Build our shortwave radio

Listen to the world with this nifty

Three-band shortwave radio

If you think that hobby electronics these days is just a matter of plugging in ICs, this shortwave radio will change your mind. Although it does have an IC, you'll still have to get down to the real nitty-gritty: winding coils, aligning and tuning. And when it's all finished, you can tune in to the many international broadcasts operating on the shortwave bands.

by COLIN DAWSON

Recently, after checking through our file of shortwave radio projects, we realised that it has been over six years since our last design. The "1980 Multiband Superhet" used discrete components throughout its RF sections. Our latest design — the Three Band Shortwave Receiver — is rather more up-to-date in that it uses a single AM radio IC.

The front panel controls are for volume, tuning and band switching.

These devices have become so cheap in the last few years that it is not economical to use discrete components any more. Furthermore, you can have all of the benefits of a sophisticated design without using lots of components.

The AM radio IC is the Philips TEA5550. Its main use is in car radios, where it is used by the thousands. It is also ideal for a simple shortwave receiver. It is quite sensitive, requiring an input of only about 20uV, and its automatic gain control (AGC) operates over a range of 86dB, which is very large indeed.

This last feature means that the IC can accommodate a huge range of input signals — you can operate at only a few kilometres from the transmitter, or from thousands of kilometres away. It can also compensate for fading signals which can be a real problem on the shortwave bands.

Virtually all you need for a basic radio based on the TEA5550 are several inductors (for tuning and for the oscillator) and an audio amplifier. Our circuit goes a little further than this because we wanted good performance while still keeping the total circuitry fairly simple.

Main features

As it stands, our new receiver can tune from 0.48MHz to around 17MHz over three bands. There is, however, a small gap in the coverage between Bands 1 and 2. Band 1 (the broadcast band) covers the range from 0.48MHz to 1.9MHz; Band 2 from 2.15MHz to 7.7MHz; and Band 3 from 6.12MHz to 17.12MHz.

Instead of opting for a simple passive RF stage (the "front end"), we have designed an active stage around a dual-gate Mosfet. The advantage here is that instead of losing signal through the front end, there is actually a moderate amount of gain which improves the overall sensitivity.

The payoff is that very high input signals may overload the front end. Should this happen, there is provision for an optional Local/DX switch.

An audio amplifier has also been included in the design, as the TEA5550 is only capable of delivering about 150mV. We used a four-transistor design which can drive either headphones or an eight ohm loudspeaker. The idea of using a hybrid "one chip" audio amplifier was certainly appealing, but the discrete design has the advantage of using garden variety components. And it works better than most small IC amplifiers.

Current drain for the circuit is quite hefty at 30mA. Carbon zinc batteries would at best give about five to six hours use while alkaline cells would give about 15 hours. Unless they are rechargeable, this would suggest batteries as being unsuitable as a long term power supply.

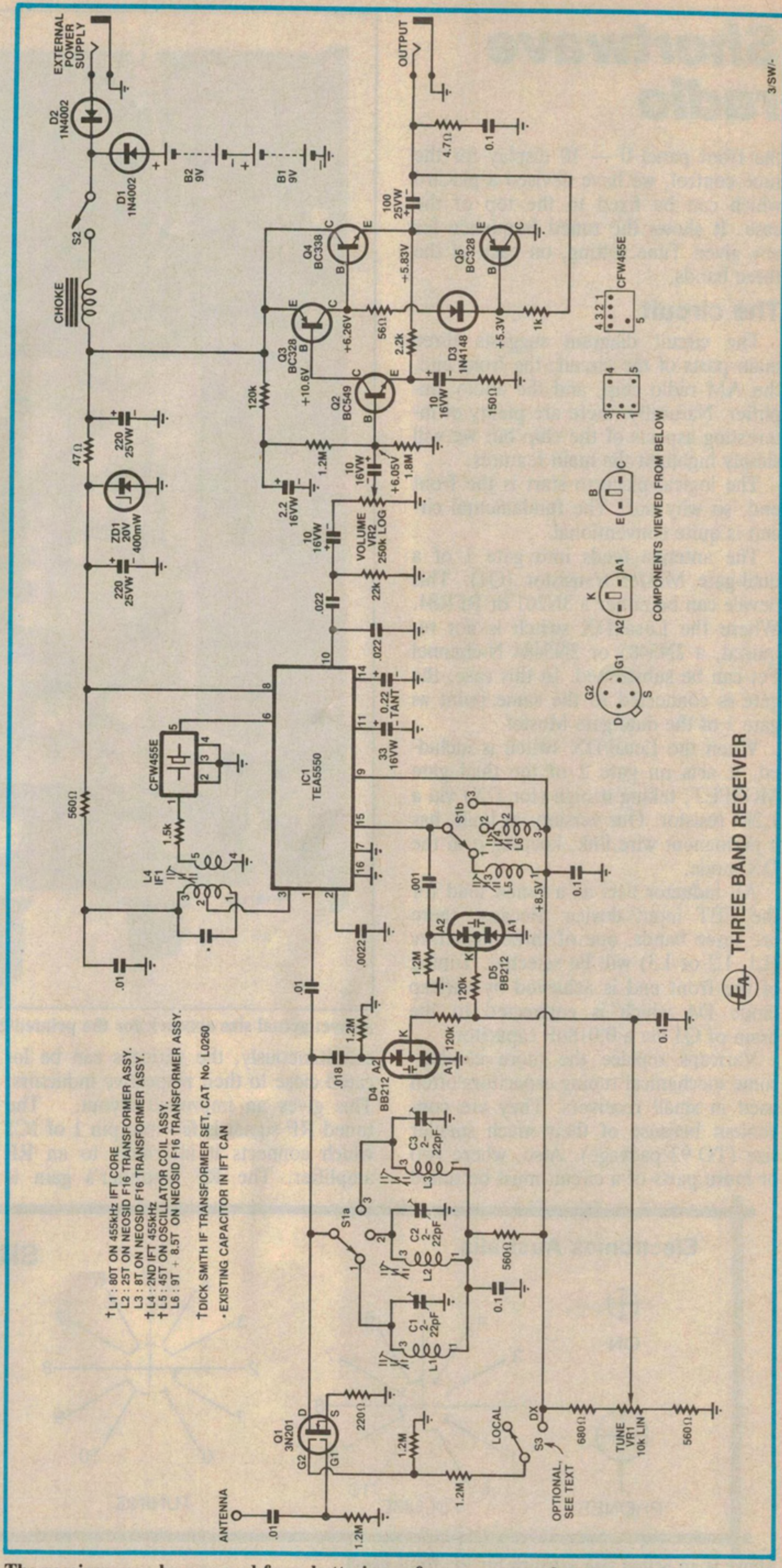
For this reason, there is a socket for connection of an external power supply on the back panel. Any DC voltage between 11V and 20V is suitable. The obvious choice is a 12V power supply. A mains plugpack could be used (it will increase the hum level), but better still would be the 12V car power supply.

