducing the value of bypass capacitor C16 introduces selective negative feedback which also inhibits response at the lower audio frequencies.

Suggested alternative values for these capacitors are given in Table 3.1. Readers will no doubt wish to experiment until the audio response meets their needs.

## POWER SUPPLY

Even small power amplifiers induce large voltage variations in the supply rail, and the four transistors in this circuit must have their own battery supply (or a supply isolated by an electronic regulator and ample smoothing).

Voltage fluctuations on a common supply will cause erratic regeneration, problems with electronic tuning systems (described next month) and low frequency oscillation or "motor boating". The receiver battery is switched by S1a. The other half of the toggle switch, S1b, can be used to control the supply to the Speaker Amplifier (described last month) or other audio amplifiers.

## SEMICONDUCTORS

The *pnp*, bipolar transistor used as the r.f. amplifier, TR1, is not particularly critical. Any small signal device with an  $f_T$  of at least 100MHz and an  $H_{fe}$  of 200 or more should perform well. The audio preamplifier, TR4, can be almost any small signal *npn* silicon transistor, but low-noise, high gain ( $H_{fe}$  at least 400) devices are to be preferred.

Most *n*-channel field effect transistors should function in the detector (TR2) and *Q* multiplier (TR3) stages. In addition to the specified 2N3819's, the BF244A, BF245B, J304, J310, TIS14, K168D and MPF102 have all been "in circuit" tested and found to be satisfactory.

Note that base connections for all of these devices vary and should be checked.

## CONSTRUCTION

Most of the receiver components are assembled on a compact printed circuit board (p.c.b.). The topside component layout, together with the full-size underside foil master pattern and off-board wiring are illustrated in Fig.3.5. This board is available from the EPE PCB Service, code 405 (Regen).

The tuning coil L2 and variable capacitor VC1 are mounted separately. This gives greater freedom in the choice of tuning arrangements. A small p.c.b. which will take most miniature screw or tag fixing polythene dielectric variable capacitors is shown in Fig.3.7. This board is also obtainable from the EPE PCB Service, code 406 (T/Cap).

Solder pins inserted at the lead-out points ease the task of off-board wiring. They should be inserted into the printed circuit board first. Follow these with the resistors, then the capacitors, smallest first; and, finally, the semiconductors. It is good practice to use a miniature crocodile clip as a heat shunt whilst soldering the field effect transistors in place.

On completion, the p.c.b. should be examined for poor soldered joints and

bridged tracks, and the orientation of semiconductors and electrolytic capacitors should also be checked.

It is a good idea to wire the printed circuit board to the controls and tuning components on the work bench, and test it before mounting it in an enclosure. Current consumption of the receiver should be in the region of 4mA.

## COIL WINDING

Details of the tuning coil L2 are given in Fig.3.6. It is wound on an off-cut of 20mm (3/4in.) outside diameter plastic electrical conduit and preset VR2 and its bypass capacitor C6 are located at one end of the former. Solder tags are used to anchor the windings and the preset potentiometer.

Plastic electrical conduit for the hand-wound coil is retailed at most DIY outlets. Suppliers of enamelled copper wire and tuning capacitors are mentioned in the *Shoptalk* column. The remaining components are widely available.

The specified variable capacitor (VC1) will tune coil L2 from 4.8MHz to 14.6MHz. This covers the 20, 30 and 40 metre amateur bands, and the 25, 31, 41, and 49 metre broadcast bands.

Details of hand-wound coils covering 150kHz to 30MHz will be described next month, together with switched coil packs, incorporating commercial coils, for general coverage and amateur bands receivers.

Constructors who like to experiment with their own coils should tap longwave inductors at 5 per cent of the total turns, and all other coils at 10 per cent. The short-wave coil covering up to 30MHz may require a 15 per cent tapping point to secure regeneration when the tuning capacitor is set at maximum. Commercial coils in spares boxes can be pressed into service by adding turns to form the source tapping point.

## ASSEMBLY AND WIRING

Construction of the set must be rigid and robust or the receiver will not perform well, especially on the short-wave bands. Diecast boxes are best for chassis or enclosures, but receivers assembled on or in aluminium boxes are acceptable. A metal front panel is essential for screening purposes.

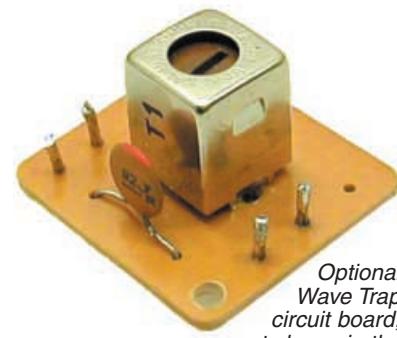
Layout is not particularly critical, but locate the tuning components close to the relevant solder pins on the receiver printed circuit board. Keep signal input leads away from output leads. The regeneration potentiometer VR4

can be located in any convenient position (it is decoupled from the signal circuits).

The general interwiring from the p.c.b. to the off-board components is shown in Fig.3.5. Some variable capacitors are secured by screws driven into their front plates. Check the length of the screws to ensure that they do not project too far and foul the capacitor vanes.

Metal potentiometer cases should be connected to the 0V rail. Leads between the aerial terminal, the input attenuator, VR1, and the receiver printed circuit board, should be screened, as should the leads between the volume control, VR6, the power amplifier and the receiver board. The screening must, of course, be connected to the "ground" or 0V rail.

Most polyvaricon capacitors designed for a.m. or a.m./f.m. portable receivers will be suitable. The calibrated dial reproduced (half-size) in Fig.3.8 should be reasonably accurate if the tuning capacitor mentioned in the Components List is used and the coil is wound in accordance with Fig.3.6.



*Optional Wave Trap circuit board, not shown in the author's model below.*



*General layout inside the metal case. The speaker amplifier module is in the foreground. The wave trap is mounted on the underside boxed chassis.*

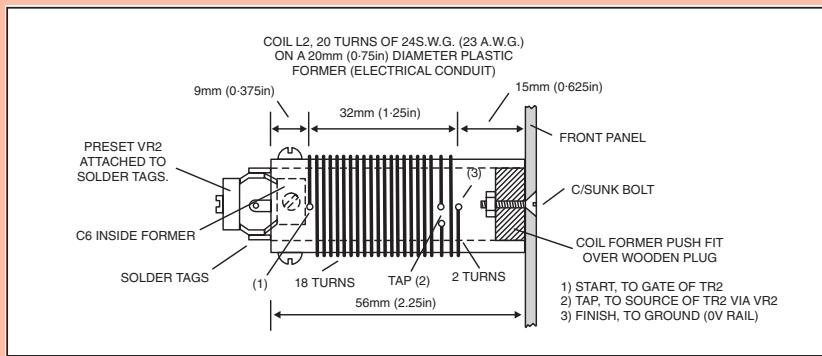


Fig.3.6. Coil winding details for the tuning coil L2. The coil former also carries preset VR2 and capacitor C6 – see photo opposite.

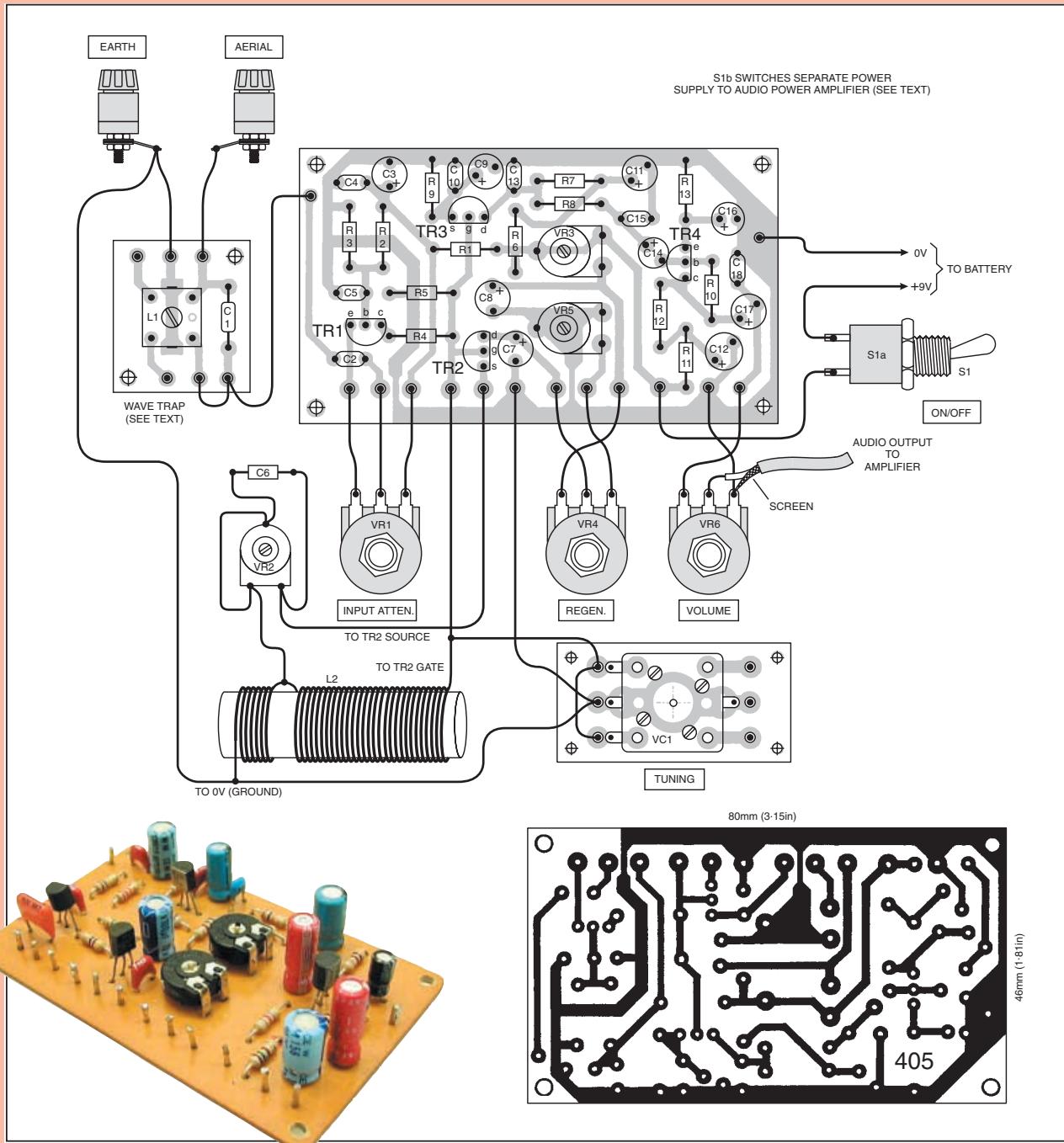
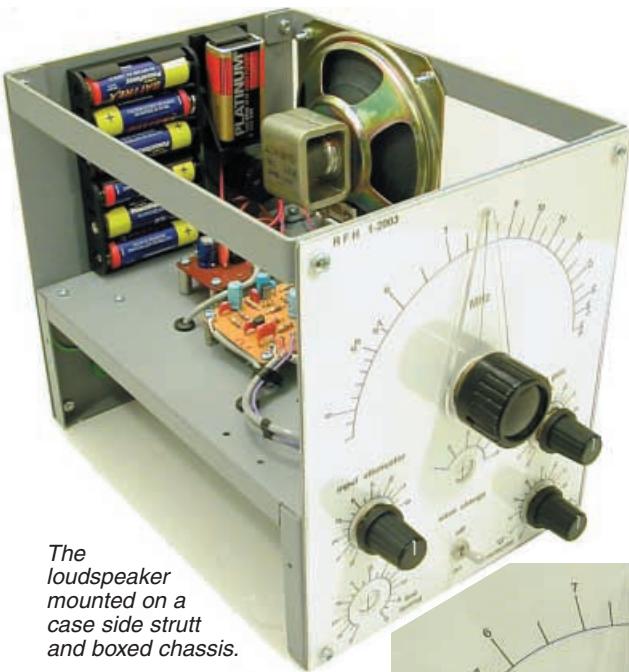


Fig.3.5. Printed circuit board component layout, interwiring details and full-size copper foil master for the Regenerative Receiver. Note you will need an additional VR2 preset and capacitor C6 for each waveband coil.



The loudspeaker mounted on a case side strut and boxed chassis.

Polyvaricons intended for inexpensive 'hi-fi' systems often have 300pF or larger a.m. gangs. These capacitors have a deeper case, around 20mm ( $\frac{3}{4}$ in.) compared to the 10mm ( $\frac{3}{8}$ in.) or so for the lower value units. Only one gang should be connected if a capacitor of this kind is fitted.

The accompanying photographs show this simple version of the receiver assembled on the metal chassis used to test and evaluate the circuits. A 6:1 reduction drive is fitted to the spindle of the tuning capacitor but this is not adequate for easy tuning over the shortwave bands.

Further, the value of the tuning capacitor, whilst it gives good coverage with the single coil, is too high and regeneration becomes difficult to adjust at the high frequency end of the range. These questions are addressed next month when more refined tuning systems are discussed.



Front panel fascia of single band version showing general layout.

Readers may wish to try connecting only one of the capacitor gangs into circuit. This gives a swing of 5pF to 130pF and coverage with the specified coil is around 6.5MHz to 15.5MHz. Coverage is reduced but control of regeneration, at the higher frequencies, is easier.

## SETTING UP

Connect the receiver to the Speaker

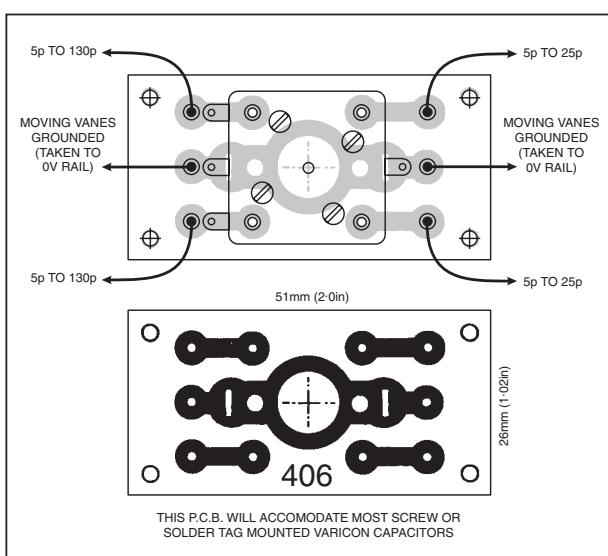


Fig.3.7. Tuning capacitor mounting p.c.b. details. Connections to a typical a.m./f.m. four-gang polythene dielectric variable capacitor. Capacitance values and connections may vary and should be checked.

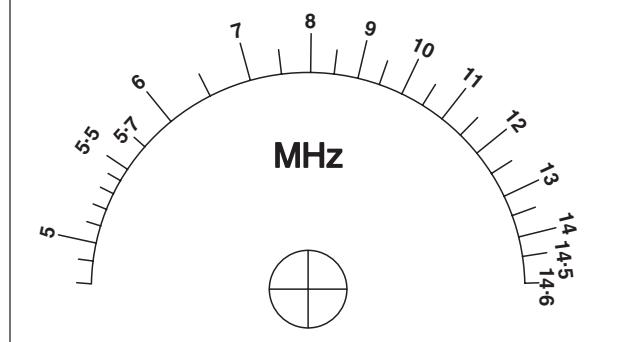


Fig.3.8. Half-size calibrated dial (MHz). Calibration with the specified tuning capacitor and coil L2. Receivers will vary, but it is a good guide to coverage.

Amplifier described in Part 2. Connect an aerial comprising at least 30 feet (10 metres) of wire located as high as possible and well clear of any telephone or power lines and earthed objects.

Set preset VR2 to maximum, and presets VR3 and VR5 to minimum resistance. Rotate the slider of Regen. control VR4 to put the maximum voltage on the drain (d) of TR2. Set the other potentiometers to half-travel.

Now connect a fresh 9V battery and tune in a weak signal with variable capacitor VC1, set close to its maximum value.

Reduce the resistance of preset VR2 until the *Q* multiplier begins to oscillate (indicated by a rushing sound or faint whistle). Turn down Regeneration control VR4. The receiver should slide gently out of oscillation.

When regeneration is set close to oscillation, the perceived strength of signals will be greatly increased and tuning much sharper.

Turning down VR1 to attenuate input signals, as necessary, gradually open the vanes of VC1 to tune the receiver up in frequency. Less regeneration will be required to maintain sensitivity as the tuning capacitance is reduced, and VR4 will have to be progressively turned down. When VC1 is fully open, increase the value of preset VR5 until regeneration can be set just below the threshold of oscillation when VR4 is at minimum.

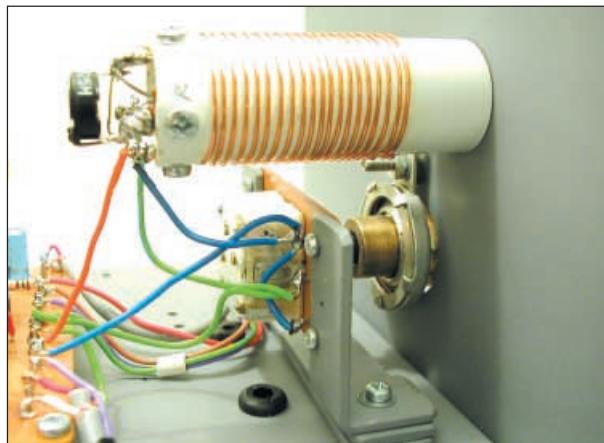
Refine the adjustment of preset potentiometers VR2, VR3 and VR5 until the action of the regeneration control VR4 is as gentle as possible across the entire tuning range. Because of the wide swing of the tuning capacitor, VC1, in this simple version of the receiver, presets VR3 and



(Above) The tuning capacitor mounted on the p.c.b.



(Right) Completed tuning coil showing preset soldered to tags bolted on one end of former.



*Close-up view of the mounting arrangement for the tuning coil and variable capacitor. Note the reduction drive fitted to the tuning capacitor spindle.*

VR5 will have to be set close to minimum resistance to give VR4 sufficient control.

## OPERATION

Best results will be obtained if the Regenerative Radio is operated with VR1 set to attenuate the input as much as possible and the audio frequency gain (Volume) control turned up to ensure adequate sound output. This is good practice with complex sets and essential with this simple receiver. If this procedure is not followed it will be impossible to hear weak signals close in frequency to powerful ones.

For best reception of a.m. (amplitude modulated) signals the Regeneration control VR4 must be adjusted, as the receiver is tuned across the band, to keep the *Q* multiplier circuit close to oscillation. When regeneration is correctly set, rocking the tuning control should produce a faint whistle on either side of the station.

A useful technique when searching for very weak signals is to advance the

an oscillating valve with up to 100V on its anode forms a good transmitter.

Reception was, therefore, marred by whistles and howls propagated by neighbouring receivers. The problem became so acute that, in 1928, the BBC issued a handbook guiding the public on the correct operation of the regeneration control. During that year so many complaints were received that listeners were warned that their licenses would be withdrawn if they didn't exercise more restraint.

With this modern transistor design, the grounded base radio frequency stage isolates the very low powered oscillator and interference problems do not arise.

## AMATEUR BAND RECEPTION

For the reception of amateur s.s.b. (single-side-band) transmissions, the regeneration control must be advanced until the *Q* multiplier is oscillating. The locally generated oscillation replaces the

regeneration control until the stage is just oscillating in the absence of a carrier signal. When a station is tuned in its carrier will suppress the oscillation and the weak signal will become audible.

## PUBLIC WARNING

This practice was widely adopted when regenerative receivers were popular for domestic listening. Unfortunately there was usually no radio frequency stage to isolate the detector from the aerial, and

carrier suppressed at the transmitter so that the signals can be demodulated in the usual way (more about this later).

Very precise tuning is required to clarify these signals, and the simple slow motion drive fitted on this version of the receiver is completely inadequate. Fortunately, the operation of the regeneration control produces a very slight shift in the *Q* multiplier's frequency of oscillation, and this can be used to fine tune and clarify these transmissions (increasing the drain voltage produces a very slight reduction in the gate to source capacitance).

The signals will still be difficult to resolve, however, and next month a tuning system dedicated to the three most popular amateur bands will be described.

An "earth" connection may improve reception. Guidance on constructing an earth system was given in Part 1.

## PERFORMANCE

The Regenerative Radio described here is a modern evocation of the 1913 circuit that made man's dream of long distance radio reception a reality. However, it should not be regarded as a historical novelty. Correctly built, connected to a decent aerial and skillfully operated, it will permit the reception of at least 90 per cent of the signals receivable on a modern, high performance communications receiver.

Skilful operation is the key to unlocking its performance. The need for this is, perhaps, the main reason why it was replaced by the more easily controlled superhet receiver.

It lacks automatic gain control, automatic input attenuators and pushbutton tuning. It does, however, offer a standard of performance out of all proportion to the minimal outlay of money and effort involved in its construction.

Next month's article, dealing with more refined tuning systems and general coverage and amateur bands coil packs, will help readers to get the best out of the receiver.

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# PRACTICAL RADIO CIRCUITS

RAYMOND HAIGH



## Part 4: Tuning systems, coils and coil packs for general coverage and the amateur bands.

*Circuits for the set builder and experimenter*

In Part Three the basic requirements of a regenerative receiver for serious listening on the long, medium and shortwave bands were listed and a simple but effective practical circuit described.

This month, we explore the merits of tuning systems and give details of add-on coil packs to extend the coverage of last month's High Performance Regenerative Radio into the amateur bands.

### TUNING SYSTEMS

Ease of tuning is crucial in a receiver to be used for searching for weak signals. Large movements of the control knob should produce only a small change in frequency and the drive must be free from backlash. For these requirements to be met components must be of good quality and set construction rigid and strong.

The Regenerative Radio design described last month incorporated the simplest possible tuning arrangements. Alternative and more refined systems will now be described.

### VARIABLE CAPACITORS

Charles S. Franklin, an engineer who spent most of his career in the service of Marconi, invented the variable capacitor in 1902. Receivers began to have more than

one tuned circuit, and Franklin introduced capacitor ganging in 1907.

Air-spaced variables with ceramic insulation are the components of choice for traditional tuning systems. They are more stable and have a higher  $Q$  factor (the greater the  $Q$  the more selective the tuning circuit) than solid dielectric capacitors. Unfortunately, the increasing use of electronic tuning is making them something of an expensive rarity.

A selection of the kind of air-spaced units still manufactured in the UK and the USA is shown in the photographs. Values range from 5pF to 365pF or more; and one, two, and three-gang versions can be obtained – at a price!.

Variable capacitors with a polythene dielectric are the standard tuning component in inexpensive domestic receivers. They were discussed and illustrated in Part One. The solid dielectric results in smaller size and makes them less prone to microphony (electro-mechanical feedback via the capacitor vanes). Minimum capacitance is lower (5pF instead of 10pF per gang).

Because of their low cost, ready availability and versatility, polyvaricons have been chosen for the receivers described in this series of articles. Constructors wishing to get the most out of these comparatively

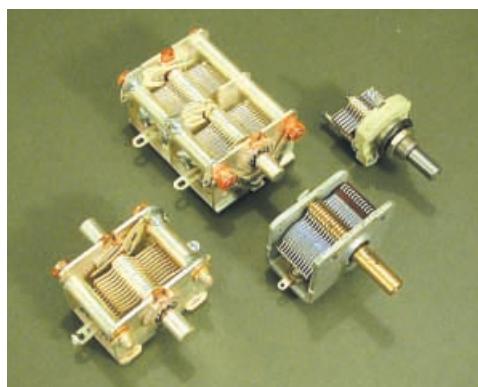
simple circuits should substitute air-spaced variables. Remember that moving vanes are connected to the "ground" or 0V rail; fixed vanes are connected to the "hot" end of the tuning coil.

### CAPACITOR SWING

The  $Q$  of a tuned circuit reduces as tuning capacitance increases. With regenerative receivers, positive feedback must, therefore, be gradually increased in order to keep the receiver in a sensitive condition. Setting up the circuit to ensure sufficient feedback at maximum capacitance can make regeneration fierce when the tuning capacitor is turned low, and smooth control can only be secured over a limited capacitor swing.

For long and medium wave coils, the maximum capacitance should be no greater than 400pF. On the highest shortwave range (up to 30MHz), smooth regeneration will be difficult to achieve if the maximum capacitance exceeds 100pF, and a 50pF component is to be preferred.

A reasonable compromise for general coverage regenerative receivers spanning 150kHz to 30MHz is a 200pF tuning capacitor, and provision for reducing the swing to around 100pF on the highest frequency shortwave range is most desirable. Receivers covering the narrow amateur bands are best tuned with a 25pF variable capacitor.



Group of air-spaced variable capacitors.



Slow-motion drives.



Spindle couplers.



Tuning "drums", spindle, springs and cord.

## SWING LOW

Fixed capacitors can be connected in series with tuning capacitors in order to reduce their swing. This technique, adopted in the circuits illustrated in Fig.4.3 and Fig.4.4, eases regeneration problems and reduces the tuning rate.

A 1000pF fixed capacitor will reduce the swing of a 260pF variable to 206pF. A 470pF fixed capacitor will reduce the swing of a 365pF variable to 205pF.

Always use polystyrene or low K ceramic components for this purpose. Medium and high K ceramic capacitors (usually values above 200pF or so) have a lower Q factor and this will impair the efficiency of the circuit.

## TUNING RATE

The sought after standard when communications receivers were tuned by variable capacitors was a frequency change of 5kHz for each full turn of the tuning control. This was seldom achieved with basic superhet designs, especially on the high frequency bands.

Tuning has to be set to within 25Hz or so of the signal frequency in order to clarify a single-sideband transmission. Doing this at 28MHz calls for a very slow tuning rate and a receiver of robust and rigid construction.

The tuning rate can be reduced by mechanical or electrical means, or a combination of both. The first method involves gears, pulleys or epicyclic ball drives: the second a low value fine tuning or vernier capacitor wired in parallel with

the main tuning component.

Both methods have the same drawback: an arrangement which produces an acceptable tuning rate at 2MHz is still much too fast at 20MHz. (Constant tuning rates can only be achieved with superhets of complex design; e.g., sets with tunable intermediate frequency (i.f.) amplifiers or synthesized oscillators).

The only mechanical reduction system currently available to home constructors is the epicyclic ball drive. A pointer mounting flange is sometimes fitted and the drives usually offer a 6:1 reduction. They can be coupled in tandem to give ratios of 36:1 and, if three are used, almost 220:1. Standard and miniature versions are depicted in the photographs.

A drum or large pulley driven by a cord wrapped around a 6mm (1/4in.) spindle forms an effective slow motion drive, and the component parts are shown in the photographs. The cord is secured to the drum and tensioned by a spring. Although still fitted in most capacitor-tuned portable radios, the parts are no longer retailed.

## VARICAP TUNER

### Easy-tune using a varicap diode

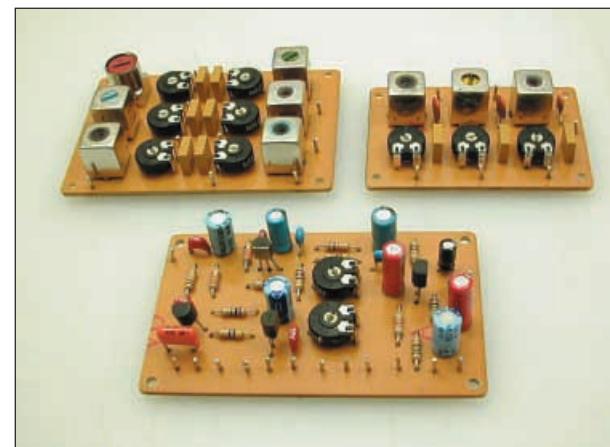
Electronic tuning systems exploit the way the capacitance across a semiconductor diode junction can be varied by applying a reverse bias. Special diodes, known as "varicaps" or "varactors", with swings of up to 500pF, are produced for this purpose.

Capacitance change is reasonably linear over the mid-range of reverse bias. At low bias levels, when capacitance is approaching maximum, the tuning rate is higher. At high bias levels the rate of change is much lower.

Varicaps are comparatively inexpensive and very convenient to use. The potentiometer Tuning control can be mounted remotely from the diode and this greatly simplifies receiver layout. Bandspreading involves no more than the addition of a second potentiometer.

## DRAWBACKS

There are disadvantages. They have a comparatively low Q, especially when the capacitance is approaching maximum.



General Coverage and Amateur Bands coil pack p.c.b.s together with the Regen. Radio board (last month).

Some constructors will, however, be able to salvage them from discarded receivers, and the drums will usually fit directly onto the stubby spindles of polyvaricon capacitors. Combining a large (say 100mm or 4in.) drum with an epicyclic drive gives a worthwhile reduction of around 120:1.

A fine tuning, or vernier, capacitor value of 10pF is a good compromise for a general coverage receiver. The main tuning component is called the Bandset, and the fine tuner the Bandspread, control. If both are fitted with 6:1 reduction drives the arrangement represents a very acceptable tuning system for simple receivers.

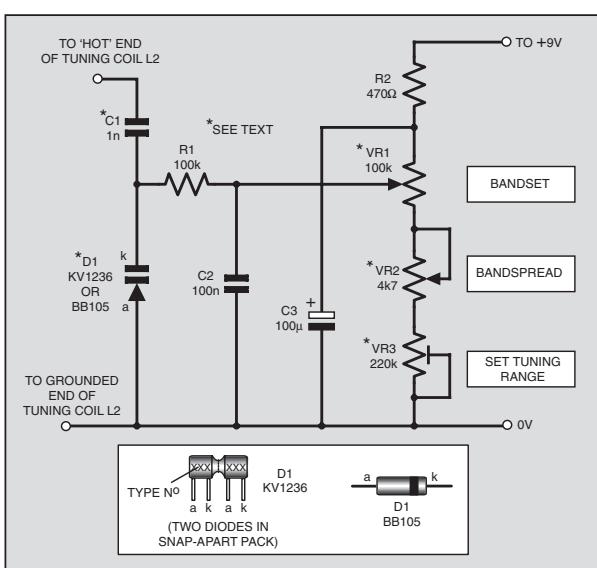
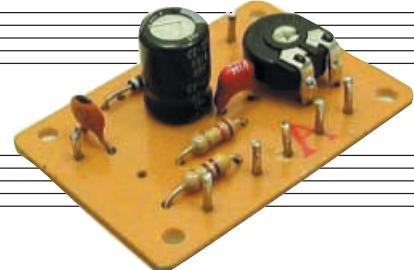


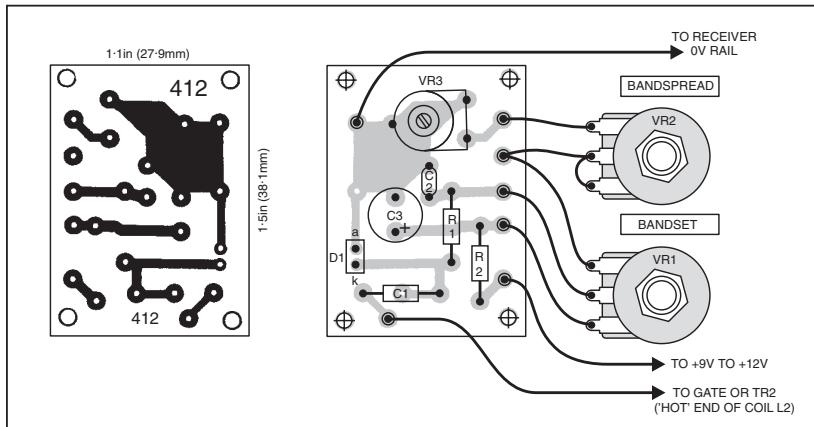
Fig.4.1. Circuit diagram for a simple Varicap Tuner. For Bandset and Bandspread tuning, use half of a twin KV1236 varicap. For Bandspread tuning only, use a BB105 varicap diode and a 22pF capacitor for C1. Also, omit VR2 and connect VR1 to VR3.

Moreover, high value types have a high minimum capacitance, and thermal drift can be greater than with conventional variable capacitors. The drawbacks become more evident when high capacitance diodes are used above 10MHz or so, but low capacitance types are satisfactory for fine tuning throughout the shortwave spectrum.

## VARICAP TUNER

A typical Varicap Tuner circuit is given in Fig.4.1, where D1 is the varicap diode and VR1 the potentiometer (Bandset) that sets the reverse bias. Signal frequencies are isolated from the bias network by resistor R1 (the diode passes no current so the resistor does not reduce the voltage). Capacitor C2 eliminates potentiometer noise and C1 prevents the bias being shorted to the 0V rail through the tuning coil.

Potentiometer VR2 produces a small change in the bias and acts as a fine tuning or Bandspread control. Potentiometer VR3



**Fig.4.2.** Printed circuit board component layout, wiring details and full-size underside copper foil master for the Varicap Tuner. Clockwise rotation of the pots. reduces the capacitance and increases frequency. The lead-off wires go to last month's Regenerative Radio.

determines the minimum bias voltage thereby fixing the varicap's swing.

In mains powered equipment, the bias supply must be well smoothed and regulated. With battery equipment, regulation is still essential if the tuning potentiometer has a calibrated dial. If the varicap acts only as a low value fine tuning capacitor, regulation, although still desirable, can be dispensed with, but supply-line fluctuations must not be imposed by other circuits (e.g., audio power amplifiers).

### CONSTRUCTION

The "electronic tuning" Varicap Tuner is assembled on a small printed circuit board that must be mounted close (within 50mm or 2in.) to the coil or coils and wavechange



switch. Tuning potentiometers can be located in any convenient position.

Details of the printed circuit board (p.c.b.) topside component layout, full-size copper foil master and the off-board wiring details are shown in Fig.4.2. This board is available from the EPE PCB Service, code 412. Full tuning and just vernier tuning alternatives were given earlier. General guidance on construction is given later.

## COMPONENTS

### VARICAP TUNER

#### Resistors

R1	100k
R2	470Ω
All 0.25W 5% carbon film	

See  
SHOP  
**TALK**  
page

#### Potentiometers

VR1	100k rotary carbon, lin.
VR2	4k7 rotary carbon, lin. (see text)
VR3	220k enclosed carbon preset

#### Capacitors

C1	1n polyester or polystyrene (full tuning) or 22p ceramic "low k" (bandspread only) – see text
----	---

#### Semiconductors

D1	KV1236 varicap diode (full tuning) or BB105 varicap diode (bandspread only) – see text
----	--

#### Miscellaneous

Printed circuit board available from the EPE PCB Service, code 412 (Varicap); multistrand connecting wire; insulated p.c.b. mounting stand-off pillar (4 off); solder pins; solder etc.

