AM3

The walkabout radio

Most miniature AM radios compromise on sound quality but you'll be surprised how good this one sounds. It's a "Walkman" style unit that comes as a kit of parts, ready for easy assembly.

by STEVE PAYOR and DAVID WHITBY

Despite the availability of very cheap commercially manufactured receivers, many people still prefer the satisfaction of building their own, even if the results may not be quite as good as a "bought one".

However, this new circuit, which we have dubbed the AM-3, has a performance for which no apologies are necessary. When fitted in the optional dark brown case, with a precision vernier tuning dial, it has a solid look and a feeling of quality. The sound quality is also excellent — equal to any "Walkman" style portable.

Tuning with the vernier dial is infinitely easier than with the plastic thumbwheel normally found on AM pocket radios.

Building this radio will also save you money on batteries. It requires only a single 1.5V AA cell, and the current drain is so low (only a few milliamps) that the continuous battery life will be measured in months, instead of hours as it often is for a normal 9V transistor radio.

The AM-3 is available as a complete kit of parts from Technicraft Electronics, which saves the effort normally spent in locating the specialized parts such as the ferrite rod and tuning capacitor, not to mention all the "fiddly bits" like screws, spacers etc. High quality components are supplied throughout, including a tinned fibreglass printed circuit (PC) board.

Construction is a "breeze" — all components, including the tuning and gain controls, ferrite rod aerial, battery and headphone socket, are mounted on the PC board. You can build it in this "short" form, then simply drop it into the optional case. The case is supplied with attractive, silk-screened gold lettering and is pre-drilled, so no special tools are needed for a "professional" finish.

Quality lightweight headphones will be made available with either the "short form" or complete kit. Alternatively, you can use any existing type of headphone if you already have a pair.

The circuit is based on the Ferranti ZN414 "radio-on-a-chip" integrated circuit. Previous builders of small radios using this IC will have noticed some shortcomings in its performance: in particular its limited "strong" signal handling capability, and the need for an audio transformer for driving low impedance "hifi" type headphones. The volume level is also inadequate for noisy environments.

These problems have all been rectified in this latest design. An "RF GAIN" control has been added to the basic circuit, which enables the ZN414 to be adjusted for optimum reception of signals of any strength.

A one-transistor audio amplifier has also been added to eliminate any complaints about the volume level.

The AM-3 delivers good quality sound into a pair of headphones.

The ZN414: basic circuit

The ZN414 forms the heart of the circuit. When fed with the signal picked up by a small ferrite rod aerial, it performs all the necessary functions of radio-frequency amplification and demodulation, to produce an audio output sufficient to drive most headphones directly at a modest volume.

Internally, its operation is fairly complicated, but this need not concern us. We can simply view it as a "black box" which produces an output current which is linearly proportional to the amplitude of the RF input.

Physically, it looks like a standard 3-pin transistor package. Normally we would expect an IC to have at least four external connections: IN, OUT, GND and V+. The ZN414 makes do with only three pins by combining the function of power supply and output.

How it achieves this is interesting. In essence, the IC varies its supply current a small amount in proportion to the amplitude of the incoming signal. Thus, by feeding the power to the "output" pin through a 1kΩ resistor, there will be a small AC voltage developed across this load which follows the amplitude variations of the incoming signal.

This is the demodulated audio we are looking for, although it is necessarily rather small, as the "output" pin voltage cannot be allowed to fluctuate too much, since the rest of the circuit derives its power from this point. An audio amplifier is needed for anything more than "headphone listening" sound levels.

