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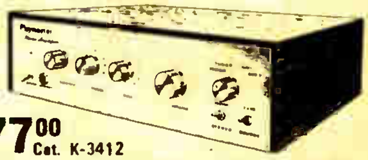

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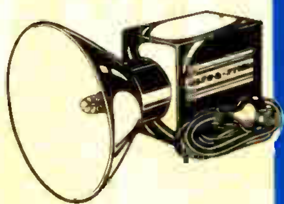

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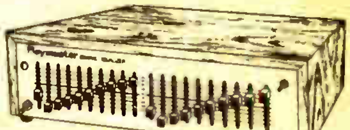

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# TOP PROJECTS
# Vol. 7




**Editor:** Jan Vernon
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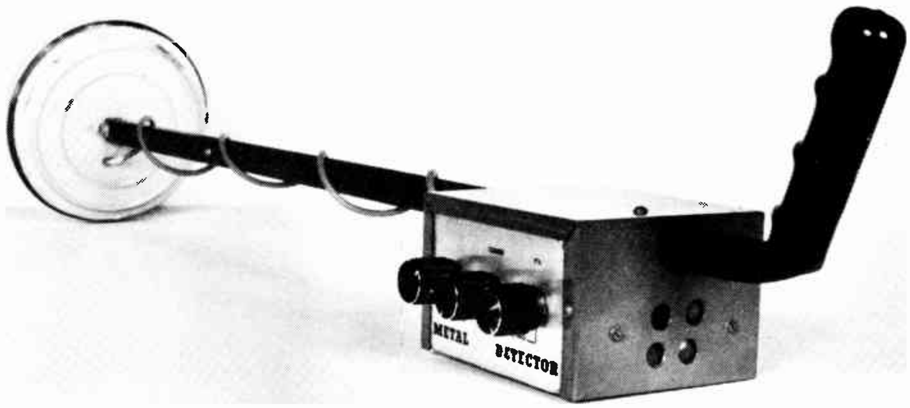
**Advertising:** Sydney 33-4282
Melb. 662-1222

**Top Projects Vol. 7** was printed by Offset Alpine Printing Pty Ltd, Derby & Wetherill Sts, Silverwater, NSW 2141.
Distributed by Gordon and Gotch.
*(Recommended and maximum price only).

# Simple, sensitive metal detector

**Phil Wait**

The metal detecting hobby is enjoying quite a boom at the moment and treasure hunters are not just after gold. Though the price of the precious metal has fallen in recent months, at around $600 an ounce it's worth going after. Old coins and relics fetch high prices too, so there's lots to find out there . . .




METAL DETECTORS depend on detecting one of several effects that can be observed when a metal object influences the magnetic field surrounding a coil of wire carrying an alternating current. The principal effects are: the pattern of the magnetic field surrounding the coil will be altered and the inductance of the coil will change.

The various types of metal detector devised exploit these changes, electronically detecting the alteration induced in the coil by the metallic object. Non-metallic objects or material can also affect the coil in similar ways.

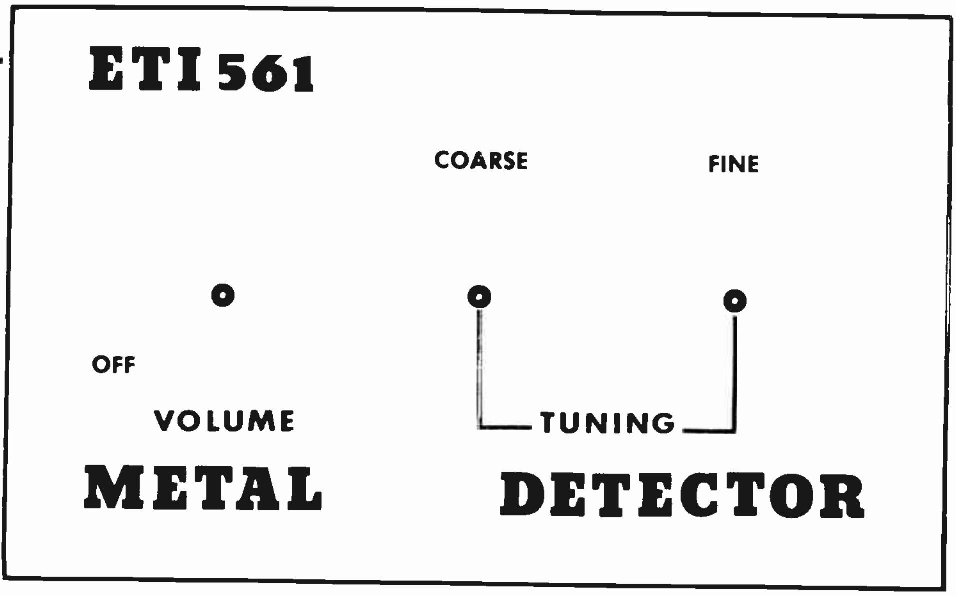
There are three basic methods employed to exploit the above effects. "Induction Balance" (IB) metal detectors employ two coils. One is driven by a modulated oscillator. The other is connected to a detector and amplifier. The two coils are carefully positioned with respect to one another such that the receiver coil picks up very little of the energy radiated by the transmitter coil when no metal or mineral material is nearby. When the coils are brought near a metal object, the field pattern is distorted, greatly increasing the transmitted energy picked up by the receiver coil. The modulated signal is detected and can be indicated by amplifying the recovered modulation to speaker level as well as indicating it on a meter. For obvious reasons, this type of metal detector is often referred to as a "transmit-receive" or TR detector, sometimes as an IB/TR detector. Chief advantages are good pinpointing ability and good depth penetration, and they are not sensitive to small ferrous objects. Sensitivity suffers badly in mineralised or ironstone ground. We described an IB/TR metal detector back in our May 1977 issue (Project 549) and it is still a popular project. The problem for the home constructor lies in correct construction and alignment of the coils.

Most IB detectors operate at a frequency between 85 kHz and 150 kHz. As they are badly affected by mineralised ground a technique was developed using very low frequency to energise the transmit coil. The 'VLF' types operate at frequencies around 4 – 6 kHz, a frequency range which penetrates all types of soil quite well. However, they need to run at a fairly high power to achieve sufficient sensitivity with small objects, hence battery drain is quite high, and pinpointing ability is poor.

"Pulse Induction" detectors employ coils in the search head that are set up in much the same manner as the IB detector. However, the transmitter is pulsed so that high energy bursts are transmitted by the search coil. The receiver then compares the phase of portion of the received pulse with the transmit signal. When a ferrous or magnetic object is brought near the search coils the phase of the received signal is *advanced* with respect to the transmit signal. The *opposite* occurs when a non-magnetic conductor is brought near the search coils. Thus, this type of detector can effectively 'discriminate' between ferrous and non-ferrous metals as well as exclude ground effects – simply by setting the detection circuitry to exclude signals of the unwanted phase characteristics. Thus, a "Ground Exclusion" control is often featured with these detectors. As the strength of the received signal also varies, depending on the 'target' object's characteristics, this effect may also be included in the detection process.

**FEATURES**

- Good sensitivity
- Excellent stability
- Good pinpointing ability
- Loudspeaker output
- Simple construction and set up
- Tuning allows for ground
- Low cost




Full size print of the front panel.

Clearly, an IP detector presents many problems to the home constructor.

The simplest technique detects the change in inductance of a single search coil. If this coil is part of the tuned circuit of an oscillator, then comparing the frequency of the 'search' oscillator with a stable reference oscillator will indicate the presence of a metal object. This detector is called the "Beat Frequency Oscillator" or BFO type. The two oscillators are set such that there is a slight difference in their frequencies and their outputs mixed. The resultant will be a 'beat' frequency which is equal to the difference between the two oscillator frequencies. The main advantages of this type are simple circuitry and setting up along with good pinpointing ability. In the past, most published designs have suffered from a distinct lack of sensitivity as well as poor tuning stability. A cunning mixing technique and a few other fillips can overcome these problems.

Hence, our new metal detector is a BFO type incorporating some modern refinements. It has proved to have similar sensitivity to our IB detector, the ETI-549, but is generally easier to build and set up, there being no critical adjustments.

## Design features

Our new metal detector has three controls: COARSE frequency adjust, FINE frequency adjust and VOLUME on/off. The coarse frequency control is used to initially set the frequency of the search oscillator, compensating for the various factors affecting any drift in this oscillator (mainly temperature and battery voltage). The fine frequency control is then used to set the note to a low pitch when the detector is placed over the ground, permitting compensation for the effect of the ground on the frequency of the search oscillator. The volume control adjusts the loudness of the output from the speaker.

The two main design problems this type of detector presents are the frequency stability of the two oscillators and the minute frequency change which has to be detected.

The search oscillator we finally used was settled on after some experimentation. Our first try employed an LC oscillator built around a CMOS gate chip. This proved to be not as stable as we required and we found that trying to obtain dc control of the frequency by varying the supply rail voltage had drawbacks. After some experimentation with oscillator configurations we hit on a discrete component oscillator which we found behaved much as we were seeking.

The search coil in the circuit we used is the inductor in a Colpitts oscillator. However, this particular circuit may be a little unfamiliar to many readers. To increase the RF current in the coil, it is placed in the collector circuit of Q1. Feedback is between collector and emitter and the base is effectively at RF ground. The frequency determining capacitance of the tuned circuit is 'tapped' to provide feedback, C2 and C3 performing this function. Careful attention has been paid to the basic frequency stability of this oscillator. Good quality styroseal capacitors have been used for C2 and C3. These have a temperature coefficient roughly opposite to that of other temperature influences on the frequency of the oscillator. In general, the short-term stability of this oscillator is quite good.

The particular circuit configuration of the oscillator gave us a very useful bonus – dc control of the oscillator frequency over a small range. Varying the base bias on a transistor will vary the collector-base capacitance. In this circuit, the c-b capacitance is part of the overall 'stray' capacitance that determines the exact frequency of oscillation. As the base bias is increased the c-b capacitance decreases, increasing the oscillator frequency. In this way, the oscillator frequency can be varied over a range of about ten percent. We have provided two controls, the FINE control providing a variation of about one-tenth that of the COARSE control.

The search oscillator is loosely coupled via a 47p capacitor to a following CMOS Schmitt trigger and two inverters which square the output. The loose coupling isolates the oscillator from the subsequent circuitry, further enchancing the stability of the search oscillator.

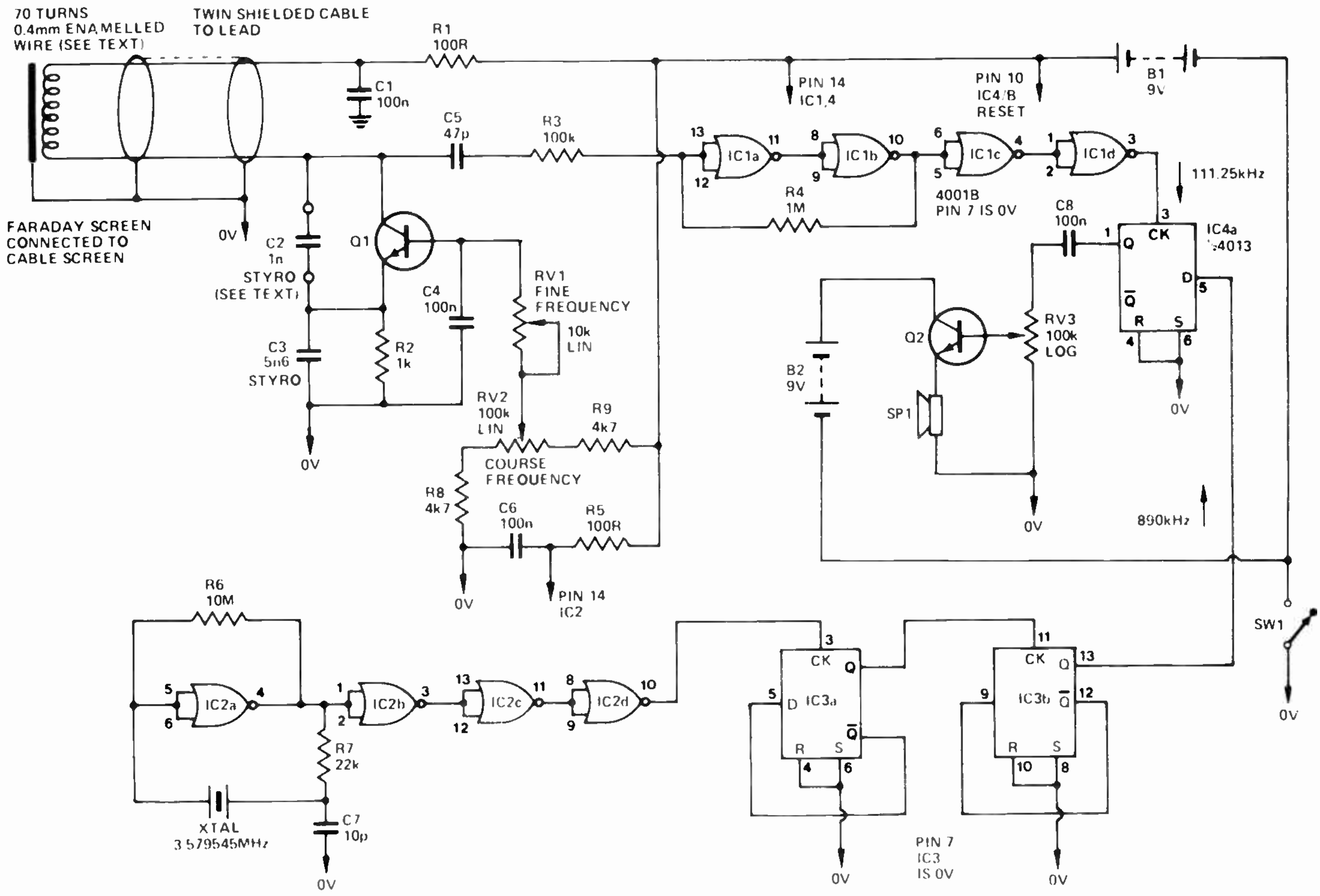
For the reference oscillator, we chose to use a crystal, because of its inherent stability. It has been argued that if an ordinary LC circuit is used for the reference oscillator it will have similar drift characteristics as the search oscillator and the overall drift will be reduced. In fact, the reference oscillator can be made using a standard 455 kHz IF transformer. In practice however, the two tend to drift at markedly different rates. We think the best approach is to make both oscillators as stable as possible. Hence the crystal – which is an easily available type and cheaper than an IF transformer!