Approx. Cost  
Guidance Only

£9  
excl.



General Coverage Receiver.

## GENERAL COVERAGE AND AMATEUR BANDS RECEIVERS

### Upgrading the Regen. Radio (Part 3) to receive LW, MW, SW or Amateur Bands signals

It is our understanding that the only commercial coils available to home constructors in the UK are those produced by the Japanese manufacturer Toko. These miniature coils, with their ferrite cup or slug tuned cores and bright plated brass cans, are ubiquitous.

Any reader who has removed the back of a transistor radio will have seen them or an imitation. The adjustable cores permit wide variation of the inductance.

### GENERAL COVERAGE RECEIVER

The circuit diagram for a switched coil pack, General Coverage Receiver incorporating Toko inductors is shown in Fig.4.3. Coils L2a to L2f are tuned by the Bandset or Tune capacitor VC1, formed by connecting both a.m. gangs of a polyvaricon (polythene dielectric capacitor) in

parallel. The tuning sweep being reduced to around 200pF by series capacitor C19.

Fine or Bandspread tuning is carried out with VC2, one of the f.m. gangs of a second polyvaricon. The swing of this component is reduced to around 10pF by capacitor C20.

Readers using the receiver primarily for long and medium wave listening should delete capacitor C20 and leave VC2 at its full value. Where shortwave coverage is the area of interest, readers may prefer to reduce capacitor C20 to, say, 6.8pF in order to produce a slower tuning rate.

The inductors (L2a to L2f) are switched by S2a, and the TR2 source bias presets (VR2a to VR2f) by S2b. The circuit details around TR2 were given last month, see Fig.3.4.

Connections to the coil windings vary in order to increase inductance and/or to

improve the feedback tapping ratio. Details of the base connections are also given so that constructors wishing to use the coils individually, without the switching, can easily do so.

### AMATEUR BANDS

Amateur transmissions occupy narrow segments of the high frequency spectrum and the actual band allocations are listed in Table 4.1. Speech signals are in a mode known as single-sideband (s.s.b.), and tun-

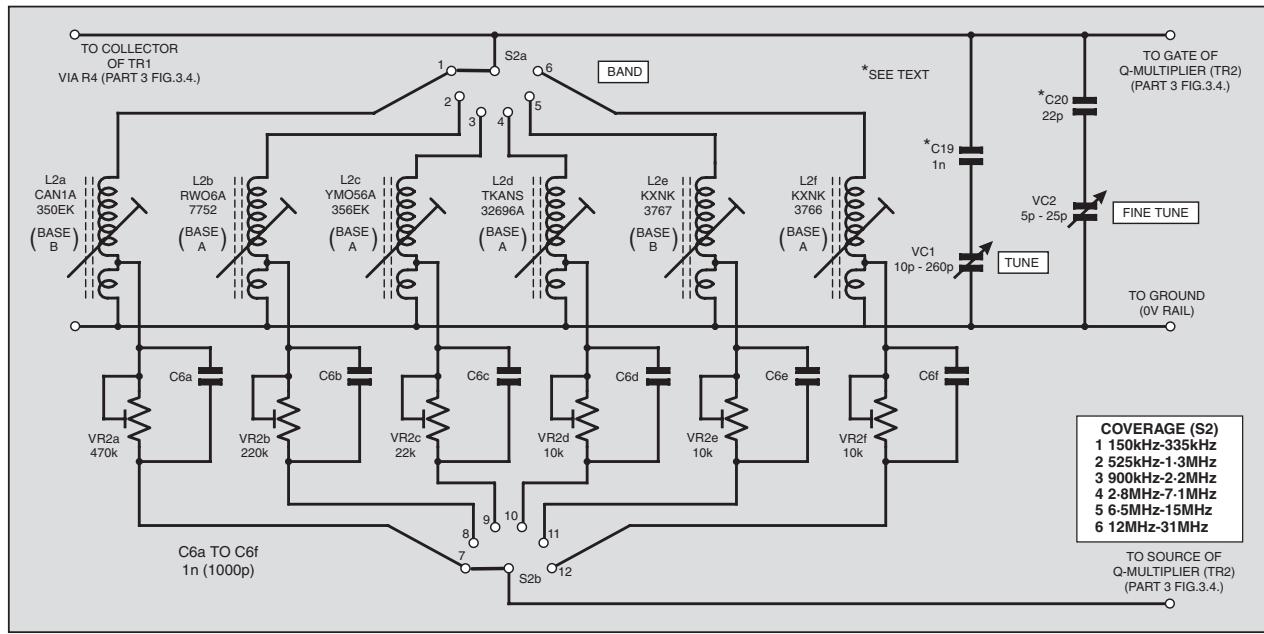


Fig.4.3. Coil pack circuit diagram for providing a switched 6-band General Coverage version of last month's Regen. Radio (see Fig.3.4). Maximum capacitance for VC1 (Tune) is set to 200pF approx. by series capacitor C19 and for VC2 (Fine) to 10pF approx. by C20.

**Table 4.1: Amateur Band Allocations and Marker Frequencies**

Band Metres	Frequency Allocation MHz	Marker Frequency MHz	Crystal Harmonic
80	3.5 to 4 (3.5 to 3.8 in UK)	3.58	Fundamental
40	7 to 7.3 (7 to 7.1 in UK)	7.16	Second
30	10.1 to 10.15	10.74	Third
20	14 to 14.35	14.32	Fourth
15	21 to 21.45	21.48	Sixth
12	24.89 to 24.99	25.06	Seventh
10	28 to 29.7	28.64	Eighth

The crystal frequency has been rounded up to 3.58MHz.

ing has to be very precise to make them intelligible. Because of the narrow bands and need for critical tuning, improved results will be obtained with the coil and capacitor combinations illustrated in Fig.4.4.

The circuit arrangement shown covers the three most popular allocations: 80, 40, and 20 metre bands. Coils L2a, L2b and L2c are switched by S2a, and brought to resonance within the band by fixed capacitors C19, C20 and C21.

Tuning is by one of the 5pF to 25pF f.m. gangs of a polyvaricon. Even this swing is excessive for the 40m and 20m bands and switch S2c connects series capacitors C22 and C23 into circuit in order to reduce it.

Source bias presets VR2a to VR2c, together with their bypass capacitors C6a to C6c, are switched by S2b. Again, coil base connections are given for readers who wish to use crocodile clips to connect coils into circuit. (The coil can/screen must be securely held in place or vibrations will affect tuning).

## COIL PACK CONSTRUCTION

Coils, presets and capacitors are assembled on printed circuit boards. These boards

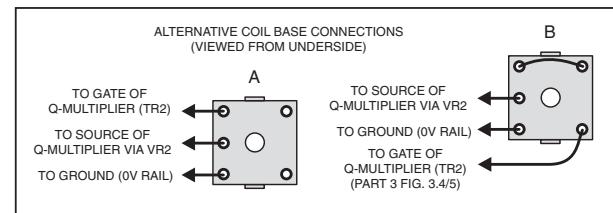


Fig.4.3a (above) and Fig.4.4a (below). Base connections for those wishing to "plug-in" individual coils, without any switching, into the General Coverage and Amateur Bands receivers.

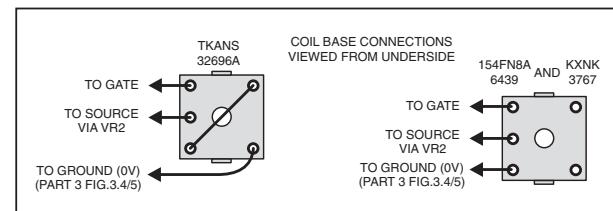
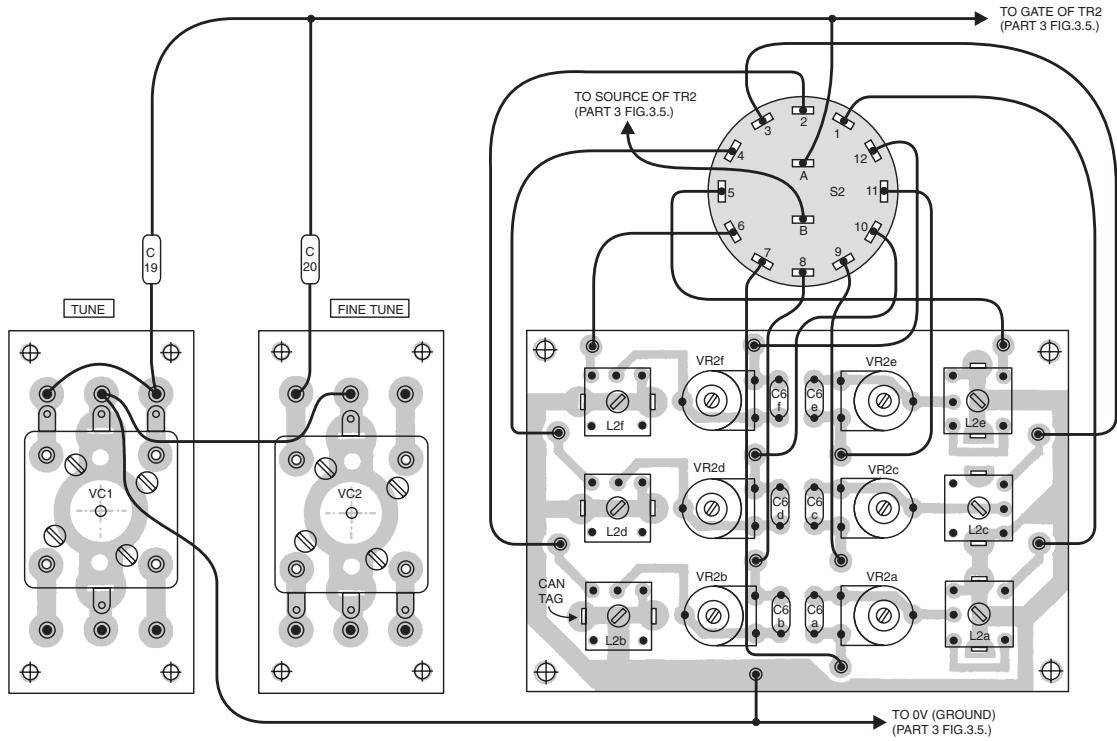


Fig.4.4. Circuit diagram for a 3-band Amateur Band version of last month's Regen. Radio (see Fig.3.4). Bands shown with an asterisk (\*) are wider in the USA: 3.5MHz-4MHz and 7MHz-7.1MHz. The coil and capacitor combinations will give full USA coverage.



## COMPONENTS

### GENERAL COVERAGE REC. (Coil Pack)

#### Potentiometers

VR2a	470k enclosed carbon preset
VR2b	220k enclosed carbon preset
VR2c	22k enclosed carbon preset
VR2d to	10k enclosed carbon preset (3 off)
VR2f	

#### Capacitors

C6a to C6f	1n polycarbonate (6 off)
C19	1n polystyrene
C20	22p polystyrene or ceramic "low k"
VC1	10p to 260p polythene dielectric variable capacitor (see text)
VC2	5p to 25p polythene dielectric variable capacitor (see text)

#### Miscellaneous

L2a	CAN1A350EK Toko screened (metal can) coil
L2b	RWO6A7752 Toko screened (metal can) coil
L2c	YMOS6A356EK Toko screened coil
L2d	TKANS32696A Toko screened coil
L2e	KXNK3767 Toko screened coil
L2f	KXNK3766 Toko screened coil
S2	2-pole 6-way rotary switch

Printed circuit boards available from the EPE PCB Service, code 413 (Coil Gen. Cover) and code 406 (T/Cap – two required); slow-motion drive (2 off); spindle extenders and/or couplers (see text); front panel card and protective 2mm thick Perspex sheet; p.c.b. stand-off pillars; connecting wire; solder pins; solder etc.

Note: Case is the Regenerative Radio in Part 3.

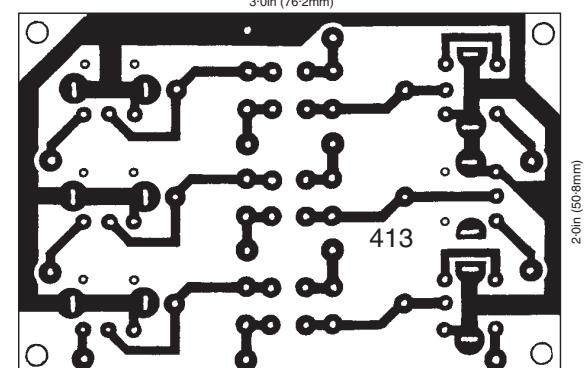


Fig.4.5 General Coverage Receiver coil pack printed circuit board component layout, full-size underside copper foil master and interwiring details to band selection switch S2, two varicon (polythene) variable capacitor p.c.b.s and lead-off wires to last month's Regen. Radio (see Fig.3.5). Wiring to actual unit must be kept as short as possible and direct.

See  
SHOP  
TALK  
page

### HAND-WOUND COILS (General Coverage Rec.)

Potentiometers	
VR2	100k enclosed carbon preset (4 off)
(Ranges 1 to 4)	
VR2 (Range 5)	22k enclosed carbon preset
VR2 (Range 6)	10k enclosed carbon preset

#### Capacitors

C6 (Ranges 1 to 6)	1n polyester (6 off)
--------------------	----------------------

#### Coils (see Table 4.2 and Fig.4.7)

Enamelled copper wire for coils, 50g (2oz) reels, sizes: 36s.w.g. (32a.w.g.), 32s.w.g. (30a.w.g.), 24s.w.g. (23a.w.g.), 18s.w.g. (16a.w.g.); plastic tube, 20mm (3/4in.) outside diameter (o/d) for coil former; thin card for coil bobbins; adhesive; clear cellulose; nuts; bolts, washers and solder tags.

Approx. Cost  
Guidance Only

£27  
excl. slow-motion drives & case

available from the EPE PCB Service, codes 413 (Gen.) and 414 (Amateur).

Details of the component side of the general coverage coil pack board, full-size copper foil track master and the wiring to the wavechange switch and tuning capacitors are given in Fig.4.5.

The component side of the amateur bands board, p.c.b. foil master together with the wiring to the wavechange switch and tuning capacitor are shown in Fig.4.6. Swing reducing capacitors, C22 and C23, are mounted on the tags of switch S2c: provision is not made for these components on the printed circuit board.

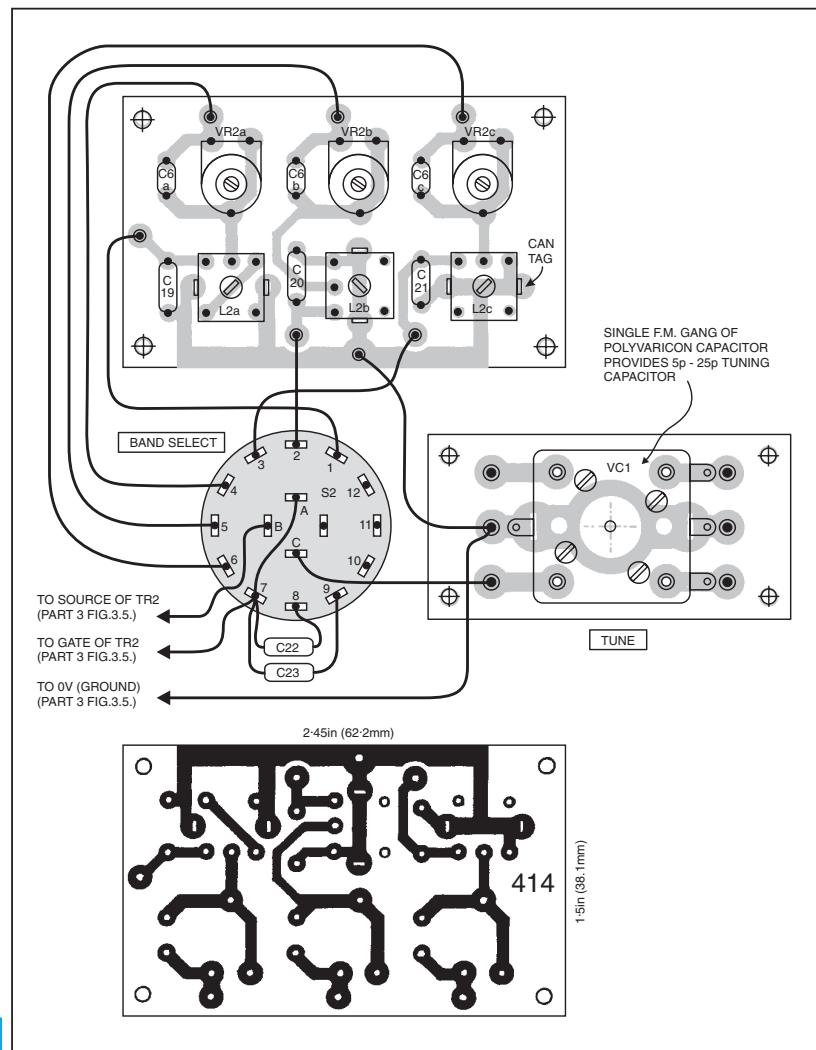
Note that the wiring to the variable capacitor is correct for the component suggested in the Components List. Alternatives should have their values and connections checked.

Coil pack, capacitors and wavechange switch S2 must be mounted very close to one another and all wiring kept as short as possible and direct. These components must also be very close to the terminal pin side of the Regen. Radio printed circuit board. Lead lengths should certainly be no more than 75mm (3in.). Guidance notes on construction are given later.

## HAND-WOUND COILS

With a little care and patience, efficient coils can be wound by hand on the plastic tubing manufactured for plumbing services and electrical conduits.

With the Regen. Radio circuit given in Part Three, the "feedback" tapping should be about 5% of the total number of turns for the longwave coil, and 10% of the total on all other ranges. The highest shortwave range; i.e., up to 30MHz, may require a



## COMPONENTS

### AMATEUR BANDS (Coil Pack)

#### Potentiometers

- VR2a 220k enclosed carbon preset
- VR2b 100k enclosed carbon preset
- VR2c 22k enclosed carbon preset

**See  
SHOP  
TALK  
page**

#### Capacitors

- C6a to C6c 1n polyester (3 off)
- C19 15p polystyrene or ceramic "low k"
- C20, C21 82p polystyrene or ceramic "low k" (2 off)
- C22 27p polystyrene or ceramic "low k"
- C23 18p polystyrene or ceramic "low k"
- VC1 5p to 25p polythene dielectric variable capacitor (see text)

#### Miscellaneous

- L2a TKANS32696A Toko screened (metal can) coil
- L2b 154FN8A6439 Toko screened (metal can) coil
- L2c KXNK3767 Toko screened (metal can) coil
- S2 4-pole 3-way rotary switch

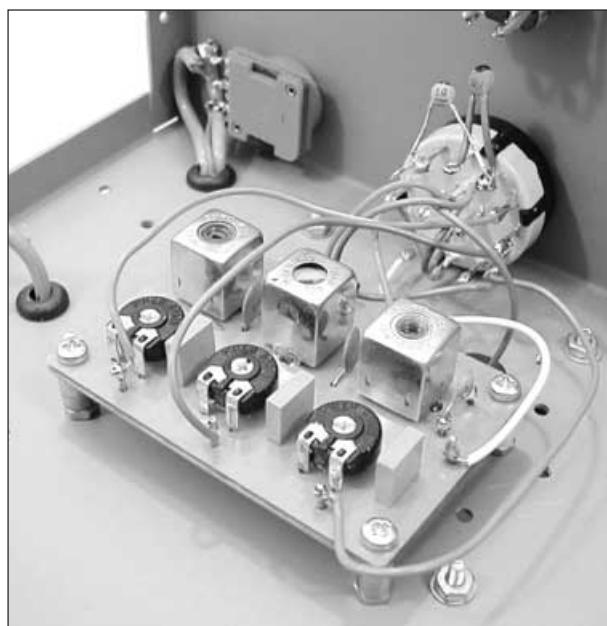
Printed circuit boards available from the EPE PCB Service, code 414 (Amateur) and code 406 (T/Cap); slow-motion drive (see text); spindle extender/coupler (see text); front panel card and protective 2mm thick Perspex sheet; p.c.b. stand-off pillars; connecting wire; solder pins; solder etc.

Note: Case is the Regenerative Radio in Part 3.

Approx. Cost  
Guidance Only

£15  
excl. slow-motion drive & case

Fig.4.6. Amateur Bands coil pack printed circuit board component layout, full-size copper foil master and interwiring to range switch, tuning capacitor p.c.b. and lead-off wires to last month's Regen. Radio (see Fig.3.5). All wiring should be kept short and direct.



Completed Amateur Bands coil pack p.c.b. wired to the wavechange switch.

15% tapping if the value of the tuning capacitor exceeds 100pF.

Winding details for a range of coils for a general coverage receiver are given in Table 4.2. The specified coverage is based on a tuning capacitor with minimum capacitance of 10pF and a swing of 200pF; i.e. both gangs of a polyvaricon with the swing limited by C19. (On the highest shortwave range, just one gang should be switched into circuit to give a swing of around 115pF.)

The higher inductance long and medium wave coils must be sectionalized to reduce self-capacitance and maintain an acceptable tuning range. This is done by winding the coils in a series of "pies" (the traditional term) or piles, held in place by card bobbins. Full details are given in Fig.4.7.

Thin card (postcard) glued with Durofix, or a similar quick setting adhesive, is ideal for the coil bobbins. It is a good idea to dip the bobbins in cellulose paint, in order to stiffen them, allowing the paint to harden before sliding them onto the plastic tubing.

## CLOSE CALL

When producing close-wound coils (turns touching), wind the turns on tightly and slightly spaced, and keep pushing them together with the thumb of the hand holding and rotating the former, as the winding proceeds. For space-wound coils, just concentrate on winding on the correct number of turns as tightly as possible, then carefully even out the spacing with the tip of a screwdriver (avoid damaging the enamel coating) when the ends of the coil have been anchored.

A coat of clear cellulose can be applied to hold the turns in place. Coils wound on bobbins can be protected by strips of masking or insulating tape but they must not be impregnated.

Solder tags are a convenient means of anchoring the ends of the windings. Wire gauges are not especially critical, but thicker material may not be accommodated in the bobbins or on the formers.

## COIL CHANGING

The coils can be connected into circuit by short (no more than 75mm or 3in.) flying leads terminated with miniature crocodile clips. Source bias preset VR2 and capacitor C6 can be mounted on solder tags at the end of the coil former (see Fig.3.6, last month) when this connection method is adopted.

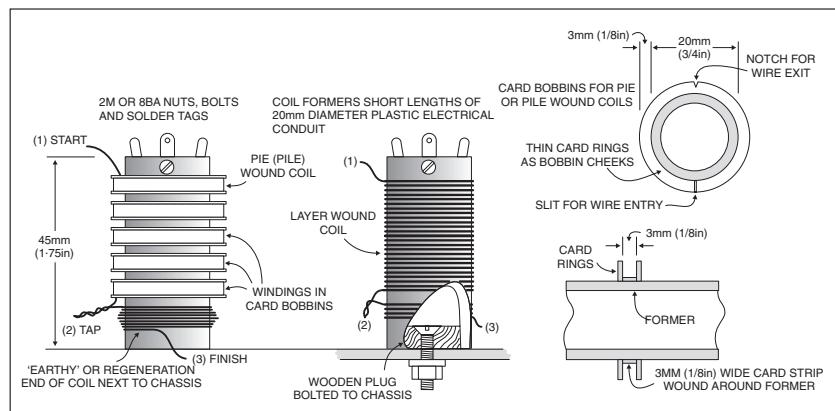
If hand-wound coils are arranged in a coil pack with wavechange switching, provision must be made to short out the coil next higher in inductance to the one in use. If this is not done it will be tuned by its self-capacitance to resonate within the tuning range of the coil in circuit and draw energy from it. This will cause a regeneration dead-spot.

Switches can be obtained which short all unused windings. They are much to be preferred for packs of *unscreened* coils.

Screening afforded by the metal cans and cup cores makes shorting arrangements unnecessary with Toko coils.

## CALIBRATION

An accurately calibrated dial adds greatly to the enjoyment of using a receiver and the following guidance is offered to readers who do not have access to a signal

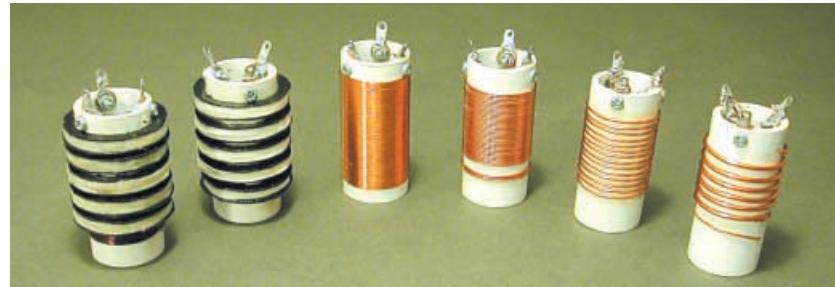


**1 – START of winding (to TR2 gate of Q-multiplier, see Fig.3.5 Part 3)**

**2 – TAPPING (to TR2 source of Q-multiplier, see Fig.3.5 Part 3)**

**3 – FINISH of winding (to 0V rail or ground, see Fig.3.5 Part 3)**

*Fig.4.7. Construction details for producing hand-wound coils for the General Coverage Receiver. see Table 4.2 for winding details and bands covered. A collection of completed hand-wound coils is shown below.*



**Table 4.2: Details of Hand-Wound Coils**

No. (S2)	Wave Band	Turns 1-2	Turns 2-3	S.W.G.	A.W.G.	Type of Winding	Range	VR2
1	LW	600	20	36	32	5 bobbins of 120 plus pile of 20	141kHz-345kHz	100k
2	MW1	160	16	32	30	4 bobbins of 40 plus bobbin of 16	520kHz-1.28MHz	100k
3	MW2	100	10	32	30	Close wound	1MHz-2.6MHz	100k
4	SW1	35	3	24	23	Close wound	2.6MHz-6.7MHz	100k
5	SW2	12	2	24	23	Spaced	6.4MHz-16.8MHz	22k
6	SW3	6	1	18	16	Spaced	13.5MHz-33.8MHz	10k

### NOTES:

- (1) Enamelled copper wire used throughout.
- (2) Tuning capacitor for Ranges 1 to 5: 10pF min. to 210pF max.
- (3) Tuning capacitor for Range 6: 5pF min. to 120pF max.
- (4) The Range 6 shortwave coil (SW3) has a separate 24s.w.g. feedback winding located at the "earthy" end of the tuned winding. Finish of both windings connected to the 0V rail and all turns wound in the same direction.

generator, crystal calibrator or frequency counter.

On medium waves, careful listening, during daylight hours, aided by a copy of the local and regional transmitter schedules (e.g., the *Radio Times*), should enable stations and frequencies to be identified and the receiver dial calibrated.

This procedure would be impossibly tedious on shortwaves. Here the simplest calibration method is to keep the Regen. receiver's tuning in step with the tuning of another receiver with an accurate, preferably digital, dial.

If the calibrating receiver has a beat frequency oscillator (b.f.o.), switch it on and

place its aerial lead close to the regenerative receiver's p.c.b. Advance the regeneration control until the *Q*-multiplier is oscillating. When both sets are tuned to the same frequency the calibrating receiver will pick up the signal radiated by the *Q*-multiplier circuitry and reproduce it as a tone.

Adjust the regenerative receiver's tuning to make the tone lower in pitch until it is an almost inaudible fluttering. This is the zero beat position and the tuning of the two receivers is then very precisely matched. By setting the calibrating receiver to precise spot frequencies, the regenerative receiver's dial can be marked out.

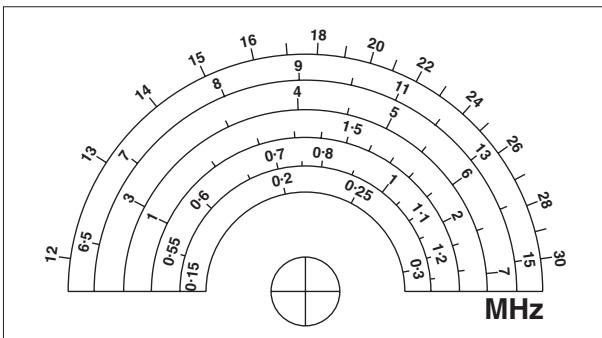


Fig.4.8. General Coverage Receiver dial, approx. half-size. Receivers will vary, but it gives a good idea of coverage to be expected.

## CONSTRUCTION NOTES

Solder pins at the lead-out points ease the task of off-board wiring. They should be located in the printed circuit boards first. Follow these with the resistors; then the capacitors, smallest first; and, finally, the semiconductors.

Take care to insert the coils in the correct positions on the printed circuit board. Identification lettering on the cans is quickly erased by handling. Readers wishing to preserve it should apply a piece of clear sticky tape. Stressing the coil pins can result in open-circuit windings, and they should be treated with great care.

Some variable capacitors are secured by screws driven into their front plates. Check the length of the screws to ensure that they do not project too far and foul the capacitor vanes.

Wiring between the printed circuit boards making up the receivers should be short and direct. **The ground plane on the coil pack p.c.b.s must be connected directly to the ground or 0V pin on the Regenerative Radio board. The Regeneration control may function erratically if there is a separate return via the case metal chassis.**

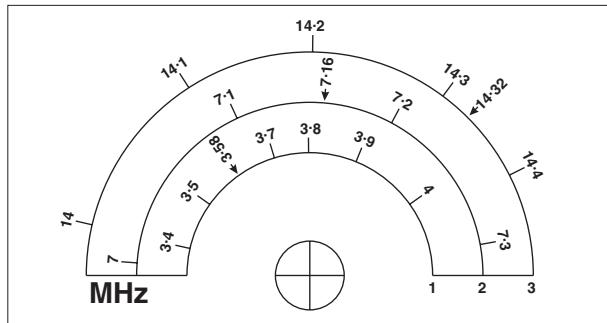
## FINAL CHECKS

On completion the printed circuit boards should be checked for poor soldered joints and bridged tracks. Check the orientation of semiconductors and electrolytic capacitors, the positioning of Toko coils, and the inter-board wiring.

The electronic tuning printed circuit board should be wired to the potentiometers, on the workbench, and tested before being mounted



General Coverage coil pack p.c.b. wired to the wavechange switch.



# PRACTICAL RADIO CIRCUITS

**RAYMOND HAIGH**



## Part 5: Super-regeneration: A highly sensitive receiving system

### Circuits for the set builder and experimenter

**T**HIS month we consider the technique known as super-regeneration. No other radio circuit, it is claimed, produces more gain from a single valve or transistor.

Readers who have access to a Frequency Counter may wish to use it as a digital readout dial for the Regenerative Receivers covered in Parts Three and Four, and the Direct Conversion receiver to be described later in the series. Details of a simple buffer amplifier for linking receiver to counter are given this month.

Before we tune-in to the subject of super-regeneration, readers may care to build the simple low-cost Crystal Marker calibration aid shown opposite. This is aimed particularly at last month's amateur bands receiver.

### SUPER- REGENERATION

Regeneration, whereby positive feedback from an amplifier is used to cancel out losses in a tuned circuit and increase its *Q* factor, was covered at length in Part Three. For the greatest increase in sensitivity and selectivity, the feedback has to be sufficient to almost completely overcome the losses. A little more and the circuit oscillates and becomes unsuitable for processing signals (other than single-sideband transmissions).

In practice it is impossible to set and hold a Q-multiplier on the very threshold of oscillation when a signal is being received, and the ultimate sensitivity which regeneration can offer is never fully realised.

The super-regenerative receiver overcomes this by imposing an oscillating voltage on the Q-multiplier to repeatedly sweep it across the critical threshold. This "quench oscillation", as it is called, can be provided by a separate stage or the multiplier itself can be made to perform a dual function.

Quenching must be at a supersonic frequency or it will be heard as a tone in the headphones or loudspeaker. In practice, the signal frequency is usually more than

1000 times the quench frequency, and this confines the circuit to the radio spectrum above 20MHz.

### SENSITIVITY

Oscillations in the super-regenerator build up from a signal voltage developed across the tuned circuit. In the absence of an external signal, the random movement of electrons, or "noise", triggers the action.

During the build-up, the amplitude of the oscillations can exceed that of the signal by as much as a million times. These phenomena give rise to the enormous sensitivity of the circuit and the loud hiss emitted by the speaker under no-signal conditions.

It is important that Q-multiplier oscillations die away during quench cycles or they will build up again from fading oscillations instead of the signal. Some means of controlling quench amplitude must, therefore, be provided.

### QUENCHING

Signal frequency oscillations can be "quenched" before they reach their maximum amplitude. The peak amplitude of the oscillations is then proportional to signal voltage and the receiver is said to operate in the *linear* mode.

If the quenching action is such that the oscillations reach, or even momentarily rest at, their maximum value, the circuit is said to be in *logarithmic* mode. Signals across the tuned circuit then speed up the rate at which the oscillations rise to, and decay from, their maximum value.

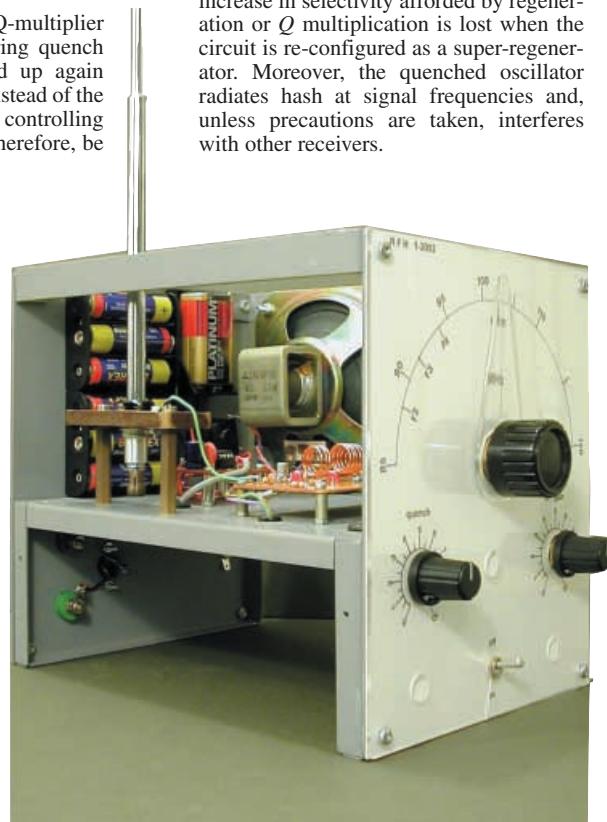
Operation in logarithmic mode causes Q-multiplier current drain to

follow the signal modulation. Because of this, the circuit combines detection with signal amplification, delivering an audio output that has a logarithmic relationship to the applied signal.