Besides RF amplification and demodulation, all "serious" radio receivers

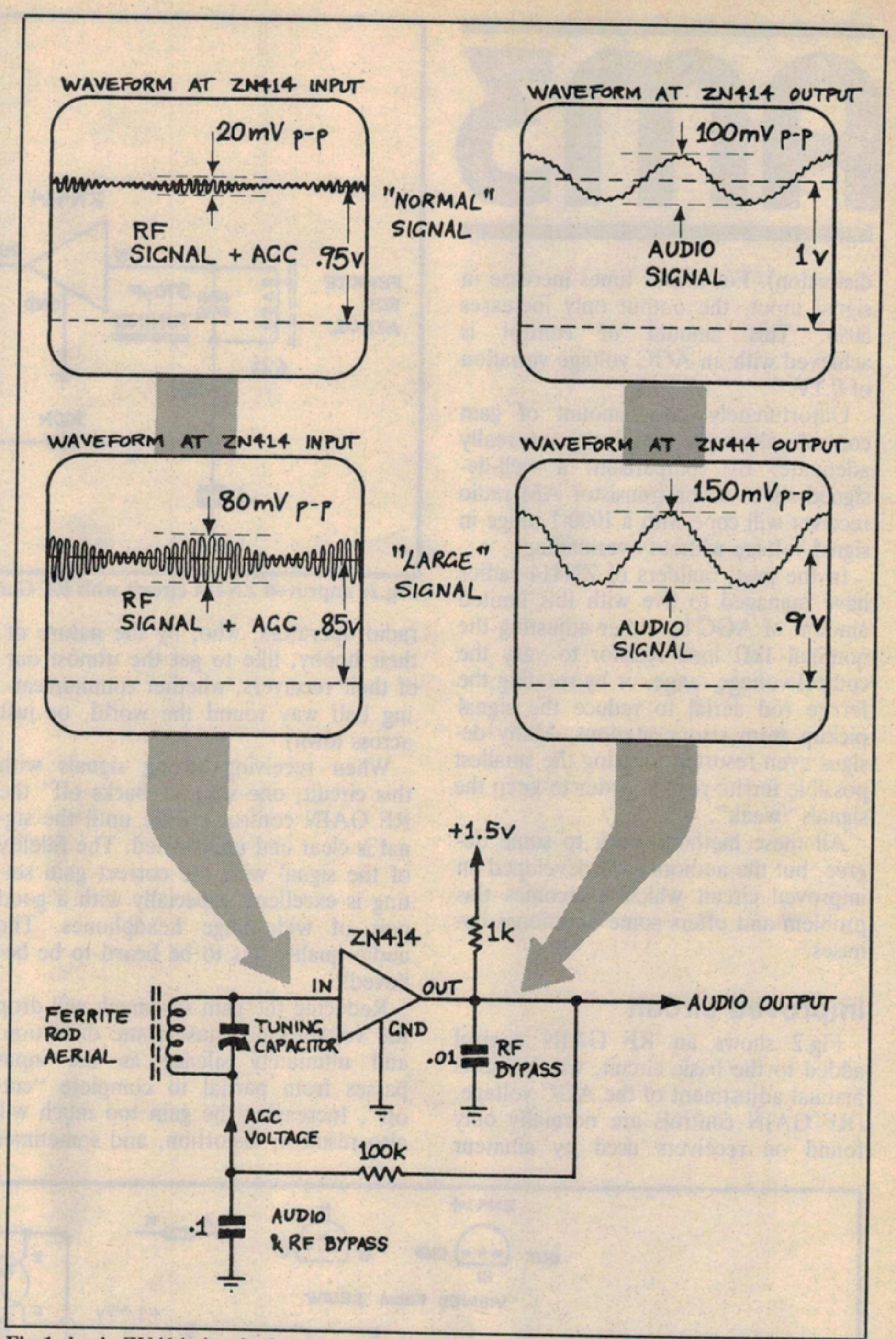

Fig.1: basic ZN414 circuit showing typical waveforms for various signal conditions.

also include some form of *A*utomatic *G*ain *C*ontrol (AGC). This is essential as the amplitude of signals from various stations (some close by, others further away) can vary from 10μV to 100mV or more. Without AGC, nearby stations would overload the receiver, giving a harshly distorted output, while distant stations would be barely audible.

The normal ZN414 circuit implements a moderate amount of automatic gain control by feeding the *average* DC voltage at the output back to the input, where the gain is strongly affected by changes in DC bias. When a signal is received, the average voltage at the output drops slightly, and consequently the DC input voltage is reduced, which tends to "turn off" the radio frequency amplifier, reducing the overall gain.