The reference oscillator is a simple 'inverter' crystal oscillator built around one gate from a CMOS quad NAND gate, IC2. This has a square wave output and drives a divide-by-four circuit, IC3, via the other three gates in IC2, acting as buffers.

The crystal we used is a 3.579545 MHz type (NTSC chrominance subcarrier frequency) commonly available from a number of suppliers. We used one in our Electronic Tuning Fork (ETI-606) published November 1979. The output of IC3 is at a frequency of about 890 kHz. The *exact* frequency is unimportant, just so long as it's *stable*.

The search oscillator operates at a little above 100 kHz, about one-eighth of this frequency.

The secret of our metal detector's overall sensitivity lies in the mixer circuit. This employs one section of a 4013 flip-flop. The reference oscillator's divider output (at 890 kHz) is applied to the D input of IC4a and the squared-up search oscillator's output is applied to the clock input. If the clock frequency (i.e: the search oscillator frequency) changes by 1 Hz, the output beat (from the Q output of IC4a) will change by 8 Hz (see 'How it Works'), thus considerably *multiplying* the smallest changes in oscillator frequency. ▶




## HOW IT WORKS - ETI 561 Metal Detector

The beat frequency metal detector employs two oscillators: a very stable reference oscillator and a search oscillator. The search oscillator uses a tuned circuit designed to be influenced by metal or mineral objects which are brought into its field. The two oscillators are adjusted so they are harmonically related and fed to a mixer. When the search frequency is adjusted so the reference frequency fed to the mixer is eight times the search frequency, the output of the mixer is zero. The search frequency is slightly adjusted so that an output appears from the mixer which is the difference between the two input frequencies. This can be adjusted to an audio tone.

When a piece of metal or mineral is brought near the search coil the frequency of the oscillator varies, which in turn varies the output frequency from the mixer. The change in pitch can easily be heard from the speaker.

The reference oscillator employs a crystal in a CMDS oscillator circuit using one gate from IC2a. The resistor R6 biases the gate into its linear region. IC2 b, c and d, are used as buffer stages to prevent oscillator "pulling" and to further square its output waveform. Two flip-flops, IC3a and b, divide the reference signal by four to 890 kHz.

The search oscillator uses a discrete transistor in grounded base configuration, with the search coil in the collector. Using the coil in the collector increases the strength of the field around the coil and hopefully overcomes some of the losses in the ground. Feedback is set by the ratio of C2 to C3 from collector to emitter and their value determines the frequency of the oscillator. The base is grounded at RF by C4.

By varying the bias on the transistor the inter-element capacitances can be varied. This varies the oscillator frequency as the transistor capacitances form part of the 'strays' in the LC circuit. RV1 and RV2 provide fine and coarse frequency control. The resistors R8 and R9 limit the maximum and minimum voltage on the base to prevent over-dissipation in the transistor or drop-out of the oscillator.

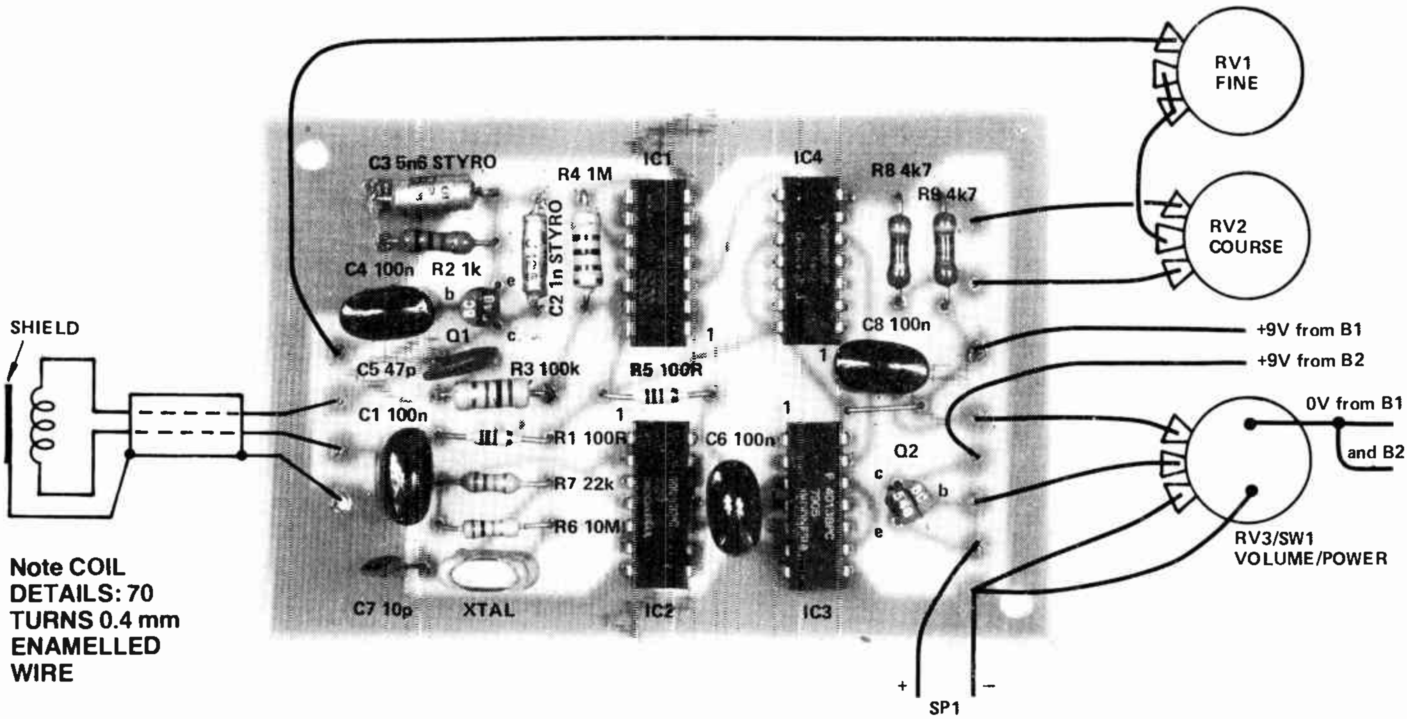
The output of the search oscillator is fed to a Schmitt trigger, consisting of IC1a and b, where it is squared and further buffered by IC1c and d. The search frequency is then fed to the mixer.

Both oscillators are decoupled from each other by supply line decoupling R1–C1 and R5–C6.

The mixer consists of half a dual-D flip-flop. The search and reference frequencies are fed to the clock and D inputs respectively. The flip-flop looks at the reference oscillator (D) on every positive transition of the search oscillator (clock), and transfers this level to the Q output until the next clock transition. If the two oscillators are exactly evenly harmonically related (i.e: 2nd, 4th, 6th, or in our case 8th, harmonic) the D input will always be the same level at each clock pulse. The output from the mixer at the Q pin will always be the same – no pulses.

However, if the search frequency is varied and the D and clock inputs are no longer harmonically related but are changing in phase with respect to each other, after a few clock pulses the D input will no longer be the same – the output will change state. The effect of all this is to produce a chain of square waves at the Q output, the frequency of which is eight times the change in frequency of the search oscillator.

Capacitors C8 and RV2 form a differentiating network which feeds a pulse to the audio amplifier, Q2, for each output transition from the mixer. Each cycle from the mixer produces two pulses in the speaker. If the frequency of the search oscillator is shifted one hertz the output of the mixer changes by eight hertz, producing an output of eight pulses per second in the speaker.




The output of the mixer is fed to a simple audio amplifier driving a loudspeaker. The search and reference oscillators must be well decoupled from each other and buffered from the mixer stage to prevent 'pulling' of the oscillators, which would result in erratic operation, especially when set for a low frequency output. We have used supply line decoupling as well as buffer stages after each oscillator. We also found it necessary to use a separate battery for the audio stage to prevent the very short, but high current pulses to the audio stage affecting the oscillators.

## The search coil

The most important characteristic of the search coil is its size. Surprisingly enough the actual inductance doesn't seem to have much effect on sensitivity. The greater the coil diameter the greater the penetration depth, but the less sensitive it is to small objects. As a general rule the penetration is about equal to the search coil diameter, while the sensitivity is roughly proportional to the cube of the object diameter (as expressed as a function of the search coil diameter). Sensitivity is also inversely proportional to the sixth power of the distance between the coil and the object.

All this means is that if the object size is halved the sensitivity is reduced to one-eighth. Also, if the depth is doubled the sensitivity is reduced to one sixty-fourth. It's easy to see why all metal detectors which are designed to pick up small objects use small coils, (150 to 300 mm diameter) and really only skim the soil surface. If the search coil is doubled in diameter for greater penetration the sensitivity to small objects falls to one-eighth. You rapidly encounter the law of diminishing returns.

Some of the more expensive metal detectors improve the penetration, while retaining sensitivity, by using a very complex arrangement of coils which modifies the field pattern. This can be done to some extent by making the coil on the BFO detector oval in shape.

We chose a round coil of 150 mm diameter to give good sensitivity to small objects giving about 100–150 mm penetration which is easy to build, but this is open to considerable experimentation. Remember though, that if the coil diameter is increased the number of turns will have to be reduced so that the search oscillator remains at the same frequency (about 110 kHz).