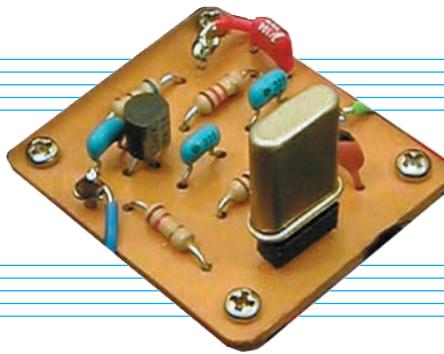
This condition introduces noticeable distortion on a.m. (amplitude modulation), but the drawback is not so pronounced with f.m. (frequency modulation). Logarithmic operation imposes a limiting action on noise spikes and strong signals, and the inherent a.g.c. (automatic gain control) is very apparent.

In the case of separately quenched receivers, they can be made to operate in either mode. Self-quenching receivers, which are, in effect, squeegging oscillators, operate logarithmically.

Whatever the mode, the enormous increase in selectivity afforded by regeneration or *Q* multiplication is lost when the circuit is re-configured as a super-regenerator. Moreover, the quenched oscillator radiates hash at signal frequencies and, unless precautions are taken, interferes with other receivers.



# **CRYSTAL MARKER**



## *Calibration aid*

The amateur bands receiver described last month presents particular calibration problems. Signals can be weak and difficult to resolve; sometimes the bands are dead.

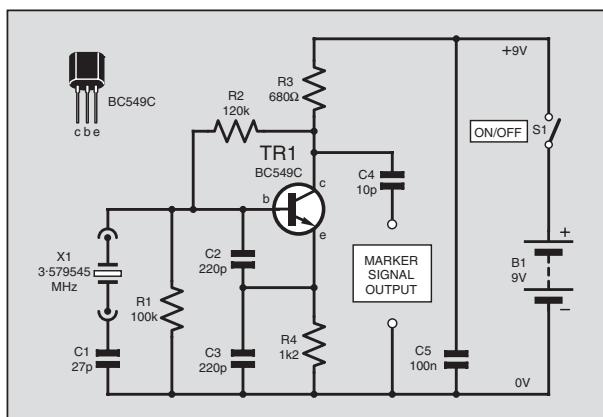
Constructors who do not have access to a calibrated receiver with a b.f.o. need some means of locating them. This can take the form of a simple and inexpensive crystal marker and, as the bands have a harmonic relationship, one crystal will pinpoint them all.

A circuit diagram for a simple amateur bands Crystal Marker is given in Fig.5.1, where transistor TR1 and crystal X1 are configured in Clapp's version of a Colpitt's oscillator. The crystal acts as a tuned circuit with high inductance, very low capacitance, extremely high  $Q$ , and exceptional stability.

Feedback from TR1 emitter is applied to the capacitance tap provided by C2 and C3. Crystal loading capacitor C1 is usually a 5pF to 60pF variable used to set the crystal frequency to its stated value against a known standard. The simpler circuit given here is accurate enough for our purposes.

Base bias is fixed by resistors R1 and R2, and TR1 emitter bias is developed across R4. Collector load resistor R3 must not be greater than R4 or oscillation will be inhibited. The signal output is taken from TR1 collector, via capacitor C4. Capacitor C5 avoids the possibility of erratic operation with ageing batteries.

The marker crystal used in this circuit is a 3.579545MHz component used in the colour sub-carrier circuitry of American



*Fig.5.1. Circuit diagram for an amateur bands Crystal Marker.*

*Fig.5.2 (right). Crystal Marker printed circuit board component layout, inter-wiring and full-size copper foil master. Also shown is the completed prototype; note the spare crystal compartment.*

# COMPONENTS

CRYSTAL MARKER

**Resistors**

R1	100k	<b>See SHOP TALK page</b>
R2	120k	
R3	680Ω	
R4	1k2	

All 0.25W 5% carbon film

## Capacitors

C1	27p polystyrene or ceramic "low k"
C2, C3	220p polystyrene or ceramic "low k" (2 off)
C4	10p disc ceramic
C5	100n disc ceramic

## Semiconductors

Semiconductors

TR1	BC549C <i>npn</i> silicon transistor
X1	3.579545MHz crystal (American TV colour sub-carrier)

### Miscellaneous

S1 s.p.s.t. toggle switch

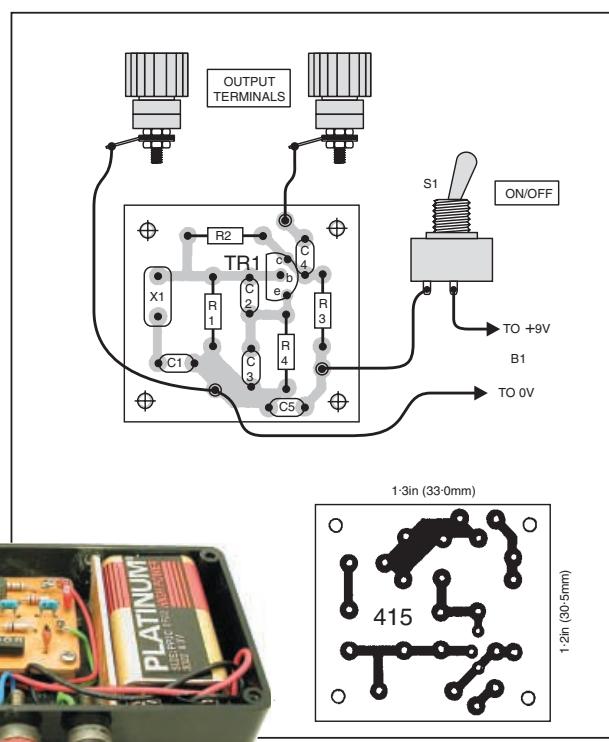
Printed circuit board available from the *EPE PCB Service*, code 415 (Crystal); plastic case, size 111mm x 57mm x 22mm approx.; 4mm terminal/socket (2 off); 2-pin crystal holder, cut from i.c. socket (3-pins, see text); 9V battery and holder; connecting wire; solder pins; solder etc.

*Approx. Cost  
Guidance Only*

£9

 excl case & hatt

The lead spacing on common HC-49/U and the lower profile U4 crystals is 4.88mm. This spans three pins on an i.c. holder, from which a socket can be cut.



# SUPER-REGENERATIVE RECEIVER

A low-cost super sensitive three-band (85MHz to 150MHz) regenerative receiver

## PRACTICAL CIRCUIT

A practical, semiconductor interpretation of a Super-Regenerative V.H.F. Receiver is shown in the circuit diagram of Fig.5.3. Originality is not claimed: the design is typical of many produced during the late sixties and seventies.

Grounded base signal amplifier TR1 isolates the regenerative detector TR2 from the aerial circuit. The audio preamplifier stage TR3 boosts the demodulated signal so that a decent loudspeaker output can be delivered by the simple audio power amplifier described in Part Two.

Emitter resistor R1 and bias resistors R2 and R3 fix the operating conditions of transistor TR1. Incoming signals from the aerial are applied to TR1 emitter via capacitor C1, and coupling coil L1 acts as the collector load. The stage is decoupled from the supply by R4 and C3, and C2 grounds TR1 base (b) at radio frequencies.

Input impedance is of the order of 50 ohms: a reasonable match to coaxial aerial cables. Quite short whip aerials are a quarter wavelength long at v.h.f., and they, too, can be adjusted to present a decent match.

The output from the r.f. stage is lightly coupled by L1 to the tuned circuit formed by coil L2 and tuning capacitor VC1. Increasing coupling to maximize signal transfer is likely to result in the erratic operation of the detector.

## REGEN. OSCILLATOR

Super-regenerative detector, TR2, is configured as a Colpitts oscillator. Colpitt's capacitor tapping is a little obscure with this v.h.f. version of his circuit. The internal gate-source capacitance of TR2 forms one element and trimmer capacitor VC2 the other. The trimmer presets the feedback that makes the transistor oscillate at the signal frequency.

The source (s) of TR2 is held at r.f. potential by r.f. choke L3 and C5 is a d.c. blocking capacitor. Quenching action is adjusted by potentiometer VR1, the range of control being confined to the critical region by resistor R6. Supply line decoupling is provided by R5 and C4, and this capacitor also eliminates potentiometer noise.

The tuning capacitor VC1 is one of the 5pF to 25pF f.m. gangs of a polyvaricon.



Stray capacitances with this simple receiver are comparatively low, and the swing is consequently too great for the required tuning range (88MHz to 108MHz). Moreover, if the tuning capacitance is too high, the super-regenerator will behave erratically or not function at all. Accordingly, fixed capacitor C6 reduces the maximum capacitance to suit the tuning range, and alternative values for different bands are given in Fig.5.5. Winding and construction details of the coils, including r.f. choke L3, are also depicted in Fig.5.5.

## AUDIO OUTPUT

An audio signal is developed across TR2 source resistor R7; and C7, R8 and C10 remove residual radio and quench frequencies. The signal is then applied to the base (b) of audio preamplifier TR3 by d.c. blocking capacitor C9.

The preamplifier stage is biased by R9 and emitter resistor R12. Resistor R11 forms TR3's collector (c) load which is shunted by capacitor C8 in order to attenuate the higher audio frequencies. Decoupling is effected by R10 and C14. Blocking capacitor C15 couples the output to Volume control potentiometer VR2.

Audio and radio frequency bypass capacitors, C12 and C13, ensure the

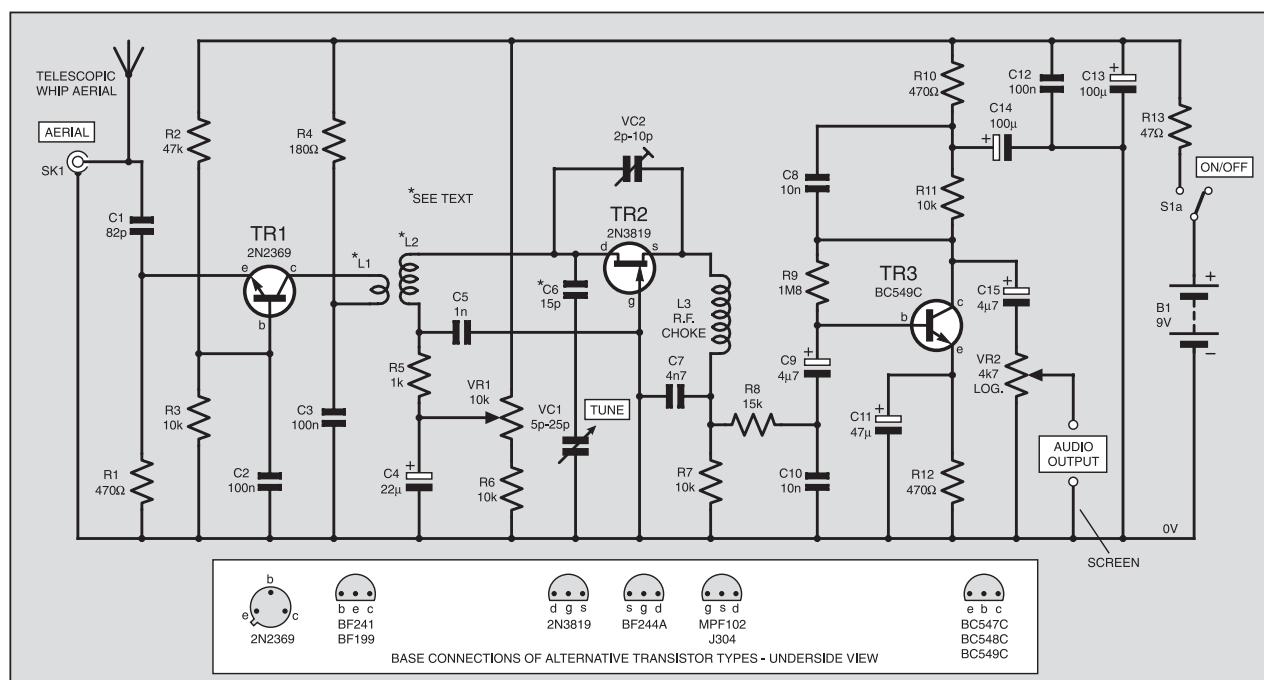


Fig.5.3. Full circuit diagram for a Super-Regenerative V.H.F. Receiver. Successful alternative semiconductors are shown inset. The other half of switch S1(b) controls the power supply to the simple Power Amp module from Part 2.

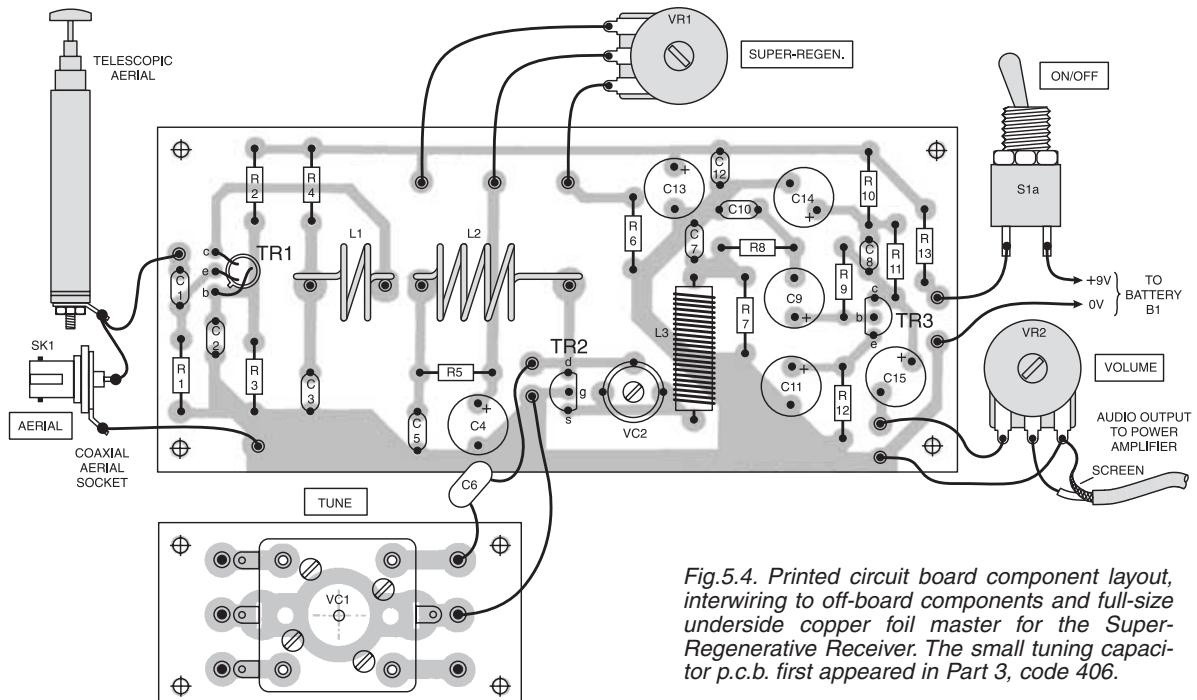
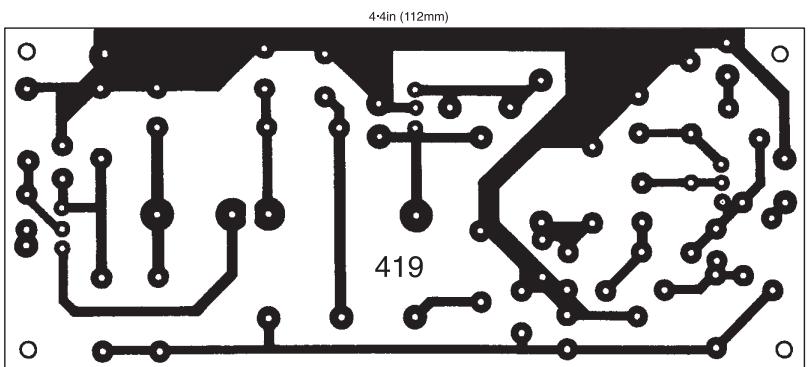


Fig.5.4. Printed circuit board component layout, interwiring to off-board components and full-size underside copper foil master for the Super-Regenerative Receiver. The small tuning capacitor p.c.b. first appeared in Part 3, code 406.



stability of the circuit, and resistor R13 isolates the battery and its supply leads at radio frequencies (signal pick-up by off-board wiring can make simple v.h.f. receivers behave erratically). The other half of the On/Off switch S1 (S1b) controls the supply to the audio power amplifier module, see Part Two.

As with the Regenerative Radio (Part 3), separate battery supplies for the receiver and audio power amplifier are strongly recommended. Even low power audio amplifiers can cause significant voltage swings on the supply rail and this will disturb the operation of receivers of this kind, even when decoupling is generous.

## SEMICONDUCTORS

Transistor types are not critical, and base connections for a number of alternative devices are included in Fig.5.3. The r.f. stage transistor, TR1, should have a high  $f_T$ , preferably not less than 500MHz.

Of all the devices tested in the TR2 position, only the 2N3819 would oscillate up to 150MHz, and available samples of J310 did **not** work well in this circuit. The suggested alternative transistors will,



Completed Super-Regen. circuit board.

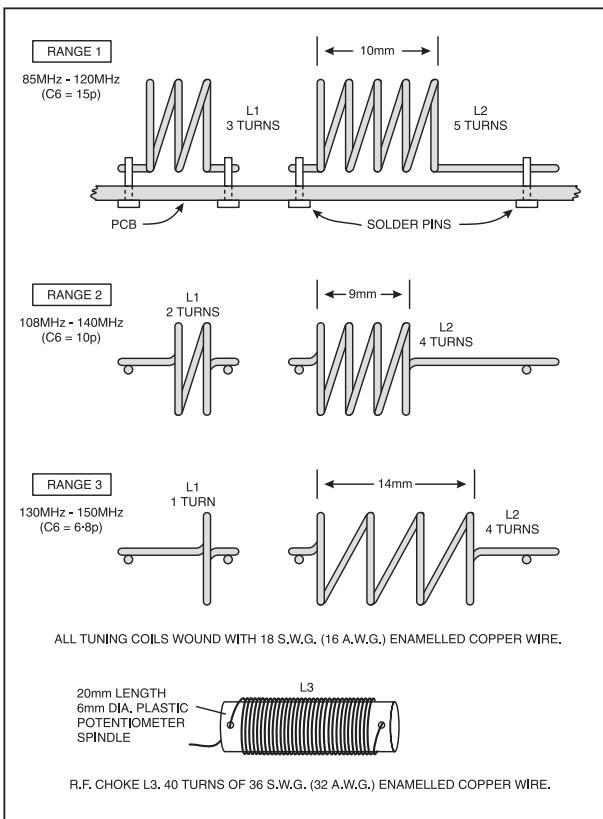
however, function on the v.h.f. f.m. band. Any small-signal *npn* transistor should work in the TR3 position, but a low-noise device with an  $h_{fe}$  of 500 or more is to be preferred.

## CONSTRUCTION

All of the components, with the exception of tuning capacitor VC1, swing limiting capacitor C6 and potentiometers VR1 and VR2, are mounted on a single-sided printed circuit board. The topside component layout, full-size copper foil master

and the off-board wiring details are illustrated in Fig.5.4. This board is available from the EPE PCB Service, code 419, together with the small variable tuning capacitor p.c.b., code 406.

Begin construction by inserting solder pins at the lead-out and coil mounting points, then solder the resistors and capacitors in position. Mount the semiconductors last. The leads of TR1 and TR2 should be kept quite short: just leave sufficient to attach a miniature crocodile clip to act as a heat shunt during soldering.



*Fig.5.5. Individual coils and r.f. choke details for the three tuning ranges. Tuning coils L1 and L2 both have a 10mm internal diameter. Wind around the shank of a 10mm drill*

## COILS

The simple coils are hand-wound and full details are given in Fig.5.5. Coupling and tuning coils, L1 and L2, are formed by winding them around the shank of a 10mm drill bit. Wind the turns on tightly, and bend the ends as shown in the diagram, before withdrawing the drill from the coil.

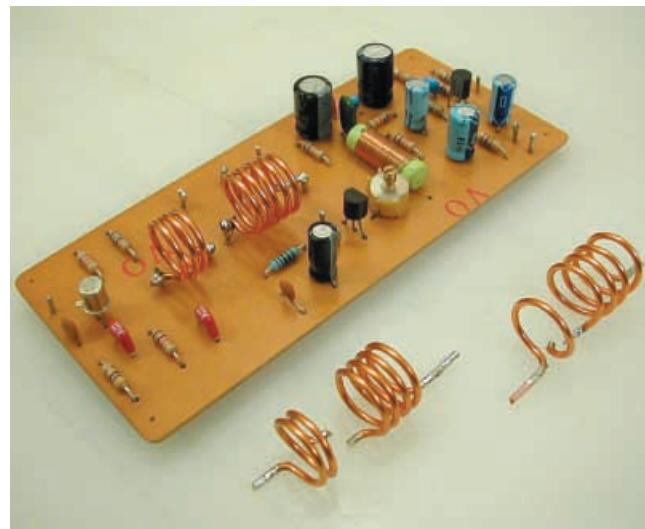
Radio frequency choke L3 is wound on a short length of 6mm diameter plastic potentiometer spindle (you could use a piece of wood dowelling). Holes, drilled close to the ends, secure the turns of wire.

Scrape the enamel from the wire until bright metal is exposed, then thoroughly "solder tin" the ends of the windings. Failure to make a perfect connection will prevent the receiver functioning at these frequencies.

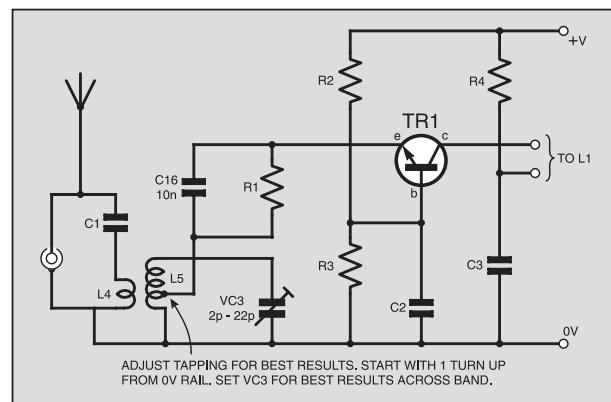
Coupling and tuning coils are mounted on solder pins. The short, horizontal extension to the tuned winding permits the coil to be squeezed or extended to adjust its inductance and frequency coverage.

Quite small changes in coil dimensions, wiring and components have a significant effect on coverage at these frequencies. If, however, the receiver is constructed as described, the coils depicted in Fig.5.5. should be within gentle "squeezing and pulling" range of the specified bands.

The Range 1 coils, which span the v.h.f. f.m. band, should be soldered in place first. Broadcast signals on these frequencies are strong and reliable, and this is of great assistance during the setting-up process. The Range 2 coils cover the v.h.f. Aircraft Band, and Range 3 the Two Metre Amateur band.



*Completed receiver board with alternative bands coils.*



*Fig.5.6. Circuit diagram for a simple front-end modification for tuning the input to the receiver. Note that L4 and L5 are identical to L1 and L2.*

## TESTING

Check the printed circuit board for poor soldered joints and bridged tracks. Check the semiconductors and electrolytic capacitors are correctly orientated. If all is in order, the board can be tested on the work-bench before being mounted on a chassis or in an enclosure.

Connect variable capacitor VC1 to the receiver p.c.b. using the leads of capacitor C6 as the "hot" connection, and wire up controls VR1 and VR2, see Fig.5.4. Use screened audio/coaxial leads to connect the receiver to the audio power amplifier described in Part Two. Set the vanes of trimmer capacitor VC2 to quarter-mesh and connect the batteries, via S1. Current consumption should be in the region of 3mA.

Advance Quench control VR1 until a loud hiss is heard in the speaker, indicating that TR2 is oscillating and quenching or squeegging. If the set seems dead, or if the hiss dies away at the maximum or minimum setting of the tuning capacitor, adjust trimmer VC2. The setting of VC2 is fairly critical and varies from transistor to transistor. It should, however, lie between 10 percent and 50 percent of full mesh.

Now connect a short length of flex (about 600mm or 24in.) to act as an aerial, and rotate tuning capacitor VC1 very slowly. Broadcast transmissions should be heard. When they have been identified, coil L2 can be compressed or expanded until the entire band is covered.

Despite the fairly broad selectivity of the super-regenerative detector, tuning at these frequencies is quite critical. Demodulation of the f.m. signal is achieved by tuning the receiver onto the carrier's side skirts. There are thus two, closely spaced, points on the dial where each station can be heard comparatively free from distortion.

After tuning the receiver, refine the adjustment of Quench control VR1: best results will usually be obtained with it set as low as possible.

## ASSEMBLY

The printed circuit board and tuning capacitor must be rigidly mounted and located so that the wiring between the two is as short as possible. Indeed, the back of the capacitor should almost touch the receiver p.c.b. Tuning will be considerably eased if tuning capacitor VC1 is fitted with some form of slow-motion drive.

The accompanying photographs show the board and VC1 mounted on the metal chassis and front panel used to evaluate other receivers in the series. The arrangement works well and the printed circuit board is reasonably accessible for coil changing.

If an aluminium box is used as an enclosure, make sure it is big enough for the coupling and tuning coils to be spaced at least 25mm (1in.) from its metal sides.

# COMPONENTS

Approx. Cost

Guidance Only

excl. case, batt, wire, slow-motion drive & whip aerial

£14

## SUPER-REGEN. RECEIVER

### Resistors

R1, R10, R12 470Ω (3 off)

R2 47k

R3, R6, R7, R11 10k (4 off)

R4 180Ω

R5 1k

R8 15k

R9 1M8

R13 47Ω

All 0.25W 5% carbon film

### Potentiometers

VR1 10k rotary carbon, lin.

VR2 4k7 rotary carbon, log.

### Capacitors

C1 82p disc ceramic

C2, C3, C12 100n disc ceramic (3 off)

C4 22μ radial elect. 16V

C5 1n disc ceramic

C6 (Range 1) 15p ceramic "low k"

(Range 2) 10p ceramic "low k"

(Range 3) 6p8 ceramic "low k"

C7 4n7 polyester

C8, C10 10n disc ceramic (2 off)

C9, C15 4μ7 radial elect. 16V (2 off)

C11 47μ radial elect. 16V

C13, C14 100μ radial elect. 16V (2 off)

C16 10n disc ceramic (optional – see text)

VC1 5p to 25p polythene dielectric variable

capacitor (see text)

See  
SHOP  
TALK  
page

### VC2

2p to 10p min. film dielectric trimmer capacitor

### VC3

2p to 25p min. film dielectric trimmer (optional – see text)

### Semiconductors

#### TR1

2N2369 *npn* small signal, high frequency transistor

#### TR2

2N3819 *n*-channel field effect transistor

#### TR3

BC549C *npn* low power general purpose transistor

### Miscellaneous

#### L1, L2, (L4, L5)

hand-wound with 18s.w.g. (16a.w.g.) enamelled copper wire – see text and Fig.5.5)

#### L3

r.f. choke, hand-wound with 36s.w.g. (32a.w.g.) – see Fig.5.5

#### S1

d.p.s.t. toggle switch

#### SK1

coaxial aerial socket

Printed circuit board available from the EPE PCB Service, code 419 (Super-Regen.) and optional 406 (T/Cap); 50g (2oz) reel 18s.w.g. (16a.w.g.) enamelled copper wire for coils; 50g (2oz) 36s.w.g. (32a.w.g.) enamelled copper wire for r.f. choke; 20mm approx. length, 6mm dia., plastic rod for r.f. choke former; one large and two small control knobs; telescopic whip aerial (optional); tagstrip (see text); batteryholder, with clips; slow-motion drive, spindle extender and/or coupler (optional – see text); multistrand connecting wire; solder pins; solder etc.

## ALTERNATIVE TUNING

The electronic tuning (Varicap Tuner) system, described last month, can be used with this receiver; at least on the v.h.f. f.m. band. The fine-tuning version, incorporating a BB105 varicap diode, should be built, and the connections between the boards must be as short as possible.

The varicap diode bias supply can be taken from the battery used to power the receiver. When this arrangement is adopted, it is *imperative* that the audio power amplifier be connected to a separate battery.

Readers who wish to carry out serious experiments with super-regenerative receivers should fit an air-spaced variable

capacitor with ceramic insulation. A Jackson C804 with a 3pF to 10pF swing would be suitable, and series capacitor C6 would only be required on Range 3. The slightly higher *Q* of the air-spaced component should help to maximize the operating frequency of the circuit.

## R.F. STAGE TUNING

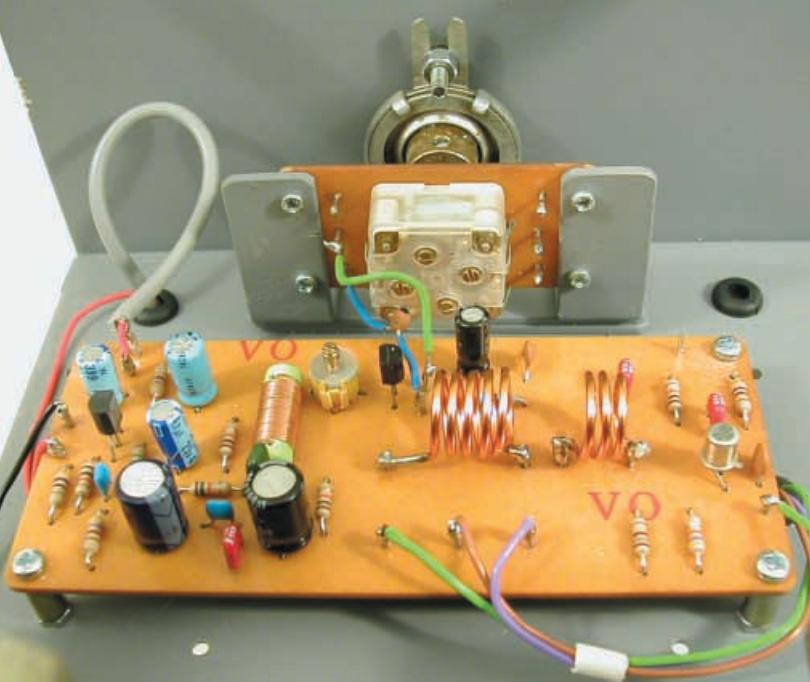
The grounded-base r.f. stage (TR1) isolates the super-regenerative detector from the aerial, helps to reduce the radiation of oscillator "hash", and makes the performance of the receiver more predictable. However, the simple arrangement adopted here provides little or no signal gain, and readers may wish to try an additional tuned circuit at the input in an attempt to improve performance.

The circuit diagram for a simple front-end modification is given in Fig.5.6. Aerial coupling coil L4 and the additional tuned winding L5 are duplicates of L1 and L2. A 2pF to 22pF trimmer capacitor, VC3, tunes L5 to the centre of the band.

Emitter resistor R1 is connected to the 0V rail via a tapping on L5. One turn above the 0V rail is a good starting point, but the position which gives the best signal-to-noise ratio should be found by trial and error. The emitter resistor R1 must be bypassed by additional capacitor C16.

Increasing TR1's collector current may improve performance. To do this, connect resistors ranging in value from 100 kilohms to 22 kilohms in parallel with R2 (the lower the value the greater the current).

The additional coils and trimmer capacitor can be mounted on a short solder tagstrip, and L4 and L5 must be orientated at right angles to L1 and L2. If the



Super-Regen. Receiver board mounted on the metal chassis, via stand-off pillars, and wired to the tuning capacitor.

## HISTORY

The discovery of super-regeneration is attributed to that great American radio pioneer, Howard H. Armstrong. In presenting his paper on the technique to the American Institute of Radio Engineers in 1922, he paid tribute to the earlier work of Turner and Bolitho. L. B. Turner had used critical biasing to hold a valve on the threshold of oscillation and make a signal-activated relay more sensitive. Bolitho patented a refinement of Turner's design in which the mechanical relay was replaced by a valve.

RCA purchased Armstrong's patents and various experimenters made attempts to apply the technique to medium wave reception which, by that time, had growing commercial importance in the USA. Designs usually incorporated a small frame aerial to overcome shortcomings in selectivity, and crude audio filtering to reduce the whistle from quenching oscillations.

For reasons already outlined in the main text, the circuit is unsuited to amplitude modulated broadcast reception, particularly on medium waves. Not surprisingly, therefore, the concept was not taken up by domestic receiver manufacturers, and ownership of the patent rights failed to produce much income for RCA (Radio Corporation of America).

During the twenties and thirties the circuit was used extensively by the police and emergency services. The Second World War saw the technique adopted for I.F.F (identification-friend-or-foe) responders. These devices received a radar pulse and responded, with a minimum of delay, by transmitting an identifying signal.

German air interception radar systems also relied upon the circuit. Perhaps the best known of these war-time applications was the American "walky-talky", in which the super-regenerative detector doubled as the transmitter valve.

The post-war years saw the establishment of high-quality frequency modulation broadcasting systems in Europe and America. In 1947, B. D. Loughlin developed a design for a double-triode (12AT7) super-regenerative f.m. tuner, one valve being used as a frequency changer, the other as the detector. Known as the "Fremodyne", the circuit was licensed by the American Hazeltine Electronics Corporation. Whilst the Fremodyne suffered all of the defects super-regenerators are prone to, it did have the advantages of simplicity and low cost.

At the present time, super-regeneration is still used for simple toy and model control receivers, car central locking and garage door opening systems.

modification causes instability, fix a metal screen between the tagstrip and the printed circuit board.

## PERFORMANCE

This simple Super Regen. circuit effectively demonstrates the extremely high sensitivity of Armstrong's super-regenerative system. Frequency stability is remarkably good, hand-capacitance effects are not too pronounced and the super-regeneration

control is smooth and effective. Automatic gain control action (a.g.c.) is very evident, and the loud hissing which characterizes circuits of this kind is completely suppressed by a strong signal.

On the v.h.f. f.m. band, careful adjustment of the tuning and super-regeneration controls enables an acceptable compromise to be struck between audio output and distortion. However, as constructors of the Hazeltine Fremodyne (including the

author) found, performance falls short of a conventional superheterodyne receiver with a ratio detector or Foster-Seeley discriminator as the signal demodulator.

Domestic f.m. superhets have seven or more tuned circuits and perhaps five transistors amplifying at radio frequencies. A basic super-regenerator has only one tuned circuit and one valve or transistor providing gain at radio frequencies. Armstrong's genius continues to inspire.