Actual measured voltages for a typical circuit are shown in Fig.1. Notice that the AGC voltage is roughly equal to the output voltage, with any audio or radio-frequency signals removed by the low pass filter formed by the 100kΩ resistor and 0.1μF capacitor. Waveforms are shown for a "normal" signal level (one which just gives full output), and a "large" signal (at the point of output

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distortion). For a four times increase in signal input, the output only increases 50%. This amount of control is achieved with an AGC voltage variation of 0.1V.

Unfortunately, this amount of gain control, although useful, is not really adequate. By comparison, a well-designed six or seven-transistor AM radio receiver will cope with a 1000:1 range in signal voltage without overloading.

In the past, builders of ZN414 radios have managed to live with this limited amount of AGC by either adjusting the nominal 1kΩ load resistor to vary the control voltage range, or by rotating the ferrite rod aerial to reduce the signal pickup from strong stations. Many designs even resorted to using the smallest possible ferrite rod, in order to keep the signals "weak".

All these methods work to some degree, but the authors have developed an improved circuit which overcomes this problem and offers some additional bonuses.

Improved circuit

Fig.2 shows an RF GAIN control added to the basic circuit, which allows manual adjustment of the AGC voltage. (RF GAIN controls are normally only found on receivers used by amateur radio operators, who, by the nature of their hobby, like to get the utmost out of their receivers, whether communicating half way round the world, or just across town).

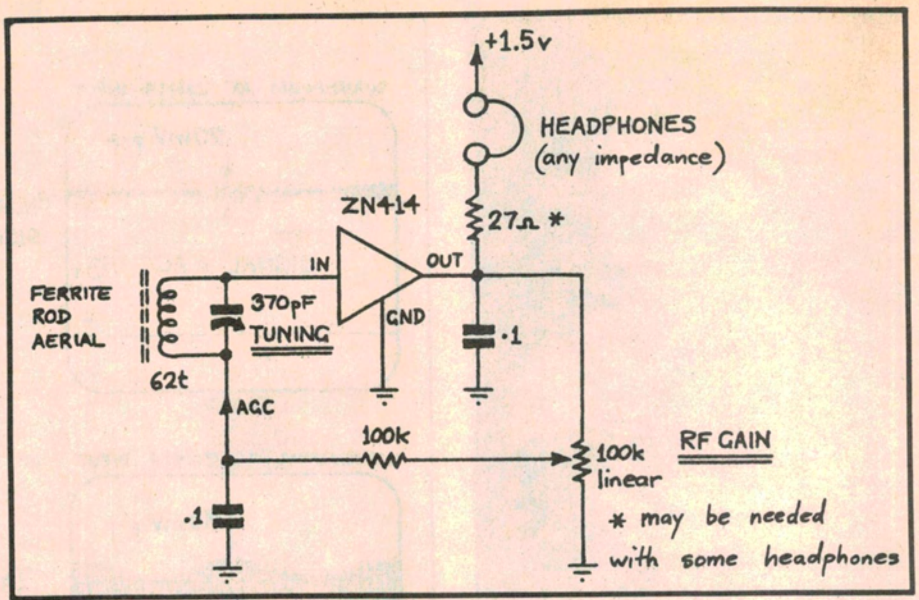


Fig.2: improved ZN414 circuit with RF Gain control.

When receiving strong signals with this circuit, one simply "backs off" the RF GAIN control a little until the signal is clear and undistorted. The fidelity of the signal with the correct gain setting is excellent, especially with a good pair of wide-range headphones. The audio quality has to be heard to be believed!

Reducing the gain too much will drop the volume and cause some distortion, and ultimately silence as the input passes from partial to complete "cut-off". Increasing the gain too much will also result in distortion, and sometimes complete silence on very strong signals, because the ZN414 output stage will be completely "saturated".

On weak signals, the control is advanced to the point where the input just starts to draw appreciable current. This gives the maximum possible gain for receiving distant stations.

You can tell if the control has been advanced too far, as the tuning will become quite broad, and stations will merge together. This is because the input impedance of the ZN414 drops as the input starts to draw current, and the normally sharp response of the tuned circuit becomes progressively damped. The most sensitive point is just before this happens.