In some ways, the radio is ideally suited for in-car use. It includes a noise suppression choke to minimise interference from the alternator and ignition system, as well as protection from dangerous voltage spikes. If you could contrive a suitable adaptor, the car's antenna would be quite suitable.

So that you will be able to interpret

TUNE	BAND 1	BAND 2	BAND 3
0	.480	2.15	6.12
1	.622	2.71	7.22
2	.764	3.26	8.32
3	.906	3.82	9.42
4	1.05	4.37	10.52
5	1.19	4.96	11.62
6	1.33	5.48	12.72
7	1.47	6.03	13.82
8	1.62	6.59	14.92
9	1.76	7.14	16.02
10	1.90	7.70	17.12

This actual size artwork can be attached to the top of the tuner to indicate the tuned frequency.



The receiver may be powered from batteries or from an external power supply.

Shortwave radio

the front panel 0 — 10 display for the tune control, we have devised a placard which can be fixed to the top of the case. It shows the tuned frequency for any given Tune setting, on each of the three bands.

The circuit

The circuit diagram suggests three main parts of the circuit: the front end, the AM radio chip, and the audio amplifier. Naturally, there are plenty of interesting aspects of the chip but we will simply highlight the main features.

The logical place to start is the front end, so why not? The fundamental circuit is quite conventional.