## BUFFER AMPLIFIER

### Adding tuned frequency digital readout

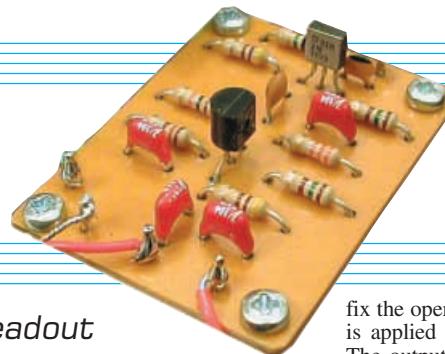
Some readers who have built one of the versions of the regenerative radios described in Parts Three and Four will have access to a Digital Frequency Counter, and they may wish to use it to give a digital readout of receiver tuning.

Damping of the receiver's tuned circuit must be kept to an absolute minimum, and the signal levels across it are usually too low to reliably trigger most frequency counters. Direct connection is, therefore, out of the question, and a buffer amplifier must be placed between the two units.

### BUFFER CIRCUIT

The circuit diagram for a suitable Buffer Amplifier is given in Fig.5.7.

Field-effect transistor TR1 is arranged as a common drain or source follower stage. Its high input impedance, together with the low value of coupling capacitor C1 minimises disturbance and damping to the receiver's tuned circuit. The d.c. potential on TR1 gate is held at 0V by resistor R1 and TR1's output is developed across source load resistor R3. Supply rail decoupling is provided by R2 and C2.



fix the operating conditions, and the signal is applied to TR2 base via capacitor C3. The output signal is taken from TR2 collector to the Frequency Counter, via capacitor C6. The collector load resistor is R7, and R6 and C5 decouple the output stage.

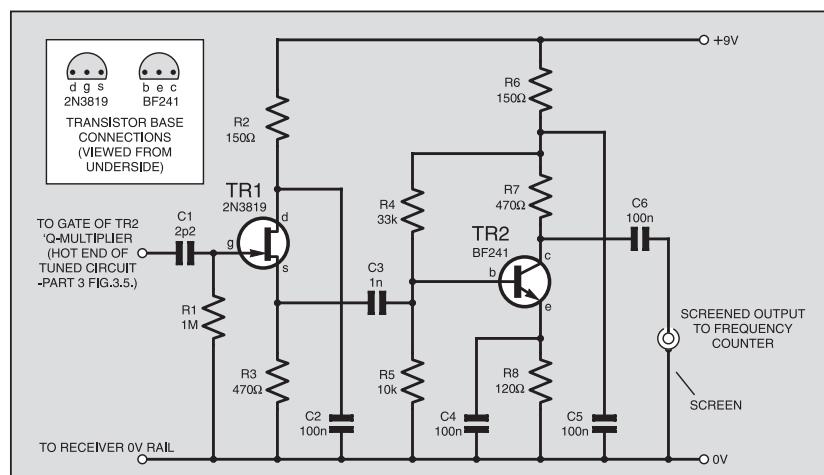


Fig.5.7. Circuit diagram for a Buffer Amplifier for a Digital Frequency Counter. A frequency counter, connected to the tuned circuit via this buffer, will give a digital display of the receiver tuning. This arrangement is NOT suitable for the Super-Regen. Receiver – see text.

# COMPONENTS

## BUFFER AMP.

### Resistors

R1	1M	See SHOP TALK page
R2, R6	150Ω (2 off)	
R3, R7	470Ω (2 off)	
R4	33k	
R5	10k	
R8	120Ω	

All 0.25W 5% carbon film

### Capacitors

C1	2p2 disc ceramic
C2, C4	
to C6	100n disc ceramic (4 off)
C3	1n disc ceramic

### Semiconductors

TR1	2N3819 n-channel field effect transistor
TR2	BF241 npn small signal, high frequency transistor

### Miscellaneous

Printed circuit board available from the EPE PCB Service, code 420; input connector, to suit frequency counter; single-core screened audio cable; multistrand connecting wire; solder pins; solder etc.

Approx. Cost  
Guidance Only

£8

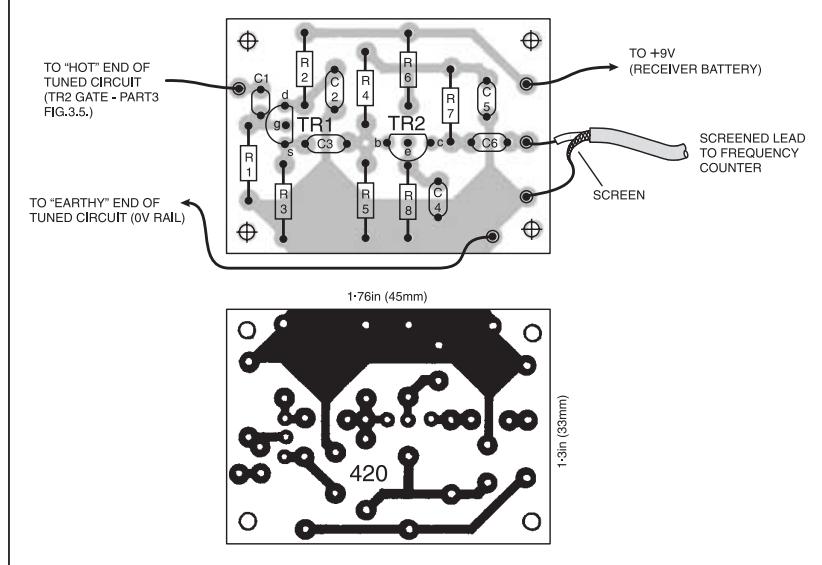


Fig.5.8. Buffer Amplifier printed circuit board component layout, wiring details and full-size copper foil master.

Most n-channel field-effect transistors will prove suitable for TR1. The BF199, BF494 and 2N22A were in-circuit tested in the TR2 position and they all worked well. Base connections vary and should be checked.

## CONSTRUCTION

All of the Buffer Amp. components are mounted on a small printed circuit board and the component layout, copper foil master and wiring details are shown in Fig.5.8. This board is available from the EPE PCB Service, code 420.

Solder pins at the lead-out points simplify the off-board wiring, and they should be inserted into the p.c.b. first. Follow these with the resistors, then the capacitors and, finally, the transistors. As before, keep the transistor leads just long enough to permit the use of a miniature crocodile clip as a heat shunt during soldering.

## TESTING

Check the printed circuit board for poor soldered joints and bridged tracks, and check the positioning of the transistors. Connect the unit to a 9V supply. Current consumption should be in the region of 7mA.

Make a very short connection, certainly no more than 75mm (3in.), between the buffer amplifier's input and the "hot" end of the receiver's tuned circuit. Connect the amplifier's 0V rail to the ground or 0V tag on the tuning capacitor. Power for the amplifier can be taken from the receiver battery.

Connect the output from the buffer amplifier to the Frequency Counter via a short (no more than 600mm or 24in.) length of screened cable.

## OPERATION

Set the counter's input controls, tune in a station and advance the regeneration control, turning down the receiver's input attenuator, as necessary. When tuning is correct and the regeneration setting has been optimized, the counter should display the "tuned" frequency.

The counter will normally only give a frequency reading when a station is tuned in. To check tuning on a quiet part of the dial, advance the regeneration control until the Q-multiplier is oscillating. The counter will then display the operating frequency.

When receiving single-sideband signals the regeneration control has to be advanced

until the Q-multiplier is oscillating in order to replace the carrier suppressed at the transmitter. The counter will, therefore, give a continuous frequency readout as the receiver is tuned across the amateur bands.

## OTHER RECEIVERS

The Buffer Amplifier and Frequency Counter combination cannot be used with the Super-Regen. Receiver. Here the oscillating stage is "squegging" and the



The Buffer Amplifier wired to the Regenerative Radio (Part 3) and the tuning capacitor p.c.b.s.



A frequency counter wired, via the Buffer Amplifier, to the Regenerative Radio and showing an amateur band frequency readout.

# PRACTICAL RADIO CIRCUITS

RAYMOND HAIGH



## Part 6: Single-sideband and direct conversion.

### Circuits for the set builder and experimenter

**S**UPPRESSED carrier single-sideband (s.s.b.), a highly efficient method of transmitting speech by radio, will be considered this month. A popular and simple technique for receiving these signals is known as direct conversion, and a circuit is included.

#### CARRIERS

Radio frequency transmissions cannot, by themselves, convey information. They are no more than *carriers*, and the speech or music has to be impressed upon them by a process known as *modulation*.

The amplitude of a carrier can be varied in sympathy with a speech signal, and the process is known as *amplitude modulation*. This is the oldest and still the widest used method of transmitting speech and music by radio. It was described in Part One of the series.

If a 1000kHz carrier is amplitude modulated by a 3kHz signal, two sidebands, each 3kHz wide, are produced. The radio transmission then occupies a bandwidth of 6kHz, extending from 997kHz to 1003kHz.

Assuming a reasonable depth of modulation, some 50% of the total power supplied by the transmitter is expended on the carrier and 25% on each of the sidebands. Just one sideband is carrying all of the information in the signal. The other sideband is, in

effect, a mirror image of reverse polarity removed by the rectifying action of the detector in the receiver. With conventional amplitude modulation, around 75% of the transmitter power is, therefore, wasted. By suppressing the carrier and one of its side bands, transmitter efficiency is greatly increased and bandwidth halved.

#### RECEPTION

Equipment for the reception of single-sideband transmissions must include an oscillator to replace the missing carrier. When the carrier has been restored, a diode or some other non-linear detector can make the signal intelligible in the usual way.

Simple regenerative receivers are capable of resolving single-sideband transmissions if the Q-Multiplier is made to oscillate and restore the missing carrier. An Amateur Bands Regenerative Receiver was described in Parts Three and Four.

Better performance can be obtained from a mixing circuit that combines the signal and local oscillation and, at the same time, recovers the wanted audio. Circuits of this kind are known as *product detectors*. They function in the same way as mixers in superhet receivers, but the output is at audio rather than at radio frequencies.

#### HISTORY

Single-sideband transmission was invented by John R. Carson, an American engineer. Initially, the technique was used to conserve channel space in carrier-current telephone systems, but, by the late 1920s, it was being deployed at low (60kHz) radio frequencies for the transatlantic telephone service.

During the Second World War, single-sideband transmitters were used, by the American forces, for long distance radio communication. The British avoided the technique, claiming it was technically too demanding for a battlefield environment, but they adopted it after the war.

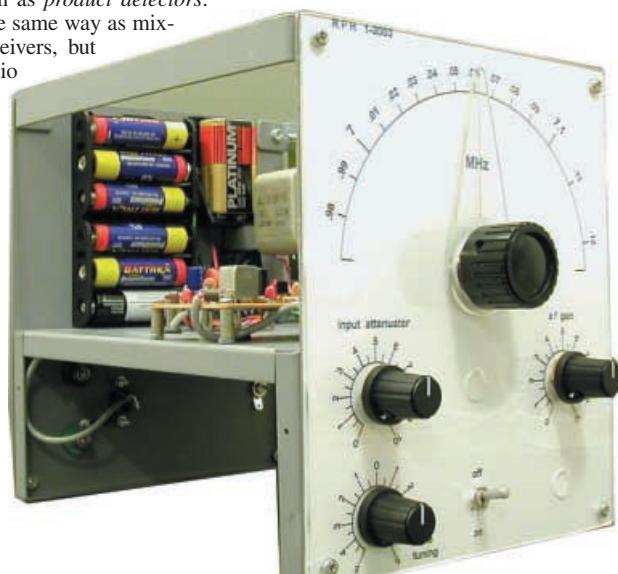
American amateurs began to test the system in the 1940s, and it was taken up, by amateurs, world-wide, during the sixties. At the present time it is the standard mode of speech transmission on all of the high-frequency amateur bands.

A simple technique adopted by radio amateurs involves feeding signals picked up by the aerial straight into a product detector and amplifying the audio frequency output. Sometimes the signals are amplified before being passed to the detector, but the crucial feature of the technique is the direct conversion of the radio frequency transmissions to an audio frequency signal, hence the term *direct conversion*.

#### PASSIVE DETECTOR

Passive product detectors use an arrangement of between one and four diodes to combine the two radio frequency inputs and produce an audio output. A typical circuit diagram is given in Fig.6.2. Its operation will be described later, but the important features are simplicity, low cost, and immunity to overloading by strong signals. On the down side, the circuit attenuates the signal by about 6dB.

The simplest receivers place a passive detector of this kind immediately after the aerial tuned circuit. There is no amplification at radio frequencies, and a very high gain audio amplifier is needed to overcome detector losses and make the signals audible.



Even when an efficient aerial is available to deliver the strongest possible signals to the receiver, results are likely to be disappointing. Moreover, the high levels of audio frequency amplification are usually accompanied by hum pick-up and microphony problems.

The microphony arises because the receiver components and wiring act as a microphone, picking up vibrations. This manifests itself as clanging and ringing sounds when the receiver is touched or adjusted, the sounds growing into howls as feedback from the loudspeaker takes over.

The situation can be improved by preceding the passive detector with a stage of radio frequency amplification. The improved gain distribution does a great deal to overcome the problems outlined above, but receivers of this kind still require high levels of audio amplification.

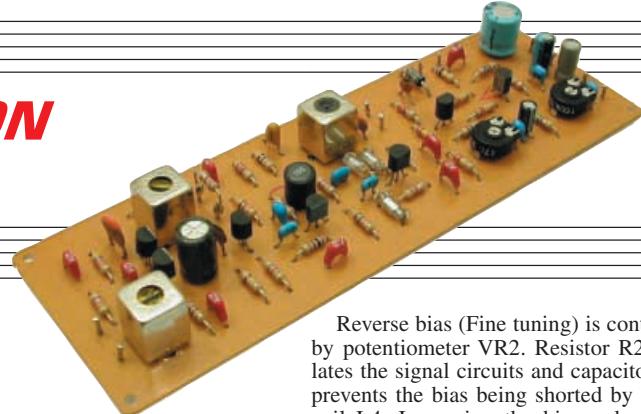
### ACTIVE DETECTOR

An active product detector, which gives signal amplification rather than attenuation, will usually transform the performance of these simple receivers. A drawback with this arrangement is the

possibility of cross modulation being caused by overloading.

When this occurs, weak signals are modulated by strong ones within the product detector and the strong signals seem to spread across the entire band. Careful use of the receiver's input attenuator will do much to prevent this.

Unwanted envelope detection, or rectification, of powerful, amplitude modulated transmissions is a more prevalent cause of breakthrough with simple active or passive product detectors. Again, the strong signals spread across the band and cannot be tuned out.



## DIRECT CONVERSION RECEIVER

*A sensitive, single-sideband, amateur band set*

The full circuit diagram for an amateur bands Direct Conversion Receiver is shown in Fig.6.1. A radio frequency amplifier, consisting of TR1 and TR2, precedes the product detector, TR3. The carrier replacement oscillator is TR5, its output being buffered and amplified by TR4. Audio amplification is provided by TR6 and TR7.

### R.F. STAGE

Field-effect transistors, TR1 and TR2 form a cascode where TR1 is configured in the common source and TR2 in the grounded gate mode. This combination gives about 20dB of gain. Input and output impedances are high and damping on the tuned circuits, L1/C4 and L2/C5, is minimal.

Source bias to TR1 is provided by resistor R3 which is bypassed by capacitor C6. The gate (g) of TR2 is held at half the supply voltage by resistors R1 and R2, and grounded at radio frequencies by capacitor C3. The stage is decoupled from the supply rail by resistor R4 and capacitor C2.

All of the windings of coil L1 are connected in series to provide an appropriate tapping ratio for Input Attenuator potentiometer VR1. This helps to maintain the *Q* factor and selectivity of the tuned circuit. The aerial is connected to the circuit via capacitor C1, which is included to protect any preamplifiers or converters against shorting by VR1.

The tuned circuit formed by coil L2 and capacitor C5 acts as the drain (d) load for TR2, and the output is coupled to the gate (g) of TR3, the product detector, by capacitor C7.

Despite the isolation between the input and output ports afforded by grounding the base of TR2, the cascode r.f. stage is not unconditionally stable. Indeed, because of the light loading on both tuned circuits, the stage will come close to oscillation when they are precisely aligned to the same frequency.

Accordingly, resistor R5 is connected across the coupling winding L3 to provide additional damping. This increases the stability margin and the problems are avoided. When the alternative passive detector circuit (described later), given in Fig.6.2, is used, the damping imposed by the diodes and balance potentiometer serves the same purpose.

### PRODUCT DETECTOR

Field-effect transistor TR3 is configured as a product detector. Signal input is to the gate, oscillator input to the source through capacitor C11, and the audio frequency output is taken from the drain.

The drain load resistor is R8 and R7, C8 and C9 decouple the stage from the supply rail at audio and radio frequencies. Source bias for TR3 is provided by resistor R9, and the d.c. potential on the gate is held at 0V by R6.

### OSCILLATOR

A Colpitts oscillator, TR5, replaces the carrier suppressed at the transmitter. The capacitance tap across tuning coil L4 is formed by capacitors C20 and C21, and feedback is developed across emitter resistor R17. The stage is biased by resistors R18 and R19, and heavily decoupled by R15, R16, C14 and C15.

All sections and windings of oscillator coil L4 are connected in series to obtain the required inductance, and it is brought to resonance within the 7MHz amateur band by capacitor C22. Main tuning is by VC1, one of the 5pF to 25pF f.m. gangs of a polyvaricon tuning capacitor, and capacitor C23 reduces its swing to restrict coverage to the 7MHz amateur band.

Without some means of fine tuning, the single-sideband signals will be difficult to clarify. A shift of one or two picofarads is all that is required, and the varactor properties of an ordinary power rectifier diode, D1, can provide this.

Reverse bias (Fine tuning) is controlled by potentiometer VR2. Resistor R20 isolates the signal circuits and capacitor C24 prevents the bias being shorted by tuning coil L4. Increasing the bias reduces the capacitance across the semiconductor junction of D1.

### BUFFER STAGE

The output from oscillator TR5 has to be amplified to ensure the correct operation of either the transistor or the alternative diode mixer. The oscillator also needs isolating in the interests of frequency stability.

Buffer transistor TR4 performs these functions. Oscillations are applied to its base by capacitor C16, and the stage is biased by resistors R13, R14 and R12. The output is developed across collector load resistor R11; and R10 and C10 decouple the stage from the supply rail.

### AUDIO PREAMPLIFIER

The directly coupled preamplifier formed by transistors TR6 and TR7 is an adaptation of the front-end circuitry found in most high-fidelity amplifiers.

Current through TR6 is kept below 100 $\mu$ A by high-value collector load resistor R22 and d.c. feedback resistor R21. The low collector current reduces the noise introduced by the stage.

Preset VR3 sets the gain of the two transistor combination. The calculated value with VR3 at maximum is approximately 200, and 2000 with it turned to zero resistance.

The biasing of transistor TR7 is determined by resistors R21 and R26. The amplifier's output, developed across collector load resistor R25, is coupled to the signal feedback loop by capacitor C29, and to the Volume control potentiometer VR5 by C30. Supply line decoupling is provided by R24 and C31 and, in view of the high level of gain, is generous.

### AUDIO RESPONSE

Signal-to-noise ratios are improved, and clarity increased, if the frequency response of a speech communication system is rolled off below 300Hz and above 3000Hz.

The low values of capacitors C17 and C30, and bypass capacitor C27, reduce response to the lower audio frequencies (gain reducing negative feedback, which increases as frequency lowers, is introduced because of the low value of C27). Bypass capacitors, C12, C18, and C28 curtail the high frequency response.

Signal feedback preset VR4 can be progressively shunted by capacitor C26. This increases negative feedback, and reduces gain, at the upper audio frequencies and enables the response of the amplifier to be tailored to suit individual preferences.

## ON BALANCE

The active product detector depicted in the circuit of Fig.6.1 is not balanced and this makes the receiver more vulnerable to breakthrough from powerful broadcast transmissions.

An alternative, balanced arrangement is shown in Fig.6.2, where signal diodes D2 and D3 are switched in and out of conduction, by the oscillator voltage, in order to produce the desired mixing action.

To avoid confusion, it should be stressed that the silicon diodes are used here as switches and their poor performance as rectifiers of weak signals is not relevant. The oscillator must, however, be vigorous enough drive the diodes into conduction, and buffer stage TR4 ensures the delivery of sufficient power.

Balancing potentiometer VR6 optimizes immunity to the envelope detection of strong, amplitude modulated signals. Some

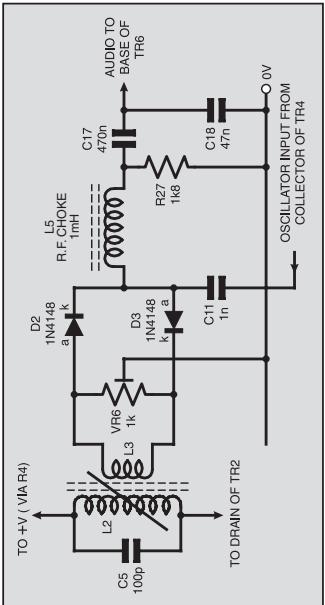


Fig.6.2. Alternative passive balanced product detector. This circuit can be substituted for TR3, the active detector, see text.

advocates of the circuit bring the potentiometer out as a panel control so that it can be adjusted to reduce break-through under varying reception conditions.

The balanced diode arrangement shown in Fig.6.2 attenuates signals by about 6dB. The active product detector included in Fig.6.1 gives about 6dB of gain. The 12dB difference is very noticeable, but readers may wish to try the balanced alternative and the increased protection against breakthrough that it offers.

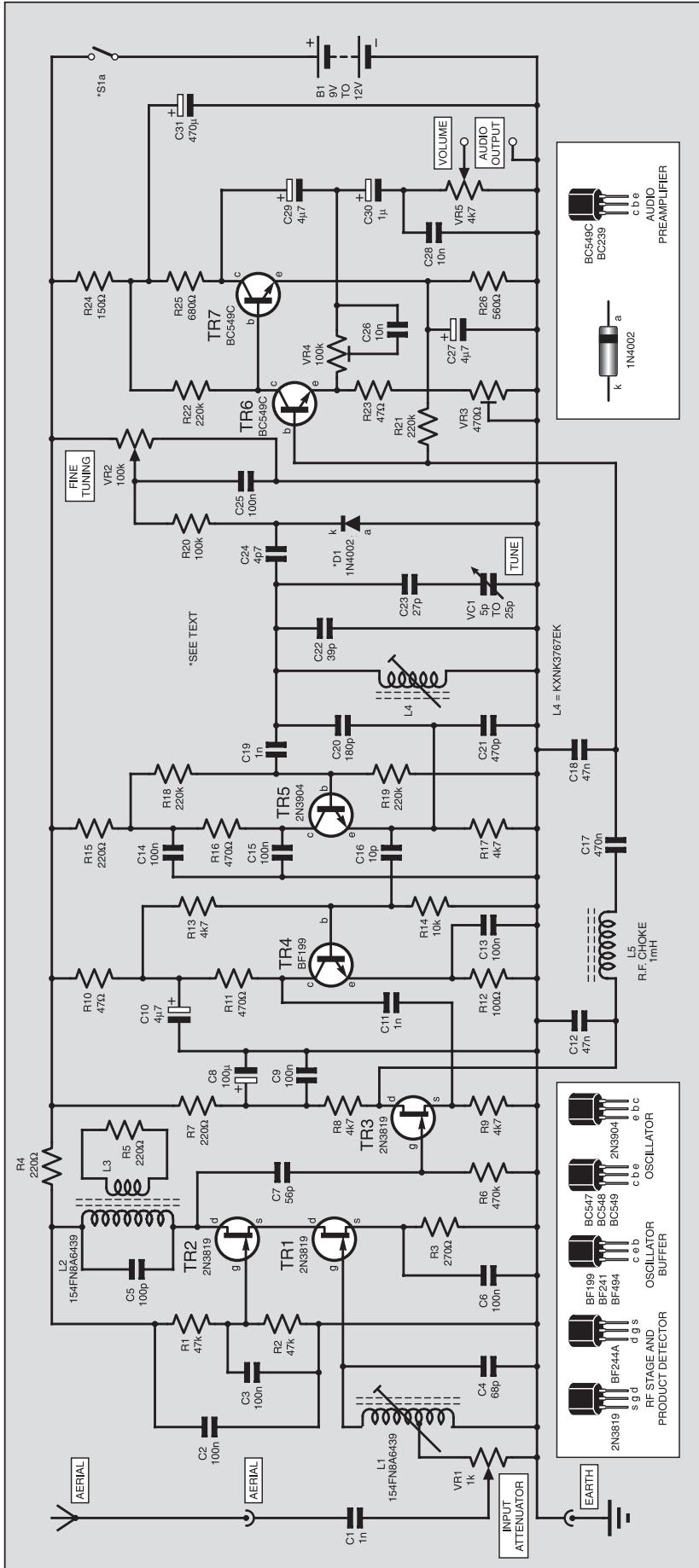


Fig.6.1. Circuit diagram for the Direct Conversion Receiver for the 7MHz (40m) amateur bands.

## POWER SUPPLIES

Even small audio power amplifiers impose voltage swings on the supply rails, especially when batteries are ageing. These signal induced fluctuations can cause low frequency instability, and the receiver and power amplifier must have *separate* batteries. This is particularly important when electronic tuning bias is derived directly from the receiver battery.

Switch S1a controls the supply to the Receiver; S1b (the other half of the switch) is used to switch the amplifier battery.

## COMPONENTS

Transistor types are not critical and base connections for alternative devices are shown inset in Fig.6.1. In the interests of stability, the r.f. stage field-effect transistors

should have the same lead out sequence as the specified 2N3819. Buffer stage transistor TR4 must be a small-signal r.f. type with an  $f_T$  of at least 200MHz.

Almost any small-signal *n-p-n* transistor in the BC107, BC108 and BC109 families, or their plastic-cased variants, should work in the oscillator and audio preamplifier stages. For best performance, TR6 should be a high-gain, low-noise device such as the BC549C.

The forward resistance of the diodes used in the alternative product detector (Fig.6.2) should, preferably, be matched with a test meter, and it will be easier and cheaper to produce a matched pair if silicon types are used. Most small power rectifier diodes can be pressed into service as a "varactor" diode for D1. Readers who prefer to use a true varactor diode should fit a BB105.

Any miniature 1mH r.f. choke will be suitable for L5. If a wire-ended component is substituted for the bobbin wound choke, mount it vertically and as close as possible to the printed circuit board.

## CONSTRUCTION

Most of the components for the Direct Conversion Receiver are assembled on a single printed circuit board (p.c.b.). The tuning capacitor (VC1) has its own small p.c.b. for ease of assembly and mounting. These boards are available from the EPE PCB Service, codes 423 (Dir. Conv. Rec.) and 406 (T/Cap).

The Receiver topside p.c.b. component layout, together with the underside copper foil master and interwiring to off-board components, is illustrated in Fig.6.3. Solder pins, located at the lead-out points,

# COMPONENTS

### DIRECT CONVERSION RECEIVER

#### Resistors

R1, R2	47k (2 off)
R3	270Ω
R4, R5, R7, R15	220Ω (4 off)
R6	470k
R8, R9, R13, R17	4k7 (4 off)
R10, R23	47Ω (2 off)
R11, R16	470Ω (2 off)
R12	100Ω
R14	10k
R18, R19, R21, R22	220k (4 off)
R20	100k
R24	150Ω
R25	680Ω
R26	560Ω
R27	1k8 (optional – see Fig.6.2 and text)

All 0.25W 5% carbon film or better

#### Potentiometers

VR1	1k rotary carbon, lin.
VR2	100k rotary carbon, lin.
VR3	470Ω enclosed carbon preset
VR4	100k enclosed carbon preset
VR5	4k7 rotary carbon, log.
VR6	1k enclosed carbon preset (optional – see Fig.6.2 and text)

#### Capacitors

C1, C11, C19	1n ceramic (3 off)
C2, C3, C6, C9	100n ceramic (8 off)
C13 to C15, C25	
C4	68p ceramic "low k" or polystyrene
C5	100p ceramic "low k" or polystyrene
C7	56p ceramic "low k"
C8	100μF radial elect. 25V
C10	4μ7 tantalum bead 35V
C12, C18	47n ceramic (2 off)
C16	10p ceramic
C17	470n ceramic
C20	180p polystyrene or ceramic "low K"
C21	470p polystyrene or ceramic "low k"
C22	39p polystyrene or ceramic "low k"
C23	27p polystyrene or ceramic "low k"
C24	4p7 ceramic "low k"
C26, C28	10n ceramic (2 off)
C27, C29	4μ7 radial elect. 25V (2 off)
C30	1μ radial elect. 25V
C31	470μ radial elect. 25V
VC1	5p to 25p one f.m. gang of a polythene dielectric variable capacitor (see text)

#### Semiconductors

D1	1N4002 rectifier diode (see text)
----	-----------------------------------

See  
SHOP  
TALK  
page

Approx. Cost  
Guidance Only  
**£25**  
excl. case, slow-motion drive, batt. & optional items

D2, D3	1N4148 signal diode (2 off) (optional – see Fig.6.2 and text)
TR1, TR2, TR3	2N3819 n-channel field effect transistor (3 off)
TR4	BF199 n-p-n high frequency transistor or similar (see text)
TR5	2N3904 n-p-n low power, small signal, transistor
TR6, TR7	BC549C n-p-n small signal transistor

Miscellaneous	L1, L2/L3	154FN8A6439 Toko screened (metal can) coil (2 off)
	L4	KXNK3767EK Toko screened (metal can) coil
	L5	1mH r.f. choke (see text)
	S1	d.p.s.t. toggle switch

Printed circuit boards available from the EPE PCB Service, codes 423 (Dir. Con. Rec.) and 406 (T/Cap); screw terminal for aerial and earth (2 off); slow-motion drive (optional); one large and three small plastic control knobs; audio type screened cable; multistrand connecting wire; p.c.b. stand-off pillars; front panel card and protective 2mm thick Perspex sheet; battery holder and connector; solder pins; solder etc.

Note: Case is Regenerative Radio from Part 3.

**SWITCHED 3-BAND VERSION**  
(Component changes and additions – see Fig.6.4 and Table 6.1)

#### Capacitors

C20 (14MHz Band)	82p polystyrene or ceramic "low k"
C21 (14MHz Band)	180p polystyrene or ceramic "low k"
C22 (3.5MHz Band) (14MHz Band)	82p polystyrene or ceramic "low k" not required – see text
C23 (3.5MHz Band) (14MHz Band)	200p polystyrene or ceramic "low k" 15p polystyrene or ceramic "low k"
VC1 (3.5MHz Band)	5p to 130p polythene dielectric variable capacitor (one a.m. gang of specified cap.)
	5p to 25p polythene dielectric variable capacitor (one f.m. gang of specified cap.)

#### Miscellaneous

L1, L2/3 (3.5MHz Band)	154AN7A6440 (2 off)
(14MHz Band)	KXNK3767EK (2 off)
L4 (3.5MHz Band) (14MHz Band)	154FN8A6439
S2	KXNK37677EK
	4-pole 3-way rotary switch

Note: The main circuit (Fig.6.1) and components list covers the 7MHz Band.

Also, you will need two additional main p.c.b.s (code 423) if you go for the switched-band option; but you only build the front end up to, and including, r.f. choke L5 and resistor R20.

will simplify off-board wiring, and they should be inserted first. Follow these with the tuning coils.

Next, solder in place the resistors, then the capacitors, smallest first, and, finally, the diodes and all the transistors. Semiconductor leads should be just long enough to permit the use of a miniature crocodile clip as a heatsink during soldering.

If the alternative product detector (Fig.6.2) is used, mount preset VR6 and diodes D2 and D3 on the p.c.b. solder pins connected to coil L3. Resistors R5 to R9, together with capacitors C7, C8, C9 and C12, and transistor TR3, must be removed from the board.

Failure to remove capacitor C12 will result in the oscillator output being shorted to the 0V rail. Use wire links to connect the buffer stage, TR4, to the diodes via capacitor C11, and the output from the diodes to r.f. choke L5.

## SETTING UP

The printed circuit board can be tested before being mounted on a chassis or in an enclosure. First, check the placement of all of the components and examine the printed circuit board for poor soldered joints and bridged tracks.

Use the leads of capacitor C23 to make the "hot" connection to tuning capacitor

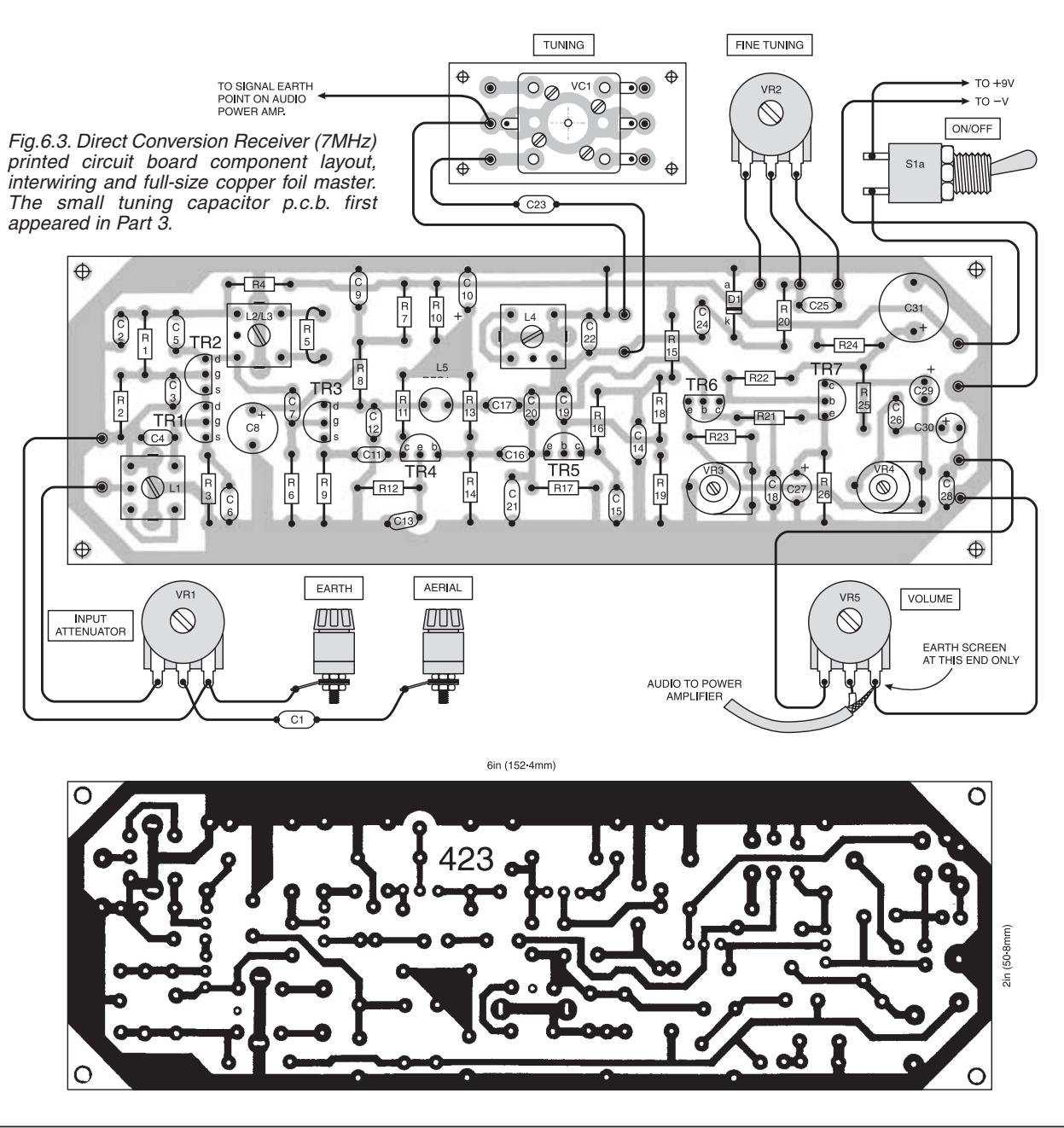
VC1 and wire up the three off-board potentiometers. Connect the audio output to the Speaker Amplifier described in Part Two with *screened* cable. Receiver current consumption should be approximately 13mA with a 9V supply.

