The latest in circuit integration.....

P.E. TRIFFID SINGLE CHIP I.C. RADIO

By F. R. HEATH B.Sc. (Hons.) (Ferranti Ltd.)

NEW CDI integrated circuit technology has enabled Ferranti engineers to produce the smallest radio i.c. device in the world that offers a satisfactory alternative to the superhet. This article will take a brief look at the CDI techniques used to produce this device and then describe in full how you can build a high quality medium and/or long wave portable radio of superior quality for modest cost.

For the constructor there is, at least, a rest from some of the tedious coil-winding operations so often necessary in radio construction. There is no recourse to expensive alignment equipment, as no setting up is required.

This article does not aim to stress an overall small size, such as in a matchbox radio, because the majority of constructors will want a radio with a speaker and cabinet, ferrite aerial, and room for a long lasting battery. To make full use of the superior sound quality available from the radio i.c. these items are essential. Anybody wishing to make a "micro-radio" or a medium and long wave tuner for an existing hi-fi system, will be able to adapt from the design in this article.

The "P.E. Triffid" design has been tried in most parts of the British Isles, from Exeter to Edinburgh, and gives good results on stations which are of normally reasonable signal strength for the area. The only problem (occurring with all t.r.f. designs) is when the receiver is being used very close to the transmitter. In such a case rotation of the rod aerial is necessary to find a null. Although desgined for reception of BBC Radio 1, 2, 3 and 4, the set works well on many foreign stations, especially Radio Luxemburg.

COLLECTOR DIFFUSION ISOLATION (CDI)

CDI is a new bipolar integrated circuit manufacturing technique which possesses the following inherent advantages:

1. Simplicity of processing
2. High component density
3. High switching speed
4. Low supply volts.

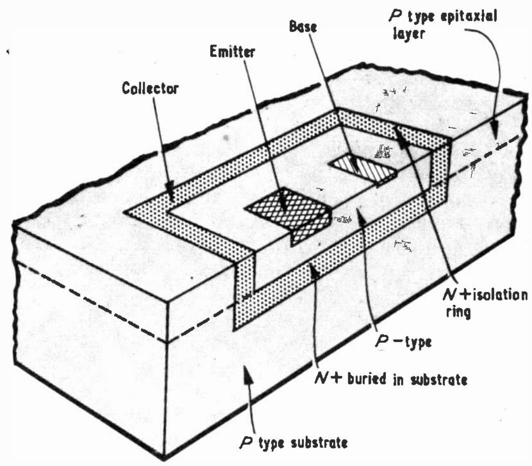


Fig. 1. Cross section view through a CDI transistor

CDI in its basic form, as developed by Bell Laboratories, was limited to a 3V supply voltage. Ferranti carried out a major development programme to achieve a 5V process for compatability with current logic i.c. systems.

The processes involved in the production of CDI devices are much simpler than for standard bipolar techniques. Only five masks are required which compare directly with MOS processing; four less than for conventional bipolar i.c. processes. The transistor size is much smaller due to the self isolating properties of CDI, and much thinner (1 micron) epitaxial layers can be used in processing.

This simplicity is of direct importance in achieving low cost and yielding large quantities, both factors being passed on to the consumer as cheaper i.c.s.

A cross-section of a CDI transistor is shown in Fig. 1. Buried *n* regions are diffused into a *p*-type substrate wherever transistors, diodes or resistors are required. A thin, high resistivity *p*-type epitaxial layer is then grown over the slice.

Table 1: BASIC CDI TRANSISTOR CHARACTERISTICS

V_{CBO}	7·5 volts
h_{fe}	60
f_T	1GHz
R_{sat}	10 ohms
V_{offset}	5mV
I_{CBO}	1·0pA
h_{fe} (inverse)	20
C_{ob}	0·3pF

A block diagram of the radio chip is shown in Fig. 2. Basically, the circuit is a 10 transistor t.r.f. tuner which will operate from 150kHz to 3MHz and requires about 1·3 volts power supply. Audio output is typically 30mV r.m.s.