## Faraday shield

If the search coil is moved around, the capacitance between it and the ground ▶

### PARTS LIST - ETI 561

**Resistors** all ½W, 5%

| | |
|---|---|
| R1 | 100R |
| R2 | 1k |
| R3 | 100k |
| R4 | 1M |
| R5 | 100R |
| R6 | 10M |
| R7 | 22k |
| R8, R9 | 4k7 |

**Potentiometers**

| | |
|---|---|
| RV1 | 10k lin |
| RV2 | 100k lin |
| RV3 | 100k log switch pot |

**Capacitors**

| | |
|---|---|
| C1 | 100n greencap |
| C2 | 1n styroseal |
| C3 | 5n6 styroseal |
| C4 | 100n greencap |
| C5 | 47p ceramic |
| C6 | 100n greencap |
| C7 | 10p ceramic |
| C8 | 100n greencap |

**Semiconductors**

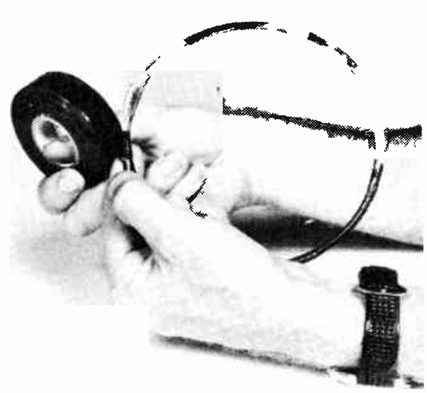
| | |
|---|---|
| Q1, Q2 | BC548, BC108, etc. |
| IC1, IC2 | 4001B |
| IC3, IC4 | 4013 |

**Miscellaneous**

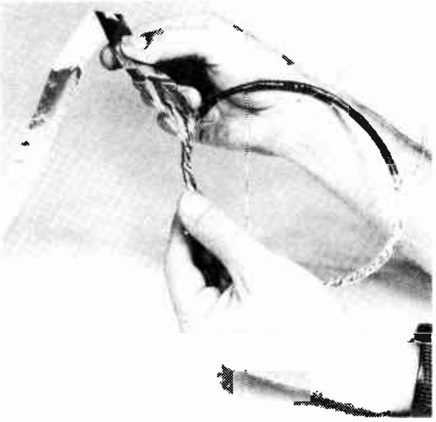
| | |
|---|---|
| SP1 | 8 ohm speaker |
| B1, B2 | 9 Volt battery (type 216) |
| XTAL | 3.579545 MHz NTSC colour xtal |
| ETI-561 | pc board |

Length of twin shielded cable, plastic pot stand (approx 150 mm dia), length of steel or aluminium tube (approx 600 mm long, 20 mm dia), length of plastic rod or wood dowel to fit inside pipe (approx 200 mm long), 0.4 mm enamelled wire, aluminium foil, Araldite, box to suit (approx 105 x 125 x 75 mm), three knobs, battery clips, insulation tape, two right angle brackets.

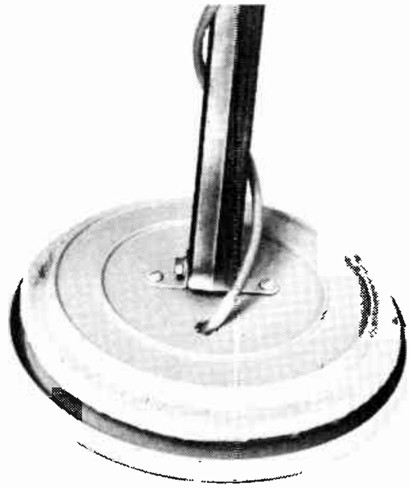
## SEARCH HEAD CONSTRUCTION



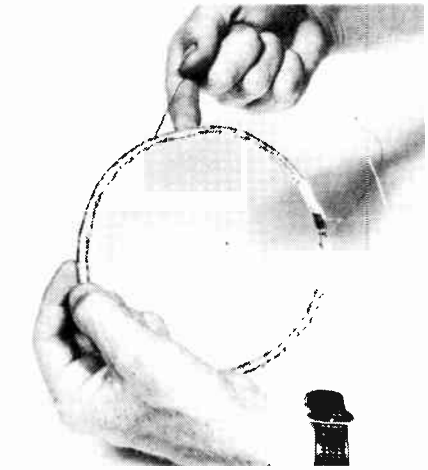
1: Having wound the coil as described, wrap it with two layers of insulation tape.



2: Next wind the Faraday shield using two strips of aluminium foil, leaving a break where the coil ends come out.



5: Press the assembled coil into the rim of the pot stand, terminate the wires as described and epoxy the coil to the pot stand.



3: Wind tinned copper wire over the shield, passing the end out where the coil leads pass out.

4: Cover the whole coil assembly with two more layers of insulation tape.

or other objects changes. This changing capacitance 'pulls' the oscillator frequency and can completely swamp out the small change in inductance we are looking for. The coil can be screened from this capacitance effect by using a Faraday Shield around the coil. This consists of a ring of tubing, or in our case – a wrapping of aluminium foil, around the coil but broken at one point so it does not make a shorted turn. This shield is then connected to the common supply rail (OV) on the oscillator.

## Construction

We have deliberately chosen commonly available mechanical and electronic components so that construction of this project is as easy as possible – especially for the newcomer. The search coil is mounted on a 165 mm diameter plastic pot stand which may be purchased at hardware stores and nurseries (if you must know, we used a Decor *497!). The electronics is mounted inside a simple aluminium box attached to a stem made from a length of tube specified for C2 and C3 or performance which extends down to the search coil and serves as the handle. Connection to the search coil is via a length of shielded cable. The controls mount on one side of the box housing the electronics. Which side you mount them depends on whether you are right or left handed. The speaker mounts on the end of the box facing the operator. As can be seen from the picture, the handle was made with an upwards bend at the end which you grip. This balances the instrument reasonably well, avoiding arm strain.

Construction should commence with the electronics. Mount the components on the pc board, taking care with the orientation of the transistor (Q1) and the ICs. Do not substitute another type of capacitor for the styroseal types may suffer. The crystal specified comes with flying leads and may be soldered in place. Don't use too much heat though, solder quickly and you will avoid possible damage to the crystal.

The next step is to make the stem. The easiest way is to take a length of 25 mm diameter electrical conduit about 850 mm long and make a bend about 100 mm from one end for the grip. To do this, heat the point of the bend over a flame (not *in* the flame) until it softens and then carefully bend it about 60° from straight.

A length of aluminium tube may also be used for the handle. The bend for the grip can be made by first flattening the point of the bend somewhat with a hammer then placing the short piece in a vice and carefully making the bend. A section of wood dowel or plastic tube should be placed between the search coil and the end of the metal tube to keep the mass of metal about 200 – 250 mm away from the search coil. A piece of wood dowel of the right size, jammed in the end of the aluminium tube, is generally the easiest way to go about it.

We used a small aluminium box which comes in two pieces. We drilled a hole in either end of the 'bottom' of this box so that it could be slipped over the stem (see accompanying photograph). A nut and bolt was used to secure it to the stem on the side 'below' the grip. The small speaker is mounted in this part of the box, before it is secured to the stem, on the end which faces upward toward the operator. A small hole is drilled in the opposite end and a grommet inserted. This permits entry of the cable to the search coil.

The pc board and controls are mounted to the 'lid' of the box. Position the controls on the side that suits your handedness. Our model was made for right handed operators.

Now for the search coil. This is wound so that it can be tucked inside the rim of the up-turned plastic pot stand. First make a cardboard former of the appropriate diameter. Roll a strip of heavy cardboard around the rim such that it fits loosely and tape or staple it securely (to avoid it popping open at an awkward moment).

Lift the former off the pot stand and

then wind the coil onto this former as per the details given in the parts list. Leave a short length of wire spare on each end to make the connection. Tie the coil up with a few lengths of string at various places and then slide it off the former. Now wind two layers of insulation tape around the coil, leading the two ends out at the same place.

Next, wind the Faraday screen. Cut some aluminium kitchen foil into strips about 15 mm wide and wind this around the coil to make two layers but leaving a small gap about 5 mm to 10 mm wide where the coil ends come out. It is very important that the two ends of the Faraday shield do not connect as this would make a 'shorted turn' and the coil would not work as intended.

To secure the foil tightly around the coil, and to make connection to the shield, wind a length of tinned copper wire around the shield with about a 10 mm pitch (i.e: about 10 mm between successive turns). The end of this wire is taken out at the same place as the coil connections.

Now wind another two layers of insulation tape around the whole assembly. Drill a 3 mm hole in the side of the pot stand and then press the coil down into the rim with the connecting wires adjacent to the hole. Pass the wires through the hole. Pour quick-setting epoxy over the coil to hold it in place.

The search head is mounted to the stem using two right-angle brackets and a bolt passed right through the end of the stem. Small pieces of metal here don't seem to adversely affect the operation of the detector.

Solder the coil connections to the twin shielded cable, the Faraday shield connecting to the cable's shield, and glue the cable and wires underneath the pot stand to hold them rigid. If you wish, the 'underside' of the pot stand may be completely filled with epoxy.

Wind the cable around the stem to keep it mechanically rigid and pass it through a grommeted hole in the box. Terminate the cable to the pc board.

## Using it

When the construction is complete, turn on the detector, advance the volume control and rotate the coarse frequency knob. You will hear a number of 'heterodynes' or beats, one being very strong. This heterodyne is the one commonly used, the others being odd multiples of the reference signal beating with multiples of the search oscillator. You may find that some of these weaker signals are more sensitive to buried objects than the stronger one.

Set the fine frequency control to mid-range and set the course frequency control to near the strong heterodyne with the search head held away from the ground. Lower the detector to the ground and you will notice a frequency shift. This is the effect of the ground and will vary between different types of soil. Use the fine frequency control to set the beat to a low pitch and sweep across the surface. A metal object will cause a change in the pitch which is clearly audible.

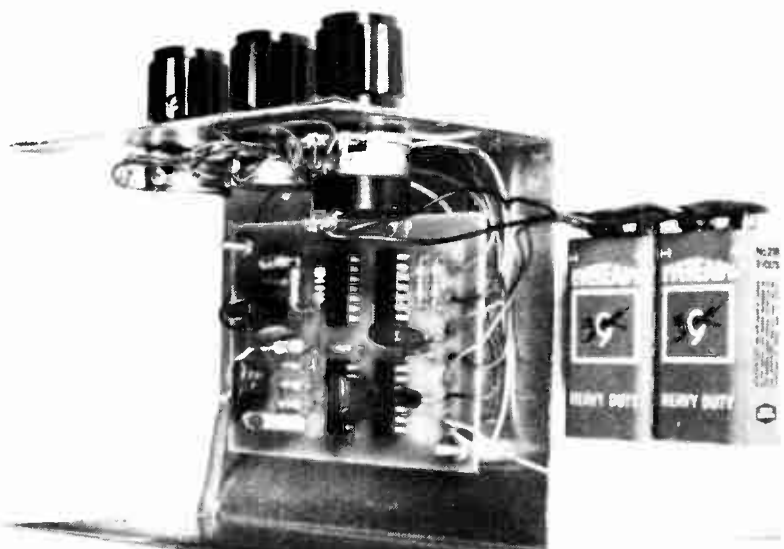
The ear is more sensitive to changes in pitch at low frequencies than at high frequencies and thus it is best to adjust the fine frequency control to a low pitch that can be heard at a comfortable volume from the loudspeaker.

Theoretically, the frequency of the search oscillator should *increase* when a non-ferrous object comes within range of the search coil and *decrease* when a ferrous (or diamagnetic) object is within range. This effect is difficult to detect in practice as eddy currents in ferrous materials swamp the effect and they react much the same as non-ferrous metals. However, minerals such as hematite may show the effect. With the search oscillator set on one side of zero beat, metal objects near the search coil will cause the pitch to *increase*, while magnetic minerals will cause the pitch to *decrease*. With the search oscillator set to the other side of zero beat, the opposite will occur.

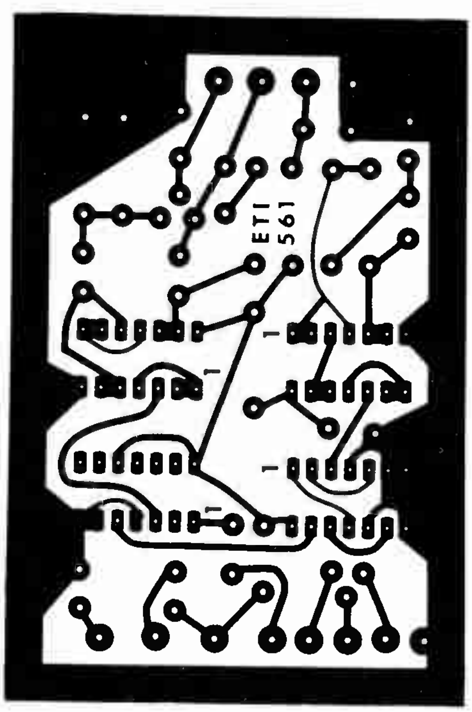
You could try a few experiments to show up this effect.