All this may sound a little involved, but in practice the correct setting of the

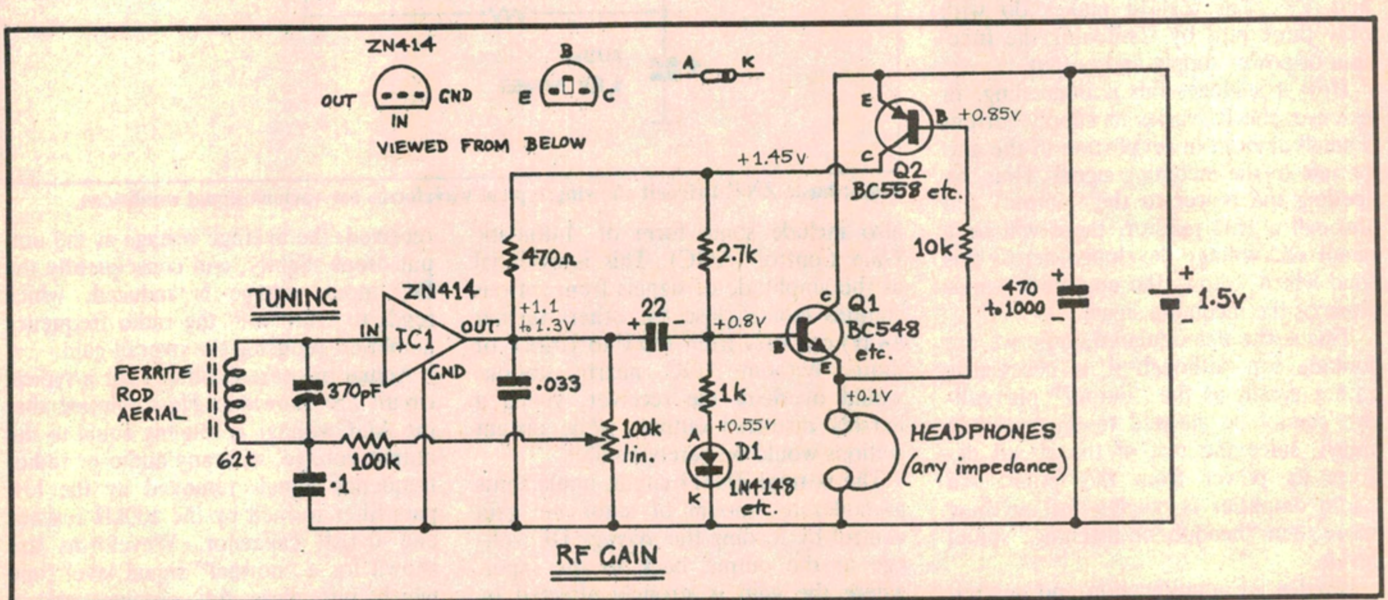


Fig.3: the final circuit for the AM-3 radio. The voltages marked are with 15-ohm headphones in circuit.

gain control is easily found, and this slight added complication is well worth the following benefits:

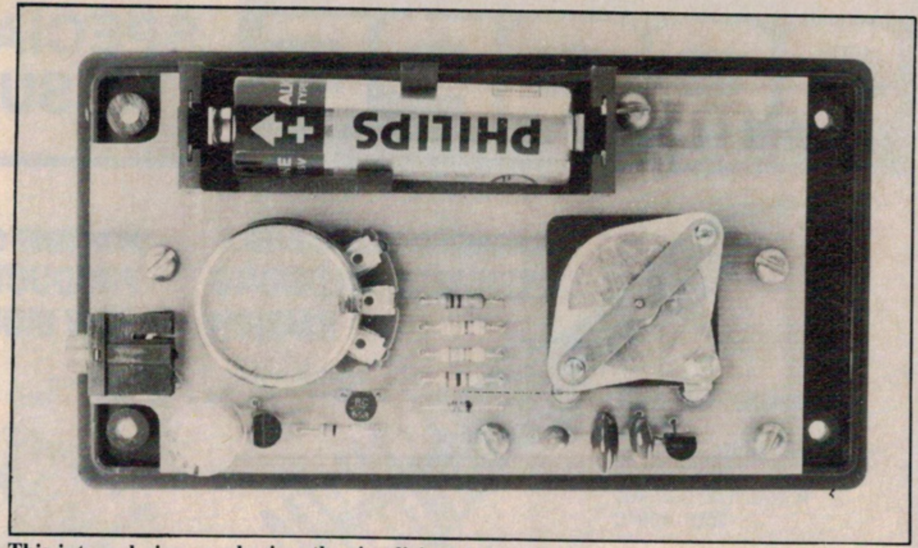
Firstly, distortion is easily minimized, and the sound quality approaches that of the best wideband AM tuners.