The i.c. requires the minimum of external circuitry and effective a.g.c. action is available. Distortion from the chip is very low (typically 2%), which is three or four times better than in an average superhet. Current requirements for the i.c. are approximately 0·5mA and the characteristics are shown in Fig. 3 and 4 and in Table 2.

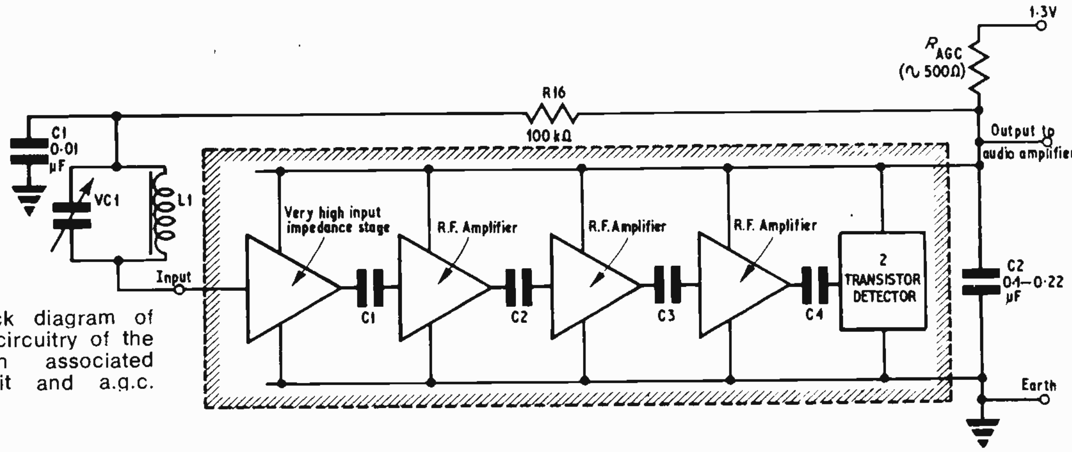
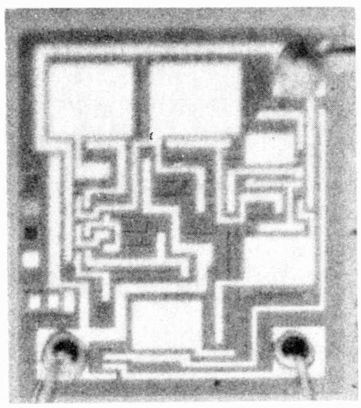


Fig. 2. Block diagram of the interior circuitry of the ZN414 with associated tuned circuit and a.g.c. components

Isolation, deep collector contact, interconnection crossunders, and definition of base and resistor areas are all achieved by a single selective n_+ diffusion through this epitaxial layer. The isolating n_+ diffusion completely surrounds each buried layer island, complete isolation being provided by the *p*-type epitaxial layer and the substrate between the n_+ diffused regions. The *p*-type epitaxial layer which is completely enclosed is used to form transistor bases and *p*-type resistors (medium value resistors 2kΩ to 50kΩ).

Another n_+ diffusion defines the transistor emitters, and can also be used for low value resistors. Contact holes are then cut and the basic aluminium interconnection pattern is evaporated onto the device.

The parameters of CDI devices are shown in Table 1.



RADIO CHIP DESIGN

The design of the ZN414 radio chip began in November 1970. A basic circuit was produced and then "breadboarded" using discrete CDI devices. As in many basic t.r.f. designs, instability was the major problem. Intensive development work culminated in a design that is stable provided certain external requirements are satisfied.

Many prototype experimental circuits were tried and found to be capable of excellent quality. The first i.c. radio was working in July 1971. The present day radio chips are predictable and consistent.