Set the cores of all of the coils about two turns down from the tops of the cans. The core of L4 is particularly brittle and a plastic trimming tool should be used for the adjustments.



*Completed circuit board for the Direct Conversion Receiver.*

**Fig.6.3. Direct Conversion Receiver (7MHz) printed circuit board component layout, interwiring and full-size copper foil master. The small tuning capacitor p.c.b. first appeared in Part 3.**





Receiver p.c.b. mounted on the metal chassis and wired to the tuning capacitor board.

**Fig.6.4 (right).** Block diagram showing switching of three p.c.b. "front-ends" to give coverage of the 80 (3.5MHz), 40 (7MHz) and 20 (14MHz) metre amateur bands. VC1 is a 4-gang a.m./f.m. variable capacitor, one gang permanently connected to each board. One a.m. gang is not connected.

Connect an aerial (at least 10 metres or 30ft of wire located as high as possible). Set input Attenuation control VR1 for maximum input and turn up Volume control VR5. There should be a faint hissing in the loudspeaker and signals should be heard if Tuning capacitor VC1 is slowly rotated and/or the core of L4 is adjusted.

## ALIGNMENT WITH A RECEIVER

If you have access to a Communications Receiver, connect a short aerial wire to it and lay the wire near to the Direct Conversion set. Switch on the communications receiver's b.f.o. (beat frequency oscillator) and tune it to 7MHz.

Turn Tuning capacitor VC1 to maximum capacitance, and slowly adjust the core of L4 until a tone is heard in the speaker of the communications receiver. This receiver is, of course, picking up the signal radiated by the oscillator in the direct conversion set.

With input and volume controls turned up, rotate VC1 towards minimum capacitance. Even if tuning coils L1 and L2 are badly out of alignment, the direct conversion set should pick up some signals.

When a single-sideband transmission has been tuned in, adjust the cores of L1 and L2/L3 for maximum output. It will be necessary to turn back the Input Attenuator and the Volume control as the circuits are brought into alignment.

## ALIGNMENT WITH A CRYSTAL MARKER

If a communications receiver is not available, use the simple Crystal Marker described in Part Five. Placing this unit close to the input of the direct conversion receiver will inject a 7.16MHz signal. This is just above the UK upper band limit of 7.1MHz (at the centre of the USA 7MHz to 7.3MHz allocation).

Readers in the UK should set VC1 close to minimum capacitance before adjusting the core of oscillator coil L4 until a tone is heard in the speaker. If necessary, switch the marker on and off to make sure that the correct signal has been identified. Adjust the cores of L1 and L2/3 to peak the response.

Connect the long aerial wire to the receiver, slowly turn VC1 towards maximum capacitance and tune in a single-sideband signal. Adjust the cores of L1 and L2/L3 for maximum output.

## ENCLOSURE

The printed circuit board and tuning capacitor must be rigidly mounted, preferably in a diecast or aluminium box. At the very least an aluminium chassis and front panel should be provided.

The accompanying photographs show the board mounted on the chassis and front panel assembly used for the evaluation of most of the receivers in the series. This arrangement works well and microphony (feedback via the speaker) is not a problem at normal volume levels.

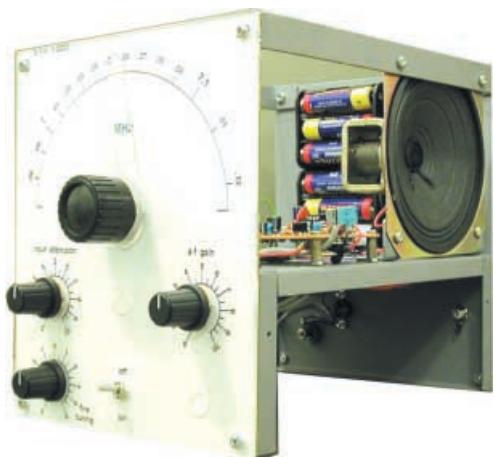
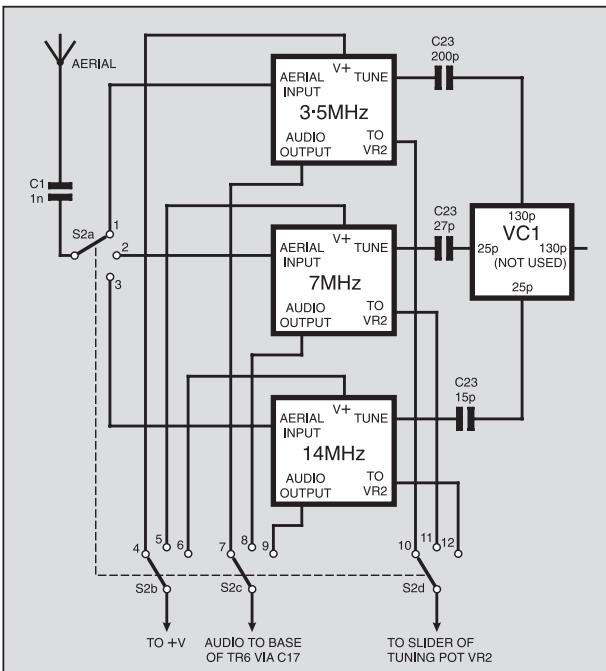
Keep the tuning capacitor, VC1, very close to the connecting pins on the receiver printed circuit board. Because of the provision of a fine tuning system, it is not absolutely essential to fit a slow motion drive to VC1. It will, however, make the receiver more pleasant to operate.

## MULTIBAND OPERATION

Some readers may wish to extend coverage to the 3.5MHz and 14MHz amateur bands. Attempts to switch the tuning and oscillator coils are likely to result in unstable and erratic operation. A better solution is to construct three separate front-end boards. (Components up to, and including, r.f. choke L5 and resistor R20 are required.)

A block diagram of the arrangement is given in Fig.6.4, where a four-pole, three-way, rotary switch S2 connects the three boards into circuit. The aerial is switched from board-to-board by section S2a, the battery power supply by S2b, the audio output from the product detector by S2c, and the fine tuning voltage from the slider of VR2, by S2d.

The polythene dielectric tuning capacitors used in a.m./f.m. receivers have two



Completed 7MHz version of the Direct Conversion Receiver. If a 3-Band version is to be built, the band change rotary switch is mounted in the blanked-out hole just below the tuning knob.

25pF and two 130pF (or thereabouts) gangs. One of the 25pF f.m. gangs is connected to the 7MHz board, the other to the 14MHz board. The 3.5MHz front-end is tuned by one of the 130pF a.m. gangs.

Providing each board with its own variable capacitor avoids the problems associated with switching high impedance r.f. circuits. Only one r.f. lead, the aerial, is switched. This is at low impedance and can be screened without causing problems.

Connections between the tuning capacitor gangs and the three front-ends must be as short as possible. This calls for a compact arrangement of the boards around the tuning capacitor.

Aerial and audio links between the boards and switch S2 must be screened. Earth the screen at *one end only*: do not use it to carry the negative supply rail to the board.

Align the additional boards in one of the ways described earlier. Details of amateur

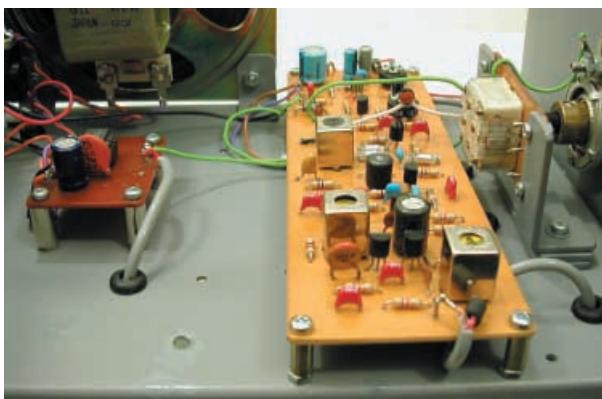
**Table 6.1: Toko Coils and Tuning Capacitor Values for three popular Amateur Bands (80, 40 and 20 metre)**

Band	L1	C4 (pF)	L2/L3	C5 (pF)	L4	C22 (pF)	C23 (pF)	VC1 (pF)	C20 (pF)	C21 (pF)
3.5MHz (80)	154AN7 A6440	33	154AN7 A6440	47	154FN8 A6439	82	200	130	180	470
7MHz (40)	154FN8 A6439	68	154FN8 A6439	100	KXNK 3767EK	39	27	25	180	470
14MHz (20)	KXNK 3767EK	47	KXNK 3767EK	82	KXNK 3767EK	—	15	25	82	180

#### Notes.

- (1) Fixed capacitors must be polystyrene or low-k ceramic types.
- (2) 3.5MHz band: the values quoted here will give coverage of the wider USA allocation.
- (3) 7MHz band: the C23 value given here restricts coverage to the UK's 7.1MHz band limit.
- For the wider 7.1MHz to 7.3MHz allocation, connect VC1 directly across L4.
- (4) The quoted tuning capacitor values are nominal. Measured values for the component used in the prototype receivers are: f.m. gangs, 4pF to 22.5pF; a.m. gangs, 4pF to 127pF.

A small signal r.f. transistor must be used for TR5 on the 14MHz board to maintain oscillator output at the higher frequency. Any of the r.f. types listed in Fig.6.1, together with the 2N2369, should prove suitable.



The Receiver board wired to the Speaker Amplifier (Part 2) using screened cable. These boards must have separate battery supplies.

band allocations were given in Part Four. Toko coil numbers and tuning and swing-reducing capacitor values for the 3.5MHz and 14MHz bands are given in Table 6.1.

## OPERATION

Tuning has to be very carefully adjusted to transform the garbled sounds into clear speech. Fine tuning potentiometer VR2 shifts the tuning across just one or two amateur transmissions and is very useful for clarifying signals. Reception may also be improved by an earth connection.

Activity on the amateur bands varies. The 7MHz allocation was chosen for the receiver described here because plenty of signals can usually be heard during the day. When setting up the tuning on 3.5MHz or 7MHz, listen in around 10a.m., when these bands are busy. Activity on 14MHz is more variable, but the early afternoon will usually produce some signals.

Readers who have access to a frequency counter can use it to obtain a digital display of operating frequency. A buffer circuit was described last month. It should be connected, by very short leads, to the emitter of oscillator transistor TR5.

## PERFORMANCE

The version with an active product detector is sensitive. Using ten yards of flex as an aerial, quite weak signals can be brought up to a good loudspeaker volume when the sim-

ple power amplifier described in Part Two is used. Gain preset VR3 will probably have to be turned well down. If the passive product detector is used, sensitivity should be adequate if VR3 is set for maximum gain.

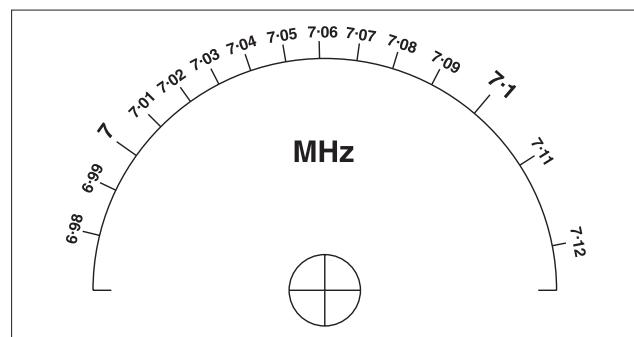
Signals are reproduced with great clarity, and the receiver is not fatiguing to listen to. After a five-minute warm-up period, frequency drift is minimal.

Unlike diodes and other devices that demodulate by a rectifying action, the heterodyning product detector will continue to function down to the lowest signal levels. In theory, therefore, the ultimate sensitivity of receivers with product detectors should be greater. In practice, received and internally generated noise are limiting factors.

The receiver cannot match the selectivity of a superhet. Its performance in this respect is similar to the Regenerative Receiver described in Part Four. When the bands are busy, the severe crowding of transmissions results in a faint background of unintelligible chattering. However, only the wanted signal is clarified, and this makes the interference less distracting.



The two separate power supply battery "packs", one for the receiver and the other for the amplifier, located on the rear panel.

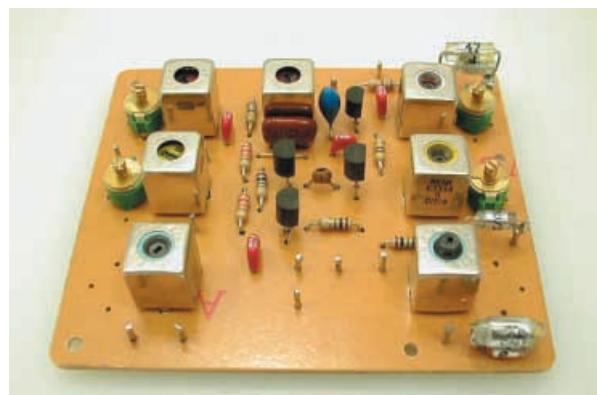


Calibrated tuning dial (half-size approx.) for the 7MHz version of the Direct Conversion Receiver.

There are no discernible overloading or cross-modulation problems with either product detector. Indeed, the feature which separates this receiver from the regenerative set is its ability to cope with strong signals without the need for adjustment of the input attenuator.

Breakthrough from powerful broadcast transmitters can be a problem after dark, particularly on the 7MHz band. Careful adjustment of the cores of L1 and L2/L3 will usually clear up the problem, and refinements of this kind should be carried out during the setting up process. Keeping the signal input low will also minimize interference of this kind.

Next Month: The Superhet



# PRACTICAL RADIO CIRCUITS

**RAYMOND HAIGH**



## Part 7: The Superhet: Preselectors, mixers and oscillators

*Circuits for the set builder and experimenter*

THIS month we begin to consider a simple to operate receiving system capable of the highest levels of selectivity and sensitivity. Known as the supersonic heterodyne, or **superhet** for short, it has been the dominant receiver technology for seventy years. Its application is now universal, from the simplest domestic portable to state of the art equipment used in government listening stations.

### HOW IT WORKS

With the superhet system, all incoming signals, whatever their wavelength, are changed to a fixed frequency at which almost all of the amplification takes place.

Frequency changing is achieved by "beating" or "heterodyning" a locally generated oscillation with the incoming signal. The frequency difference between signal and oscillation is kept constant, and the resulting beat frequency is, therefore, also fixed and constant.

By converting all signals to a fixed frequency, known as the *intermediate frequency* (i.f.), the problems of instability and inconsistent performance that can afflict multi-stage tuned radio frequency (t.r.f.) receivers are avoided. The main cause of this instability is feedback via the ganged tuning capacitor and wavechange switch wiring. The inconsistent performance arises from the change in the *Q*-factor and impedance as the tuning capacitor is rotated.

In the superhet, ganged variable capacitors and coil switching are eliminated from the fixed frequency i.f. stages, and very high levels of gain can be achieved without instability. Moreover, performance is not affected by changes in tuning capacitor values.

Fixed frequency amplification makes possible the introduction of crystal, mechanical or ceramic filters capable of tailoring selectivity to suit all types of signal and reception conditions (more about this later). It is also easier to provide effective automatic gain control (a.g.c.) systems.

The inclusion of frequency changing circuitry makes the superhet different from all other types of receiver. Unfortunately, it brings with it some unique problems, and the evolution of the circuit has been largely shaped by attempts to overcome them.

Germanium diodes are still widely used for the detection or demodulation of the signal (see Part One). In addition to recovering the audio modulation, the diode produces a d.c. voltage which varies relative to signal strength. This is used to change the base bias on the transistors in the i.f. amplifier and reduce their gain when strong signals are being received. This facility is known as automatic gain control, or a.g.c. for short.

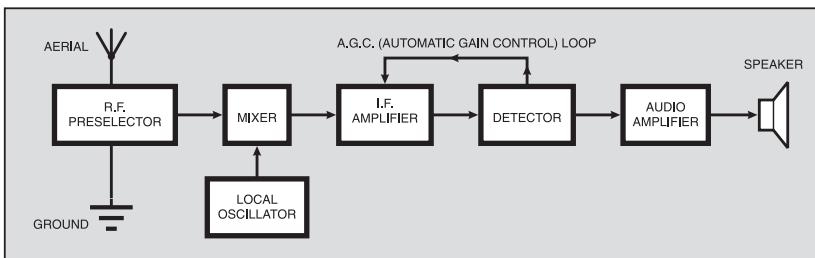


Fig.7.1. Block schematic diagram of a basic superhet receiver.

### BASIC CIRCUIT

A block diagram for a basic superhet receiver is given in Fig.7.1. The receiver is tuned to the desired station by a Pre-selector stage comprising one or more tuned circuits.

The Local Oscillator operates at a higher frequency than the incoming signal, the difference between the two being equal to the intermediate frequency (i.f.). This difference has to be maintained over the swing of the tuning capacitor. How this is done is described later.

The input signal and local oscillation are combined in the Mixer stage. This results in the production of a number of frequencies, and a tuned circuit in the mixer's output selects oscillator frequency minus signal frequency; i.e., the desired intermediate frequency.

Signals, at this new and fixed frequency, are amplified in the I.F. Amplifier. In basic receivers, intermediate frequency amplifiers usually comprise two transistors coupled by radio frequency transformers (known as i.f. transformers) tuned to the i.f. Higher performance receivers incorporate a ceramic, mechanical or crystal filter to improve selectivity.

Audio amplifier stages are similar to those discussed earlier in the series (see Part Two).

### WHISTLES

Superhet receivers are prone to spurious responses. At their simplest, they take the form of a whistle that changes in pitch as the set is tuned through a station. The principle cause is second channel or "image" interference.

Second channel interference arises because the mixing process can produce an output, at the intermediate frequency, from two, different, incoming signals. These are at the oscillator frequency *minus* the intermediate frequency, and at the oscillator frequency *plus* the intermediate frequency (the "second channel"). The image signal is, therefore, spaced from the wanted signal by twice the intermediate frequency.

Whistles are caused when the interfering signal is not quite twice the i.f. distance from the wanted station, say one or two kilohertz out, the resulting beat producing the whistle as the receiver is tuned through the station.

Strong signals spaced twice the i.f. above the frequency reading on a silent part of the dial can be heard and mistaken

for transmitters operating at the actual dial reading. These "phantom" stations become more intrusive as the receiver is tuned up through the shortwave bands.

This is because simple preselector stages become less and less able to reject signals spaced by only 910kHz (i.e. twice a standard i.f. of 455kHz) from the wanted station as the reception frequency rises above 5MHz or so. It is for this reason that inexpensive receivers sometimes appear so "lively" on the shortwave bands.

Reception of signals in close proximity to the receiver's i.f. can also be a cause of whistles. More difficult to trace are whistles caused by harmonics produced by the non-linear action of the receiver's own detector.

## INTERFERENCE

The problem of second channel interference can be greatly reduced by either increasing the selectivity of the preselector stage, or raising the intermediate frequency, or both.

High performance receivers of the valve era with i.f.s of 460kHz had three tuned circuits in the preselector stage. When the i.f. was increased to 1600kHz, two tuned circuits were considered adequate. Domestic valve receivers often adopted a bandpass arrangement to improve preselector action on medium and shortwaves. A typical circuit diagram, featuring modern coils, is given in Fig.7.2.

The lower the intermediate frequency, the greater the selectivity of the receiver (more about this later). This imposes limitations on raising the i.f. to reduce second channel interference, and designers began to include two or more frequency changers. This permitted the use of a *high* first i.f. to minimize image interference followed by a *low* second to ensure adequate selectivity.

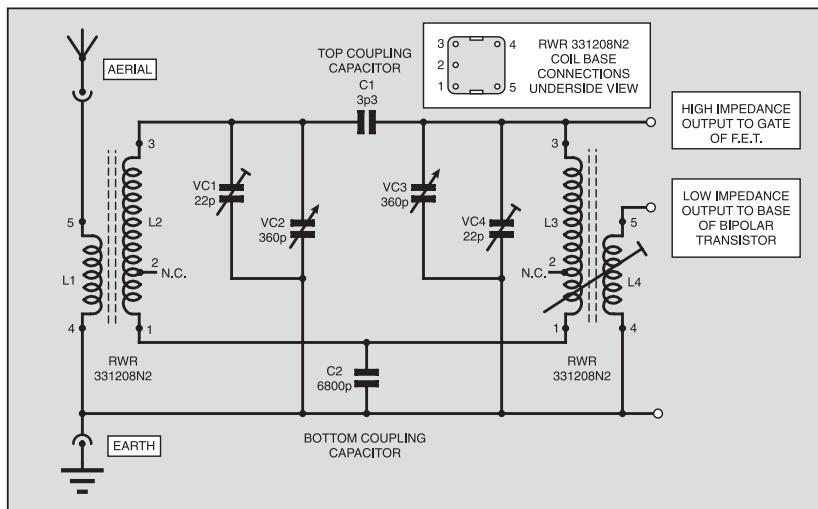


Fig.7.2. Circuit diagram for a bandpass tuned circuit for improving the selectivity of the r.f. preselector stage. The coil type shown is for medium wave reception.

Modern, high performance communications receivers often have a first i.f. of 45MHz, followed by a transitional stage of 10.7MHz and a final of 455kHz. Each of the three frequency changers tends to cause spurious responses, and these receivers have to be designed with the utmost care or the attempted cure only aggravates the problem.

Whistles caused by the reception of signals close to the intermediate frequency can usually be cured by the insertion of a wave trap, tuned to the intermediate frequency, at the aerial input. Wave traps were discussed in Part Two.

Problems caused by the radiation of harmonics produced by the detector can be avoided by adequate post-detector filtering, sensible receiver layout, and screening.

## FREQUENCY CHANGERS

The term frequency changer was coined early in the development of the superhet. It is something of a misnomer. Combiner, mixer, or even modulator would better describe the process which takes place when the local oscillation heterodynes or beats with the incoming signal to produce the intermediate frequency.

Mixer is currently the most favoured term, but audio engineers and radio engineers have a completely different understanding of the word. Audio engineers demand a high degree of linearity in a mixing stage to ensure that the signals being merged onto the same path remain unchanged. They must not interact with one another to produce new frequencies.

## BRIEF HISTORY

The Superhet had its origins during the earliest years of radio. Indeed, seminal patents predate the valve.

In 1901, Dr. R. A. Fessenden patented a system whereby two unmodulated signals, radiated by a transmitter, were combined at the receiver. The signals differed in frequency by about 1kHz and the resulting beat note produced an audible tone from a diaphragm activated directly by the fine iron wire core of the receiver's tuning coil. Fessenden's receiver could have been described as a sonic heterodyne.

He later improved the arrangement by substituting a locally generated oscillation for one of the transmitted signals. In this way the frequency difference and, hence, the tone of the beat, were brought under the control of the operator.

These experiments predated the valve, and high frequency alternators were used to generate oscillations in the 50kHz to 100kHz range at the transmitting and receiving stations.

American Navy researchers increased the sensitivity of Fessenden's system in 1913, when they used a rectifier to mix the signals and produce an audible beat note in conventional earphones.

Lee de Forrest patented his triode valve in 1903 and, by 1913, researchers in Europe and America had discovered its usefulness as an oscillator. During that same year, Captain H. J. Round used a single valve as oscillator and mixer. He called his circuit the Autodyne.

The 1914-18 war gave an enormous impetus to the development of the superhet. There was a need to operate at frequencies between 500kHz and 3000kHz which, at the time, were considered very high. The triode was still the only amplifying device available to designers.

Unfortunately, because of the capacitance between its grid and anode (input and output pins), it became unstable at frequencies

much above 100kHz. By adopting the superhet principle and converting all incoming signals to a frequency below 100kHz, these primitive valves could be made to provide the necessary amplification.

Captain H. J. Round, M. Latour and Major E. H. Armstrong for the Allies, and W. Schottky for the Germans, researched the problem. Schottky filed a patent application in June 1918, but he was unable to develop his circuit. Armstrong's patent was filed in December, six months later. Like Schottky's, it made reference to all of the essential features of the superheterodyne.

Unlike Schottky's, it was based on the construction of a working receiver. Credit for the invention of the circuit is, therefore, usually ceded to Armstrong.

In 1918, L. A. Hazeltine patented a feedback circuit known as the Neutrodyne, which neutralized the triode's grid-anode capacitance and made stable amplification at higher radio frequencies possible. This, together with the development of the screen-grid valve (which greatly reduced the capacitance between the input and output), prolonged the life of the t.r.f. receiver through the 1920s in America and well into the 30s in Europe. The superhet then began to dominate the domestic receiver market.

Subsequent developments have been directed towards eliminating spurious responses, increasing selectivity, and overcoming the effects of oscillator drift. The weight and mechanical complexity of some of the best receivers of the valve era have been replaced by electronic sophistication in the high performance sets manufactured today.

In terms of the crucial ability to resolve the weakest signals under difficult reception conditions, there have been few, if any, significant improvements since the end of the valve era.

Conversely, radio mixers (other than mixers that function purely as modulators) must possess a degree of non-linearity to ensure that the local oscillation combines or heterodynes with the signal to produce the intermediate frequency at the output.

Diodes, which display the most extreme form of non-linearity, were used as mixers in primitive superhets (they still are in some communications receivers and receivers operating at frequencies approaching 1GHz). This is why mixers were referred to as the first detector in the early days of radio. Mixers which function by passing two signals through a non-linear device are known as additive mixers.

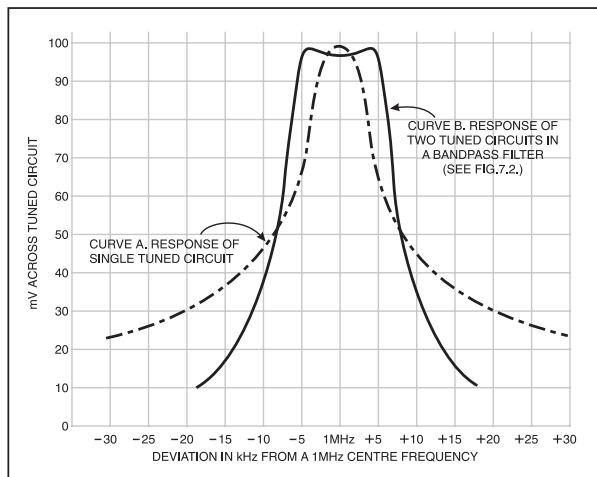


Fig.7.3. Comparing the selectivity of a single tuned circuit with two tuned circuits in a bandpass filter.

The development of multi-grid valves in the late 1920s and special frequency changer valves in the 30s permitted a different mode of mixing. Known as multiplicative mixing, the locally generated oscillation was applied to a subsidiary grid placed in the electron stream so that it modulated the incoming signal frequency. The valve operated in a linear fashion, and the intermediate frequency was selected at its output (anode), by a tuned circuit, in the usual way.

This form of mixing was the norm until the end of the valve era. The introduction of the transistor in the 1960s brought about a return to non-linear, additive mixers.

## TRACKING

As we have seen, the oscillator must operate at signal frequency plus intermediate frequency over the full swing of the tuning capacitor. Maintaining this constant difference is known as *tracking*.

Taking the medium waveband as an example, the signal or preselector circuits will tune from 550kHz to 1650kHz. Assuming an i.f. of 450kHz, the oscillator will have to run from  $550 + 450 = 1000$ kHz to  $1650 + 450 = 2100$ kHz.

The difference in coverage is achieved by using a lower inductance tuning coil in the oscillator circuit. Its inductance is calculated so that the frequency of oscillation is 2100kHz when the tuning capacitor is set to its minimum value.

This measure, by itself, is not sufficient to ensure accurate tracking. The maximum

value of the tuning capacitor must also be reduced to ensure that the frequency of oscillation is 1000kHz when its vanes are fully meshed. Sometimes a lower value oscillator section is ganged with the signal tuning capacitor. More commonly, both sections of the ganged capacitor are identical and a fixed capacitor is placed in series with the oscillator tuner to reduce its maximum value. This fixed capacitor is known as a *padder*.

With the correct choice of inductor and padder values, tracking is perfect at three points on the dial: close to either end and around the centre point. At all other points the error is minimal.

## UNDER AND OVER

The oscillator in some of the first general coverage, solid state receivers ran below the signal frequency on the highest shortwave range (12MHz to 30MHz) because of the limited performance of early transistors.

Operating the oscillator above signal frequency is, however, standard procedure. Indeed, simple arithmetic will reveal that, with workable tuning swings, it becomes difficult and then impossible, as frequency is lowered, to run the oscillator below signal frequency.

It's now time for us to take a look at some circuits.

## PRESELECTING

Increasing the efficiency of the preselector circuits will do much to overcome the inherent defects of the superhet system. In Fig.7.2, two tuned circuits L2/VC2 and L3/VC3, have been coupled to increase

selectivity. Known as a bandpass filter, its performance is compared with a single tuned circuit in the graph of Fig.7.3.

Correctly set up, this arrangement passes a narrow band of frequencies beyond which the response falls off comparatively steeply. In this way, good selectivity is achieved without attenuating the higher audio frequencies on the boundaries of the modulation envelope (see Part One). For this reason, two tuned circuits, coupled inductively, formed the basis of all intermediate frequency transformers (i.f.t.s) during the valve era. (The miniature i.f.t.s used in most transistor radios are now singly tuned.)

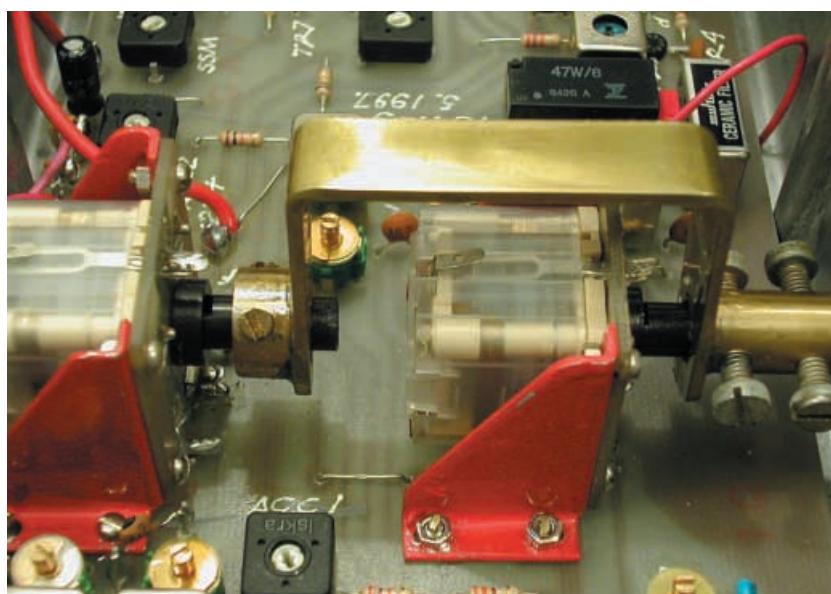
Returning to Fig.7.2, signal transfer is effected by C1 and C2, known as the series and shunt (or top and bottom) capacitors respectively. As frequency increases, coupling increases via C1 and reduces via C2. With falling frequency the reverse is the case. This ensures that the response of the filter is reasonably constant over the swing of ganged tuning capacitors, VC2 and VC3.

Coupling windings, L1 and L4, match the high impedance tuned circuits to the aerial and base of a bipolar transistor mixer. The high impedance gate of a field-effect transistor can be connected directly to winding L3. Preset trimmer capacitors, VC1 and VC4, and adjustable inductor cores, permit the two circuits to be exactly matched to one another in a process known as *alignment*.

The values quoted for capacitors C1 and C2 will produce a passband, on medium waves, around 10kHz wide. Reducing C1 and increasing C2 will narrow the response, ultimately to a single peak.

## GANGING-UP

When the preselector has two tuned circuits the receiver requires a three-gang tuning capacitor. Three-gang air-spaced variables are still manufactured but are expensive. An alternative is to link two, polythene dielectric tuning capacitors to produce a four-gang arrangement at modest cost. Details of this solution are given in the mechanical diagram Fig.7.4.



Author's method of providing a metal brace between two solid dielectric tuning capacitors to form a four-gang unit.

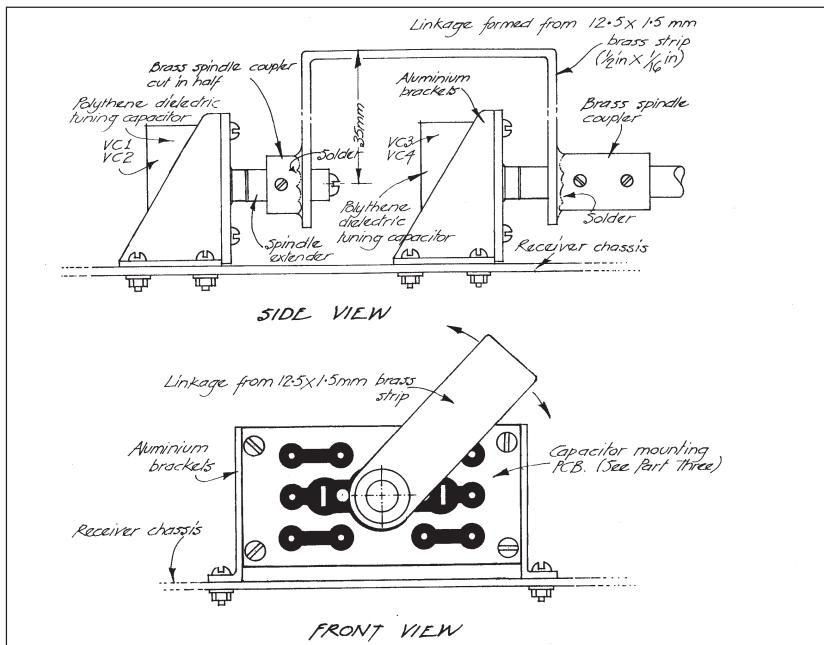


Fig.7.4. Mechanical details for linking solid dielectric tuning capacitors to produce a four-gang unit.