Secondly, the 1kΩ load resistor is no longer critical, and the circuit, as it stands, will accept any load between 20Ω and 1.5kΩ. This means that almost any pair of headphones can be used directly, with no real need for the usual output transformer to match impedances.

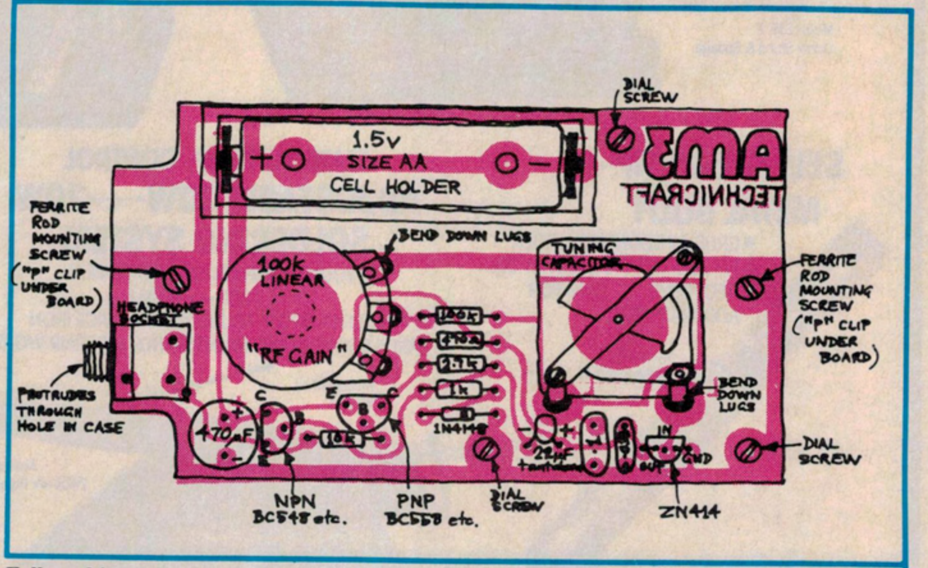
Even with low-impedance "hifi" headphones, the output is better than that obtained using a 1kΩ load resistor and an audio transformer, and the frequency response is limited only by the headphones.

A further spin-off is the fact that simply un-plugging the phones turns off the circuit — no battery switch is needed.

Finally, this circuit is quite tolerant of falling battery voltages. With low-impedance phones, the battery voltage can drop to as low as IV before you run out of adjustment with the RF GAIN control.



This internal view emphasises the simplicity of the AM-3.



Follow this parts layout diagram when installing components on the PC board.

The AM-3: circuit description

The ultimate development of this simple circuit is Fig.3. Here we have added a one-transistor audio amplifier to boost the output to a level sufficient to drive even the most insensitive of modern high-fidelity headphones.

The "auto-power-off" facility has been retained by using an additional transistor to "disconnect" the power to the ZN414 and the audio amplifier when the headphones are unplugged.

RF section: The load for the ZN414 has been set at 470Ω, which is large enough to allow a fair amount of normal AGC action, but small enough to feed sufficient current to the ZN414 under low-battery conditions. With this load, the RF GAIN control will need manual adjustment on only the strongest stations.

The exact value of the gain control potentiometer is not critical — any value from 20kΩ to 200kΩ will do. From here the AGC voltage is filtered by the 100kΩ resistor and 0.1μF capacitor before being applied to the "cold" side of the aerial tuned circuit.

At the ZN414 output, a .033μF capacitor bypasses any RF signals, while a 22μF capacitor couples the audio signal to the output stage.