Table 2: MAIN CHARACTERISTICS OF THE ZN414

Supply volts	1·1–1·5 volts
Temperature range	0 to + 70°C
Supply current	0·5mA maximum
Frequency range	200kHz–3MHz
R.F. input impedance	1·5MΩ typical
Output impedance	500Ω typical
Sensitivity	100μV r.m.s.
Power gain	70dB typical

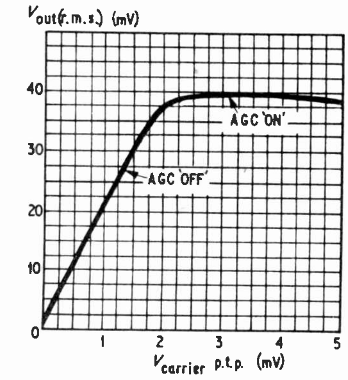


Fig. 3. Graph of voltage gain showing the effective a.g.c. region

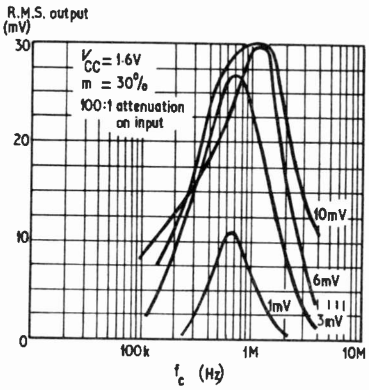


Fig. 4. Bandwidth of the ZN414 on the medium wave band

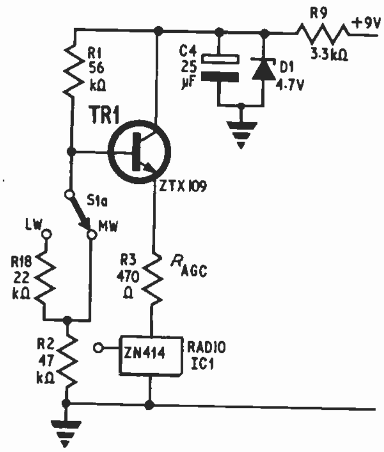


Fig. 5. The integrated circuit is driven from a constant voltage source of 1·3 volts derived from a 9 volt supply

HIGH QUALITY RADIO SET

To obtain the best possible results from the ZN414, certain rules must be adhered to. All leads in the radio circuitry must be kept short, and the i.c. should preferably be soldered flush to a printed circuit board. The aerial coil should have a high *Q* or selectivity will suffer.

The only problem occurs when a very strong station swamps the front end. Here, rotating the set until a null is found will solve the problem. A demonstration radio gave better reception of Radio Luxemburg than a superhet, not because selectivity was better, but because the superhet gave out so many whistles and shrieks that any pleasure from the programme was impossible to achieve.

One other important requirement is to keep the a.g.c. resistor within the range 470 to 1,000 ohms, and for best selectivity keep to the lower end. This means that if the radio is powered from a 9V battery, then a constant voltage source is needed to derive the 1·3 volts necessary. This is done using the circuit shown in Fig. 5.

Fig. 4. shows that the gain of the chip falls off at long wave frequencies. For this reason, a switch is fitted to increase the supply volts (and consequently increase the gain of the chip) on long wave so that the volume is kept approximately the same when the different bands are selected. Fig. 5 shows the circuit changes needed to accomplish this.

A typical case used to house the P.E. Triffid receiver

AMPLIFIER AND CASE

The output amplifier and loudspeaker should be of good quality to do justice to the signal from the receiver. Several i.c. amplifiers were tried. All gave some results, but most were tricky to stabilise and did not give the quality needed. For this reason a discrete amplifier was used, low power output at 500mA being suitable for a personal radio. Low cost and battery power consumption are kept to a minimum making this receiver suitable for the inexperienced radio constructor.

Cabinet and speaker design is dependent on personal taste so the following constructional details deal mainly with the circuitry aspect. Most constructors will want to design their own housing for the unit, and there are many cases available to cater for those who do not like woodwork.

The case must not contain large metal parts near to the ferrite rod, as this will damp the *Q* of the coil.

AMPLIFIER DESCRIPTION

The amplifier is not claimed to be a revolutionary design; rather it is intended to be easily built, and of good enough performance to match the radio i.c., whilst maintaining battery current economy and using inexpensive transistors.

The circuit in Fig. 6 shows a class-AB amplifier with a constant current source (TR4) enabling a

NOTE: The earthy side of VC1 (moving section) must be connected to C1/R16.