Contact faces on the linkage strip and brass spindle couplers should be tinned and the parts assembled on a length of 6mm (1/4in.) spindle before being "sweated" together. This ensures perfect alignment.

Lack of screening precludes the insertion of a signal frequency amplifying stage between VC1 and VC2. These capacitors can, therefore, only be used for the band-pass circuit already described. Such a stage could, however, be provided between VC2 and VC3 if adequate screening is installed. Instability does not normally arise through interaction between signal and oscillator circuits because they operate at different frequencies. Receiver component layout should, however, separate them as much as possible.

## SELF-OscillATING MIXER

The self-oscillating mixer circuit used in almost all of the transistor portable receivers manufactured since the 1960s is shown in Fig.7.5.

The tuned circuit formed by tuning capacitor VC1 and the ferrite loop aerial, L1, selects the station. To minimize damping, signal transfer to the low impedance base of transistor TR1 is via coupling winding L2.

This transistor version of Alexander Meissner's oscillator is tuned by L5 and VC4, with capacitor C5 acting as the swing-reducing padder. Feedback from TR1 collector (c) to emitter (e) is via coils L3 and L4, the latter winding providing oscillator injection at the emitter. Oscillation amplitude is sufficient to drive the device into the non-linear region of its characteristic curve and this produces the desired mixing action. (This is an additive mixer).

Base bias for TR1 is fixed by resistors R1 and R2, and capacitor C1 is a d.c. blocking capacitor. Emitter bias is provided by resistor R3 which is bypassed by C3. Transformer IFT1, with its tuned primary, selects the 455kHz intermediate frequency (i.f.).

high *Q* (and hence selectivity) of the ferrite rod aerial and its modest signal pick-up. Injecting stronger signals via a long wire aerial results in spurious responses, cross modulation problems and oscillator "pulling" (the oscillator tends to lock onto strong signals).

Performance of the simple mixer/oscillator deteriorates on the shortwave bands. Again, the modest signal pick-up of the set's whip aerial does much to hide the defects of the circuit, but spurious responses increase as frequency rises.

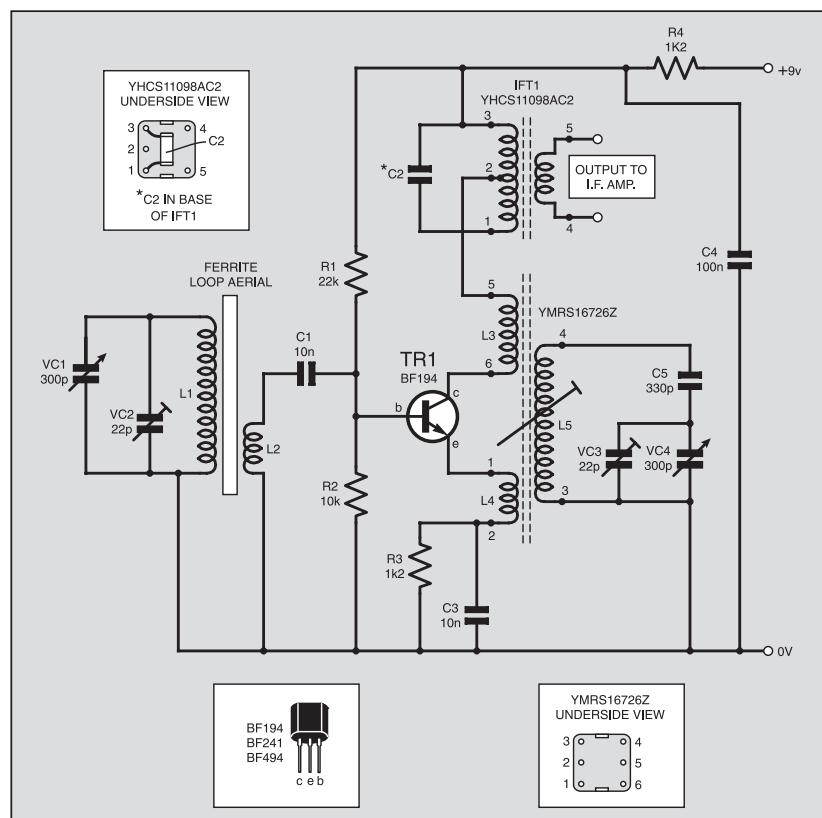
Moreover, a reluctance to oscillate becomes evident, above 10MHz or so, if the amount of tuning capacitance in circuit is much above 200pF. Emitter bias resistor R3 may have to be selected to ensure reliable operation at higher frequencies.

As far as the author is aware, three winding oscillator coils are not available, to home constructors, for the long and shortwave bands. On these ranges, TR1 emitter (e) should be connected, via resistor R3 and its bypass capacitor C3, to a tap close to the "earthy" end of coil L5.

## BETTER PERFORMANCE

Separating the mixer and oscillator stages and the use of field-effect transistors improves performance. Field-effect transistors have a square law relationship between their drain current and gate/source voltage, and overloading produces only the second harmonic.

Bipolar transistors, on the other hand, exhibit an exponential base/collector current relationship, and overloading produces a range of odd and even harmonics.



# 5-BAND DUAL-GATE MOSFET TUNER/MIXER

A sensitive, 5-band superhet receiver front-end

## DUAL-GATE MOSFET TUNER/MIXER

A circuit, popular since the 1960s, for simple general coverage communications receivers, is given in Fig.7.6.

Dual-gate MOSFET TR1 acts as the mixer and TR2, a junction f.e.t., is used as the maintaining device in an Armstrong oscillator. The high impedance gates of TR1 minimize damping on the signal frequency tuned circuits and permit a direct link to the oscillator. Gate two (g2) of TR1 is held at about 1V by connecting it, via signal isolating resistor R3, to the source (most dual-gate MOSFETs work well as mixers with this arrangement).

This modern version of Armstrong's oscillator performs reliably up to about 30MHz. It is, however, prone to squegging (going in and out of oscillation at a supersonic frequency) and stopper resistor R5 and the decoupling resistor, R4, prevent this. Source bias on TR2 is optimized by preset VR2 to ensure reliable oscillation, on the highest shortwave range, when the tuning capacitor is set at maximum.

The MOSFET mixer requires an oscillator injection of between 1Vr.m.s. and 2Vr.m.s. A higher voltage is developed across coil L4 and low value coupling capacitor C4 reduces it to within this range. This is a multiplicative mixer. The oscillator voltage modulates the signal. It does not drive the MOSFET into non-linearity.

Padde capacitor C5 can be connected in series with oscillator coil L4 in order to simplify wavechange switching. Oscillator output is, however, more constant when C5 is connected directly in series with variable capacitor VC4.

Power supply to the oscillator should be well smoothed and regulated to minimize drift.

## ATTENUATION

Any receiver intended for serious listening must have some means of attenuating strong signals at the aerial input (see Part Three). Rotary potentiometer VR1 is adequate, but the switched resistor arrangement shown in Fig.7.7 is more reliable and less noisy at high frequencies.

The levels quoted take no account of aerial impedance and are approximate.

## PADDERS AND COILS

Padde values and Toko coil numbers for a five-band general coverage receiver are given in Table 7.1. The circuit diagram of Fig.7.6 is more sensitive, less vulnerable to cross modulation, less noisy than the mixer/oscillator arrangement depicted in Fig.7.5, and more immune to oscillator pulling. With its 455kHz i.f. it is still affected by spurious responses, and at least one more tuned circuit is needed ahead of the mixer to make its performance acceptable in this respect, even at medium frequencies.

Table 7.1: Toko Coil Numbers and Padder Capacitor Values for a Superhet Receiver with a 455kHz I.F.

Band	Preselector (L1/L2)	Oscillator (L3/L4)	Padder (C5 pF)	Coverage (MHz)
LW	CAN1A350EK	RWR331208N2	150	0.14 to 0.3
MW	RWR331208N2	YMRS80046N	330	0.53 to 1.6
SW1	154FN8A6438EK	154AN7A6440EK	680	1.5 to 4
SW2	154FN8A6439EK	154AN7A6441EK	1500	3.5 to 12
SW3	KXNK3767EK	KXNK3766EK	2000	10 to 30

Notes:

(1) See Fig.7.6 for circuit diagram.

(2) The quoted tuning ranges are approximate. The tuning capacitors, VC2/VC4, should have a minimum value of not much more than 10pF and a maximum of at least 300pF.

(3) Alignment on LW will be easier, and tracking improved, if a fixed capacitor of 56pF is connected across L2 and 150pF is connected across L4.

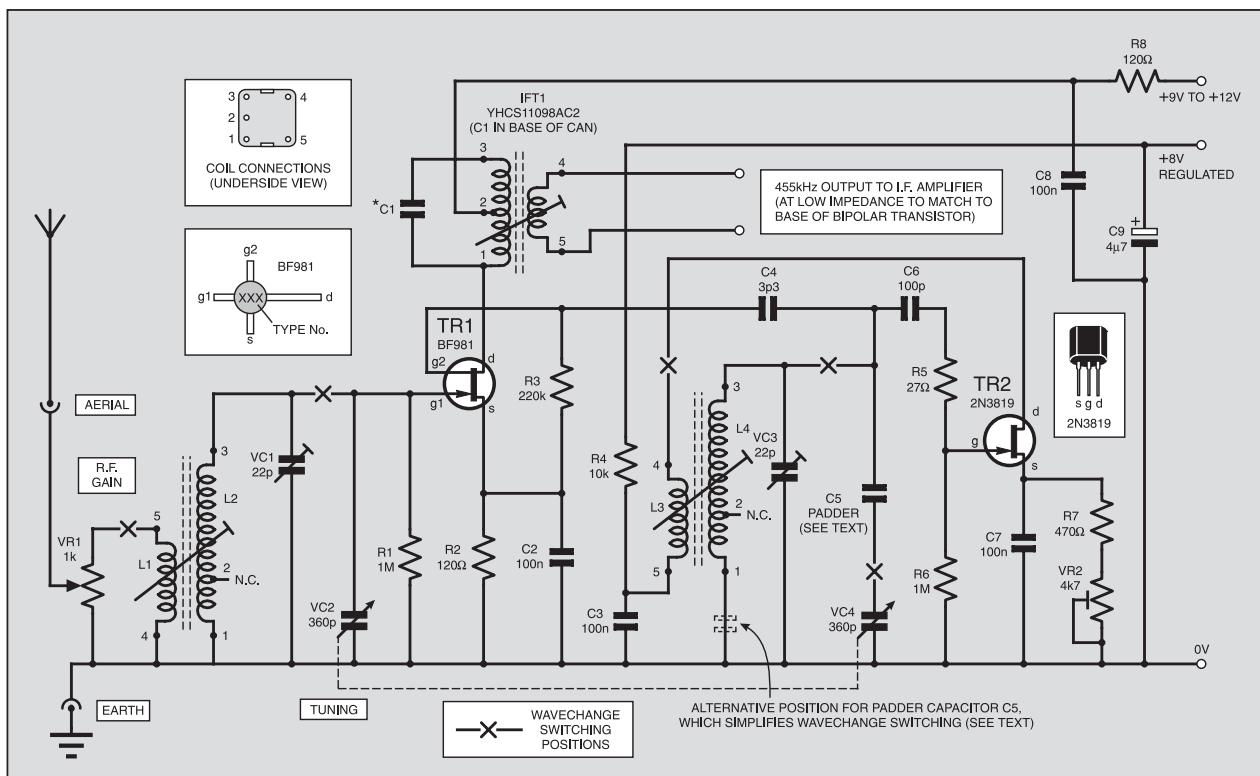


Fig.7.6. Circuit diagram for a 5-Band Tuner/Mixer using a dual-gate mixer with an f.e.t. Armstrong oscillator (455kHz i.f.). See Table 7.1 for coil and padder capacitor details. (No constructional details are given for this circuit.)

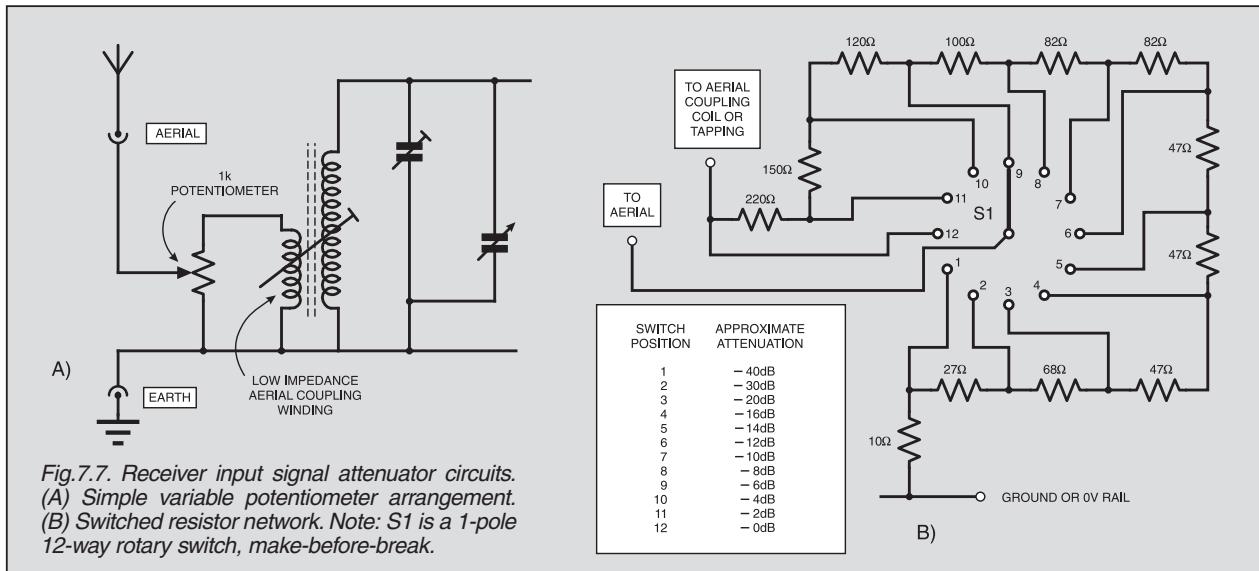


Fig.7.7. Receiver input signal attenuator circuits.  
(A) Simple variable potentiometer arrangement.  
(B) Switched resistor network. Note: S1 is a 1-pole  
12-way rotary switch, make-before-break.

## 3-BAND SW SUPERHET TUNER/MIXER

A three-band (1.7MHz to 30MHz) SW receiver front-end, with a 1.6MHz i.f.

### SHORTWAVE SUPERHET

Providing additional signal frequency tuned circuits involves considerable complication, especially with multiband receivers. Another way of reducing spurious responses is to increase the intermediate frequency, and this solution is adopted in the circuit diagram for a 3-Band Shortwave Superhet Tuner/Mixer depicted in Fig.7.8.

Some readers have reported difficulties in obtaining dual-gate MOSFETs, so two junction f.e.t.s, TR1 and TR2, have been cascaded (or cascoded!) to form the mixer. Oscillator injection is via the gate of TR1, which is biased at half the supply voltage by resistors R3 and R4. The signal path is isolated by R2 and C5 bypasses the bias supply at radio frequencies.

Field-effect transistor TR3 is the maintaining device for the Hartley oscillator, feedback from its source being applied to a tapping on tuning coil L2b, via resistor R8 and wavechange switch S1c. Padder capacitor C6b is placed in series with coil L2b in order to simplify wavechange switching, and capacitor C8 couples the oscillator to the mixer stage.

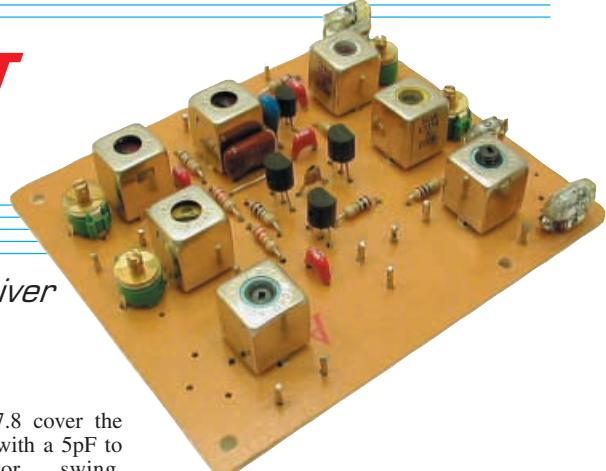
Hartley's oscillator may be marginally more drift free than Armstrong's at higher frequencies, but it was chosen because the simple tapped coil permits the series connection of commercial windings to produce the inductance values needed for the 1.6MHz i.f. Voltage regulator IC1 stabilizes the supply to the oscillator to reduce drift.

### TUNING COILS

The coils shown in Fig.7.8 cover the 4.5MHz to 11.8MHz range with a 5pF to 130pF tuning capacitor swing. Experimenters are urged to try this busy range first.

Details of the coils and padders for two other ranges, affording continuous coverage from 1.7MHz to 30MHz, are given in Fig.7.9. The differing connections to the Toko coil windings should be noted.

Intermediate frequency transformers for 1.6MHz are no longer retailed, and IFT1 comprises a standard Toko coil tuned by capacitor C2.



### CONSTRUCTION

The mixer/oscillator stage and its six tuning coils are assembled on a single printed circuit board. The component side and wiring to the 3-way 4-pole rotary wavechange switch are illustrated in Fig.7.10, together with a full-size copper track master. This board is available from the EPE PCB Service, code 426.

Table 7.2: Toko Coil Numbers and Padder Capacitor Values for a Shortwave Superhet Receiver with a 1.6MHz I.F.

Range	Preselector (L1a to L1c)	Core Depth (mm)	Oscillator (L2a to L2c)	Core Depth (mm)	Padder (pF)	Coverage (MHz)
<b>SW1</b>	154FN8A6438EK	2.5	TKANS32696	2.5	147	1.7 to 4.7
<b>SW2</b>	154FN8A6439EK	1.5	BKANK3334	2.5	330	4.5 to 11.8
<b>SW3</b>	BKXNK3766	2	BKXNK3766	1.5*	1500	10 to 30

Notes:

- (1) See Fig.7.8 for circuit diagram.
- (2) The specified coverage is obtained with a 5pF to 130pF tuning capacitor.
- (3) Core depths are measured down from the top of the can.
- (4) \*The measurement quoted for Range 3 oscillator coil (L2c) is the height of the core above the top of the can.
- (5) The core of intermediate frequency transformer IFT1 is set 2mm down from the top of the can.

## COMPONENTS

### 3-BAND SW SUPERHET TUNER/MIXER

See  
SHOP  
**TALK**  
page

<b>Resistors</b>	1M (3 off) 22k (2 off) 180Ω (2 off) 47Ω 220Ω
<b>Potentiometer</b>	1k rotary carbon, linear
VR1	

Approx. Cost  
Guidance Only  
excl. reduction drive, case & batt.

**£25**

<b>Capacitors</b>	1n ceramic (2 off) 220p polythene or ceramic "low k" C1, C3 C2, C4, C5, C9, C11, C6a (Range 1) C6b (Range 2) C6c (Range 3) C7 C8 C10
	100n ceramic (4 off) 147p polythene (100p + 47p, 2 caps.) 330p polythene 1500p polythene 270p polythene or ceramic "low k" 363 ceramic "low k" 4μF tantalum bead, 16V

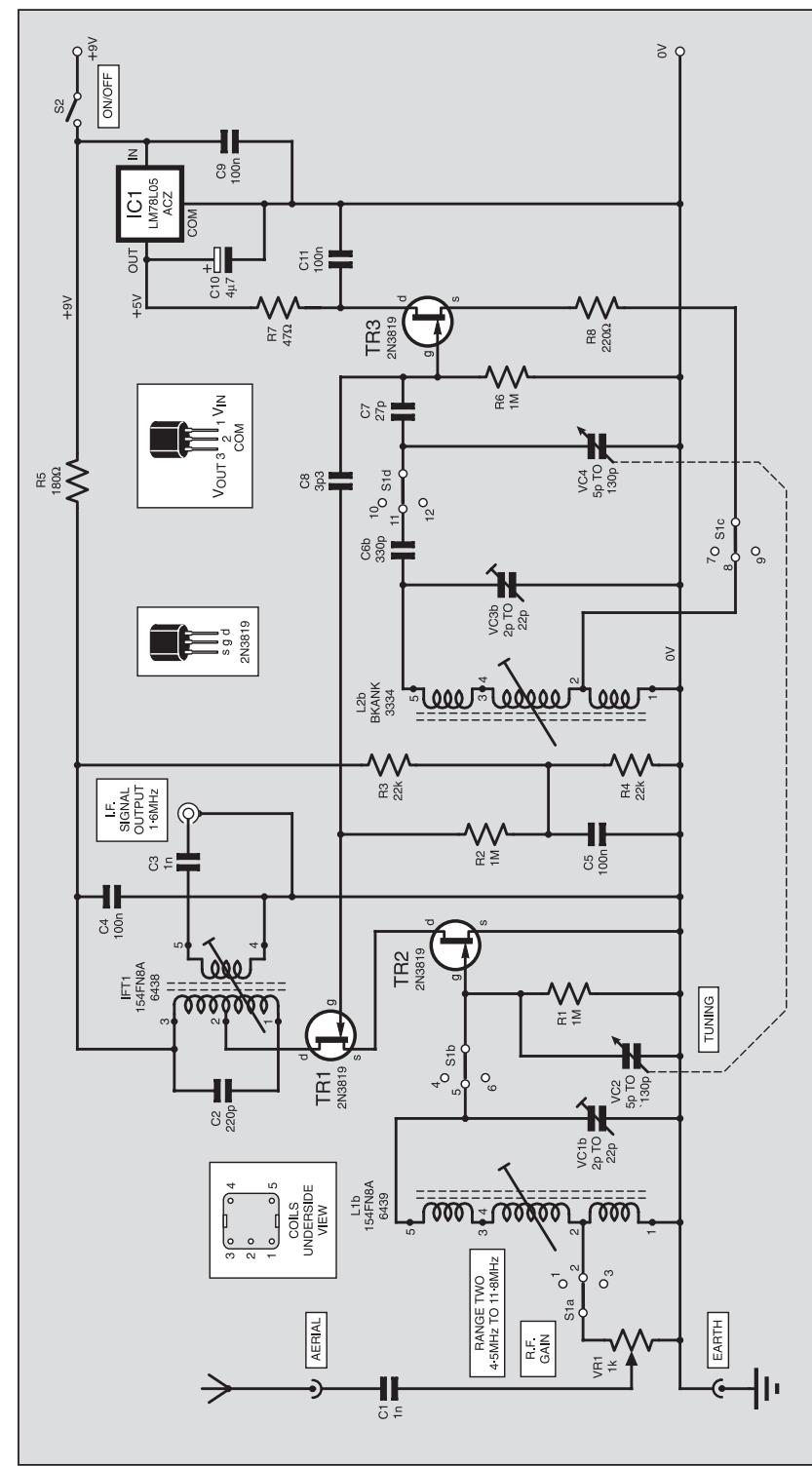


Fig.7.8. Circuit diagram for the mixer and oscillator stages for the 3-Band SW Superhet Tuner/Mixer. Coils for Range Two (4.5MHz to 11.8MHz) are shown. For ranges One and Three, see Fig.7.9.

VC1a to VC1c, 2p to 22p min. film dielectric trimmer  
VC3a to VC3c capacitor (6 off: see text for reducing this to 4 by using integral trimmers in VC2/VC4)  
5p to 130p polythene dielectric variable capacitor (with two a.m. tuning gangs, plus trimmers – see text)

VC2, VC4  
L1a, IFT1  
L1b, L1c, L2c  
L2a  
L2b

Inductors  
L1a, IFT2  
L1b  
L1c, L2c  
L2a  
Toko screened coil  
BKANK3334  
Toko screened coil

Semiconductors

TR1, TR2,  
TR3 2N3819 n-channel field effect transistor (3 off)  
IC1 LM78105ACZ +5V voltage regulator  
S1 4-pole 3-way rotary switch, make-before-break  
S2 s.p.d.t. toggle switch

Printed circuit boards available from the EPE PCB Service, code 426 (SW Mix/Osc) and 406 (T/Cap – optional); aerial and earth screw terminals; coaxial output socket; epicyclic reduction drive; one large and one small plastic control knob; single-core audio type screened cable; multistrand connecting wire; bat-

bolts, washers and p.c.b. stand-offs; solder pins; solder etc.

Note: Case is the Regen-

erative Radio from Part 3.

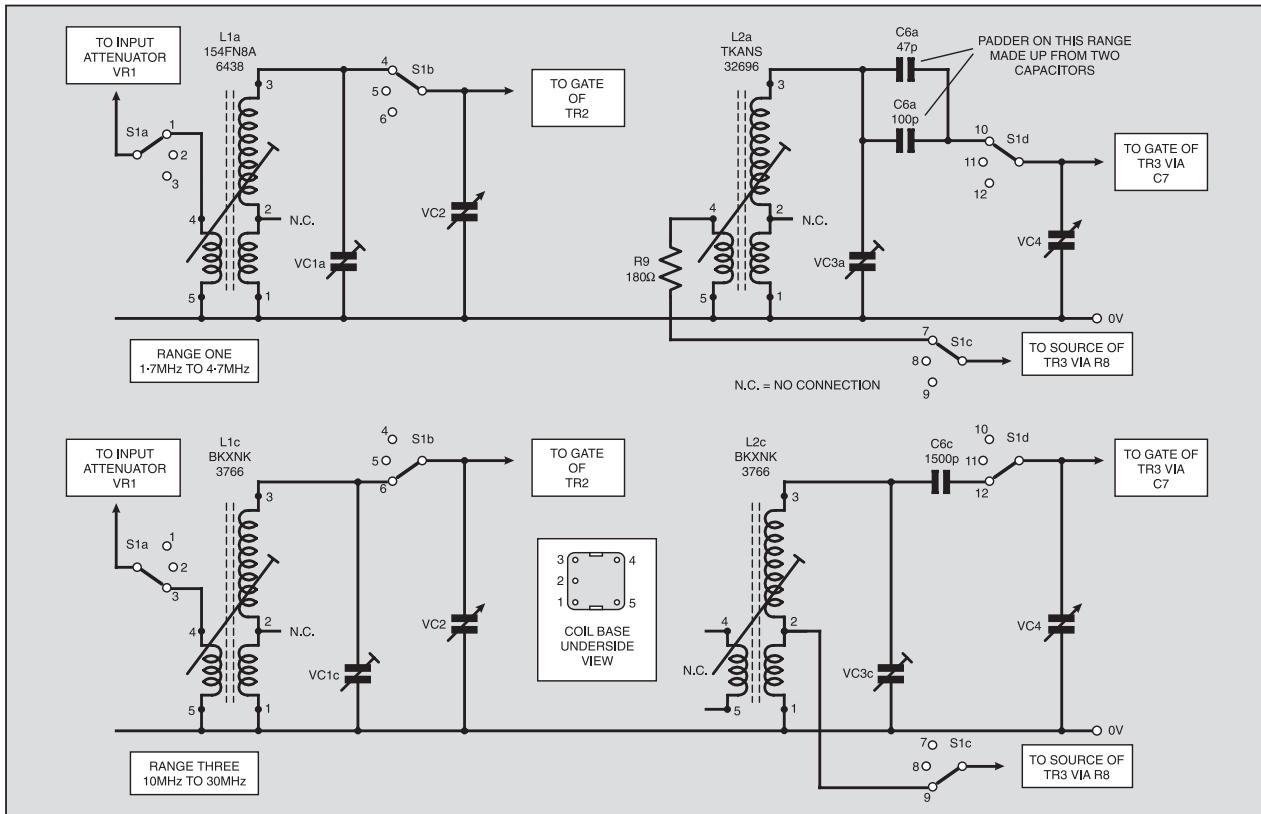


Fig.7.9. Circuit diagrams for the mixer/oscillator coil switching and padder arrangements for Shortwave Range One (1.7MHz to 4.7MHz) and Range Three (10MHz to 30MHz). VC2 and VC4 are ganged tuning capacitors and VC1 and VC3 are 2p to 22p trimming capacitors. See Fig.7.8 for Range Two details and full circuit.

Solder pins at the lead-out points simplify off-board wiring. They should be inserted first, followed by the Toko coils. Type numbers on the coil cans are easily removed by the smallest amount of handling: if they are to be retained they should be protected by clear sticky tape.

Follow the coils with the resistors, then the capacitors. Mount the transistors and the i.c. last. It is a good idea to use a miniature crocodile clip as a heatsink when soldering the field effect transistors in position.

### WAVECHANGE SWITCH

The coils have been arranged on the board so that the highest frequency inductors are closest to the wavechange switch. This minimizes lead-lengths where stray inductance would have the greatest impact. The wavechange switch and tuning capacitor must, however, be located as close as possible to the printed circuit board, and the photographs show the prototype arrangement.

Source resistor R8 and blocking capacitor C7 affect the willingness of TR3 to oscillate. Reducing the value of R8 and increasing C7 makes oscillation more vigorous. These components are used to link the p.c.b. to the wavechange switch S1. This makes them accessible to readers who wish to experiment, or who need to compensate for a low gain transistor.

Coil winding ratios make more source resistance necessary on Range One, and this takes the form of resistor R9 on the printed circuit board. See also Fig.7.9.

Provision is made on the board for a pair of trimmers, VC1/VC3, for each wave range. This will be necessary if an air-

spaced tuning capacitor, without integral trimmers, is fitted. The suggested polyvaricon has its own trimmers, which will serve for a single range version, or for range three in a multirange receiver.

### COMMISSIONING

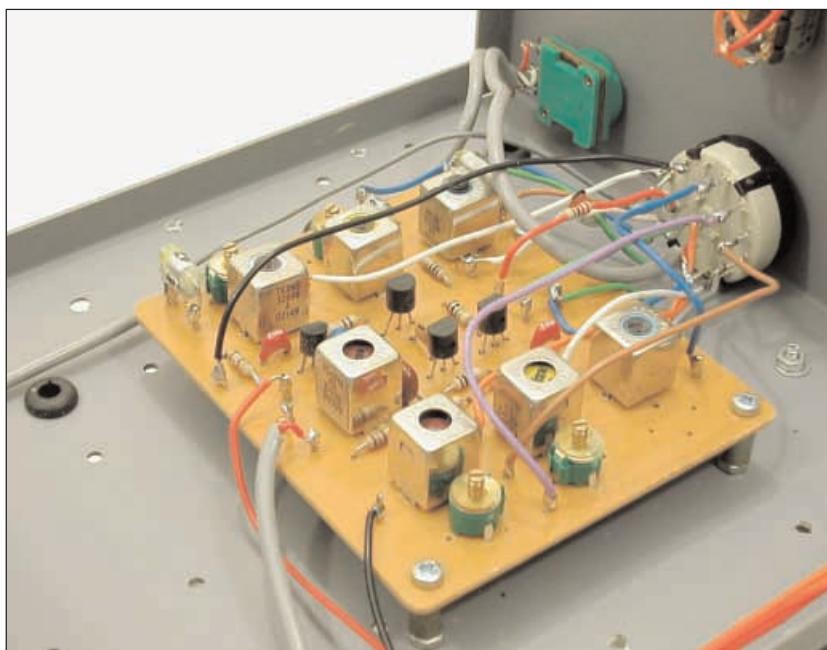
Check the board for poor soldered joints and bridged tracks. Check the orientation of IC1, the semiconductors and tantalum

capacitor C10. Check the wiring to the wavechange switch S1.

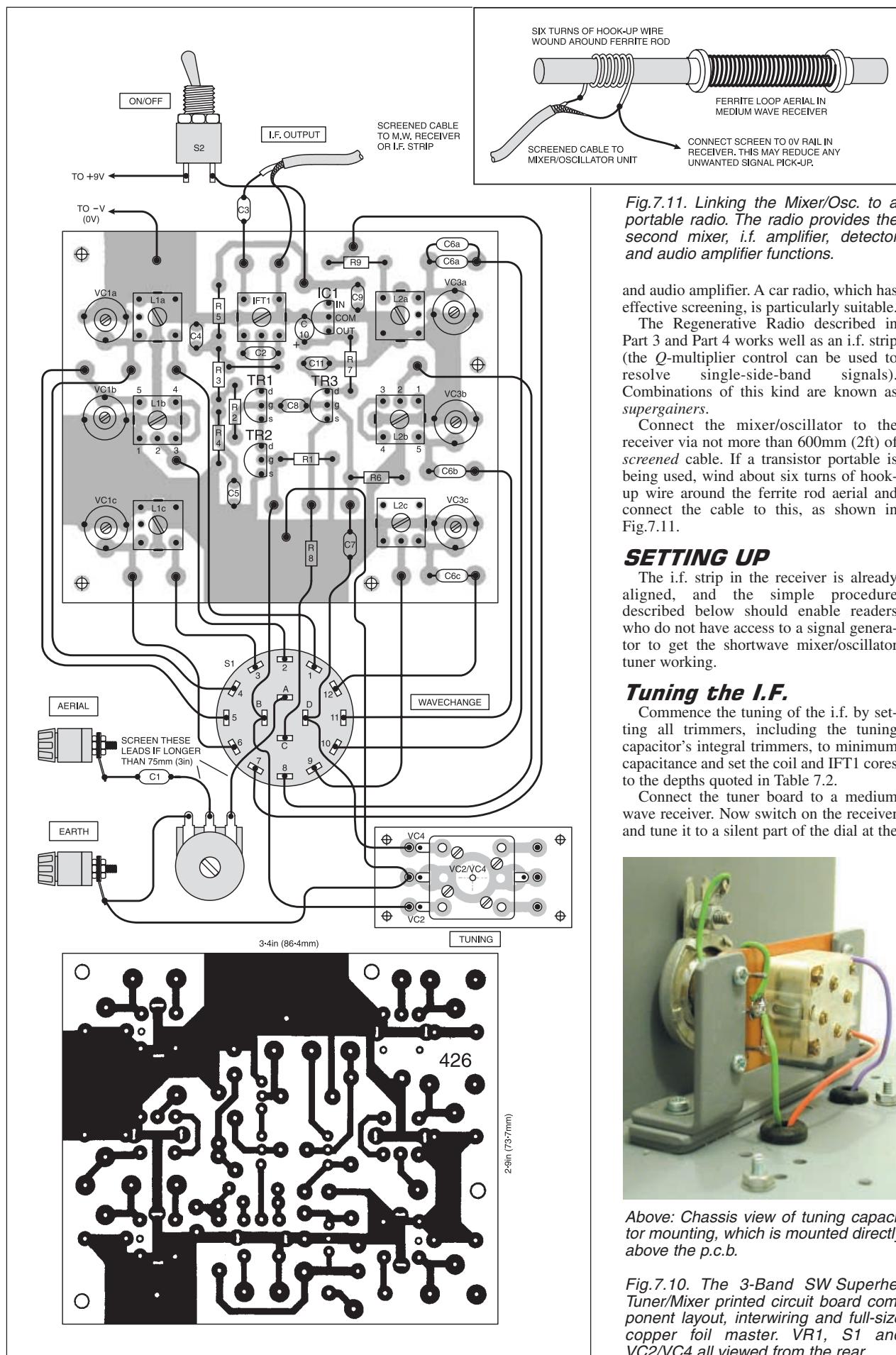
If all is in order, connect a fresh 9V battery. Current consumption should be in the region of 10mA and the voltage at the output of IC1 should be precisely 5V.