Audio amplifier: This consists of NPN transistor Q1 which "buffers" the output from the ZN414. An emitter-follower configuration is used here, as we only need to amplify the current (not the voltage) of the audio signal. Class "A" operation is achieved by setting the base voltage to approximately 0.8V, which results in a DC voltage across the load of about 0.1V, which is slightly more than the peak AC signal amplitude.

Q1's base voltage is derived from the voltage divider formed by the 2.7kΩ and 1kΩ resistors, added to the voltage drop across the forward-biased silicon

A kit of parts for this project is available from Technicraft Electronics, 338 Katoomba St, Katoomba, NSW 2780. Phone (047) 82 3418.
Two versions of the kit are available:
(1.) A short form kit: all parts except the vernier dial and case. Price $14.50.
(2.) The full kit: all parts including the vernier dial and case. Price $24.50.
In addition, quality lightweight headphones are available for $7.50 per pair.
Add $3.00 for postage and packing to all orders.

diode D1. This diode provides a voltage which matches the temperature variations of the emitter-base voltage of Q1. Without D1, the voltage across the headphones would increase excessively if the AM-3 was left out in the sun.

"Power-up" circuit: When a load is plugged into the output, current flows through the 10kΩ resistor, turning on PNP transistor Q2. This applies bias voltage to the NPN audio output stage, and the supply voltage for the ZN414, to within about 50mV of the full battery voltage. With no load, Q2 stays "off" — the only current flowing is a few nanoamps of leakage.

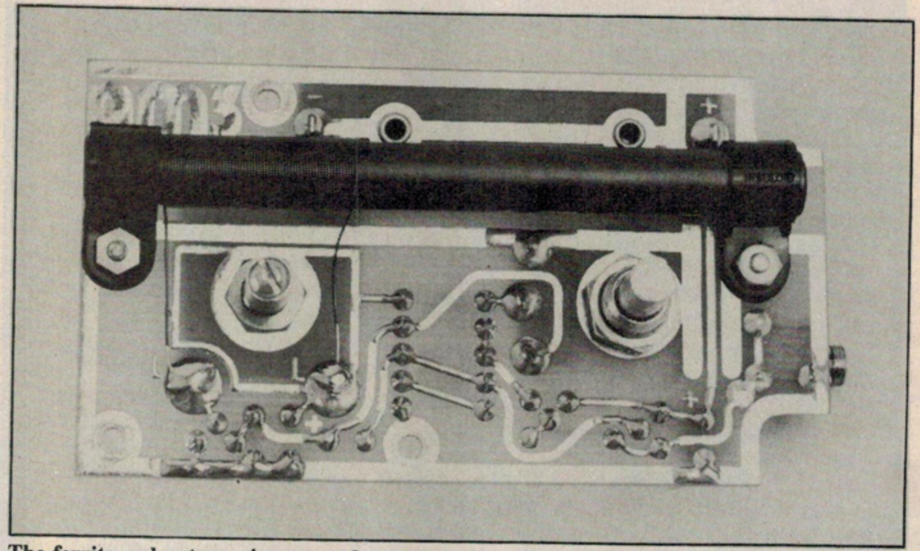
Finally, a 470μF to 1000μF capacitor bypasses any internal resistance the battery may develop as it nears the end of its life.