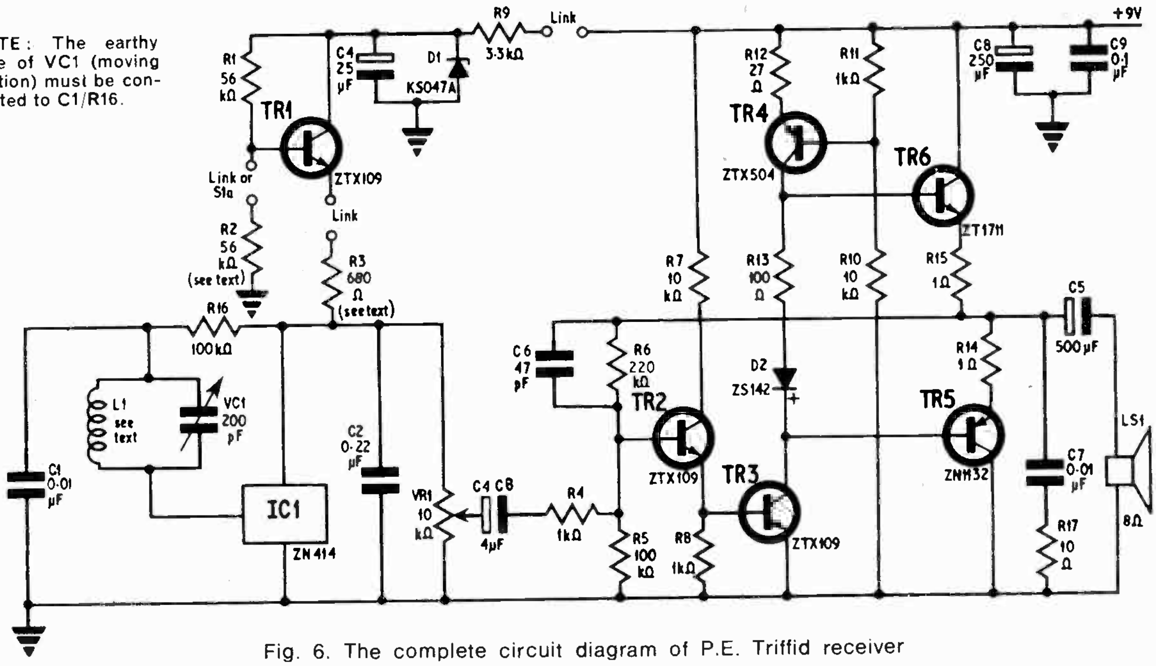


Fig. 6. The complete circuit diagram of P.E. Triffid receiver

higher voltage gain from the drive stage TR2. The current in TR4, and consequently the quiescent current taken by the circuit, is around 5mA. This *pnp* current source was found to reduce distortion in the circuit. The voltage gain at 1kHz is approximately 80, thus the input sensitivity for full output (5·7 volts before clipping) is 70mV.

The value of R13 may be lowered to give less bias voltage at the expense of distortion. Replacing it with a wire link is recommended if other output transistors are used, or any modifications are tried, as this prevents the possibility of thermal runaway.

If a reduced ouput power is acceptable, ZTX300 and ZTX500 may be used as the output pair, or BFS60 and BFS96; both sets give good results. Distortion with the standard circuit is one per cent at 1kHz and 2 volts peak output, mainly second harmonic. No crossover distortion can be seen on an oscilloscope trace at 20kHz, indicating that distortion is due mainly to non-linearity in the whole amplifier rather than to crossover "spikes".