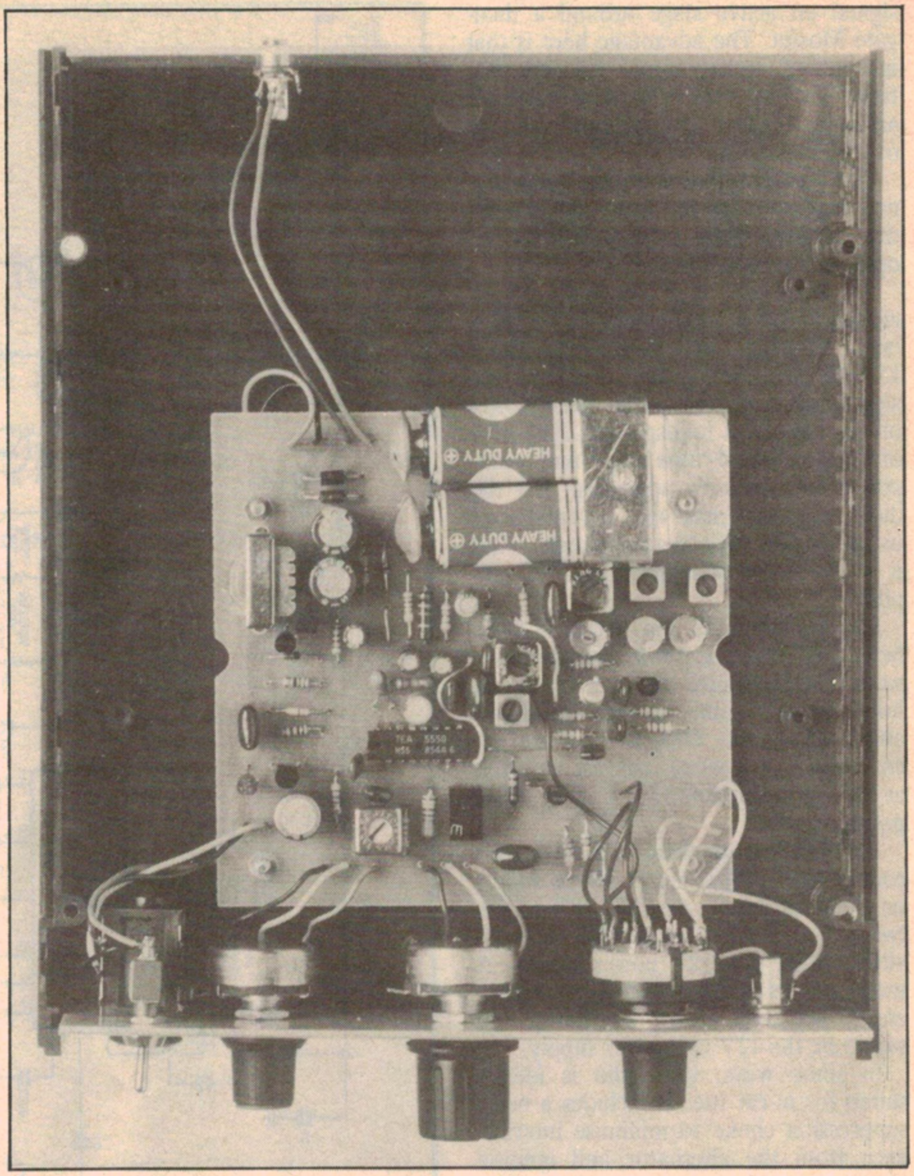
The antenna feeds into gate 1 of a dual-gate Mosfet transistor (Q1). This device can be either a 3N201 or BFR84. Where the Local/DX switch is not required, a 2N5485 or 2N5484 N-channel Fet can be substituted. In this case, the gate is connected to the same point as gate 1 of the dual-gate Mosfet.

When the Local/DX switch is included, it acts on gate 2 of the dual gate MOSFET, taking it high (for DX) via a 1.2M resistor. Our version, as built, has a permanent wire link, keeping it in the DX mode.

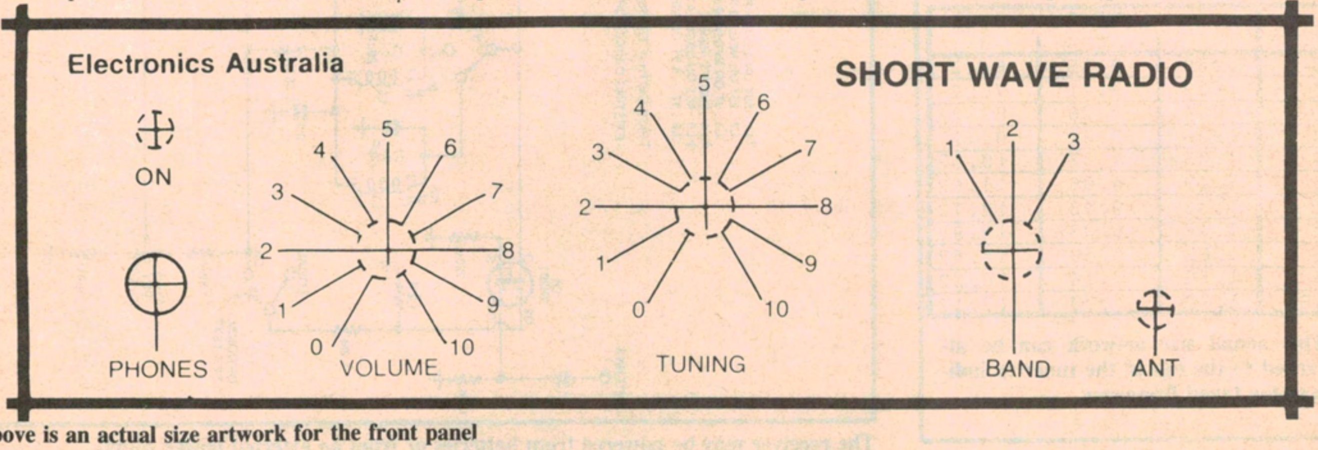
An inductor acts as a tuned load for the FET input device. Because there are three bands, one of three inductors (L1, L2 or L3) will be selected. Tuning of the front end is achieved by varicap diode D4 which is connected to the drain of Q1 via a 0.018uF capacitor.

Varicaps replace the more cumbersome mechanical tuning capacitors often used in small receivers. They are convenient because of their much smaller size (TO-92 package). Also, where two or more parts of a circuit must be tuned simultaneously, the varicaps can be located close to their respective inductors. This gives an improved layout. The tuned RF signal is fed into pin 1 of IC1 which connects it internally to an RF amplifier. The RF amplifier's gain is controlled by the internal AGC (automatic gain control) so that it (and following stages) will not be overloaded when large signals are fed in.