### I.F. STRIP

Almost any medium wave receiver will act as the second mixer, i.f. strip, detector



Printed circuit board mounted on chassis (underside) and wired-up to the rotary wavechange switch.



and audio amplifier. A car radio, which has effective screening, is particularly suitable.

The Regenerative Radio described in Part 3 and Part 4 works well as an i.f. strip (the *Q*-multiplier control can be used to resolve single-side-band signals). Combinations of this kind are known as *supergainers*.

Connect the mixer/oscillator to the receiver via not more than 600mm (2ft) of screened cable. If a transistor portable is being used, wind about six turns of hook-up wire around the ferrite rod aerial and connect the cable to this, as shown in Fig.7.11.

## SETTING UP

The i.f. strip in the receiver is already aligned, and the simple procedure described below should enable readers who do not have access to a signal generator to get the shortwave mixer/oscillator tuner working.

## Tuning the I.F.

Commence the tuning of the i.f. by setting all trimmers, including the tuning capacitor's integral trimmers, to minimum capacitance and set the coil and IFT1 cores to the depths quoted in Table 7.2.

Connect the tuner board to a medium wave receiver. Now switch on the receiver and tune it to a silent part of the dial at the



*Above: Chassis view of tuning capacitor mounting, which is mounted directly above the p.c.b.*

**Fig.7.10. The 3-Band SW Superhet Tuner/Mixer printed circuit board component layout, interwiring and full-size copper foil master. VR1, S1 and VC2/VC4 all viewed from the rear.**

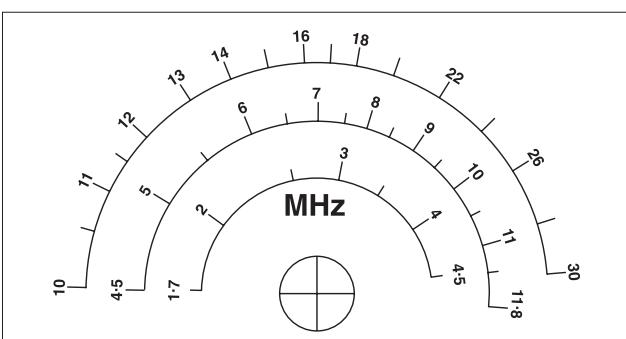


Fig.7.12. Calibrated tuning dial (half-size approx.) for the 3-Band SW Superhet Tuner.

close to *minimum* and adjust trimmer capacitors, VC1b/VC3b, to peak the output.

Repeat these adjustments until no further improvement can be obtained.

### Ranges One and Three

Switch to Range 3 and carry out the same procedure. The difficulty here will be finding a station at the high frequency end of the dial: try listening in the early afternoon. If integral trimmers are being used for the alignment of this range, set them to the lowest possible value, then switch back to Range Two and refine the adjustment of VC1b/VC3b to allow for the additional standing capacitance.

Switch to Range 1 and repeat the process. As frequency lowers the settings of cores and trimmers becomes more critical and no signals will be heard if the unit

is significantly out of alignment. Setting the cores to the stated depths and a little patience should ensure success.

The calibrated dial of the prototype receiver is reproduced, half-size, in Fig.7.12. Oscillator coil core and trimmer settings have a very significant effect on coverage, and it is only useful as a general guide.

The setting of the core of IFT1 is not critical. After carrying out the above procedure it should be adjusted to peak the output from the unit.

## PERFORMANCE

The precise frequency limits of each range cannot be set or defined without an accurately calibrated signal generator. It is, however, possible to align the unit well enough for it to give a very acceptable level of performance.

The use of field effect transistors brings all of the advantages mentioned earlier. Adopting a 1.6MHz i.f. greatly reduces the problem of spurious responses.

Tuning rate, with a single epicyclic reduction drive, is much too fast. Ways of making tuning less critical were discussed in Part Four, and next month a constant rate fine tuning system will be described.

**SHOP TALK**  
 with David Barrington

### PIC Virus Zapper

Most of our components advertisers should be able to suggest a suitable display module for the *PIC Virus Zapper*, but would be advisable to check out the pin-out arrangement of the one being offered before purchasing; you can, if you wish, hardwire it to the p.c.b. The alphanumeric display module used in the prototype was one that originally came from **Magenta Electronics** (01283 565435 or [www.magenta2000.co.uk](http://www.magenta2000.co.uk)).

For those readers unable to program their own PICs, a ready-programmed PIC microcontroller can be purchased direct from the author for the sum of £5 (add £1 for overseas). He will be supplying either the PIC16F84 or the PIC16F627, both devices are pin-for-pin compatible. Orders (*mail only*) should be sent to **Andy Flind**, 22 Holway Hill, Taunton, Somerset, TA1 2HB. Payments should be made out to *A. Flind*.

The software is available on a 3.5in. PC-compatible disk (Disk 6) from the *EPE Editorial Office* for the sum of £3 each (UK), to cover admin costs (for overseas charges see page 891). It is also available *Free* via the Downloads click-link option on the home page when you enter our main web site at [www.epemag.wimborne.co.uk](http://www.epemag.wimborne.co.uk), then enter the PIC Microcontroller source codes folder and select **PIC Virus Zapper**.

### Christmas Cheeks

After browsing through a few components catalogues, it would appear that finding an I.e.d. with an identical specification to the one used in the *Christmas Cheeks* prototype is likely to cause some problems. Most of the red ultrabright and superbright I.e.d.s that we looked at seem to have "viewing angles" ranging from 50° to 60° and not the 30° listed by the author.

The types that appear to meet the author's specification or better are ones with "water clear" packages. You can, of course, use the standard ultrabright or superbright and accept a more diffused light intensity.

### Practical Radio Circuits-7

As with previous *Practical Radio Circuits* projects, the inductors are really the only "specials" in this series. The author quotes two sources but has informed us that there may be a small delay as some coils have had to be reordered from Japan. However, by the time you read this issue they should have arrived.

All the Toko coils are available from **JAB Electronic Components** (0121 682 7045 or [www.jabdog.com](http://www.jabdog.com)), mail order only, or from **Sycom**, Dept EPE, PO Box 148, Leatherhead, Surrey, KT33 9YW (01372 372587 or [www.sycomcomp.co.uk](http://www.sycomcomp.co.uk)). You will need to order by quoting their type numbers as listed in the parts box and on the circuit diagrams.

The polyvaricon (polythene dielectric) variable capacitor will normally be found listed as a "transistor radio" type and consist of an antenna and oscillator section, plus trimmers. They are currently stocked by **ESR Components** (0191 251 4363 or [www.esr.co.uk](http://www.esr.co.uk)), code 896-110 and **Sherwood Electronics** (see page 896), code CT9. The one in the prototype was obtained from **Maplin** (0870 264 6000 or [www.maplin.co.uk](http://www.maplin.co.uk)), code AB11M.

### PIC Nim Machine

We do not expect any buying problems to be encountered when gathering together parts for the *PIC Nim Machine* project.

A pre-programmed PIC16F877-20 (20MHz) microcontroller can be purchased from **Magenta Electronics** (01283 565435 or [www.magenta2000.co.uk](http://www.magenta2000.co.uk)) for the inclusive price of £10 each (overseas add £1 p&p). The software is available on a 3.5in. PC-compatible disk (Disk 6) from the *EPE Editorial Office* for the sum of £3 each (UK), to cover admin costs (for overseas charges see page 891). It is also available *Free* via the Downloads click-link option on the home page when you enter our main web site at [www.epemag.wimborne.co.uk](http://www.epemag.wimborne.co.uk), then enter the PIC Microcontroller source codes folder and select **PIC Nim**.

### Teach-In 2004 Part 2

No problems to report on this month's instalment of our new *Teach-In '04* series. All the various transistor types mentioned should be readily available from our components advertisers, particularly **Cricklewood Electronics** (0208 452 0161).

**Good News!** We have just been informed that **Magenta Electronics** (01283 565435 or [www.magenta2000.co.uk](http://www.magenta2000.co.uk)) have produced two Teach-In components kits, one for the main components, including a plug-in breadboard, and the other containing most of the additional parts listed under "miscellaneous" in Part 1. See their ad. on pages 816/817.

Details of all the prices and ordering information for this month's printed circuit boards can be found on page 891.

### PLEASE TAKE NOTE

#### Cardboard Clock

(Nov '03)

Use normal thin card for the clock wheels as thick (art supplies) card may be too heavy and stop it. Use a rectangular file to make the grooves that support the wheels axles. Depth is correct when a screw laid in the groove is half buried. Point "D" is the 15mm horizontal section of suspension hook W2. Cement end B of the pendulum post (A1) to the backboard.

For the pendulum rod start with a 1 metre length of 24s.w.g. wire, and draw it slightly, to straighten it. Before bending it, mark the bend points with a pencil. The letter P shows on which side to position the pliers, when making bends Q and R. When readjusting the coil table rely on the rubber band, and not on the bolt through hole E.

# PRACTICAL RADIO CIRCUITS

**RAYMOND HAIGH**



## Part 8: A double-conversion superhet receiver for the SW bands

*Circuits for the set builder and experimenter*

LAST month's article covered the advantages and drawbacks of the superheterodyne (or superhet for short) receiver. A design for a mixer/oscillator unit with a 1.6MHz intermediate frequency (i.f.) output was described. Raising the i.f. to 1.6MHz, instead of the more usual 455kHz, reduces susceptibility to second channel interference, the major defect of the superhet.

This final part deals with the intermediate frequency amplifier, which provides most of the selectivity and gain. Teamed with last month's 3-Band SW Superhet Tuner/Mixer, it forms a high performance receiver for the shortwave listener.

### SELECTIVITY

Selectivity increases as the intermediate frequency is lowered.

Let us assume a receiver with the low i.f. of 100kHz tuned to a station on 900kHz with an adjacent transmitter operating on 910kHz. Signal spacing is 10kHz (910kHz minus 900kHz), and the adjacent station is, therefore, off tune from the wanted one by a mere 1.1 percent. Normal preselector, or signal frequency, tuned circuits will be unable to prevent the unwanted station reaching the mixer.

After mixing, the wanted signal will emerge at the i.f. frequency (1000kHz local oscillation minus 900kHz signal, equals 100kHz i.f.). The adjacent station will, therefore, emerge at a frequency of 90kHz (1000kHz minus 910kHz). Heterodyning has increased the difference between the signals to 10 percent, and the tuned circuits in the i.f. amplifier are better able to remove the unwanted station.

Performing this calculation with an i.f. of 455kHz reveals a difference, after heterodyning, of around two percent. The improvement with the higher i.f. is, therefore, very much less.

### EARLY DEVELOPMENTS

The first superhets had i.f.s below 100kHz in order to ensure stable operation with triode valves. Despite the introduction, during the 1920s, of neutralizing and

the screened-grid valve, measures that permitted amplification at high frequencies, i.f.s of around 100kHz persisted for another decade.

Second channel interference problems (see Part 7) intensify as the i.f. is lowered and/or reception frequency is raised, and manufacturers began to adopt the now standard i.f. of between 450kHz and 470kHz. The growing demand for domestic sets with shortwave coverage no doubt contributed to this development.

Despite the higher i.f., valve superhets with two, double-tuned i.f. transformers were selective enough for domestic listening. High performance communications receivers either incorporated a crystal filter (see below) or had a second mixer/oscillator stage that produced a final i.f. between 50kHz and 100kHz.

Current practice with simple transistor receivers is to provide three, single-tuned,

455kHz i.f. transformers. When greater selectivity is required, a crystal, ceramic or mechanical filter is built into the i.f. amplifier. Low frequency final i.f.s have fallen out of use.

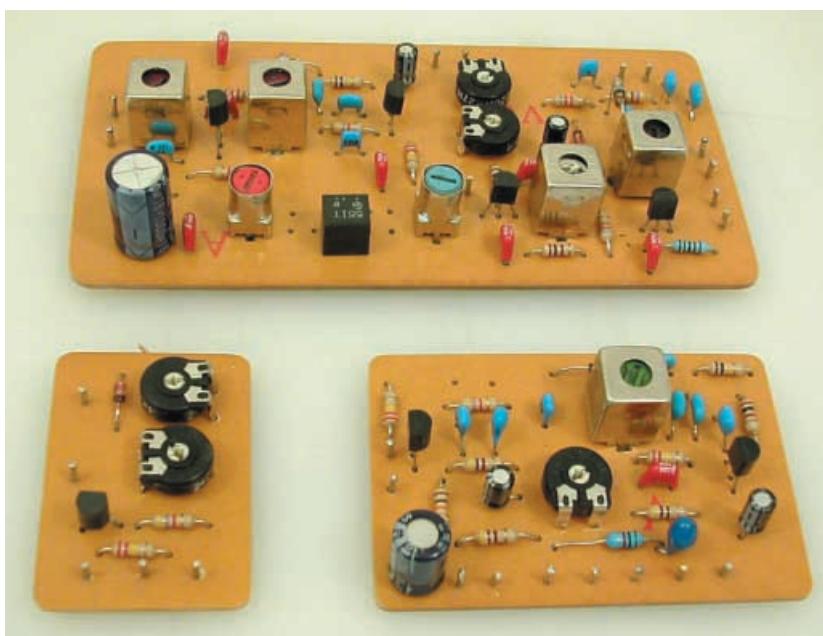
### FILTERS

#### Crystal

The first filters relied upon the piezoelectric nature of quartz, and the way slices of this crystalline material can be made to resonate, very sharply, at radio frequencies.

Professor W. G. Cady exploited this phenomenon, for the first time, in 1921, when he used a slice of quartz to control the frequency of an oscillator.

During the 1930s, circuits incorporating one or two crystals (Robinson's crystal gate and the Simmonds-Robinson two crystal filter) were forming part of high performance receivers. Passbands as narrow as 300Hz (for Morse reception) can easily be achieved with this technique.



Group photograph of this month's printed circuit boards: Second Mixer/Oscillator I.F. Amplifier (top); Signal-Strength Meter (left) and B.F.O./Product Detector (right).

## Mechanical

The Collins Radio Corporation of America subsequently developed mechanical filters in which the resonant elements are vibrating metallic discs linked by a rod. Filters of this kind can produce passbands less than 400Hz wide.

They are expensive but capable of very high performance. The signal is transferred to, and extracted from, the disc resonators by a coil wound on the link rod and mounted in the field of a permanent magnet.

Miniature mechanical filters are currently manufactured by Toko, see Table 8.1. Signal transfer involves the piezoelectric effect and the resonant mechanical element is a phosphor bronze strip. Performance is inferior to the Collins filters, but they are very inexpensive and widely used for less demanding applications. Passbands can be as narrow as 3kHz.

## Ceramic

Development of the ceramic filter by Murata and Vermiton coincided with the introduction of transistors and the resulting drive towards miniaturization. Ceramic filters also exploit the piezoelectric effect. In this respect they are similar to crystal filters, but they have a lower *Q*-factor (i.e., they resonate less sharply) and insertion losses are greater.

Manufactured from lead zirconate titanate and other compounds, they are smaller and usually cheaper. They are widely used in radio equipment, from domestic portables to high performance communications receivers.

Details of a number of low and medium priced ceramic filters, together with details of Toko's mechanical unit, are given in Table 8.1. Bandwidths (passbands) are quoted at the 6dB down (i.e., half-voltage) points. The figures represent the full passband, not the deviation from centre frequency.

The i.f. amplifier printed circuit board used here will accommodate any of the filters listed.

## PERFECTION

The perfect filter would cause zero attenuation, have a flat response within the passband, sharp cut-off at the passband boundaries, and completely attenuate all other frequencies. In practice, filters have an uneven response (ripple) within the passband, spurious responses beyond, and an insertion loss ranging from around three to ten decibels (dB).

Ceramic filters are prone to spurious responses, which are much reduced when they are combined with tuned matching and i.f. transformers.

## MATCHING

The specified filter performance will only be realized if its input and output impedances are correctly matched to the amplifying devices in the i.f. strip. This is not easy to achieve with bipolar transistors (automatic-gain-control alters bias levels and changes input impedance).

Serious mismatching causes an asymmetrical passband, increased insertion

losses and ripple. In practice, the filters detailed here will perform well despite slight imperfections in matching. They are a very convenient way of achieving high selectivity with an intermediate frequency of 455kHz.

## GAIN

During the valve era, gain within the i.f. amplifier was invariably provided by a single variable *mu* valve. Variable *mu* valves display a large change in amplification when the bias voltage is shifted by the a.g.c. circuitry. To achieve the same level of gain, transistor superhets require two i.f. amplifier stages.

Increasing use is being made, in domestic portables, of integrated circuits that contain all but the audio stages on a single chip. When these devices are employed, a miniature filter and its matching transformer provide selectivity.

Modern communications receivers usually have two, specialized, integrated circuit "gain blocks" in the final i.f. amplifier. Excellent a.g.c. performance, predictable impedances (for filter matching) and high levels of gain are achievable with these devices.

Unfortunately, they are not widely available to home constructors and, continuing the practice adopted throughout the series, the i.f. amplifier "strip" described here uses easy-to-obtain, non-critical semiconductors.



# DUAL-CONVERSION SW RECEIVER

An add-on i.f. amplifier board for last month's SW Superhet Tuner/Mixer

## SECOND MIXER/OSCILLATOR

To secure acceptable selectivity, the 1.6MHz output from our first mixer (Part 7) must be lowered to 455kHz. Constructors seeking higher selectivity will then be able to use one of the 455kHz filters already described. The i.f. amplifier must, therefore, be preceded by a second mixer/oscillator.

The full circuit diagram for the Second Mixer/Oscillator is given in Fig.8.1. Here IFT1 is tuned to the 1.6MHz incoming frequency, by capacitor C2, its low impedance coupling winding ensuring a correct match to the first mixer (See Part 7).

Signals developed across IFT1 are applied to TR1 gate (g), the second mixer, the local oscillation being injected at its source (s). Biasing of this stage is by resistor R2, which is bypassed by capacitor C4.

Tuned transformer IFT2 selects the 455kHz heterodyne and acts as TR1's drain (d) load. The stage is decoupled by R1 and C1.

The second oscillator must operate at 2055kHz (1600kHz plus 455kHz). Tuned circuit L2/C6 determines the frequency of oscillation and the maintaining device is TR2, an *n*-channel field effect transistor. Low impedance mixer coupling winding L1 minimizes damping on the tuned circuit.

Feedback for this Hartley oscillator is taken from the source of TR2 and applied to a tapping on L2 via bias resistor R5 and bypass capacitor C9. Supply line decoupling is by R4 and C10.

## BANDSPREAD

The second oscillator frequency can be altered, over narrow limits, by potentiometer VR1 which varies the reverse bias on varicap diode D1. This tunes the second

i.f. amplifier across the broad passband of the first, in effect shifting the first i.f. This results in a bandspread or fine tuning system that has a constant rate, irrespective of reception frequency.

The fine-tuning rate is preset by VR2. Potentiometer "noise" is eliminated by capacitor C11 and resistor R6 isolates the signal circuits from the bias network. Blocking capacitor C7 prevents the shorting of the bias through coil L2.

## FILTER

Intermediate frequency transformers, IFT2 and IFT3, ensure an acceptable match to any of the Toko or Murata filters listed in Table 8.1. A filter, X1, with a **total bandwidth** of 4kHz is recommended for general listening on the shortwave bands. Wider filters can be used to avoid sideband cutting, but selectivity will be excessively compromised if the passband is greater than 6kHz.

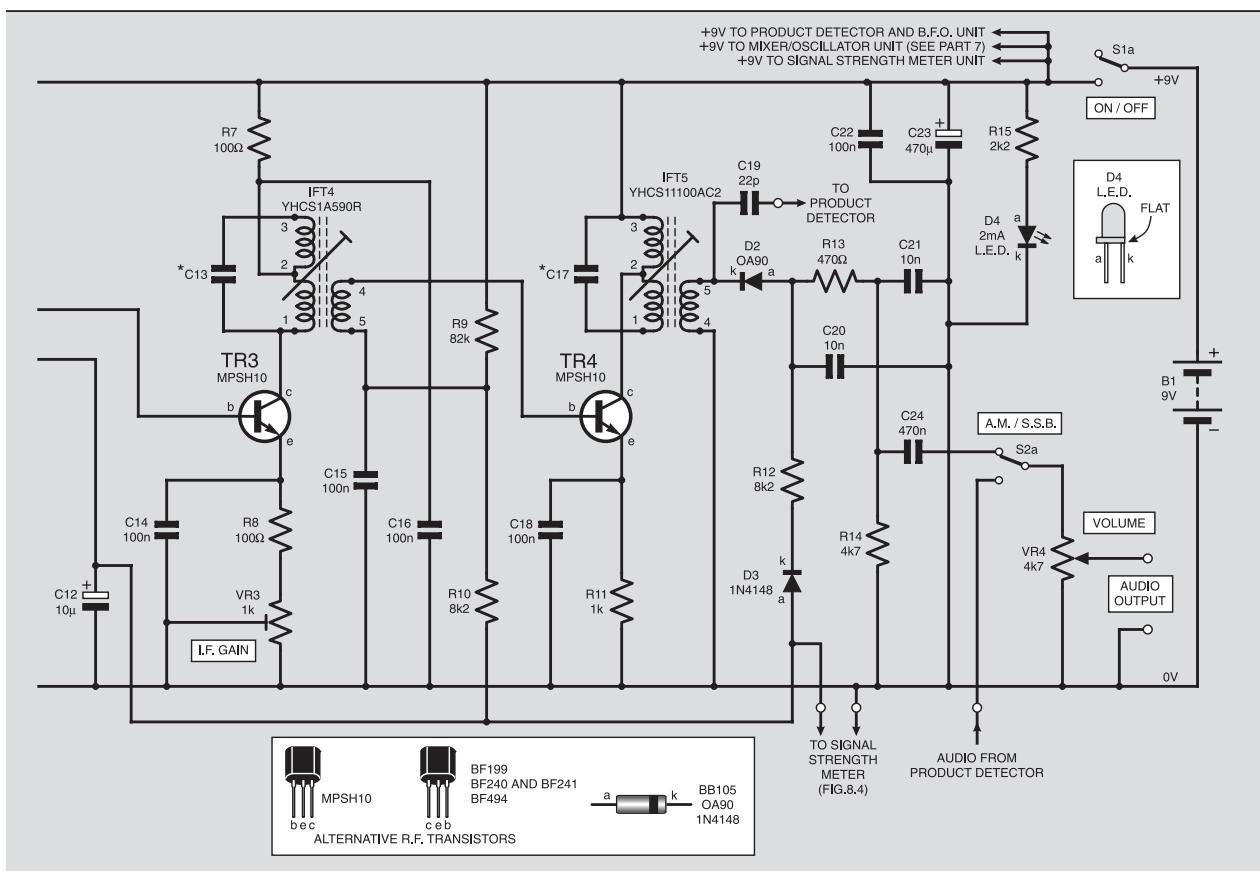
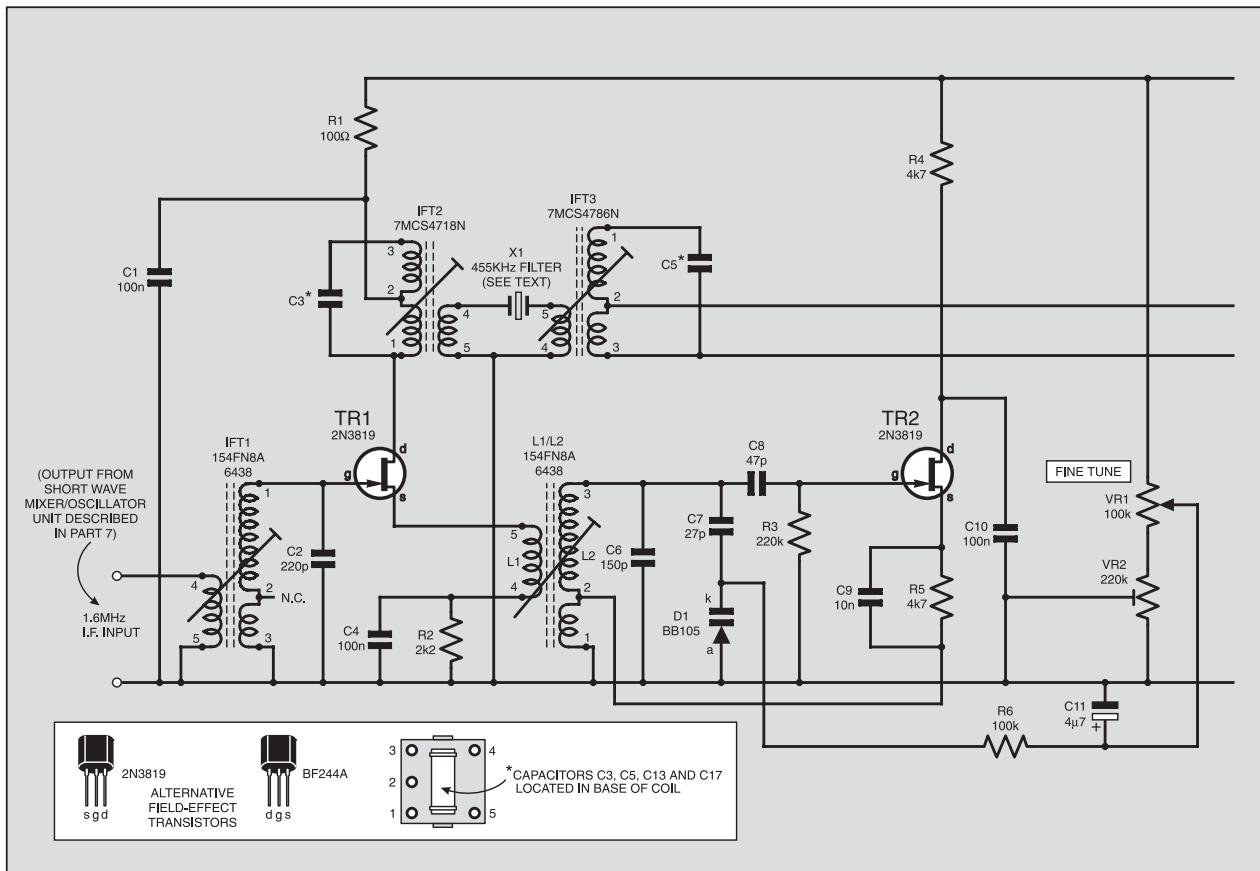


Fig.8.1. Full circuit diagram for the Second Mixer/Oscillator I.F. Amplifier for the Dual-Conversion SW Superhet Receiver. (See Part 7 for the first Mixer/Oscillator stages.)

## I.F. AMPLIFIER

Bipolar transistors TR3 and TR4 provide amplification at the 455kHz second i.f. This circuit is used, with minor modifications, in all domestic superhets fabricated from discrete components.

Transformers IFT4 and IFT5 couple the stages and tune the amplifier to 455kHz. Emitter bias to TR3 is developed across R8 and Gain preset VR3. This stage is decoupled by R7 and C16, and the emitter resistors are bypassed by C14. Emitter bias to TR4 is provided by R11 with C18 as the bypass capacitor.

## AUDIO DETECTOR

Point contact germanium diode D2 demodulates the a.m. signals, and residual radio frequencies are filtered by C20, R13 and C21. (Diode detectors were discussed in Part 1.) The audio output is developed across resistor R14 and coupled to the a.f. gain (Volume) control, VR4, by capacitor C24.

Provision is made for the r.f. output of the i.f. strip to be connected, via capacitor C19, to a product detector so that single side-band (s.s.b.) signals can be clarified. Toggle switch S2a selects either the a.m. output or the clarified s.s.b. signals. The other half of this switch,

S2b, connects the B.F.O. and Product Detector to the power supply (see Fig.8.6).

Supply line decoupling of the entire i.f. amplifier at r.f. and a.f. is accomplished by capacitors C22 and C23.

The other half (S1b) of the On/Off switch S1 is used to connect a separate battery to the simple Speaker Amplifier (Part 2). Separate batteries prevent the audio amplifier's current swings disturbing the electronic tuning systems. Power "on" is indicated by low current i.e.d. D4.

## AUTOMATIC GAIN CONTROL

The d.c. voltage produced by the detector diode D2 is used to control the gain of TR3 and TR4 by varying their base bias. As signal strength increases, the voltage becomes more negative. This reduces the bias and, hence, the current through the transistors, and gain falls.

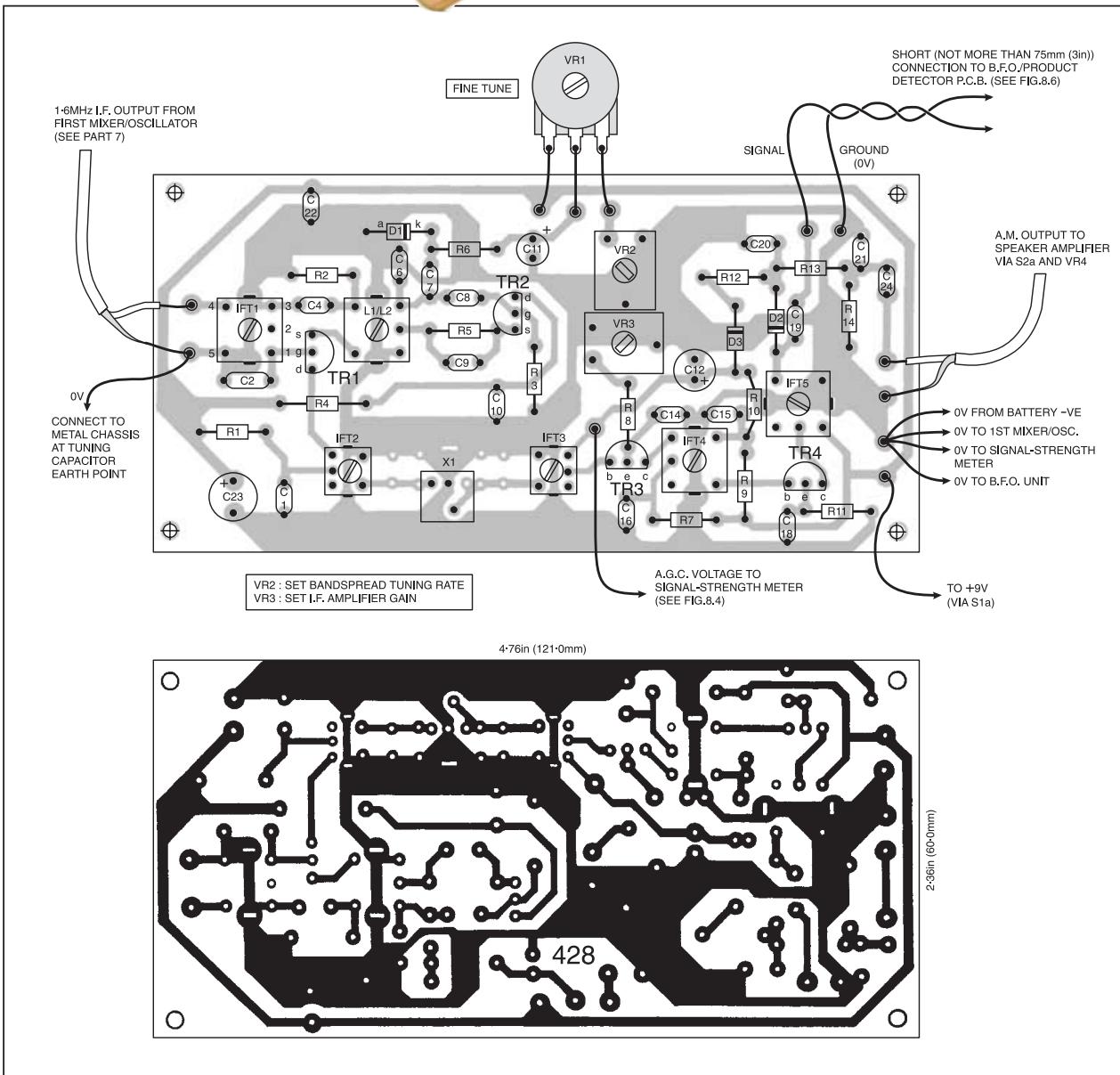
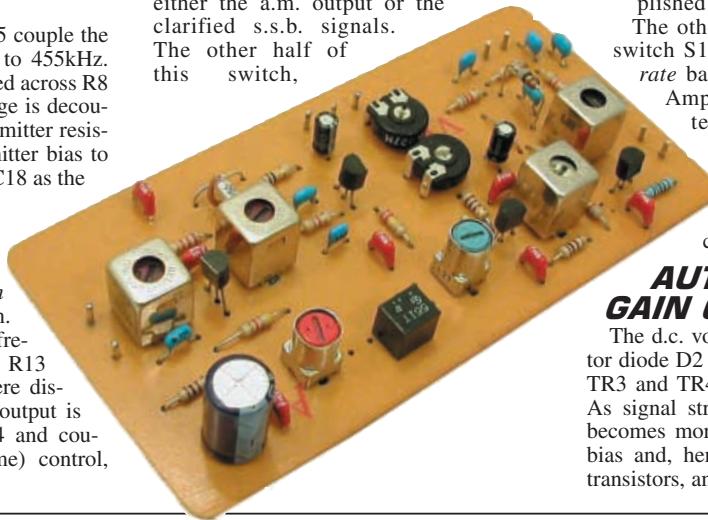


Fig.8.2. Printed circuit board topside component layout, interwiring to off-board components and full-size copper foil master for the Second/Mixer/Oscillator I.F. Amplifier.