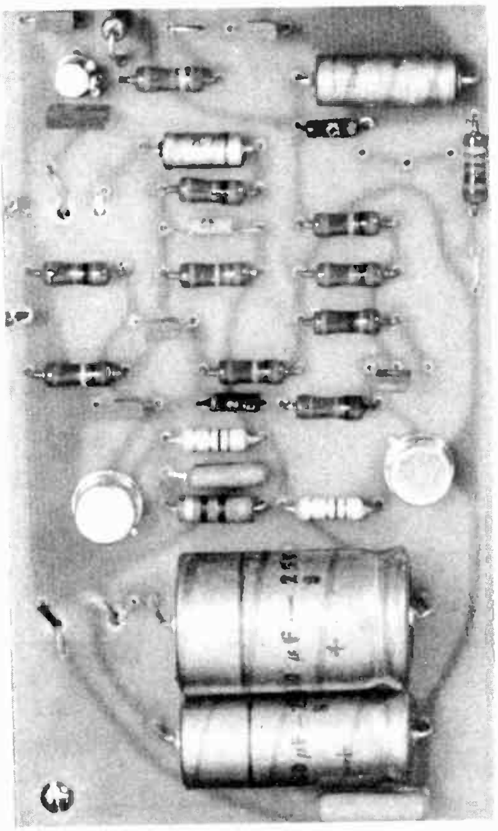
No heatsinks are necessary with the recommended output pair. Three layouts of the circuit were tried, all were stable and gave similar results.

The amplifier is certainly of good enough performance to use as an amplifier for an f.m. tuner, or record player, and experimenters can easily modify the circuit to switch in to another function or functions.

CONSTRUCTION AND LAYOUT

Provided the layout is carried out as described earlier, almost any method of construction can be used. However, a printed circuit board is recommended as it offers reliably consistent results.

The combined amplifier and radio circuit is shown in Fig. 6, the p.c.b. pattern and layout in Fig. 7. Apart from essentially sound soldered joints, two further precautions must be observed: wires from the coil-capacitor tuned circuit must be kept away from other circuitry, especially the battery leads and loudspeaker leads; the volume control must be 10kΩ or greater, if it is not to affect the a.g.c. characteristics.



Layout of components on a printed circuit board

COMPONENTS . . .

Resistors

R1	56k Ω	R8	1k Ω	R15	1 Ω 1W
*R2	56k Ω	R9	3·3k Ω	R16	100k Ω
*R3	680 Ω	R10	10k Ω 2%	R17	10k Ω
*R4	1k Ω	R11	1k Ω 2%	R18	22k Ω
R5	100k Ω	R12	27 Ω	R19	220k Ω
R6	220k Ω	R13	100 Ω		
R7	10k Ω	R14	1 Ω 1W		

All ± 5% ¼W carbon except where stated

Potentiometer

VR1 10kΩ volume control with switch (S3)

Capacitors

- C1 0·01μF
- C2 0·22μF
- C3 4μF elect 10V
- C4 25μF elect 10V
- C5 500μF elect 10V
- C6 47pF disc ceramic
- C7 0·01μF polyester
- C8 250μF elect 10V
- C9 0·1μF polyester
- VC1 200pF single gang tuning

Integrated Circuit

IC1 ZN414 (Ferranti)

Transistors

- TR1, 2, 3 ZTX109 (3 off)
- TR4 ZTX504
- TR5 ZN1132
- TR6 ZT1711

Diodes

- D1 KS047A
- D2 ZS142

Tuning Coil

L1 85 turns +250 turns 28 s.w.g. enamel wire wound on ⅜in dia. 6in ferrite rod (see text)

Miscellaneous

- LS1 8 Ω loudspeaker
- B1 9V battery style PP9
- Printed circuit board (see Fig. 7)
- Case and tuning scale