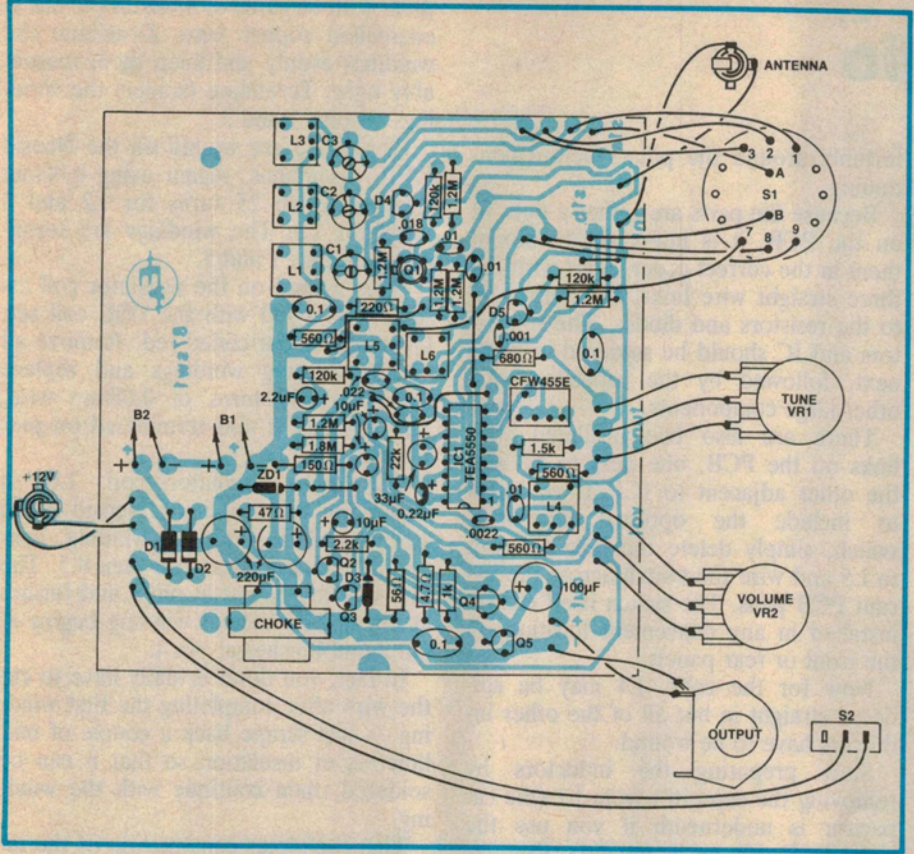
The TEA5550 operates on the superheterodyne principle. This means that



Above: actual size artwork for the printed circuit board.



Above is an actual size artwork for the front panel



Assemble your tuner exactly as shown in this wiring diagram.

the incoming RF signal is mixed with a local oscillator operating at a higher frequency. The difference in the two frequencies is the intermediate frequency (IF). In this case, it is 455kHz which is a standard IF for AM radios.

From the RF amplifier, the signal is passed to a double balanced mixer. This type of mixer cancels both the RF signal and the oscillator signal, leaving only "difference" signals. One of these is the wanted IF signal.

The next time the signal is sighted is at pin 3 of IC1, the mixer output. This is fed into the IF stage. We initially tried a design with three IF transformers, but rejected the third transformer on the grounds that the circuit was too hard to align. This then left a two-transformer IF stage.

Unfortunately, this circuit was found to be subject to FM breakthrough on Band 3. So we scrapped the second IF transformer and replaced it with a CFW455E ceramic filter. This gave far better results in terms of selectivity and FM rejection, and more than justifies the extra $5 cost. The resulting circuit is also much easier to align than the previous scheme.

The sole IF transformer used comes from the Dick Smith IFoscillator kit (DSE Cat.L-0260) which comprises three IF transformers and one oscillator coil. We used the second IF transformer from the kit for IF1 (this is colour-coded according to data supplied with the coil set).

Back now to the circuit. From the first IF transformer, the signal passes to the CFW455E ceramic filter. Unlike an IF transformer, this device requires no adjustment. It is set to 455kHz at manufacture and has a 3dB bandwidth of plus and minus 5.5kHz. This gives quite a narrow bandwidth, which is a desirable characteristic for communications receivers.

Because of the sharp roll off (80dB at plus and minus 100kHz), the ceramic filter gives very good rejection of adjacent stations and images (stations which are at local oscillator frequency plus the IF instead of at the local oscillator frequency minus the IF).

The filtered IF signal is fed back into pin 6 of the TEA5550. This is the input for the IF amplifier, which consists of three stages. The second is controlled by the AGC.

Before emerging from the IC, the signal is fed to a detector. This recovers the audio signal from the IF stage and presents it at pin 10. Because it still has a substantial 455kHz content, the signal is then fed to a filter stage consisting of two 0.022uF capacitors and a 22k resistor.