# COMPONENTS

Approx. Cost  
Guidance Only

£25

excl. case & batts

## I.F. AMP

### Resistors

R1, R7, R8 100Ω (3 off)

R2, R15 2k2 (2 off)

R3 220k

R4, R5, R14 4k7 (3 off)

R6 100k

R9 82k

R10, R12 8k2 (2 off)

R11 1k

R13 470Ω

All 0.25W 5% carbon film

See  
**SHOP**  
**TALK**  
page

### Potentiometers

VR1 100k rotary carbon, linear

VR2 220k enclosed carbon preset

VR3 1k enclosed carbon preset

VR4 4k7 rotary carbon, log.

### Capacitors

C1, C4, C10,

C14 to C16,

C18, C22 100n ceramic (8 off)

C2 220p polystyrene or ceramic "low k"

C3, C5, C13, C17 included in i.f. can  
C6 150p polystyrene or ceramic "low k"  
C7 27p ceramic "low k"  
C8 47p ceramic "low k"  
C9, C20, C21 10n ceramic (3 off)  
C11 4μ7 radial elect. 16V  
C12 10μ radial elect. 16V  
C19 22p ceramic "low k"  
C23 470μ radial elect. 16V  
C24 470n ceramic or polyester

### Semiconductors

D1 BB105 varicap diode

D2 OA90 germanium diode

D3 1N4148 signal diode

D4 5mm low current (2mA) red i.e.d.

TR1, TR2 2N3819 n-channel field effect transistor (2 off)

TR3, TR4 MPSH10 high frequency transistor or similar (2 off)

### Inductors

IFT1, L1/L2 154FN8A6438 Toko screened (metal can) coil (2 off)

IFT2 7MCS4718N Toko screened (metal can) coil  
IFT3 7MCS4786N Toko screened coil  
IFT4 YHCS1A590R Toko screened coil  
IFT5 YHCS11100AC2 Toko screened coil

### Miscellaneous

X1 CFU455IT Murata 4kHz bandwidth ceramic filter (see text)

S1, S2 d.p.d.t. toggle switch (2 off)

Printed circuit board available from the EPE PCB Service, code 428 (I.F. Amp); case, aluminium box 203mm x 152mm x 76mm (8in. x 6in. x 3in.) – 2 off (see text); white card and rubdown lettering for front panel; protective 2mm thick Perspex sheet for front panel; two large and four small plastic control knobs; aluminium sheet for tuning capacitor (Part 7) screen; i.e.d. holder; audio type screened cable; multistrand connecting wire; p.c.b. nylon stand-off pillars; battery holder and connectors; nuts, bolts and washers; solder pins; solder etc.

The a.g.c. (automatic gain control) circuit is a little obscure. A chain of components, R9, R10, D3, R12 and D2 form a shared bias network. Including detector diode D2 introduces the signal-related voltage variation. Stabilization against temperature changes is provided by diode D3 (which must be a silicon component to

provide compensation for the silicon transistors).

The a.g.c. and bias network is connected to TR3 and TR4 via the IFT's coupling windings. The full a.g.c. voltage is applied to the base of TR3. Final stage TR4 is connected via resistor R10 to limit the a.g.c. action so that, even under strong signal

conditions, sufficient output is available to drive the detector. The a.g.c. line is bypassed by C12.

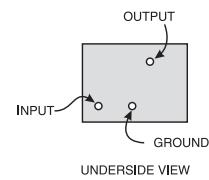
Details of the printed circuit board (p.c.b.) topside component layout, full-size copper foil master and the off-board wiring details are shown in Fig.8.2. General guidance on construction is given later.

Table 8.1: Mechanical and Ceramic I.F. Filters

### Ceramic Filter: Murata Type CFU

Type No.	Input/output impedance	6dB bandwidth
CFU455IT	2k	4kHz
CFU455H2	2k	6kHz
CFU455G2	2k	9kHz

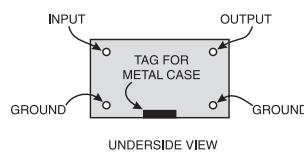
(Case size: L8mm x W7mm x H8mm)



### Ceramic Filter: Murata Type CFG

Type No.	Input/output impedance	6dB bandwidth
CFG455J	2k	3kHz
CFG455I	2k	4kHz
CFG455H	1k5	6kHz

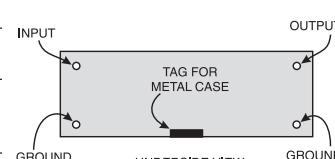
(Case size: L11mm x W7mm x H9.5mm)



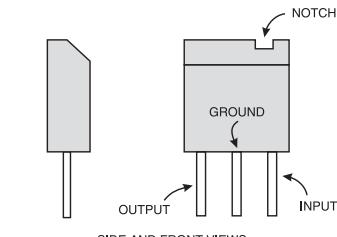
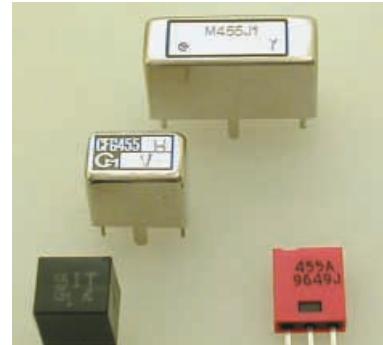
### Ceramic Filter: Murata Type CFM

Type No.	Input/output impedance	6dB bandwidth
CFM455J1	2k	2.6kHz
CFM455I	2k	4kHz
CFM455H	2k	6kHz

(Case size: L20mm x W7.3mm x H10.3mm)



Insertion loss for all of the filters, except the CFM455I and the CFG455J, is 6dB. Insertion loss for the CFM455I is 7dB; for the CFG455J, 8dB.



### Mechanical Filter: Toko Type HCFM

Type No.	Input/output impedance	6dB bandwidth
HCFM2455A	1k/1k5	4kHz
HCFM2455B	1k5/2k	6kHz
HCFM2455C	2k	8kHz

(Case size: L8.2mm x W3.5mm x H9.5mm)

# SIGNAL-STRENGTH METER

Check the reception conditions with this simple circuit

A Signal-Strength Meter is useful for monitoring reception conditions and assessing different aerial systems. It can also be of assistance during the setting up process.

The Signal-Strength Meter bridge circuit given in Fig.8.3 enables the standing voltage on the a.g.c. line to be nulled out so that the meter pointer can rest at zero under no-signal conditions.

Transistor TR1 and collector load resistor R2 form two arms of the bridge: preset

potentiometer VR2 provides the other two. Setting the slider (moving contact) of VR2 to the same potential as the collector of TR1, in the absence of a signal, brings the meter pointer to zero.

The base of TR1 is connected to the a.g.c. line via current limiting resistor R1. The a.g.c. voltage becomes more negative as signal level increases, current through TR1 decreases, and the voltage at its collector becomes more positive, driving over the meter pointer.

Panel meter full-scale deflection (f.s.d.) is set by preset VR1, and the bridge is stabilized against thermal drift by diode D1, which mirrors the base/emitter junction in TR1.

Meters of lower sensitivity can be used if the value of R1 is reduced. It ought not, however, to be taken below 100 kilohms. With this value it should be just possible to use a 1mA meter. Meters of higher sensitivity should be shunted to around  $100\mu\text{A}$ .

Details of the printed circuit board top-side component layout, full-size copper foil master and interwiring are given in Fig.8.4. General guidance on construction is given later.

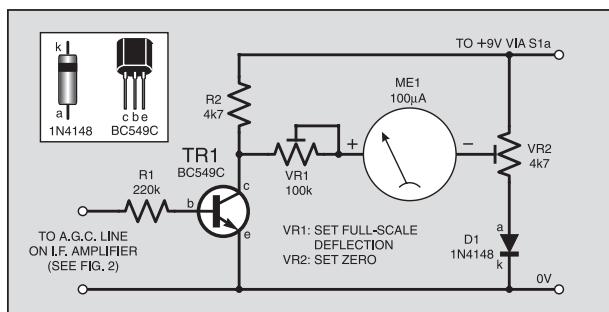


Fig.8.3. Circuit diagram for the Signal-Strength Meter.

## COMPONENTS

### SIGNAL-STRENGTH METER

#### Resistors

R1	220k (see text)	See SHOP TALK page
R2	4k7	
All	0.25W 5% carbon film	

#### Potentiometers

VR1	100k enclosed carbon preset
VR2	4k7 enclosed carbon preset

#### Semiconductors

D1	1N4118 signal diode
TR1	BC549C npn small signal transistor

#### Miscellaneous

ME1	100μA moving coil panel meter
-----	-------------------------------

Printed circuit board available from the EPE PCB Service, code 429 (Sig. Meter); multistrand connecting wire; solder pins; solder etc.

Approx. Cost  
Guidance Only

£5.50  
excl. meter

Panel Meter  
and circuit  
board mounted  
in one corner of  
the receiver top  
chassis.

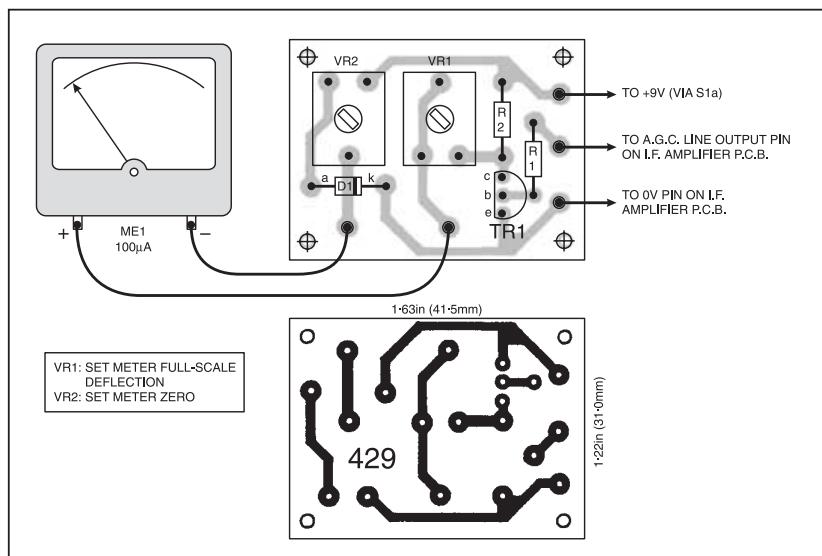


Fig.8.4. Signal-Strength Meter printed circuit board component layout, wiring and full-size copper foil master.

# B.F.O. AND PRODUCT DETECTOR

An additional circuit for receiving single-side-band transmissions.

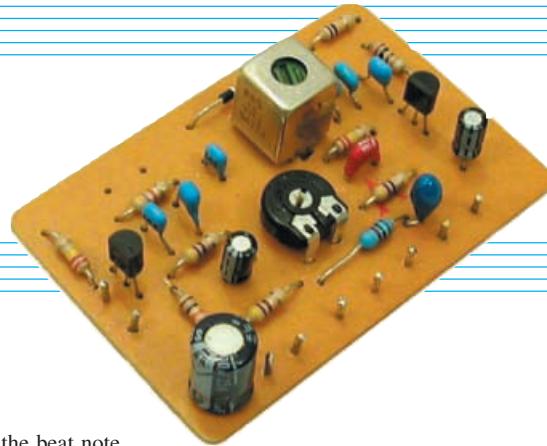
Readers interested in Morse and single side-band (s.s.b.) speech transmissions will require a beat frequency (b.f.o.) and carrier replacement oscillator.

Morse is transmitted by interrupting the carrier, and the receiver must contain an oscillator to beat with these signals and make them audible. Single side-band transmissions have their carrier suppressed at the transmitter and it must be restored, by an oscillator in the receiver, so that they can be demodulated (see Part 6).

The simplest arrangement, widely adopted during the valve era, is to inject the oscillation directly into the i.f. strip, just ahead of the detector. Unfortunately, this activates the a.g.c system and depresses receiver sensitivity. Accordingly, a simple product detector has been included to ensure the complete isolation of the oscillator.

## CIRCUIT DETAILS

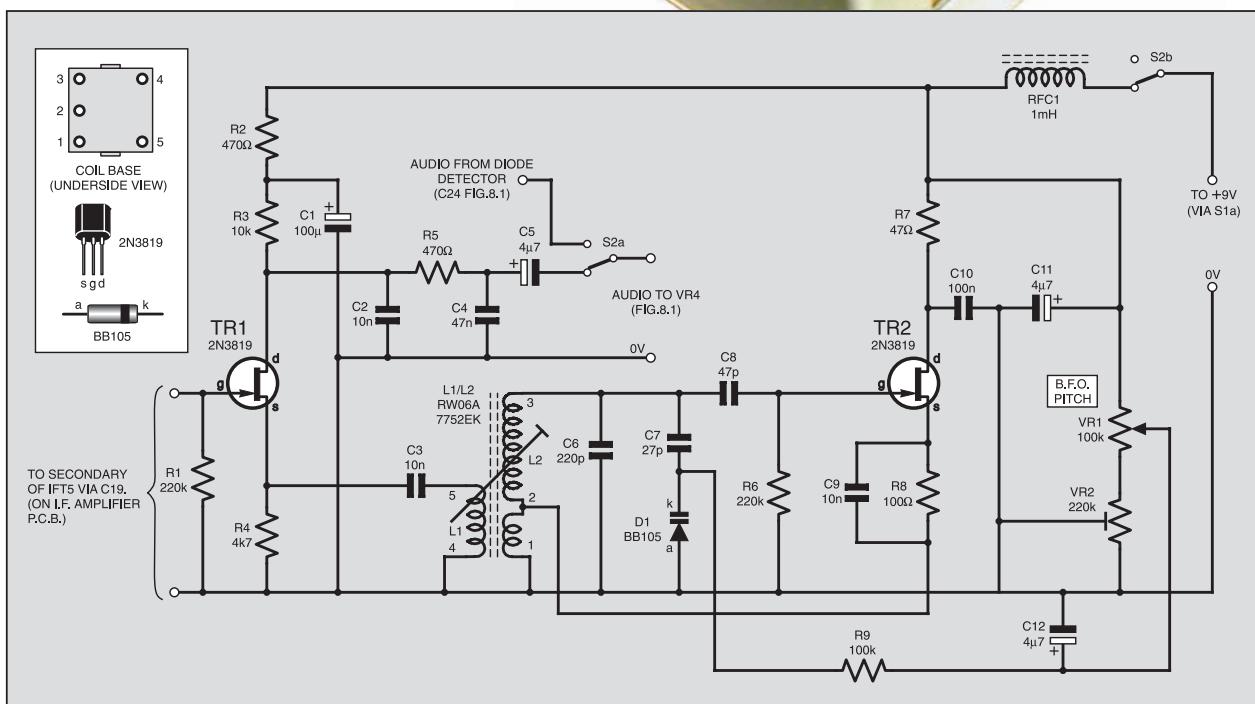
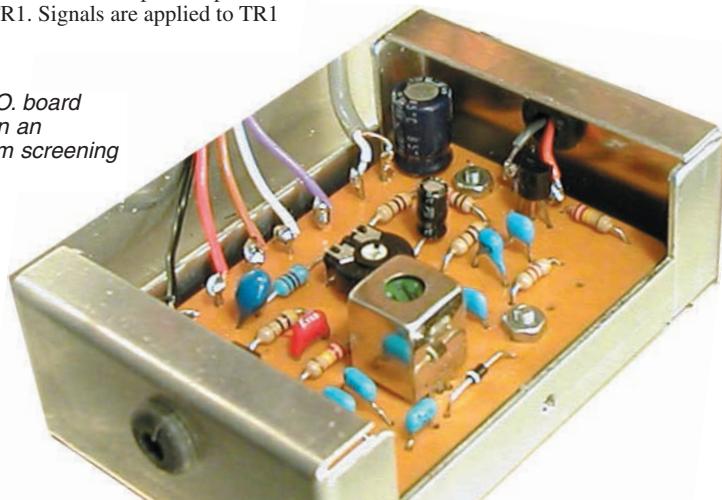
The full circuit diagram for a B.F.O. and Product Detector is shown in Fig.8.5. Transistor TR2, coil L2 and capacitor C6 form a 455kHz Hartley oscillator. Its frequency can be altered slightly by varicap



diode D1 in order to change the beat note or to accommodate the upper and lower side-band transmission modes. This oscillator circuit is almost identical to the second mixer/oscillator, and the function of the various components has already been described.

The oscillator's output is coupled, via coil L1, to the source pin of product detector TR1. Signals are applied to TR1

*The B.F.O. board housed in an aluminium screening box.*



*Fig.8.5. Complete circuit diagram for the B.F.O. and Product Detector. For clarity, switch S2a is also shown on the I.F. Amp circuit. This circuit is required for the reception of s.s.b. transmissions.*

# COMPONENTS

Approx. Cost  
Guidance Only

£12  
excl. case

**B.F.O. and PROD. DETECT**  
**Resistors**  
R1, R6 220k (2 off)  
R2, R5 470Ω (2 off)  
R3 10k  
R4 4k7  
R7 47Ω  
R8 100Ω  
R9 100k

All 0.25 5% carbon film

**Potentiometers**

VR1 100k rotary carbon, lin.  
VR2 220k enclosed carbon preset

**Capacitors**

C1 100μ radial elect. 16V  
C2, C3, C9 10n ceramic (3 off)  
C4 47n ceramic  
C5, C12 4μ7 radial elect. 16V (2 off)

See  
SHOP  
TALK  
page

C6 220p polystyrene or ceramic "low k"  
C7 27p ceramic "low k"  
C8 47p ceramic "low k"  
C10 100n ceramic  
C11 4μ7 tantalum bead, 16V

**Semiconductors**

D1 BB105 varicap diode  
TR1, TR2 2N3819 n-channel field effect transistor (2 off)

**Miscellaneous**

L1/L2 RWO6A7752EK Toko screened (metal can) coil  
RFC1 1mH r.f. choke  
S2 see I.F. Amp listing

Printed circuit board available from the *EPE PCB Service*, code 430 (B.F.O./Prod. Detect.); screening box for B.F.O., size 76mm x 51mm x 25mm (3in. x 2in. x 1in.) – see text; audio type screened cable; multi-strand connecting wire; p.c.b. nylon stand-off pillars; solder pins; solder etc.

Product detectors were discussed in Part 6. They function in the same way as mixers but combine close radio frequencies to deliver an audio signal at the output port.

Details of the printed circuit board topside component layout, full-size copper foil master and interwiring are shown in Fig.8.6. General guidance on construction is given later.

## COMPONENTS

Transistor types for the three circuits are not critical and alternatives, with base connections, are included in Fig.8.1. Other f.e.t.s, including the BF245B, J304 and J310, have been in-circuit tested and found to be satisfactory.

Detector diode D2 must be a point contact *germanium* type. The specified OA90 is often used in this circuit, but the OA47 and others should perform equally well.

The Murata CFU4551T filter is recommended, but the i.f. printed circuit board will accept any of the units scheduled in Table 8.1. Readers whose requirements are less demanding can dispense with the filter and link the coupling windings of IFT2 and IFT3 with a 100pF low-k ceramic capacitor. The performance implications of this are discussed later.

Full details of the preselector and first mixer/oscillator stages, and the switched coil pack, were given in Part 7. Details of a simple Speaker Amplifier were given in Part 2.

## GENERAL CONSTRUCTION

The three circuits are assembled on separate printed circuit boards (p.c.b.s). This permits the complete screening of the b.f.o. unit and makes it easier for constructors to omit items they do not require. These boards are available from the *EPE PCB Service*, codes 428 (I.F. Amp), 429 (Sig. Meter) and 430 (B.F.O./Prod. Det.).

The component side of the I.F. Amplifier printed circuit board, together with a full-size copper foil master, is given in Fig.8.2. Component and foil sides of the Signal-Strength Meter p.c.b. are shown in Fig.8.4 and the two sides of the B.F.O. and Product Detector board are depicted in Fig.8.6.

Off-board wiring is made easier by the use of solder pins at the p.c.b. lead-out points. They should be inserted first. Follow these with the resistors, then the coils, and then the capacitors, smallest first.

The semiconductors should be soldered in place last, their lead lengths just long enough to attach a miniature crocodile clip to act as a heatshunt. (Heat shunting is good practice with f.e.t.s and germanium diodes).

Filter matching transformers IFT2 and IFT3 are only 7mm square (the 10mm versions are no longer retailed), and particular care should be taken to avoid bridging tracks when they are soldered onto the p.c.b. Avoid stressing the pins of the coils: this can result in open-circuit windings.

On completion, double-check each board for bridged tracks and poor soldered joints. Check the orientation of the semiconductors and polarized capacitors, and check coil and i.f.t. placements.

Connect a fresh 9V battery and check current drain. The I.F. Amplifier should consume around 4mA, the B.F.O. and Product Detector around 6mA.

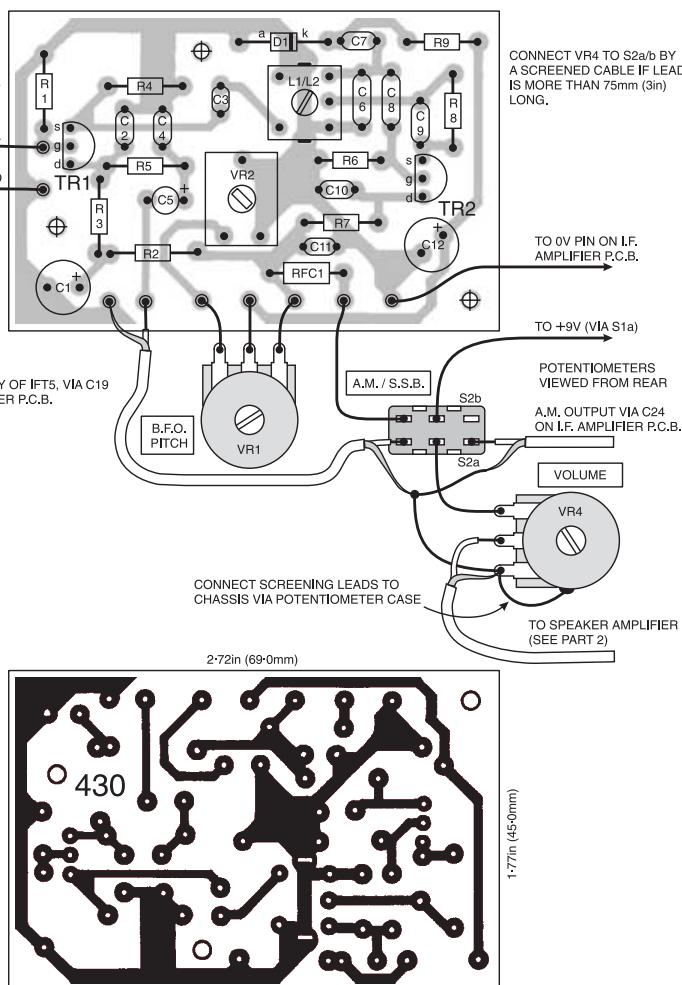


Fig.8.6. Printed circuit board topside component layout, interwiring to off-board components together with the underside copper foil master.



## RECEIVER ASSEMBLY

The chassis and front panel described in Part Three could be used for this receiver. Construction of a double-conversion superhet does, however, represent a considerable effort, and many readers will want a more "finished" look. The arrangement adopted for the prototype receiver is shown in the various photographs.

Case and chassis are formed from two standard aluminium boxes, with their U-shaped covers fixed back-to-back. The coil pack and first mixer/oscillator p.c.b., from last month, is mounted, along with the various controls, below the chassis. The tuning capacitor, i.f. amplifier, b.f.o unit, signal-strength meter and audio amplifier are located above the chassis. Receiver and audio amplifier batteries are secured, by strong rubber bands, to a hard-board platform fixed alongside the coil pack.

A small screening box encloses the b.f.o. unit, and a metal screen is fixed around the tuning capacitor. These measures are not absolutely essential, but they do help to prevent spurious responses.

The front panel is marked out on white card and annotated with rub-down lettering, see photograph. Acrylic sheet, 2mm thick (the kind used for DIY double glazing), protects the panel. The speaker is mounted beneath the top of the case, which is finished with car spray paint. Rubber feet protect the underside.

## INTERWIRING

Details of the interwiring connections between the printed circuit boards are also shown in Fig.8.2, Fig.8.4 and Fig.8.6. Screened cable must be used where indicated, but it can be of the ordinary audio variety.

Note the use of the 0V pin on the i.f. amplifier board as the *common negative* connection for *all* of the receiver p.c.b.s. Do not rely on the outer braiding of screened leads to act as negative returns for the power supply.

The negative supply lead for the Speaker Amplifier is connected directly to the appropriate pin on its p.c.b. (see Part 2). Connections to the battery positive terminals are, of course, via switch S1a for the receiver boards, and S1b for the Speaker Amplifier.

Provision is not made on any p.c.b. for the l.e.d dropper resistor R15. This component is included in the wiring to the Power On l.e.d. D4.

Mount the p.c.b.s on insulated stand-offs, and connect the "earthy" side of the i.f. board input to the metal chassis, close to the tuning capacitor. This point should also be used as the chassis connection for the first mixer/oscillator p.c.b. (see Part 7). Connect the audio amplifier board to chassis at the a.f. gain or volume control.

## ALIGNMENT

### - Second Mixer/Osc.

Alignment of the completed Double-Conversion SW Receiver cannot be undertaken without the aid of a signal generator covering 1.6MHz to 30MHz. The procedure is as follows:

- (1) Switch receiver and signal generator on and allow a thirty-minute warm-up time. Always keep the generator output as low as possible. Sensitivity will increase as alignment progresses, and eventually a direct connection between receiver and generator will no longer be required; just place the generator's output lead close to the injection point.
- (2) Coil and i.f. transformer cores, especially the small slug type, are brittle. Use a *plastic* trimming tool for the adjustments.
- (3) Potentiometers, VR1, VR2 and VR3, associated with the I.F. Amplifier, should be set at mid-travel. Switch reception mode to a.m. and turn up Volume control VR4.
- (4) Connect a high impedance voltmeter (a digital testmeter is suitable) across the Signal-Strength Meter output points on the i.f. board and switch it to a low (say 2V) range.

(5) Using the signal generator, inject a modulated 455kHz signal at the drain of the second mixer, TR1. Adjust the cores of IFT2, IFT3, IFT4 and IFT5 for maximum reading on the testmeter.

(6) Filter X1 determines the i.f. frequency, and this may not be precisely 455kHz. Rock the generator tuning control knob, very gently, in order to set its output exactly at the filter resonance. If this changes the generator setting, refine the alignment of IFT2 to IFT5.

(7) Remove the voltmeter and connect the Signal-Strength Meter p.c.b. in its place. Switch off the generator and adjust preset VR2 on the meter board to bring the pointer to zero. Reconnect the generator and inject a low-level signal. Adjust preset VR1 on the meter board to set the pointer at mid-travel. The testmeter is no longer required.

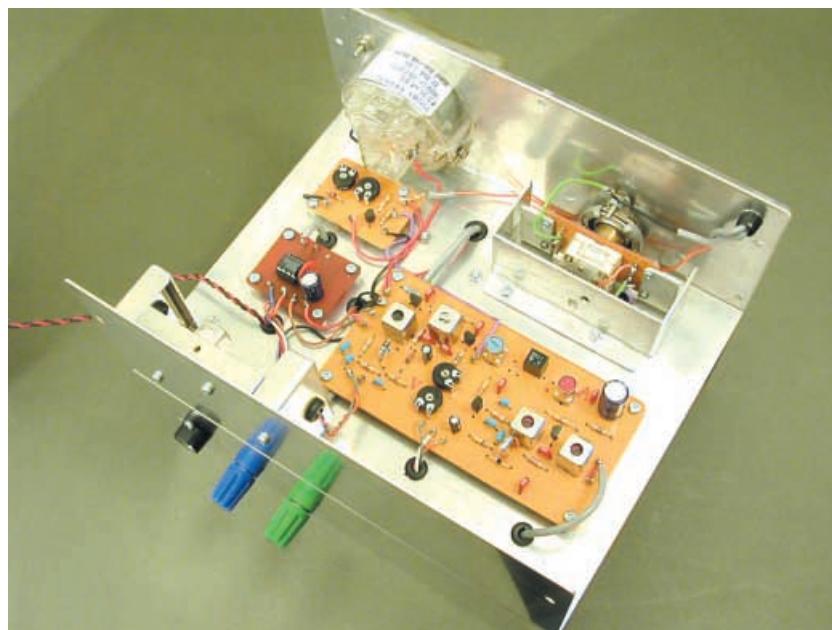
(8) The first i.f. can range from around 1600kHz to 1650kHz. It should be chosen to avoid interference from any medium wave stations that are strong in the reception area. For the purpose of this guidance, it will be taken as 1600kHz.

(9) Set the signal generator to 1600kHz and inject a weak signal at the input to the i.f. amplifier board. Adjust the core of L1/L2 (the second oscillator coil), then the core of IFT1, for maximum reading on the meter. Refine the adjustment of IFT2.

This completes the alignment of the second mixer/oscillator and the i.f. amplifier.

### - First Mixer/Osc.

Readers should now refer back to Part 7 for the circuit details and Component Numbers to be quoted in connection with the alignment of the preselector and first mixer/oscillator stages.



*General layout of p.c.b.s within the topside chassis. Note the screening bracket around the tuning capacitor. The small p.c.b., to the side of the main board, is the Speaker Amp from Part 2.*

Padder capacitors, C6a to C6c, have been calculated on the basis of a 5pF to 130pF tuning capacitor, VC2/VC4. Fixed capacitors should be wired in series with higher value polyvaricons (tuning capacitors) to reduce their swing to not much more than 130pF. Trimmers inside the case of the tuning capacitor are best not used for Range Three in this application. Set them at zero and mount separate trimmers on the p.c.b.

Remember that the receiver will function with the oscillator running at 1.6MHz above or below the signal frequency. The oscillator core setting that produces the **lowest inductance** (giving the highest frequency) is the correct one.

Screw large cores down to increase inductance. With the small cores, inductance is at maximum when they are flush with the top of the can.

Frequency coverage is determined wholly by the setting of the oscillator coil cores, L2, and trimmers, VC3. Signal frequency cores, L1, and trimmers, VC1, are adjusted to optimize alignment, thereby peaking sensitivity and minimizing second channel interference.

**(10)** Inject a 1600kHz signal at the gate of first mixer, TR1. Adjust the core of IFT1 for maximum meter reading.

**(11)** Switch to Range Three. Set trimmers, VC1c and VC3c, at about 10 percent mesh and turn tuning capacitor, VC2/VC4, to maximum value. Inject a 10MHz signal at the aerial terminal and set the core of oscillator coil, L2c, for maximum response. Adjust the core of signal frequency coil, L1c, to further peak the response.

**(12)** Set tuning capacitor, VC2/VC4, at its minimum value. Inject a 30MHz signal at the aerial terminal and adjust oscillator trimmer, VC3c, for maximum response. Adjust signal circuit trimmer, VC1c, to further peak the response.

**(13)** Swing the tuning capacitor back to maximum and refine the adjustment of the coil cores. Then back to minimum and peak the trimmers again.

**(14)** Repeat this process on Ranges One and Two, injecting the appropriate frequencies (see Table 7.2) at the tuning limits. Carry out refining adjustments on all ranges to ensure continuous coverage.

**(15)** When the three ranges have been aligned, finally peak the response with the tuning capacitor set at around 15 percent, and then 85 percent, mesh. This will help to optimize tracking over the tuning capacitor's swing.

This completes the alignment of the receiver.

### - B.F.O./Prod. Det.

The beat frequency oscillator can now be tuned, i.f. gain adjusted, and the signal-strength meter settings refined.



Receiver front panel layout and lettering.

**(16)** Switch to single-side-band mode, set b.f.o. tuning potentiometers, VR1 and VR2, to mid position, and precisely tune the receiver to a steady signal. Adjust the core of b.f.o. coil, L1/L2, for zero beat in the loudspeaker.

**(17)** Adjust i.f. gain preset, VR3. Mid-position should suit most users, but if the reception area is difficult and/or the aerial very inefficient, maximum gain may be required. This will, however, increase inter-station receiver noise.

Readers blessed with a good aerial in an ideal location may choose a minimum setting. Altering VR3 affects the adjustment of the signal-strength meter.

### PERFORMANCE

The receiver is sensitive and internally generated noise is comparatively low: the field-effect transistor mixers are probably contributing to this.

Adopting a 1.6MHz first i.f. results in a significant reduction in second channel interference, but the problem is not completely eliminated. Two tuned circuits in the preselector would make performance very acceptable in this respect (see Part 7).

The specified filter provides good selectivity but there is a noticeable attenuation of the upper audio frequencies. With the filter in circuit, weak signals sandwiched

between powerful ones can be received free from side-band-splatter.

Without the filter, the weak stations cannot be heard. Some top note cutting is not too high a price to pay for the clear reception of weak and "difficult" stations.

High selectivity makes tuning critical. The simple reduction drive on the main tuning control is not adequate. A reduction of 36-to-one or 100-to-one would be more appropriate. The constant-rate fine tuning or bandspread control does, however, ensure that the arrangement is workable.

### DRIFT

If the superhet's oscillator is not crystal controlled it will drift. High selectivity only makes the problem more apparent.

With this receiver, after a ten-minute warm-up, drift is unnoticeable up to 12MHz or so and small enough not to be a problem at higher frequencies. Special measures were not taken to minimize it, and performance in this respect could no doubt be improved.

Mounting the speaker under the top of the cabinet caused microphony when weak signals were reproduced at good volume. This was cured by loosely packing the top compartment with plastic sponge.

The aluminium box chassis and case are no more than adequate. To get the best out of the receiver, its various sections should be enclosed in diecast boxes and an (expensive) air-spaced tuning capacitor fitted.

### COMPARISONS

In a simple comparison test with a modern, high-performance communications receiver (price tag in excess of £1000), tuning was swept from 5MHz to 12MHz. Every station picked up by the communications receiver could be heard equally well on this radio. The test did, however, expose four, second-channel responses. These took the form of "phantom" stations (see Part 7).

A sweep across the 3.5MHz amateur band revealed the superiority of the commercial receiver, but very little would have been missed by a user of the set described here. □



Underside chassis showing wiring to rear of front panel controls, coil pack p.c.b. (Part 7) and arrangement of the battery packs on a hardboard platform.