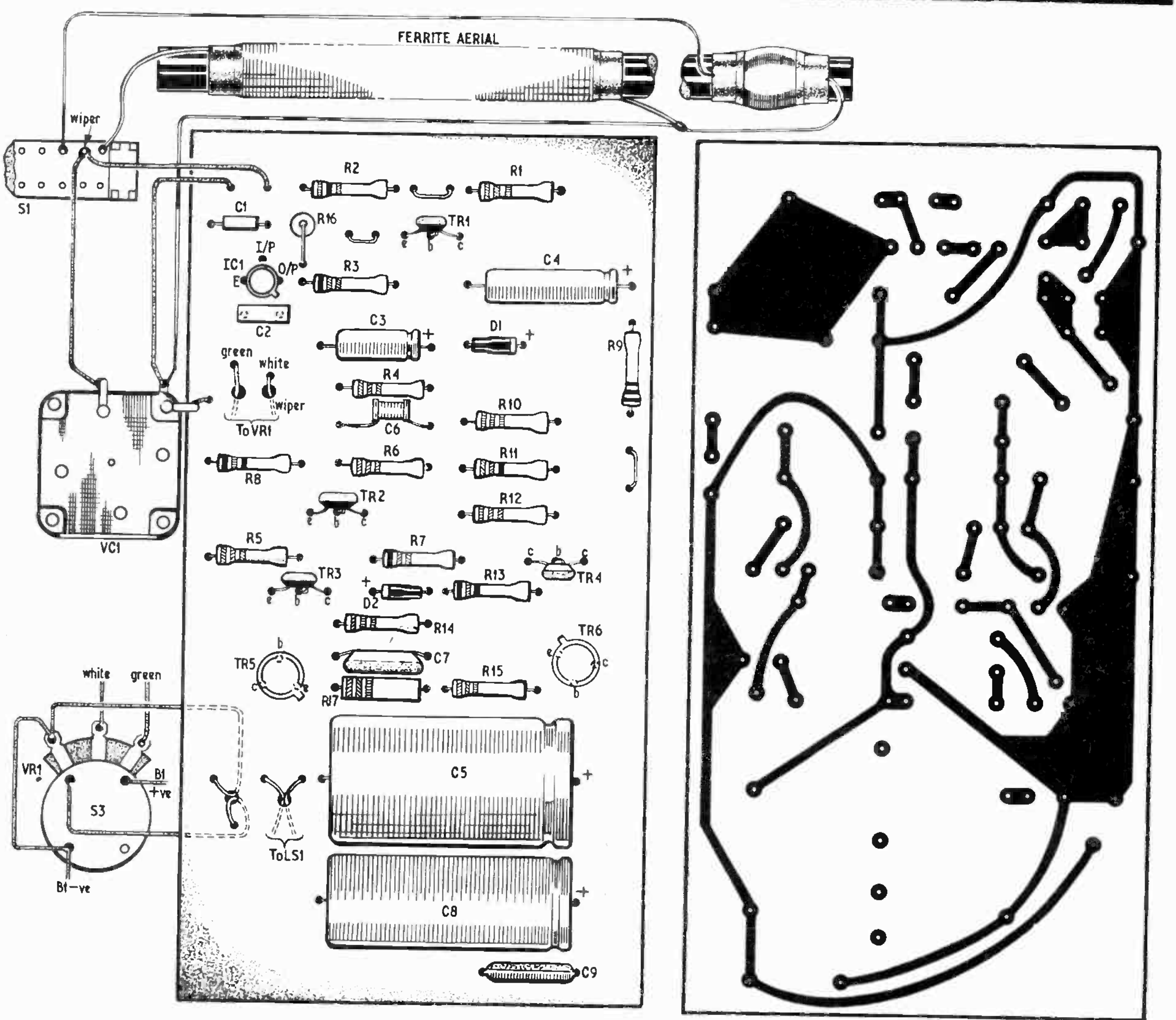


Fig. 7. Component layout and printed circuit board pattern (full size)

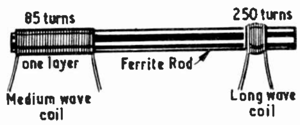
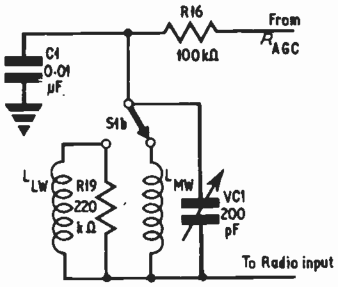


Fig. 8. Coil winding details and waveband selection



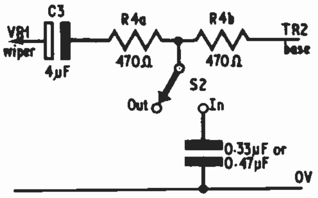


Fig. 9. A tone control circuit is inserted in the position of R4 as shown here with another capacitor

TUNING COIL

If the tuning range is tending towards the low frequencies, then fewer turns are needed on the coil. For a 6in ferrite rod with the coil feeding a 200pF tuning capacitor, about 85 turns of close wound enamelled copper or litz wire are needed; 28s.w.g. wire is suitable, but nothing is critical here, and adjustments are easy. It is better to wind more turns (say 100) and then remove some until the correct tuned frequency spread is reached. Litz wire gives highest *Q* coils and is highly recommended.