Following the detector filter, the signal is fed to the volume control and thence to a power amplifier (Q3-Q6). This four-transistor amplifier is a circuit we have used on many previous occasions and is ideal for the application. It is stable, and can deliver about 1 watt to an eight ohm loudspeaker.

Local oscillator

As yet, we have not talked about the internal oscillator circuit of the TEA5550. This is tuned with the LC circuit between pin 15 and pin 9. Only two coil assemblies are needed here: one to cover the broadcast band and the other, which is tapped, to cover the two shortwave bands.

In order to tune the local oscillator frequency, another varicap diode (D5) is used. In fact, D4 and D5 are controlled simultaneously by the "Tune" control (VR1).

Note that because the local oscillator has to operate with a smaller range of capacitance than the RF stage tuning, a series 0.001uF capacitor is used with D2. The 0.018uF capacitor in series with D4 is necessary to prevent DC from biasing this varicap but, at the same time, is large enough to have negligible effect on the range of adjustment.

Power for the circuit is normally supplied by two internal 9V batteries and these are connected to the on/off switch (S2) via D1. If an external power supply of more than the battery voltage (18V) is connected, power will be fed in through D2 to S2.

This arrangment prevents the external power supply from being connected directly to the internal batteries. Even if the batteries are not used, D2 should still be included to protect against reverse polarity connection of the power supply.

Following S2, the power supply feeds into a noise suppression choke (DSE Cat.L-1900). Its function is to suppress ignition noise when the circuit is powered from a car battery. The output of the choke is filtered by a 220uF electrolytic capacitor and the resultant DC rail used to power the audio amplifier.

A 47 ohm resistor and an additional 220uF capacitor decouple the supply to IC1. This is necessary to prevent supply fluctuations brought about by the amplifier operation from upsetting the front end. In addition, a 20V zener diode (ZD1) is included to protect the IC from excessive input voltages.

Construction

The printed circuit board (PCB) for the shortwave radio has been made as small as possible while still keeping it reasonably easy to assemble. This board is coded 87sw1 and measures 111 x 106mm. We initially designed it to suit the compact Pac-Tec case which measures 129mm wide by 39mm high by 133mm deep (Cat.CN5-125K).

It is certainly an attractive case but unfortunately it is now quite expensive. Most constructors will therefore probably install the board in a somewhat larger but cheaper case such as the one used for several recent transceiver projects. This case is available from Dick Smith Electronics (Cat.H-2520).

We have designed front panel artwork to suit both the Pac-Tec case and the one from Dick Smith Electronics.

If the Pac-Tec case is used, the first task is to file two cutouts in the PCB to clear the internal pillars of the case. These cutouts are marked out with two 6mm-diameter semicircles on the copper pattern. Check that the board fits comfortably around the pillars before continuing.

Because the parts are rather a tight fit on the PCB, it is important to mount them in the correct order. Start with the three straight wire links, then move on to the resistors and diodes. The transistors and IC should be soldered in place next, followed by the capacitors and other large components.

There are also two insulated wire links on the PCB, one next to L5 and the other adjacent to IC1. If you wish to include the optional Local/DX switch, simply delete the link adjacent to L5 and wire the switch across the vacant PCB pads. The switch itself can be installed in any convenient location on the front or rear panels.

Now for the coils. L4 may be soldered straight in but all of the other inductors have to be wound.

Start preparing the inductors by removing the capacitor from L1 (the capacitor is underneath if you use the same DSE coil set as we did). Remove all the existing windings and replace them with 80 turns of 0.08mm (40 B&S) enamelled copper wire. Distribute the windings evenly and keep them reasonably tight. Terminate (solder) the windings on pins 1 and 3.

L2 and L3 are wound on the Neosid F/F16 assemblies. Again using 0.08mm wire, wind on 25 turns for L2 and 8 turns for L3. The windings are terminated on pins 1 and 3.

L5 is wound on the oscillator coil assembly supplied with the DSE coil set. Ours was colour-coded red. Remove all of the existing windings and replace them with 45 turns of 0.08mm wire. This winding is also terminated on pins 1 and 3.

The other oscillator coil, L6, is wound on the remaining Neosid F/F16 assembly. It is a tapped winding, consisting of first 9 turns and then 8.5. The first winding begins at pin 3 and finshes at pin 2. The second winding begins at pin 2 and finishes at pin 4.

In fact, you don't actually have to cut the wire after completing the first winding — just scrape back a couple of millimetres of insulation so that it can be soldered, then continue with the winding.

This completes construction of the inductors. Before proceding further, use a tiny blob of super-glue to secure the plastic slug carriers in L1, L4 and L5. These can become loose with repeated adjustment, leading to inaccurate settings.