Construction

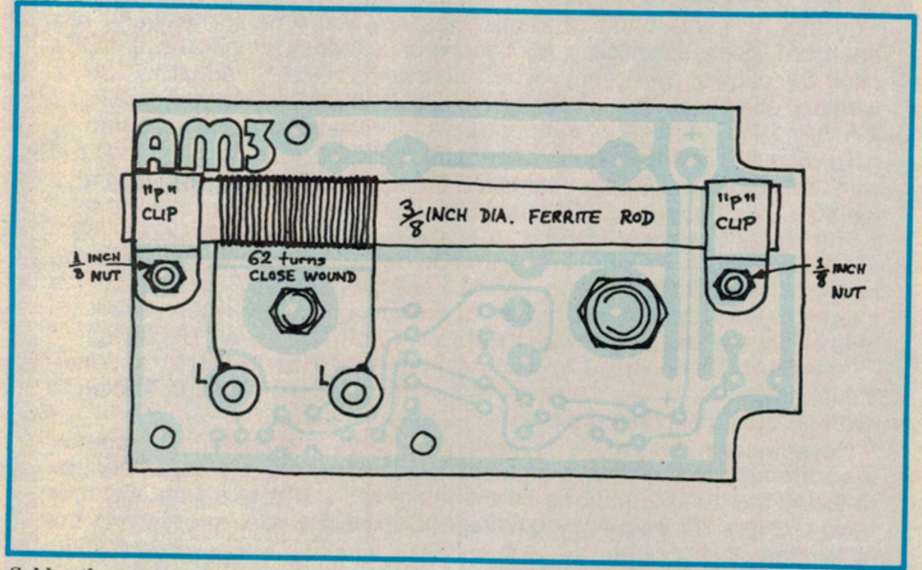
All components are mounted on a single fibreglass PC board. The potentiometer and tuning capacitor are mounted on the component side of the board, and their lugs bent down to protrude through to the track side of the board.

The battery holder and headphone socket also reside on the component side, while the ferrite rod is mounted on the track side. Leave this till last.

When fitting the smaller components, be sure to check the wiring diagram to ensure correct orientation of transistors Q1 and Q2, the diode D1, and the ZN414 (IC1). Check also that the two electrolytic capacitors are the right way around.



The ferrite rod antenna is mounted on the copper side of the board.



Solder the antenna leads to the two points marked "L" (see also above photo).

The aerial coil consists of 62 turns of 0.4mm (26 B&S) enamelled copper wire. This can be wound directly on the ferrite rod if you first remove any sharp edges with some fine abrasive paper. Alternatively, use a single layer of sticky tape under the winding.

Wind neatly and carefully in the direction shown in the wiring diagram, and secure the ends of the coil with sticky tape or two small dots of "super glue". The ends of the winding may now be stripped of enamel and tinned, ready for soldering.

This done, the ferrite rod can be mounted on the solder side of the board with two plastic "P" clips. Check the wiring diagram for the correct way around to connect the coil. Why should this matter? Read on . . .

Troubleshooting Note: (this is a general hint for any circuit using the ZN414 IC). Since the ferrite rod is such a good inductive pickup for radio signals, it also follows that any RF current flowing in the output circuit will also be picked up by the aerial circuit — this is unavoidable. There is a 50:50 chance that this will lead to instability and oscillation (depending on whether the feedback is positive or negative).

Evidence of instability includes whistles and bursts of severe distortion when the RF GAIN control is advanced.

There is no need to panic — the cure is simple. Simply reverse the connections to the aerial coil. If you stick to the circuit layout as described, and wind the coil in the direction shown, all should be well the first time around.

Having soldered the coil leads to the two pads marked "L", the AM-3 is now ready for the "smoke" test.

Initial testing

Temporarily fit the knobs to the tuning and gain controls, turn the gain right up, and set the tuning capacitor to half mesh. Insert a battery, and plug in the headphones — you should hear something at this point.

If not, try the tuning, and if there is still no sound, disconnect the battery and check the circuit carefully. It would be wise to check the current consumption at this point.

Start with the headphones unplugged, and connect up a multimeter in series with the battery. A brief surge of current will flow as the 470μF capacitor charges up, followed by nothing. When the headphones are plugged in, the cur-

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rent consumption should be between 3mA and 7mA (depending on the headphone resistance), and the maximum current with a short-circuit load should be about 10mA.

Final assembly

Assuming all is well, you may now fit the board into the case. This is delightfully easy. First, position the two tapped spacers on the bottom dial screws, and the single clearance spacer behind the top of the dial. Line up the extension shaft on the tuning capacitor with the dial bush, and seat the board on the spacers. Two short screws anchor the board to the tapped spacers, whilst one long screw goes through the top clearance spacer into the back of the dial housing.

Set the tuning dial to "0", the capacitor plates to full mesh, tighten the grub screw in the dial bush, and that's it!