Constructors who wish to wind a long wave coil and fit a wave-change switch will find that, with the values above, the coil will need about 250 turns. Multilayering is best, but again this is not critical. Fig. 8 shows the long wave components necessary.

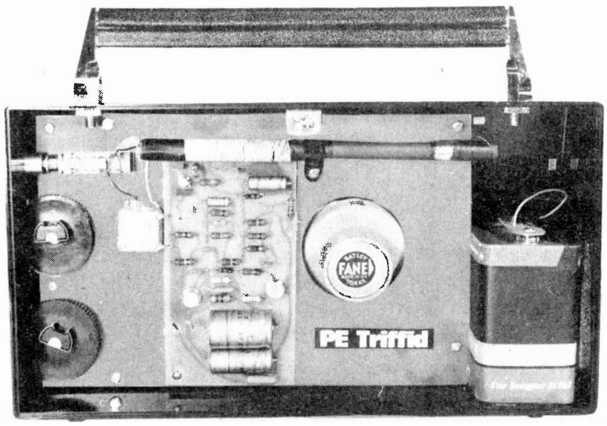
The type of ferrite rod affects the inductance, as does the type of wire, but it is easy to adjust the coil to suit the requirements of the rod obtained. Do not expect to adhere rigidly to the specified coil details for optimum results.

TESTING

Building the circuit should present no problems if carried out in the following manner:

1. Build up the amplifier unit and volume control, and test it on suitable inputs. If no signal generator is available, see if a hum is produced when the input is touched. The output (before C5) should be at 4·5 volts ±0·5 volts.
2. Wire up the radio drive circuit and put a 3·3kΩ resistor between emitter of TR1 and earth. This should have 1·3 volts ±0·2V across it.
3. Wire up the radio i.c. and test.

Interior of receiver showing the printed circuit board mounted on a plain board which also has the tuning capacitor, volume control and aerial mounted on it



If instability is encountered, the following procedure is used.

(a). Short the tuning capacitor out, if instability continues then the radio supply voltage may be incorrect.

(b). Radio frequencies generated in the amplifier may be feeding back to the i.c. To cure this a 47pF capacitor may be fitted across the 220kΩ resistor, and/or a 30μH choke placed in the supply before R9. (The link on the board is replaced by the choke.)

(c). Leads to the tuning circuit may need re-routing.

(d). If instability continues then replacing R2 by a 47kΩ resistor, and replacing the link above R2 with a 20kΩ preset, will facilitate greater control of radio supply voltage. This has an additional advantage; as the battery ages and its voltage drops, the set will still give good results (down to 6 volts with this preset in circuit.)

Happily, none of these problems occurs if neat systematic working is done, and normally the radio should work first time.

TUNING INDICATOR

A tuning indicator is very simply added to the set by inserting a 0–1mA (or 0–500μA) meter between TR1 emitter and the top end of R3. This should read approximately 0·3mA with no signal, but should read higher as one tunes through a station. The maximum reading indicates that the station is properly tuned, and depending on the signal strength, should give a reading around 0·5mA.

In normal circumstances this receiver should not drift and once set, the tuning should not need to be altered.

TAPE RECORDER OUTPUT

Provided the circuitry of the tape recorder has an input impedance of several tens of kilohms, a screened lead can be taken from the "top" end of the volume control to the tape recorder input socket most suited for a 100mV flat response input signal. Care that the bias circuitry does not interfere with the radio is needed, so a fairly long lead is recommended.

TONE CONTROL

Fig. 9. shows a recommended tone control, which in its extreme position gives a 6dB/octave roll-off above 1kHz. To fit the tone circuit, the connection between C3 and R4 has to be cut. Apart from this the board is adaptable for the modification. ★