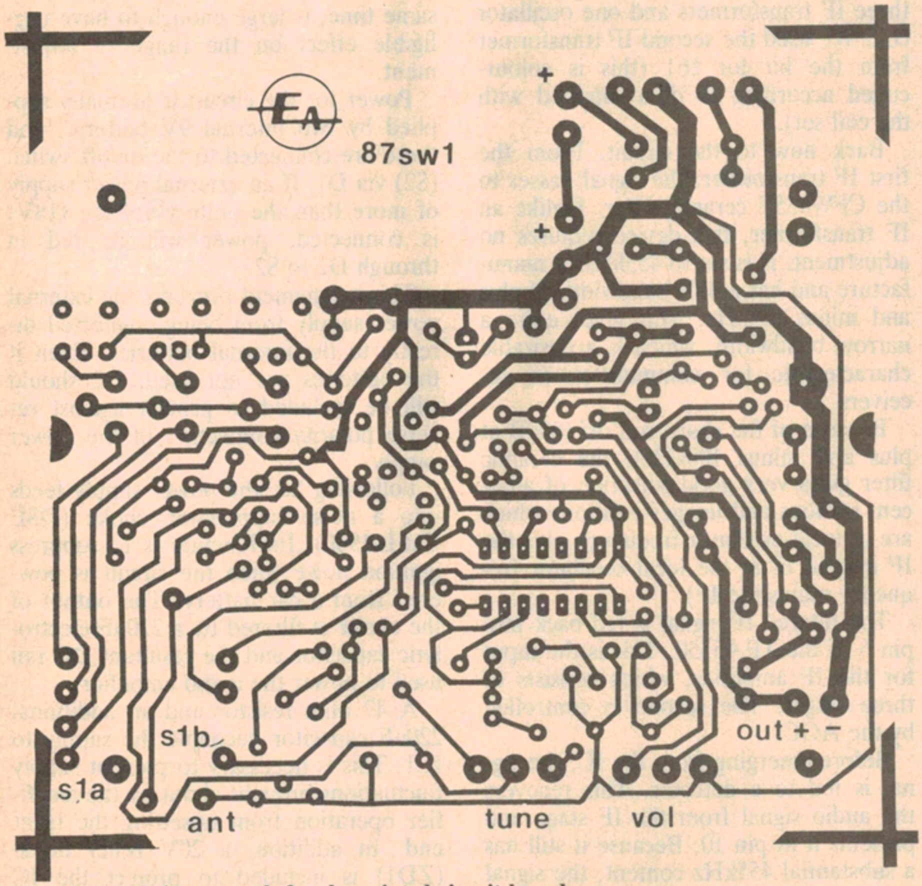
Make sure you don't get super-glue on any of the slugs though, otherwise you will not be able to turn them. The inductors can now be soldered into place on the board.

Drill holes in the front and rear panels as required. The front panel label can be used as a template for drilling the front panel. Connect all of the off-board controls and components as shown in the wiring diagram.

Note that a double-pole three-position slide switch (DSE Cat.S-2030) is used for S1 if you intend using the small Pac-Tec case. If the larger DSE case is used, a rotary switch is used in place of the slide switch.

When the wiring has been completed, the PCB can be installed in the case and secured using machine screws and nuts. We also used nuts to act as spacers between the PCB and the case.

Now check your work carefully before installing the two 9V batteries. In particular, check that you have correctly oriented the IC, transistors, diodes and electrolytic capacitors. We bent up a battery clamp from a piece of scrap aluminium.



Above: actual size artwork for the printed circuit board.

Testing

The receiver is now be ready for testing. At switch on, the first voltage to check is the regulated supply at pin 9 of IC1. This should be very close to 8.5V. Note that the input voltage must be at least 11.6V for reliable regulator operation.

If the reading you get at pin 9 is less than 8.5V, start looking for short circuited tracks and bad solder joints.

Next, check the voltages around the audio amplifier. They should closely agree with those marked on the circuit diagram. Note that an 8-ohm loudspeaker or dummy load in the form of an 8-ohm resistor is necessary for the amplifier to function properly. With no load it latches up (harmlessly) and the voltage readings are meaningless.

Note also that the voltages marked on the circuit are for no-signal conditions and assume a 12V supply. The measured voltages should be within about 10% of those given on the circuit.

Assuming that all is in order, it's time to start the alignment procedure.

Alignment

Oscillator adjustment: The following procedure will be more straightforward if you have an RF signal generator and a frequency meter (DFM), but neither is essential. First of all, set the Tune control fully anticlockwise, connect your DFM to pin 15 of IC1, and adjust the slugs of L5 and L6 to set the lowest frequencies for Band 1 and Band 2. You should get readings of 942kHz and 2.605MHz respectively.