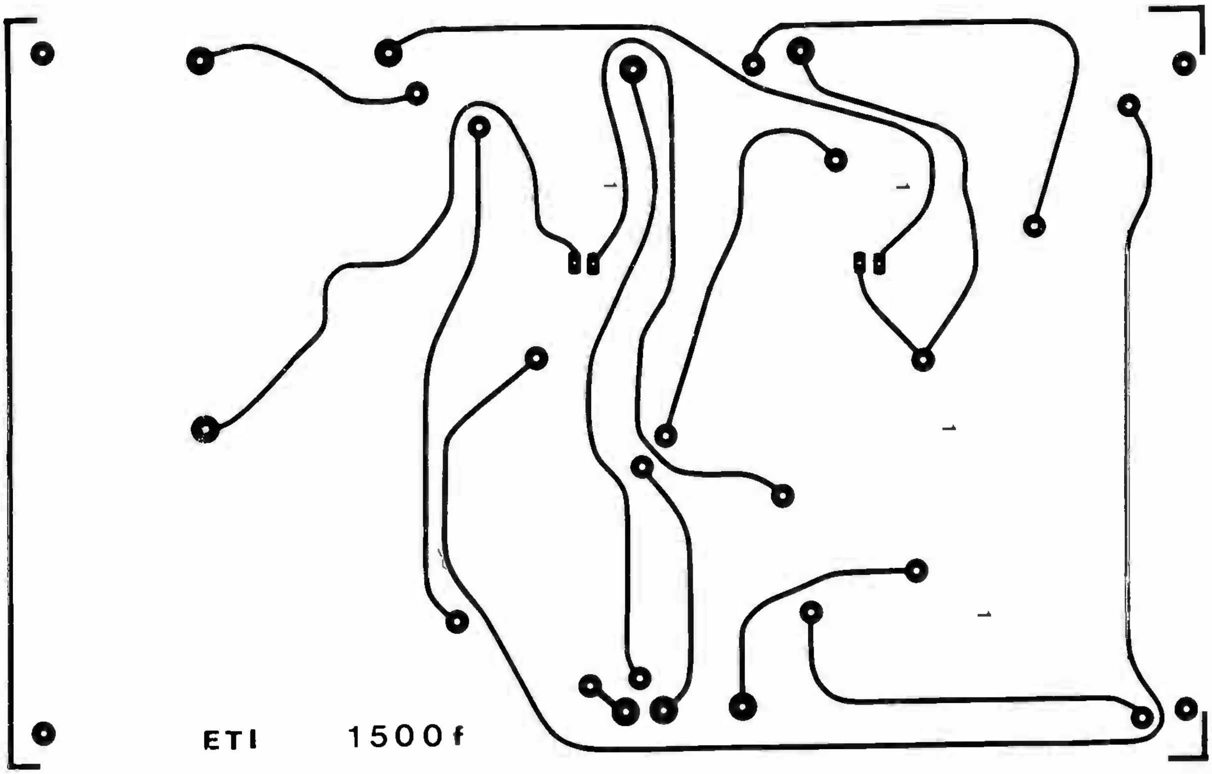
Enough theorising. In general operation, try to keep the search head a constant distance from the ground and sweep from side to side in a regular pattern. The right technique is easily developed with a little practice.

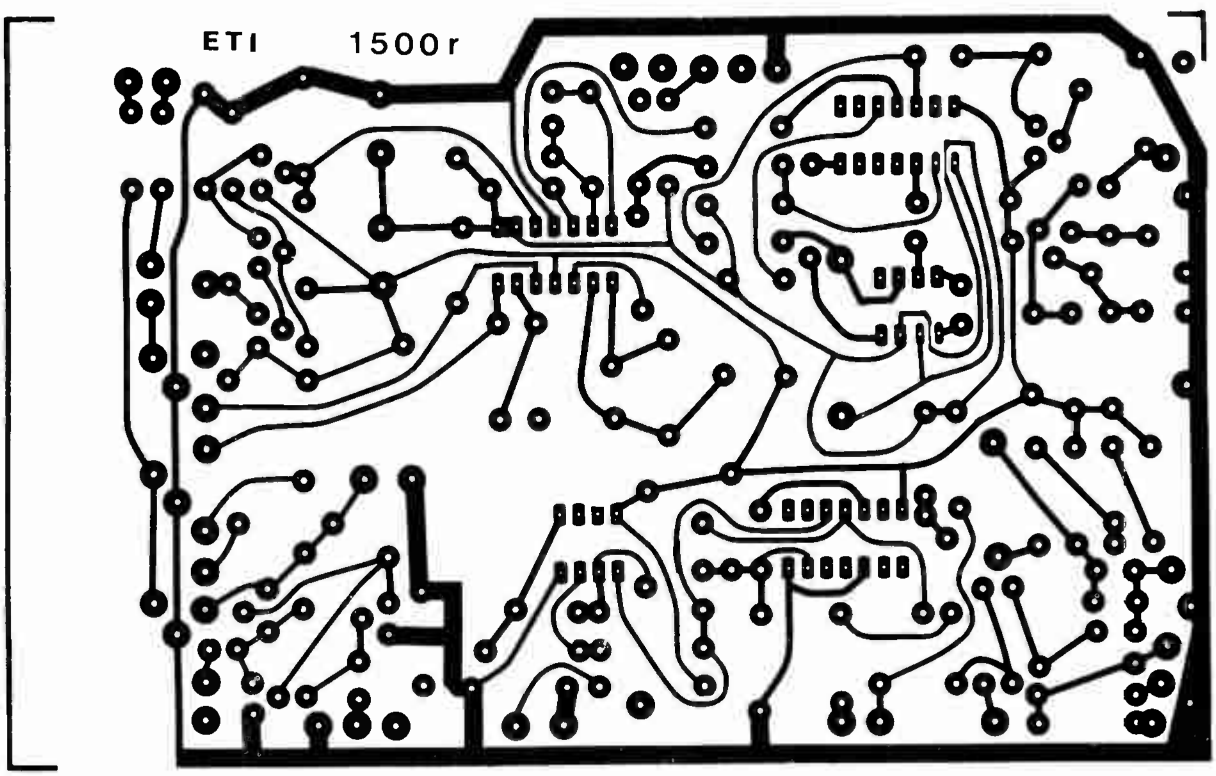
There are a number of books on metal detecting available and these show the sort of techniques the successful treasure hunter employs. ●



Internal view of the metal detector electronics showing general placement of the major components. We mounted the pc board using some 12 mm spacers, nuts and bolts. The speaker mounts on the box 'lid'.




ETI 1500f


ETI 1500r


# A 'discriminating' metal detector

This metal detector operates just like the 'bought ones' but costs only one-third to one-half as much to build it yourself. It features three 'discriminate' ranges plus VLF operation and includes an 'auto-tune' button.

design: **Lee Allen, Altek Instruments, UK**
article: **Phil Wait**

"GOLD FEVER," shrieked the news headlines following the finding of the 27 kg Hand of Faith nugget at Wedderburn in Victoria recently. It was unearthed by a couple of amateur fossickers using a metal detector, just about the most sophisticated tool ever brought to bear in the hunt for gold.

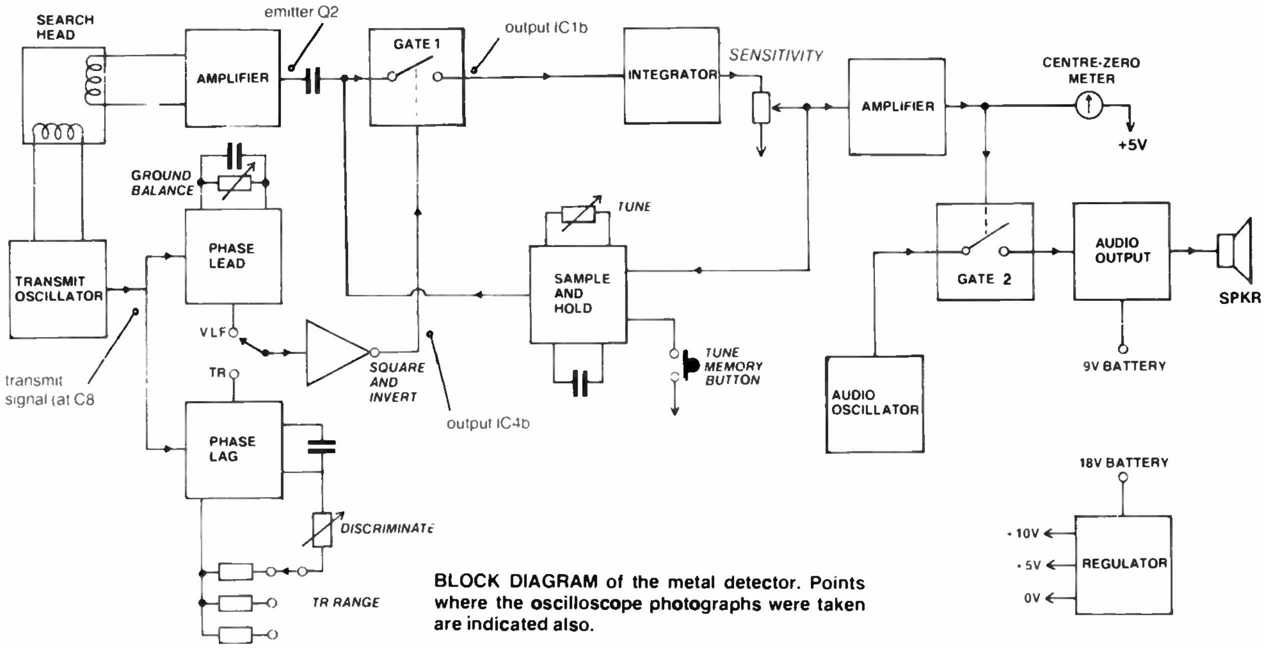
Designs for metal detectors genuinely able to discriminate between 'trash' and 'treasure' have generally been well kept trade secrets. Even the general principles of operation have been veiled in mystery. However, we are indebted to Lee Allen of Altek Instruments of the UK for providing us with the circuit design of this metal detector project via our British edition. The design incorporates all the features and refinements of modern commercially-made instruments and features performance equivalent to units costing two to three times as much.

## Principles of operation

This detector employs the basically well-known *induction balance* technique to detect the presence of a metallic 'target' in the ground, but includes a number of refinements which respond to certain characteristics of the target. The 'search head' contains two coils: an outer coil which is connected to a low frequency oscillator operating somewhere in the range 15 - 20 kHz, and an inner coil which is placed so that it is only very loosely coupled to the outer coil. The latter is connected to the 'receiver' input of the instrument. Being only very loosely coupled, the signal induced in the receiver (inner) coil from the transmit (outer) coil is very small when a target is not in the vicinity of the search head.

When the search head approaches a metallic target, the target will have a number of influences on the two coils. Firstly, the magnetic field pattern of the transmit coil will be disturbed, and thus the coupling between the transmit and receive coils will be increased. This generally produces an increase in the signal from the receive coil. In simple induction balance detectors, such as the ETI-549 (May 1977), this signal increase is detected and used to gate an audio oscillator on so that a tone is passed to a speaker or headphones.

That's all quite straightforward, but there are other influences to be taken into account. The ground in which a target is buried can have quite a profound effect on the coils in the search head. Firstly, if the ground is basically non-conducting, then it will have a permeability considerably different to that ▶




**BLOCK DIAGRAM** of the metal detector. Points where the oscilloscope photographs were taken are indicated also.

of air. This will affect the coupling between the two coils in the search head, increasing the coupling if the transmit and receive coils are initially set up away from the influence of the ground. You can compensate for this effect by physically varying the position of one coil in relation to the other when the search head is near the ground. However, different soils will have different compositions and thus have different values of permeability — even within quite a small area. The best way to compensate is by electronic means and we'll go into that shortly.

If the soil contains an appreciable amount of iron minerals (maghemite, hematite etc ... often referred to as "iron stone soils"), or mineral salts of one type or another, then it will be partly conducting.

Such soils will have a permeability often greater than basically non-conducting soils, affecting the coupling between the coils in the search head in a similar way to that just explained. Again, as the composition of the soils varies, so will the coupling. Another effect is that of 'eddy currents' induced in the conductive soil. The ac magnetic field of the transmit coil will induce a current in the ground beneath the search head and the eddy current has an effect opposing the permeability effect of the soil — and the whole effect varies in a complex and unpredictable way as you sweep the search head over the ground.

The only way to compensate for these varying, and generally unpredictable effects, is to devise circuitry that 'recognises' the effect.

Permeability effects will vary the phase as well as the amplitude of the signal coupled into the receive coil from the transmit coil while eddy current effects vary the amplitude. Knowing that, one can devise appropriate circuitry to take the effects into account.

However, we need to know how a metallic target affects the phase and amplitude of the receive signal. If the target is ferrous, it will have a much greater effect on the magnetic field of the transmit coil than will the surrounding soil as its permeability is greater and it will 'bend' or concentrate the field lines to a much greater degree. If the target is non-ferrous it will have a permeability effect opposite to that of ferrous targets, deflecting the field lines, but eddy currents also have some influence.