When the case is assembled, the headphone socket should nestle snugly in the hole in the side of the case. Additional support for the circuit board is provided by the internal ledges against which it firmly rests. The whole assembly is impressively rugged, and should literally last a lifetime.

Performance

In overall performance the AM-3 is one of the best "beginners" radios ever published. On local stations the sound is loud, and completely free of audible distortion. In fact, the major limiting factor seems to be the audio quality of the program material transmitted by most broadcast stations.

Selectivity is not as sharp as a conventional "superhet" receiver (with its multitude of fixed-tuned circuits), but, on the plus side, it means that no loss of treble results from the tuning being too sharp. The selectivity is adequate even for the Sydney area, where some stations are less than 50kHz apart, while the sensitivity is sufficient to pick up some country stations.

When tested at Katoomba, in the Blue Mountains 100km west of Sydney, all the stations were received quite clearly, and many interstate stations were received at night.

The directional aerial and direction finding

In the "good old days" of broadcasting, all the best 8-valve superhets used a loop aerial. This was simply a large, square tuning coil, up to a metre across, which picked up signals by virtue of the magnetic field of the electromagnetic radiation passing through the loop.

Compared with a normal aerial and earth system (which responds to the electric field component of the radiation), these loop aerials had the advantage of being directional, and could be rotated to pick up the maximum signal from a wanted station, or to minimise the interference from an unwanted one. Signal pickup was proportional to the area of the loop, and consequently they were quite large, but then so were the old valve radios.

All this changed with the invention of transistors and ferrite. Both the radio and its aerial shrunk to pocket size. A miniature tuning coil wound on a rod of ferrite will pick up almost as much signal as a loop aerial. Ferrite has a magnetic permeability many times that of air, and so magnetic fields on the vicinity of the rod are "conducted" through the centre of the coil. Signal pickup is proportional to the length of the rod.

The ferrite rod aerial is sharply directional, just like its ancestor, and the AM-3 uses this to advantage. If you live very close to a powerful station, and wish to receive a distant station which is on a nearby frequency, just rotate the radio (in a horizontal plane) until the interfering signal is "nulled". This will occur when the ferrite rod is at right angles to the incoming magnetic field: ie. when the rod is pointed directly at the source.

This property can be used for direction finding, and triangulation of your position. To do this you will need a compass, and a map with the locations of two or more broadcasting stations marked on it. Air and/or marine navigation charts are best for this purpose.

Attach a plastic ruler to the bottom of the AM-3 case with sticky tape, and check that it is parallel to the internal ferrite rod. Align the map in a north-south direction using the compass. (Most maps have the direction of "magnetic north" clearly marked).

Now place the AM-3 with the ruler on the map and rotate it for a complete null on a selected station. Use the ruler to draw a pencil line from the station location to your estimated position. Do this a few more times with different stations and the intersection of the lines on the map will indicate your position.

Note that longer wavelength stations are more useful as the radiation is less affected by diffraction and reflection from mountains, city buildings etc.

Other Frequency Bands

In fact, a whole band of frequencies below the broadcast band has been set aside specifically for this purpose. Most airports have NDBs (Non-Directional Beacons) which provide voice information about weather conditions etc. (Refer to the article "Weather Radio For Pilots", EA July 1985, for a list of frequencies and locations of airport NDBs).

To tune this low-frequency band, you will need to wind the ferrite rod with 200 turns of 0.25mm enamelled copper wire. On the prototype, this gave a tuning range of 175kHz to 850kHz.

The recommended winding to cover the broadcast band (531-1602kHz) is 62 turns of 0.4mm wire. On the prototype this gave a tuning range from 525kHz to above 2MHz. Less turns can be used if you are interested in reception on higher frequencies. Sydney listeners will be able to tune to VL2UV (University of New South Wales) on 1692kHz.

The ZN414 is designed to work at frequencies up to 3MHz, and individual devices may work at even higher frequencies, although the ferrite rod will start to become a bit "lossy" above this range.

Nevertheless, the AM-3 is perfectly usable for listening in on the lower frequency short-wave amateur bands. Readers can experiment by reducing the number of turns on the ferrite rod a little at a time until they have the desired frequency coverage. Sufficient wire is provided in the kit to wind several coils.