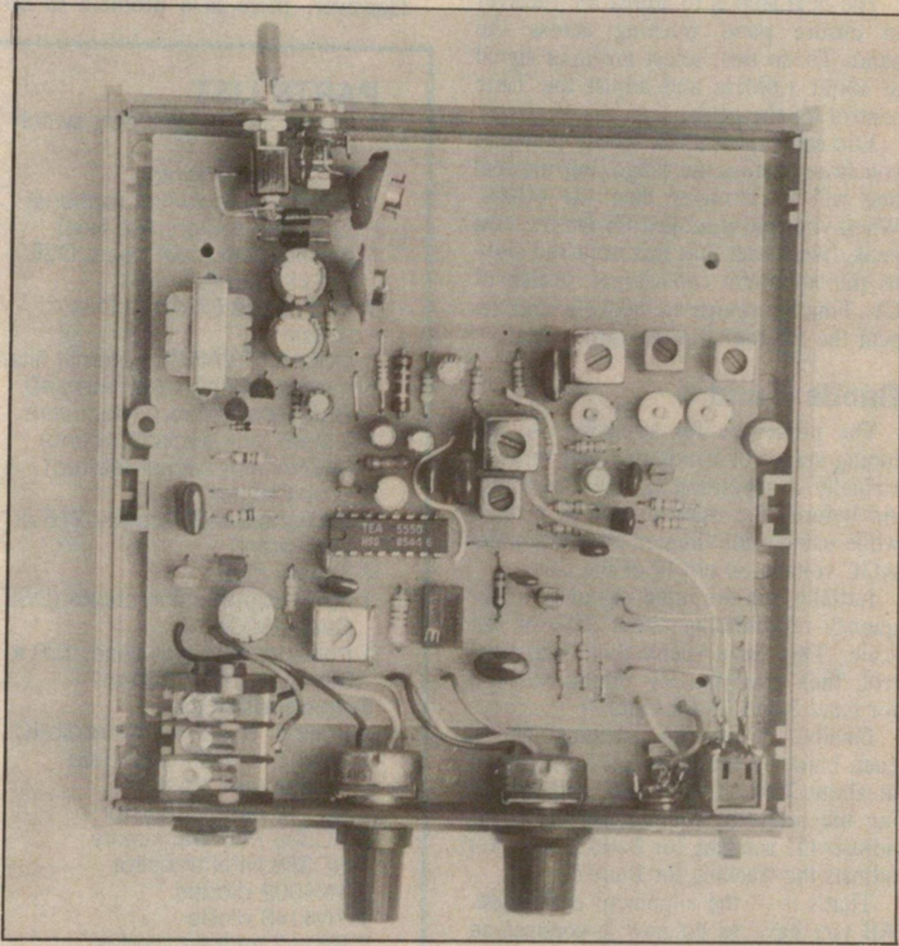
Remove the DFM after this procedure.

If you don't have a frequency meter, set both slugs 2-1/4 turns from the fully extended position. Be careful during the adjustment procedure not to bottom out the slugs too firmly — you may crush the fine wires leading to the core.

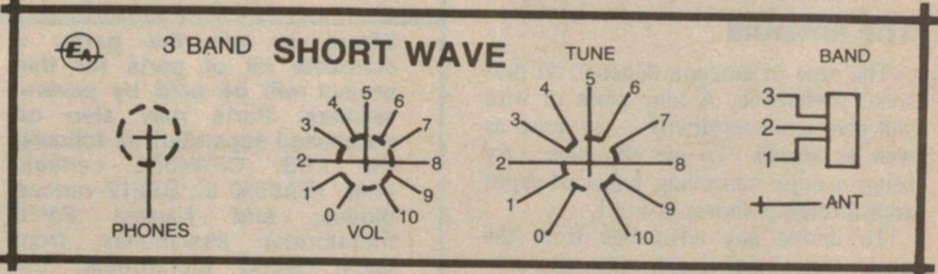
IF alignment: The next step is to align the IF stage. You will need a signal source of some type. It can be either a signal generator or a transmitted signal. A broadcast station will be OK, as long as it is at good signal strength and there are no other strong stations operating on adjacent frequencies.

Switch to Band 1 and tune to an input frequency of around 800kHz. This done, use your multimeter to monitor the AGC voltage at pin 14 of IC1. The highest voltage you can expect is 2.6V DC. If pin 14 goes immediately to somewhere over 2V, reduce the input signal. (It will be impossible to observe the peak if the AGC has already

If size is important, the PCB can be installed in this compact Pac-Tec case.



The PCB is a snug fit inside the PAC-Tec case.



This is the actual size front panel artwork for the Pac-Tec case.

reached its highest level).

Now slowly adjust the Tune control until the AGC peaks. The peak will be fairly sharp, so be carefull. The local oscillator will now be 455kHz above the incoming RF signal.

With the Tune control at this setting, adjust the slug of L4 until the reading peaks once more. Finally, repeat these last two steps a couple of times to make sure you have the best setting. From now on, don't touch L4.

RF tuning: Without changing any of the settings from the above procedure, adjust L1 for the best AGC peak. The peak won't be quite so strong this time. When you find it, the RF tuning has been set to match the oscillator — but only for this relatively low frequency.

The next step is to adjust the receiver to ensure good tracking across the band. To do this, select an input signal of about 1.6MHz and adjust the Tune control for the peak.

You can expect a few 'ghost' peaks as you sweep across the range, but the real one will be stronger than the others. When you find it, adjust C1 for the best peak. We found that this occurred close to the minimum capacitance setting of C1. Finally, return to 800kHz and repeat the RF tuning procedure.

Bands 2 and 3

The procedure for adjusting the RF tuning stages of bands two and three is virtually a repetition of the foregoing. As before, the relevant coil is peaked while using a multimeter to monitor the AGC voltage on pin 14 of the chip.