The eddy current effect in a target depends on the electrical and physical characteristics of the target. Metals which are good conductors will have greater induced eddy currents than metals which have a higher resistivity. It is a fortunate accident of nature that gold and silver are good conductors (low resistivity) while iron (especially if it's oxidised or rusty) is not so good a conductor.

If the target is ring-shaped then the eddy current effect is enhanced, whereas if it's a broken ring or just a peculiarly-shaped mass, the eddy current effect is less pronounced. The 'attitude' or orientation of the target will also affect the eddy current effects. If the main plane of the target object is aligned such that the field lines from the transmit coil cut it at right angles, then the eddy currents induced will be at a maximum. If the main plane of the target is aligned parallel to the transmit field then the eddy currents induced will be at a minimum. Obviously, the attitude of the target with respect to the transmit coil's field will vary as the head passes over it and the eddy current effect will vary accordingly — it may not be maximum beneath the centre of the search head.

The permeability and eddy current effects combine in the receive coil and the signal varies in phase and amplitude in characteristic ways.

## The instrument

The best way to understand how this instrument operates is to look at it in block diagram form. The accompanying diagram shows the basic circuit blocks employed. The transmit oscillator drives the transmit coil in the search head and supplies a signal to two phase control circuit blocks. The signal from the receive head is first amplified and then ac-coupled to the input of a gate (gate 1). This gate is controlled by the output from one or other of the phase control circuits via a block which 'squares up' and inverts the signal. The output gate consists of an ac signal superimposed on a dc level. This passes to an integrator which obtains the *average* dc level of the composite signal. This is then passed to both a dc amplifier which drives a centre-zero meter, and to a 'sample and hold' circuit. The output of this block provides a dc level to the input of gate 1 which is a measure of the average dc level of the composite signal. The initial dc level applied to the input of gate 1 is actually established by the *tune* control. Thus, a dc negative feedback path is provided.

In addition to meter indication, an audio indication is provided. The output of the dc amplifier driving the meter controls a gate which switches on or off the output of an audio oscillator. This is applied to an audio amplifier and an on-board loudspeaker or headphones.

Power for the audio amplifier is provided by two 9 V batteries in parallel. The rest of the circuitry requires two supply rails at +10 V and +5 V with respect to the common rail (0 V). This is supplied by a regulator from an 18 V source consisting of two 9 V batteries connected in series.

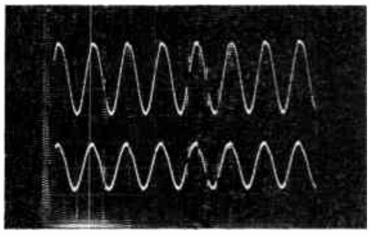
Initially, the instrument is set up in the 'VLF' mode. The search head is held in the air and the *tune* control adjusted to bring the meter to centre zero. This is done with the *tune memory* button depressed. This activates the sample and hold circuit, storing the dc level set by the feedback loop in the capacitor of the sample and hold block. Thus, a particular dc level at the output of the integrator corresponding to meter centre zero is set up.

The search head is then lowered to the ground. Naturally, this will upset the coupling between the transmit and receive coils and the output at gate 1 will change. This will change the dc level at the output of the integrator. The *ground balance* control is then adjusted to bring the meter back to centre zero. What the ground balance circuit does is to provide a signal which leads the phase of the transmit signal and thus leads the phase of the signal induced in the receive coil without the presence of ground. The ground balance control varies the phase of this signal over a range of about four to one. Thus, when you vary the ground balance control, this varies the phase of the signal controlling gate 1, thus varying the average level of the signal passed to the integrator.

The process is then repeated until no change occurs when the search head is lowered to the ground. This establishes a 'normal' condition for the output of the integrator and the sample and hold circuit maintains the appropriate dc level at the input to gate 1 such that the meter remains at centre zero.

If the search head then approaches a metallic object, the amplitude of the signal in the receive coil will vary as the coupling between the coils and the phase of the signal will be altered by the target. This will change the average level of the composite signal out of gate ▶

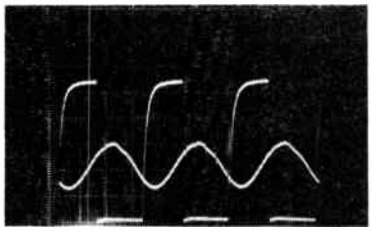
## OSCILLOSCOPE PHOTOGRAPHS



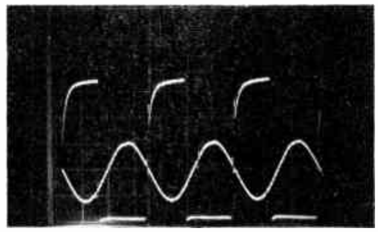
NOTE: As the effect induced by different targets is very, very small, we have had to use fairly large sample targets to show gross effects in order to demonstrate the operation of the instrument.

A) Top trace: transmit signal on C8 (Y-amp 5 V/div, ac-coupled)
Bottom trace: received signal on emitter of Q2 (Y-amp 5 V/div ac-coupled). Time base: 50 us/div.

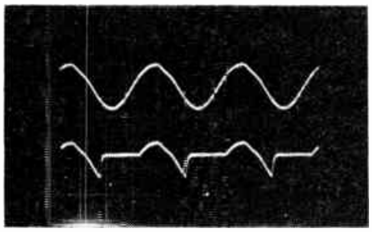
### VLF MODE



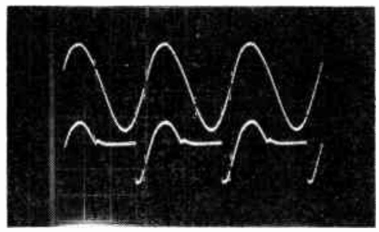
B) Received signal on emitter of Q2 (sine wave) superimposed on output of IC4b. (Both traces 2 V/div, ac-coupled; time base 20 us/div).



C) As per pic (B) but with aluminium target held near search head. Note the phase delay and change in amplitude of the received signal.

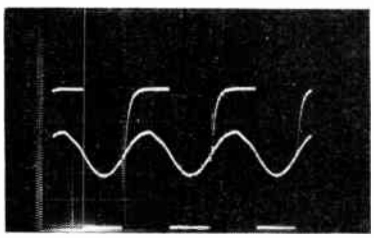


D) Top trace: received signal on emitter of Q2.
Bottom trace: output of IC1b showing composite waveform of received signal 'mixed' with a dc level. (Both traces 2 V/div, ac-coupled; time base 20 us/div).

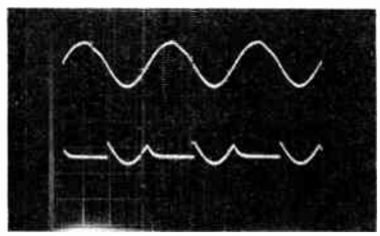


E) Same as pic (D) but with metal target near the search head. Note the increase in average dc level from the output of IC1b. The change in this signal is much larger for non-ferrous than for ferrous metals.

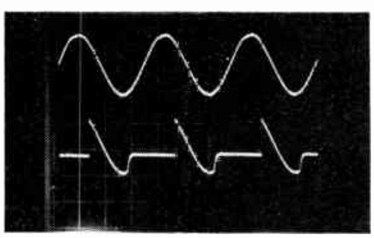
### DISCRIMINATE MODE



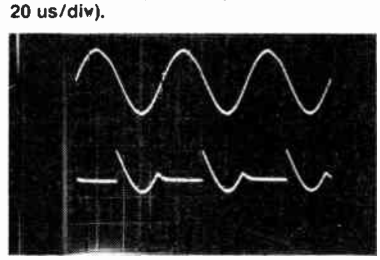
F) Received signal on emitter of Q2 (sine wave) superimposed on the output of IC4b. The phase difference between the two signals is adjustable through 180° by use of the course (TR1, TR2, TR3) and fine 'discriminate' controls. (Both traces 2 V/div, ac-coupled; time base 20 us/div).



G) Top trace: received signal on emitter of Q2. Bottom trace: output of IC1b showing composite waveform of received signal 'mixed' with a dc level. Detector set to TR1 mode, discriminate control to 9. (Both traces 2 V/div, ac-coupled; time base 20 us/div).

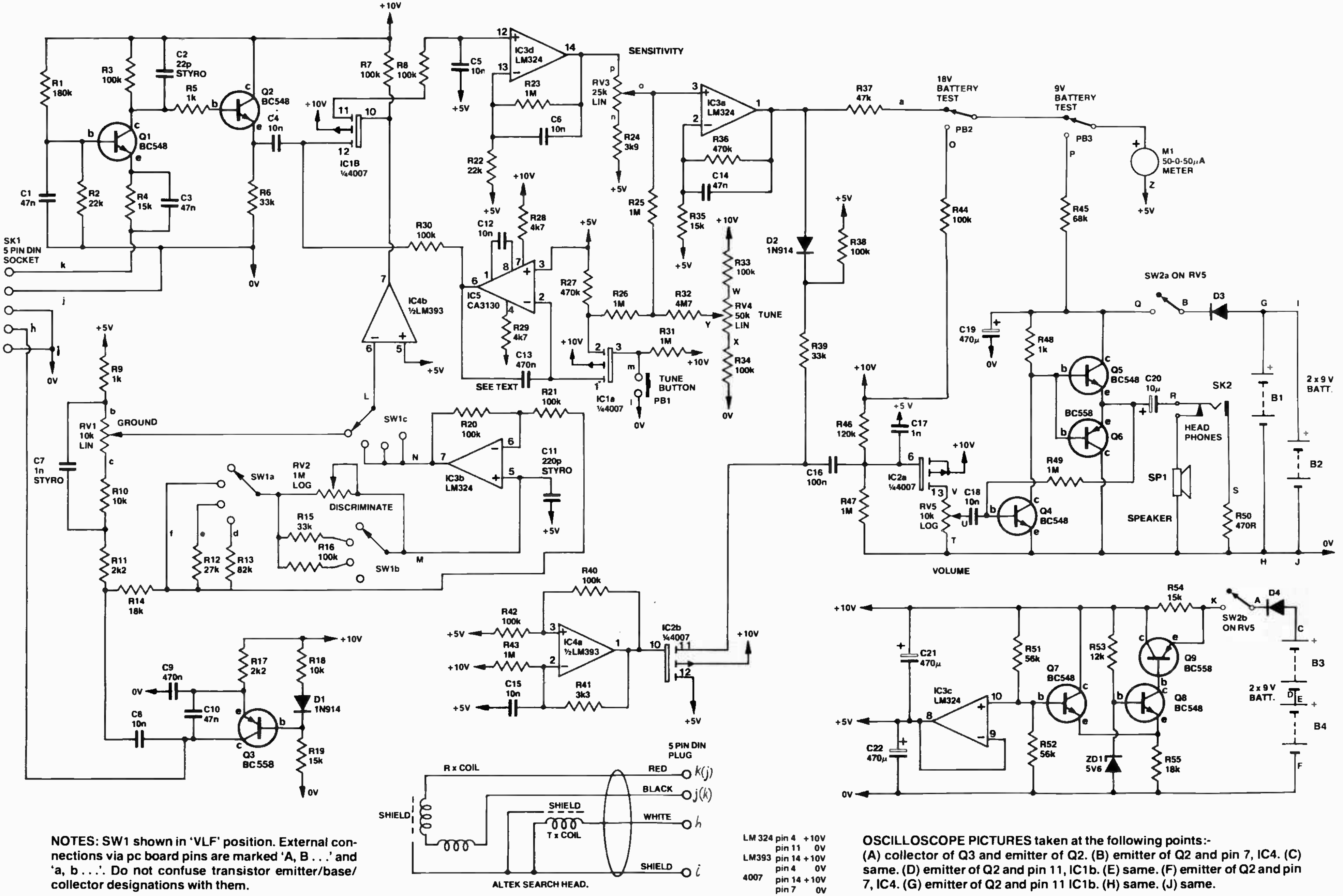


(H As per pic (G) but brass target held near search head. Note the increase in the average dc level of the signal at the output of IC1b.



I) As per pic (G) but steel target held near search head. Note the decrease in average dc level of the signal at the output of IC1b, illustrating discrimination.

# Project 1500 — super metal detector




NOTES: SW1 shown in 'VLF' position. External connections via pc board pins are marked 'A, B . . .' and 'a, b . . .'. Do not confuse transistor emitter/base/collector designations with them.

| | | |
|---|---|---|
| LM324 | pin 4 | +10V |
| | pin 11 | 0V |
| LM393 | pin 14 | +10V |
| | pin 4 | 0V |
| 4007 | pin 14 | +10V |
| | pin 7 | 0V |

OSCILLOSCOPE PICTURES taken at the following points:- (A) collector of Q3 and emitter of Q2. (B) emitter of Q2 and pin 7, IC4. (C) same. (D) emitter of Q2 and pin 11, IC1b. (E) same. (F) emitter of Q2 and pin 7, IC4. (G) emitter of Q2 and pin 11 IC1b. (H) same. (J) same.

## FEATURES

- VLF and T/R operation
- Three ranges of 'discriminate' (T/R) operation
- Can tune out aluminium ring-pull tabs
- Ground balance circuitry included
- Tune memory ('auto-tune') button
- High sensitivity (will detect 20¢ piece at depths over 250 mm)
- Pre-wound and aligned waterproof search head
- Straightforward construction, no alignment necessary
- Low battery drain
- Uses common No. 216 transistor radio batteries
- Costs around $200 in kit form

## HOW IT WORKS — ETI 1500

As the general principles of operation have been discussed with regard to the block diagram in the text, this description is confined to the circuit alone.

Commencing with the transmitter, Q3 is configured as a Colpitts oscillator, the transmit coil in the search head forming the inductance which resonates with the combination C9 and C10. Bias is applied to Q3 via R18, D1 and R19. Emitter bias is provided by R17. The transmit signal to the phase-lead and phase-lag circuitry (ground and discriminate controls) is tapped off the collector of Q3 via C8 to the junction of R11 and R14. The ground control circuitry connects via R11 while the discriminate circuitry connects via R14.

The signal from the receive coil is amplified by Q1 and applied to gate 1 (see block diagram), one CMOS gate in IC1 (IC1b), via an emitter-following buffer stage, Q2. Note that Q1 is operated as a grounded-base amplifier. The phase of the received signal through Q1 and Q2 is not altered. Output from the emitter of Q2 is applied to the drain of IC1b.

The base of IC1b is driven by a square wave derived from the transmit signal, the phase of which can be varied by either the ground or discriminate controls.

In the VLF mode, the phase of the transmit signal tapped off from Q3 can be varied using RV1. This provides a phase-advanced signal that can be varied over the range from about $+10^{\circ}$ to $+40^{\circ}$. A leading phase RC network is formed by R10 and RV1 in conjunction with C7. This signal is applied to the inverting input of an op-amp, IC4b. As this is operated at maximum gain with a high signal level at the input, it will 'square up' the signal at its output (pin 7), which drives the gate of IC1b.

In the discriminate mode, switch SW1 connects the transmit signal to circuitry which provides a lagging phase signal which can be varied over a range set by RV2 (the discriminate control) and a set of 'range' resistors: R12, R13, R15 and R16. These form a lagging phase RC network in conjunction with C11. The signal is then buffered by a non-inverting op-amp, IC3b, and applied to the inverting input of IC4b via SW1c.

The source of IC1b is connected to an integrator stage formed around IC3d. The output of this stage is connected directly to the sensitivity control, RV3. The wiper of this potentiometer goes directly to the input of a dc amplifier, IC3a, to which we shall return shortly. The wiper of RV3 is also connected to the sample and hold circuit, via R25, which involves IC5, IC1a, the tune control RV4 and the tune memory pushbutton, PB1.

The sample and hold circuit works in the following way. The junction of resistors R25, R26 and R32 will be at a dc level determined by the dc level at the wiper of RV3 and the dc level at the wiper of RV4, the tune control potentiometer. The dc level at the wiper of RV3 will depend on the signal level and phase switched through to the integrator by IC1b. When the tune memory pushbutton, PB1, is pressed, IC1a (also a CMOS switch) will apply a dc level to the input of the sample and hold circuit proportional to the dc level at the junctions of R25, R26 and R32. This will charge C13 and the output of IC5 will settle at this value. This dc level is then applied to the drain of IC1b, via R30.

Thus, the received signal and this dc level are 'mixed' at the input to gate 1 (i.e: IC1b), the composite signal being applied to the integrator.

The meter, M1, is driven by a dc amplifier, IC3a. The input to this op-amp comes from the sensitivity control and is applied to the non-inverting input (pin 3). This stage has a gain of about 30 and a little 'smoothing' (integration) of the signal is applied around the feedback by having a capacitor (C14) connected in parallel with the feedback resistor, R36.

Apart from driving the meter, the output of IC3a is fed to the source of IC2b which gates the audio oscillator through to the audio output stage (i.e: gate 2). The dc level from pin 1 of IC3a goes via D2 and R39 to pin 11 of IC2b. A positive bias is applied to the cathode of D2 from the +5 V rail via R38. Only when the dc level at the output of IV3a goes higher than 0.6 V above the bias applied to the cathode of D2, will IC2b be biased on.

The audio oscillator involves IC4a, configured as an astable multivibrator operating at a few hundred Hertz. The output, pin 1, is applied to the gate of IC2b. When IC2b turns on, the signal is applied to the input of the audio output stage.

One gate from IC2 is biased into its linear region and acts as a source-follower buffer at the input of the audio output stage. The volume control, RV5, is the source resistor for this stage and the output is taken from the wiper of RV5 to the base of Q4, capacitively coupled via C18.

The output stage is a simple complementary class-B stage employing a low power NPN/PNP transistor pair. The collector of Q4 drives the output stage, its collector load also providing bias to the output pair (R48). Both dc and ac feedback is applied to the base of Q4 by R49 from the output. Audio output can be from an 8 ohm speaker or headphones, via a dc isolating capacitor, C20. Headphone volume is reduced by a 470 ohm resistor, R50, in series with one lead to the headphone socket, SK2.

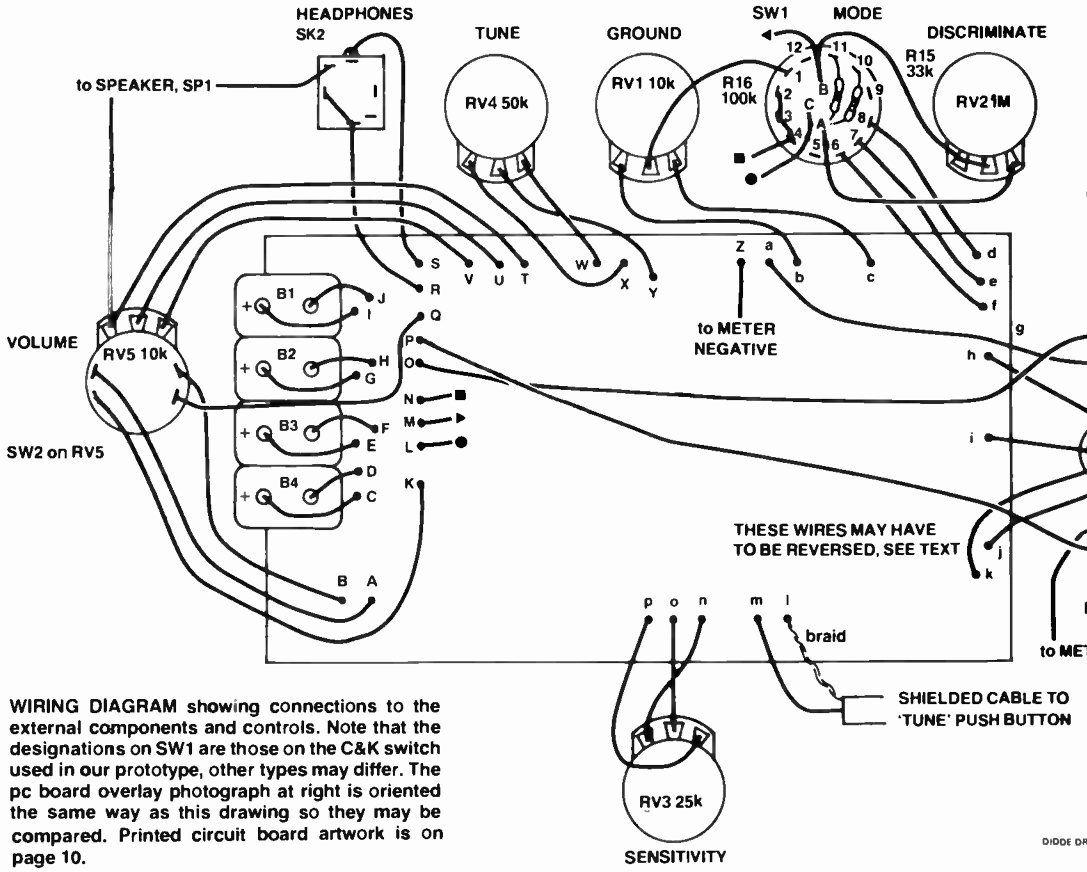
Power supply for the circuitry is split into two parts. The audio output stage is supplied by two 9 V batteries connected in parallel (B1 and B2). These are connected via a reverse-polarity protection diode, D3, and one pole of SW2 which is a switch on RV5.

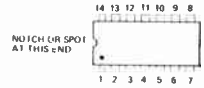
The rest of the circuitry requires a +10 V and a +5 V rail, with respect to the common rail (0 V). This is derived from two 9 V batteries, B3 and B4, connected in series and applied to a regulator circuit via a reverse-polarity protection diode, D4, and the other pole of SW2. The regulator is basically a conventional series-pass circuit, Q9 being the regulator transistor.

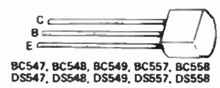
The zener diode ZD1 provides a stable reference voltage for a differential pair, Q7 and Q8, the latter controlling the base current to Q9. Resistor R54 allows a small amount of current to pass to Q7/Q8 at switch-on to ensure the regulator 'starts' correctly. The base of Q7 is biased at half the upper supply rail voltage by R51 and R52. This voltage is buffered by an op-amp, IC3c, configured as a voltage follower, and used to drive the +5 V line. Decoupling is provided by C19, C21 and C22. Note that 'battery test' facilities are provided by R44/PB2 for the 18 V supply and by R45/PB3 for the 9 V supply.

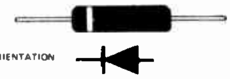
### TUNING

During the tuning operation, when the instrument is being initially set up, the circuit works in the following way: With the tune memory pushbutton operated, IC1a is gated on and a dc negative feedback loop is established from the output of the sensitivity control, back to the input of gate 1, the drain of IC1b, via the sample and hold circuitry. A portion of the voltage from the wiper of RV3 is added to the voltage determined by the voltage divider R33, RV4 and R34. This is applied to the source of IC1a. As the tune memory button is pressed, IC1a is conducting and capacitor C13 will charge to the value of the composite voltage applied to the source of IC1a. The op-amp IC5 is a low input current device and the output, pin 6, will settle at a value equal to the composite voltage applied to its non-inverting input (pin 2). This dc level is applied to the source of IC1b and the signal output from the receive coil amplifier is mixed with it. This will bring about a reduction in the dc level of the signal applied to the integrator input, and thus a reduction in the dc level at the input of IC1a and, within a second or two, a new dc condition is established. When the dc level around the loop settles, the meter will read zero (centre) and the tune memory switch is released. The dc level at the output of IC5 (and thus at the drain of IC1b) is maintained by the charge on capacitor C13. In practice, it will drift very slowly, as C13 will be gradually discharged by the input current of IC5 and the capacitor's own leakage. For this reason, the tune memory button is located on the crook of the handle where it can be operated by your thumb every now and then to re-centre the meter.




WIRING DIAGRAM showing connections to the external components and controls. Note that the designations on SW1 are those on the C&K switch used in our prototype, other types may differ. The pc board overlay photograph at right is oriented the same way as this drawing so they may be compared. Printed circuit board artwork is on page 10.