Initially, set the input signal to a frequency representing about 25% of full scale. This done, peak the Tune control, then peak the RF tuning coil (L2 for band 2 and L3 for band 3).

Finally, check the tracking across each band by tuning to an input signal at about 75% of full scale, and adjusting the relevant trimmer capacitor. C2 adjusts the tracking for Band 2 while C3 adjusts the tracking for Band 3.

That's it — the alignment is finished. All you have to do now is connect an antenna and start listening.

The antenna

The type of antenna depends on personal preference. A long piece of wire will give good sensitivity — to noise as well as signals. To cut the noise, try using a noise cancelling balanced input transformer as shown in Fig.1.

To derive any advantage from the noise cancelling transformer, the antenna has to be a loop type. We found

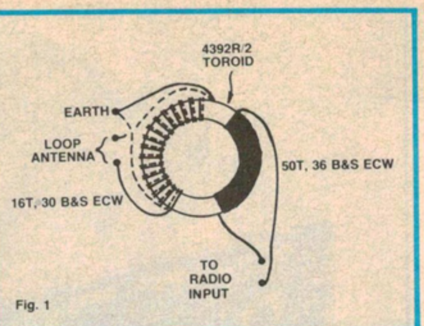


Fig.1: the balanced input transformer. It uses a 16-turn bifilar winding for the primary (antenna side) and a 50-turn winding for the secondary.

that a 100mm-diameter loop of 15 turns worked very well for Bands 1 and 2, and reasonably well for Band 3.

However, there is a problem in selecting the core material. We don't know of any that is suitable for use from 0.5MHz right through to 15MHz. We experimented with a toroidal core (type 4392R/2 from Neosid) which worked quite well for Bands 1 and 2, but actually stopped the radio from working on part of Band 3.

An alternative scheme used a ferrite VHF antenna balun as sold by Jaycar and Altronics. We wound on 10 turns for the primary (which goes to the loop antenna) and 16 for the secondary.

Predictably, this worked best for Band 3 and rather poorly on Band 1. The obvious conclusion from these experiments is that two antenna coupling transformers are necessary to cover the full range (you will have to switch between them).

PARTS LIST

1 2-pole 3-position rotary switch (see text)
1 SPDT toggle switch
1 SPDT toggle switch (optional Local/DX switch, see text)
1 plastic instrument case, DSE Cat.H-2520 (see text)
1 PCB, code 87sw1, 111 x 106mm
1 Murata CFW455E ceramic filter
5 metres 0.08mm diameter (40 B&S) enamelled copper wire
2 3.5mm jack sockets (mono)
1 6.5mm jack socket (stereo)
3 knobs to suit
2 9V batteries (Eveready 216 or equivalent)
2 battery clips
1 noise suppression choke (DSE Cat.L-1900)
1 front panel to suit case, 120 x 33mm or 168 x 50mm

Semiconductors

1 Philips TEA5550 AM radio IC
1 3N201, BFR84 dual gate Mosfet (see text)
1 BC549 NPN transistor
2 BC328 PNP transistors
1 BC338 NPN transitor
2 1N4002 diodes
1 1N4148 diode
2 BB212 varicap diodes
1 20V 400mW zener diode

Capacitors

2 220uF 25VW electrolytics
1 100uF 25VW electrolytic
1 33uF 16VW electrolytic
3 10uF 16VW electrolytics
1 2.2uF 16VW electrolytic
1 0.22uF 16V tantalum
4 0.1uF greencaps (metallised polyester)
2 0.022uF greencaps
1 0.018uF greencap
3 0.01uF greencaps
1 0.0022uF greencap
1 0.001uF greencap
3 2-22pF trimmer capacitors

Inductors

1 455kHz IF transformer with integral capacitor (from DSE coil kit)
1 455kHz IF transformer assembly (from DSE coil kit)
1 broadcast band oscillator coil assembly (from DSE coil kit)
3 Neosid F/F16 transformer assemblies

Resistors (5%, 0.25W)

1 x 1.8M, 6 x 1.2M, 3 x 120k, 1 x 22k, 1 x 2.2k, 1 x 1.5k, 1 x 1k, 1 x 680 ohms, 3 x 560 ohms, 1 x 220 ohms, 1 x 150 ohms, 1 x 56 ohms, 1 x 47 ohms, 1 x 4.7 ohms, 1 x 250k log potentiometer, 1 x 10k linear potentiometer

Where to get the parts: a complete kit of parts for this project will be sold by several retailers. Parts may also be purchased separately as follows: the PCB, CFW455E ceramic filter, TEA5550 IC, BB212 varicap diodes, and Neosid F/F16 transformer assemblies from Geoff Wood Electronics; the choke (Cat.L-1900), CFW455E ceramic filter (Cat.L-1610), and case (Cat.H-2520) from Dick Smith Electronics. The PCB is also available from RCS Radio and from Acetronics PCBs.

Note: stocks of the TEA5550 are not expected to be available until about mid-January.