## PARTS LIST — ETI 1500

**Resistors all ½W, 5%.**

- R1 ............... 180k
- R2, 22 ............ 22k
- R3, 7 8, 16, 20, 21, 30, 33, 34, 38, 40, 42, 44 ........... 100k
- R4, 19, 35, 54 ...... 15k
- R5, 9, 48 .......... 1k
- R6, 15, 39 ......... 33k
- R10, 18 ........... 10k
- R11, 17 ........... 2k2
- R12 .............. 27k
- R13 .............. 82k
- R14, 55 ........... 18k
- R23, 25, 26, 31, 43, 47, 49 ......... 1M
- R24 .............. 3k9
- R27, 36 ........... 470k
- R28, 29 ........... 4k7
- R32 .............. 4M7
- R37 .............. 47k
- R41 .............. 3k3
- R45 .............. 68k
- R46 .............. 120k
- R50 .............. 470R
- R51, 52 ........... 56k
- R53 .............. 12k

**Capacitors**

- C1, 3, 10, 14 ....... 47n greencap
- C2 ............... 22p styroseal
- C4, 5, 6, 8, 12, 15, 18 ........... 10n greencap
- C7 ............... 1n styroseal
- C9 ............... 470n greencap
- C11 .............. 220p styroseal
- C13 .............. 470n polycarbonate or styroseal
- C16 .............. 100n greencap
- C17 .............. 1n greencap
- C19, 21, 22 ........ 470μ, 16V electrolytic
- C20 .............. 10μ, 16V electrolytic

**Potentiometers**

- RV1 .............. 10k linear
- RV2 .............. 1M log.
- RV3 .............. 25k linear
- RV4 .............. 50k linear
- RV5 .............. 10k log pot with DPST switch

**Semiconductors**

- D1, 2, 3, 4 ......... 1N914, 1N4148
- ZD1 .............. 5V6, 400mW zener diode
- Q1, 2, 4, 5, 7, 8 ..... BC548, BC108
- Q3, 6, 9 ........... BC558, BC178
- IC1, 2 ............. 4007
- IC3 ............... LM324
- IC4 ............... LM393N
- IC5 ............... CA3130N

**Miscellaneous**

- SW1 .............. three-pole, four position wafer switch;C&K type RA
- SW2 .............. on RV5 (DPST switch)
- PB1, 2, 3 .......... SPST miniature momentary push buttons, push to make
- M1 ............... 50-0-50 μA meter,see text
- SK1 .............. 5-pin DIN socket
- SK2 .............. shorting type jack socket
- SP1 .............. small eight ohm speaker (75 mm dia.)
- B1 - B4 ........... nine volt transistor radio batteries (type 216)

Four battery clips for No. 216 batteries; ETI-1500 pc board; case (see text); handle (see text); search coil (see text); knobs; length of ribbon cable; two metre length of shielded cable; double-sided sticky tape to hold batteries in position, or a suitable clamp.

1 and thus the dc level at the output of the integrator will change. This will be amplified and the meter will show an indication. Also, gate 2 will be operated and a tone will be heard in the speaker.

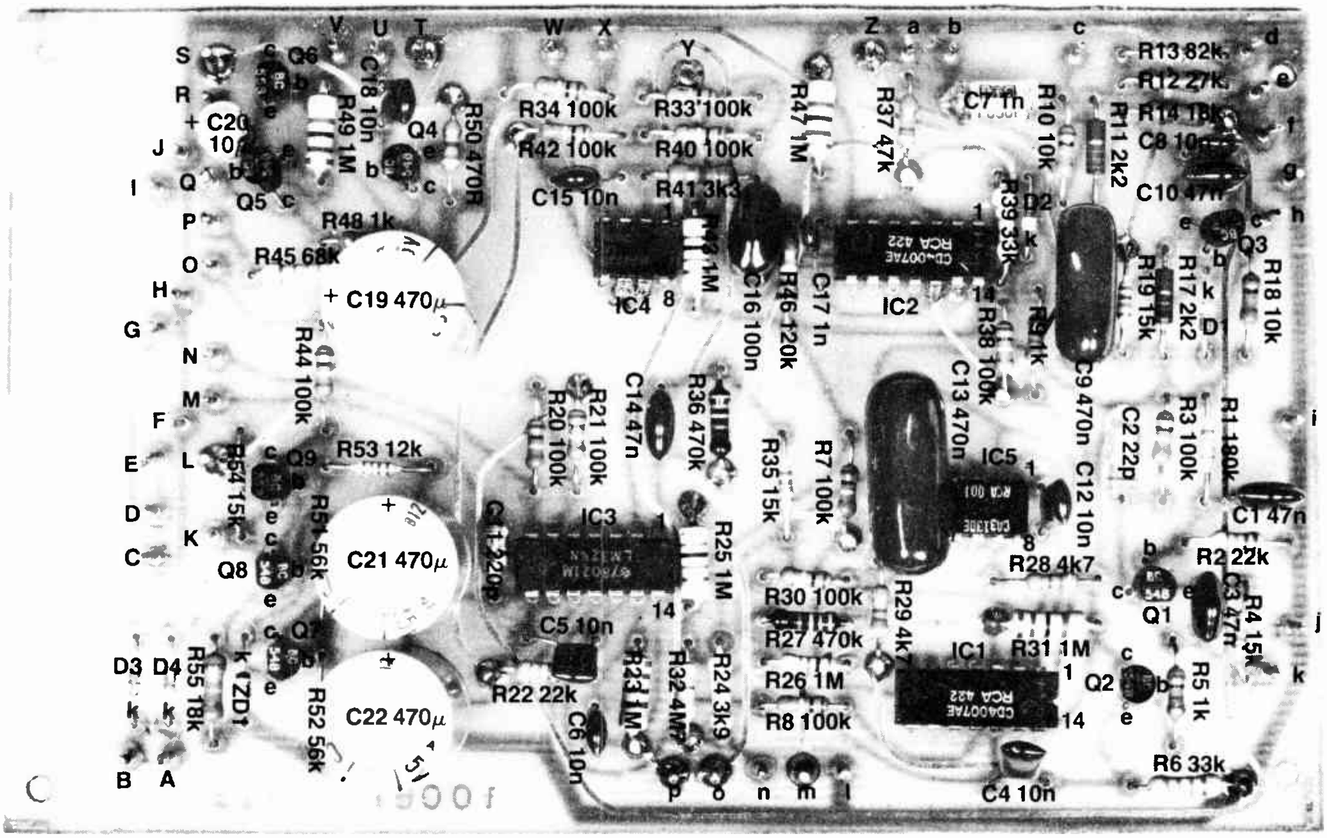
However, this method of operation will not indicate the difference between the characteristics of different targets.

In the discriminate or TR mode, the ground balance control is not used. The instrument is initially set up using the *tune* control to bring the meter to centre-zero. The different TR ranges permit varying degrees of control with the *discriminate* potentiometer. The phase-lag circuit block generates a signal which lags the phase of the transmit signal and the discriminate control provides a phase-variable signal to drive gate 1.

When a ferrous target is approached, the combined permeability and eddy current effects tend to reduce the amplitude of the signal picked up by the receive coil. This will cause a reduction in the dc level of the signal out of gate 1 and a reduction in the dc level out of the integrator. Thus, the meter will move to the negative (left hand) side of the scale. This side of the scale is marked "bad", obviously.

When a non-ferrous target is approached, the combined eddy current

**NOTE: C20 +VE connects to emitters of Q5 and Q6.**




and permeability effect tends to increase the amplitude of the signal picked up by the receive coil. This will cause an increase in the dc level of the signal out of gate 1 and an increase in the dc level out of the integrator. The meter will thus move toward the positive (right hand — "good") end of the scale.

The effects we are considering are actually quite small, hence the circuit has a considerable amount of dc gain.

Gate 2 only operates when the output from the dc amp increases (goes positive) and thus the audio output is only heard in the discriminate mode when the meter shows "good".

It is unfortunate that ring-pull tabs from drink cans are aluminium and thus indicate along with other non-ferrous metals. But, the discrimination ability of the instrument can be adjusted to exclude the small effect these targets generate — along with small trinkets, the smaller gold nuggets, etc — but who wants the tiddlers anyway!

If the dc level applied to the input of gate 1 drifts — and it may do for a wide variety of reasons, operating the *tune memory* button will restore the balance of the circuit and re-centre the meter. Quite a cunning arrangement.

## Search head

The most important properties of the search head are its size, the relationship between the transmit and receive coils, and the shielding against capacitive effects between the coils and the ground. Surprisingly, the actual inductance of the coils is not of primary importance.

The greater the coil diameter the greater the penetration depth but the less sensitive the detector will be to small objects. Penetration using simple, circular coils is about equal to the search coil diameter for small objects such as coins, while sensitivity is roughly proportional to the cube of the object diameter (expressed as a function of the search coil diameter). Sensitivity is also inversly proportional to the sixth power of the distance between the coil and the object.

All this means that if the object size is halved the sensitivity is reduced to one-eighth. If the depth is doubled the sensitivity is reduced to one sixty-fourth. See why metal detectors designed to pick up small objects use small coils and really only skim the surface? If the search coil is doubled in diameter for greater penetration the sensitivity to small objects falls to one eighth, apart from the coil assembly becoming mechanically less rigid. The law of diminishing returns again or 'you don't get something for nothing'.

Our new detector improves penetration while retaining sensitivity by using a co-planar arrangement of coils in the search head which gives a slightly magnified field pattern downwards, into the ground.

We mentioned earlier that the two coils are only loosely coupled. The positioning of the receiver coil in relation to the transmitter coil is very critical and is the major factor affecting the performance of the instrument. In fact, misplacement by a millimetre or so will markedly affect the performance.

As the search head is moved around, the changing capacitance between the coils and the ground could completely mask the minute changes in the field we are looking for. To avoid this affect the coils are enclosed in a Faraday shield.

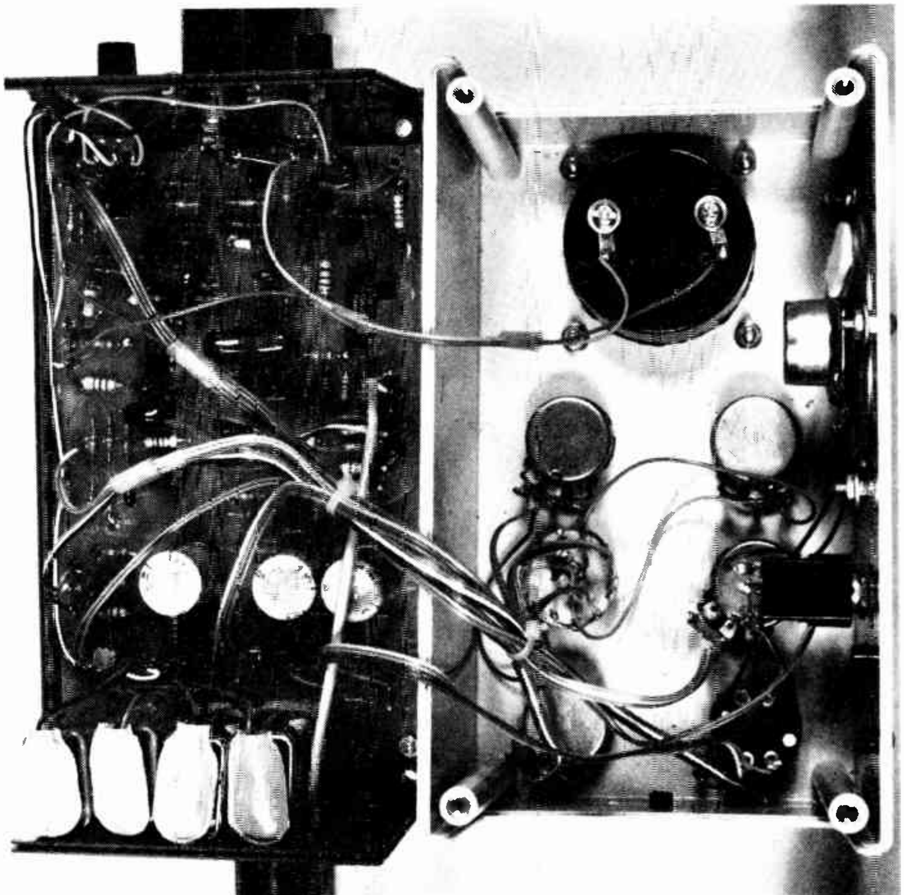
By now it should be obvious that construction of the search head is not a task to be tackled on the kitchen table on a rainy Sunday afternoon. In fact, construction and alignment of the search head would be beyond most readers' resources (anyone who has attempted our earlier induction balance metal detector knows what it's like). With this in mind we chose to use the commercially built, pre-aligned ▶

search head made by Altek Instruments. This will be available in Australia through All Electronic Components in Melbourne who have agreed to make the unit available wholesale to other suppliers, as well as retailing parts themselves, along with hardware — the plastic extendable handle and the case for housing the electronics. See Shoparound for details, page 150.

## Construction

The mechanical components for this project — the search head, handle and case, are available through Altek's Australian agent, All Electronic Components, as mentioned earlier. We recommend you obtain these as your finished instrument will then be a professional looking piece of equipment, with the features and operation of a 'bought one' two to three times the price. However, you can suit yourself and make your own handle if you so desire and we have designed the pc board such that it will also fit in a large jiffy box. You will have to use the search head recommended though, for the reasons we have explained previously.

All the electronics mounts on a single, double-sided pc board. The Altek case has two clamps on the rear enabling it to be clipped on to the handle. The Altek handle has two sections, the lower section sliding inside the upper section enabling the operator to adjust the length of the handle to suit his height. Connection between the search head and the electronics is via a length of shielded cable (supplied with the head) and a five-pin DIN plug/socket arrangement. The *tune memory* pushbutton is mounted in the end of the 'crook' of the handle (see photographs) where it can be easily operated by the thumb. It connects to the electronics via a length of shielded cable passed through the handle.



Inside the completed unit. Most of the wiring to the controls and other components external to the pc board as done using ribbon cable. The colour coding of this cable assists greatly in avoiding confusion. We suggest you place the two units as shown in this photograph to accomplish the wiring. Note how the speaker is mounted. The batteries are held in place by a strip of double-sided sticky tape.


A view of the front panel of the project. The Scotchcal front panel and meter escutcheon will be available from the usual suppliers. See Shoparound on page 150.

Construction should commence with the pc board. As it is a double-sided board (i.e: copper tracks on each side), first identify the 'front' and 'rear' side. These are marked, respectively, ETI 1500f and ETI 1500r. The rear side has the more complicated pattern of tracks. The components are mounted on the *front* of the board, where there is the less complicated set of tracks. Note that some of the resistors, IC pins and pc board pins (used for connecting external wiring to the board) must be soldered to copper tracks on *each* side of the board.

Commence with the resistors. Take care with those that cross tracks that you don't create a short circuit where it's not wanted. Next mount the capacitors. Take care with the orientation of the electrolytics. Note that capacitors C2, C7 and C11 are styroseal types, used for their good temperature stability. Be careful when soldering them in place that you don't overheat the leads as this can cause melting of the capacitor's case, possibly damaging it. The sample and hold capacitor, C13, must be a low leakage type, preferably polycarbonate or mylar. We used a greencap successfully, but whatever you manage to obtain, make sure it's a good quality type from a well-known supplier.

Now mount the semiconductors. Take care with the orientation of these as you can destroy devices if they are incorrectly inserted when power is applied. Finally, solder the pc pins in place and the four battery clips. The latter all go along one edge of the board.

Overall assembly of the pc board is clear from the overlay picture on page 17.

Once you have everything in place on the pc board and you're satisfied that all is OK, you can turn your attention to ▶

the hardware. Start with the case that houses the electronics. If not pre-drilled, you'll need to mark out and drill all the holes in the case lid. The panel artwork can be used as a template. Note that we dressed up the case with a Scotchcal panel. These should be available through the usual suppliers. Centre punch holes before drilling. The cutout for the meter can be made with a hole saw or by drilling a series of 4 mm diameter holes just inside the marked edge of the hole. When you complete the circle, the centre piece can be snapped out and the edge of the hole cleaned up with a half-round file until the meter drops in neatly.

The speaker is mounted on the left hand side of the case lid (as you would normally view the unit in use). It is held in place by large washers placed under the nuts of three bolts spaced around the outer rim of the speaker. Alternatively, you can glue it in place. Be careful not to get any glue on the speaker cone or you might end up with a rather 'strangled' sound!

The pc board mounts in the bottom piece of the case, along with the DIN socket (for the search head connector) and two battery test push buttons. A small hole in the bottom passes the cable to the tune memory button. The case bottom has four integral moulded standoffs to provide support for the pc board which is held in place with screws.

Once all the mechanical work on the case is satisfactory, the Scotchcal panel may be stuck on. Take care when positioning it as it's almost impossible to move if you misalign it. Carefully smooth out all the bubbles toward the edge of the transfer.

The controls, meter etc. may be mounted next. Then you can wire all the external components to the pc board pins. We used lengths of ribbon cable where possible to simplify the wiring. The easiest way to accomplish this part of the assembly is to place the bottom of the box, with the pc board mounted in it, on your left and the lid, with the meter and controls etc. mounted, face down on your right. Follow the wiring diagram on page 16 and complete all the interconnections. You should now appreciate pc board pins!

The tune memory button mounts in a hole in the end of the 'crook' of the handle, as we explained earlier, and the shielded cable connecting to it passes through the handle, emerging through a small hole drilled in the handle near where the cable can enter the hole provided for it in the bottom of the box. This cable is best inserted before you mount the pushbutton. Remove the handgrip. Push the cable through the hole in the handle near the case, until it appears through the end of the handle. Solder the end of the lead to the pushbutton and mount the pushbutton in the hole in the end of the hand grip (easier said than done!). Put the handgrip back and you can pass the business end of the cable into the case and terminate it. If you're lucky, kit suppliers may sell the units with this part already assembled.

Holding the batteries in place is generally left to your ingenuity. We used double-sided sticky tape (ah, that's useful stuff. . .). The battery life is quite good as the circuit has been designed for low current drain. Reverse polarity protection is provided on the pc board to avoid problems should you inadvertently attempt to connect a battery back to front.

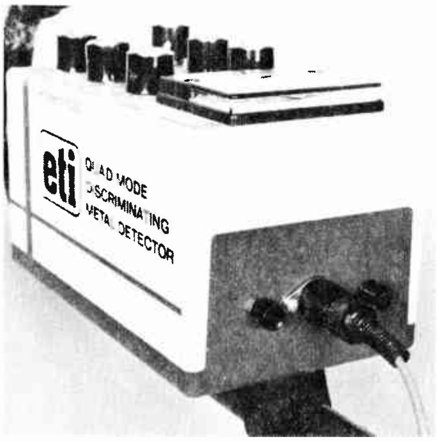
When all wiring is complete, push the case onto the handle and drill a small hole through one of the clamps and the stem of the handle. Insert a nail or a bolt and this will prevent the case from rotating on the handle. Mount the search head and adjust the length of the stem to suit yourself. Wrap the cable from the search head around the stem so that it is held quite rigidly and plug it into the DIN socket on the case.

You're ready to roll! . . . once you've tested it.

If you wish to make the search head completely waterproof, seal the hole through which the cable passes with Silastic rubber or some similar caulking compound.

## Operation

When construction is complete and you're satisfied all is well, turn the detector on and advance the *volume* control. Set all other controls to mid-




A view of the forward end of the case showing the two battery test pushbuttons and the DIN plug and socket connection to the search head. The Altek cabinet is two-tone grey plastic. The upper section is a lighter hue. Note the "GT" stripes!

range and switch the *mode selector* to *VLF*. Hold the search head up in the air and well away from metal objects, press the *tune memory* button and rotate the *tune* control. The meter should swing either side of the centre position. Set the pointer to centre scale and release the tune button. The meter should remain at this position but may drift slightly, which it will tend to do immediately after switch on. Pressing the *tune memory* button at any time should return the meter to centre position, set by the *tune* control.

The next step is to determine that the polarity of the receive coil is correct. After tuning the detector as described, bring a piece of iron near the search head. If the meter swings to the right your circuit is correct, if it swings to the left you will have to reverse the two wires on the DIN socket that connect to the receiver section on the pc board. The meter should now swing to the right.

## Ground balance

With the detector tuned, lower the search head to the ground. The meter may swing off scale. If it swings to the right turn the *ground* control to the left, if it swings to the left turn the *ground* control to the right. Raise the search head from the ground, press the tune button and the meter will return to centre scale. Lower the search head again and repeat the procedure until there is little difference in the meter reading when the search head is lowered. Setting the ground control is quite critical and may take some time to achieve the first time around. The detector can now be used in the VLF mode.

## Sensitivity control

The *sensitivity* control sets the gain of the dc amplifiers in the detector and will generally give best results at mid-range. If the control is set fully clockwise the tuning will tend to drift, requiring more frequent operation of the *tune memory* button.

## Discriminate controls

The mode switch selects one of three discriminate ranges: TR1, TR2 or TR3, while a vernier action is provided by the *discriminate* control. The discrimination ability of this circuit is extremely effective and it is possible to discriminate between an aluminium ring pull tab and a gold ring. Remember that discrimination depends on the resistivity of the target object.

When set to TR1, *discriminate* control at mid-range, the meter should show 'bad' for ferrous objects and 'good' for non-ferrous objects along with a tone from the speaker. As the discrimination controls are advanced, some non-ferrous objects such as brass will start to give a 'bad' reading, while gold and silver will give a 'good' reading. As the controls are advanced further aluminium will start to give a 'bad' reading, and so on. As you use the detector you will become familiar with its operation.

The best way of setting the discrimination controls is to carry around a few sample objects of the type you want to discriminate against just for this purpose. One thing to remember is that a corroded object will require a different setting of the controls to a non-corroded one so carry samples typical of what you are likely to dig up.

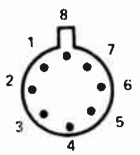
By careful setting of the controls, unwanted objects can be tuned out, giving no meter movement at all so the detector can be used to reject particular objects and at the same time discriminate between others.

Well, it's now up to you. Remember, the secret of success in metal detecting is more knowing where to look than the type of detector you have. There are many books available on the subject which could help put you on the right track.

## Notes for constructors

*(courtesy of G.N. Vayro, Broadmeadows, Victoria).*

- Take special care with the orientation of IC5 (CA3130) if an 8-pin TO-5 (circular metal case) type is supplied. Refer to the pinout diagram below.




CA3130T TOP VIEW

- Take care with the wiring of the headphone socket as not all types have the same, or similar, connections. Check this by examination or with a multimeter before wiring.

- Take care when wiring the DIN socket that connects the search head. The search head wiring is colour-coded, as shown on the circuit diagram. The red and black wires come from the receive coil. This coil has a dc resistance of around 50 ohms. The transmit coil is connected via the cable shield and the white wire. It has a dc resistance of around 12 ohms. There may be a yellow wire in the cable. Ignore it as it is not connected. The Faraday coil shields are internally connected to the cable shield.

- The wiring to the two pushbuttons PB2 and PB3 should first be sorted out with an ohmmeter before soldering it in place.

- The pushbutton in the handle needs to have good 'feel' and positive contact. One of the small C & K or Swann types should fill the bill.

- If you have or are using a metal front panel, it should be earthed to reduce spurious capacitive effects. The body of the discriminate control should connect to 0 V (Pin i) and a star washer should be inserted under its nut to provide a good contact to the panel. Otherwise, a plastic Scotchcal panel is recommended (one was used on the prototype).

- It is strongly recommended that a flux-removing solvent be used to clean the pc board following assembly. Whilst flux does not cause problems when 'new', many atmospherically bourne chemicals can and do react with the flux in time. This causes a leakage path to be established between the tracks and is especially troublesome in high impedance circuits, such as around IC5. A de-fluxed pc board will obviate later (or early) problems with the auto-tune circuit; it also looks more professional and aids identification of defective solder joints. The effort is worth it.

- If you have trouble with hand capacitance effects, plastic knobs or collet knobs may be used to advantage on the controls, particularly the variable discriminate control.

- The wiring to the pushbutton in the handle should be done with shielded cable, passed through a hole drilled in the rear of the case to avoid fouling the telescopic shaft in the retracted position.

- A battery clamp, fashioned from a small strip of aluminium, is recommended.

- The case should be mounted as close to the curve in the handle as possible for optimum weight distribution.

- A screw or bolt should be placed through the *rear* case mounting clip to stop the case rotating on the shaft. The rear clip is recommended to allow the shaft to be telescoped to minimum length. ●

# 'Auto-probe' for testing vehicle electrical systems

When it comes to probing faults or otherwise in a vehicle's electrical system, a multimeter has distinct disadvantages. This highly convenient probe is very useful in those awkward places so often encountered, plus simple to build and inexpensive.

Jonathan Scott

THE DIFFICULTIES of tracing a fault in a vehicle's electrical system using a multimeter are probably familiar to most readers. As that accursed Murphy's law generally has it, you have to contort yourself in to an awkward position before you can see where to put the test prod, or prods, and having done that, find that you can't twist yourself sufficiently to see the multimeter face. Damned annoying, isn't it!

Then again, a multimeter can give you a false indication. No, not possible, you cry. It sure is though. If, for some reason, you're measuring the voltage on a particular point and it happens to be connected to the battery via a low, but significant, resistance how do you detect the presence of that low resistance?

A voltmeter measurement won't show it. If that low resistance is the fault, an ohmmeter measurement may well be impossible.

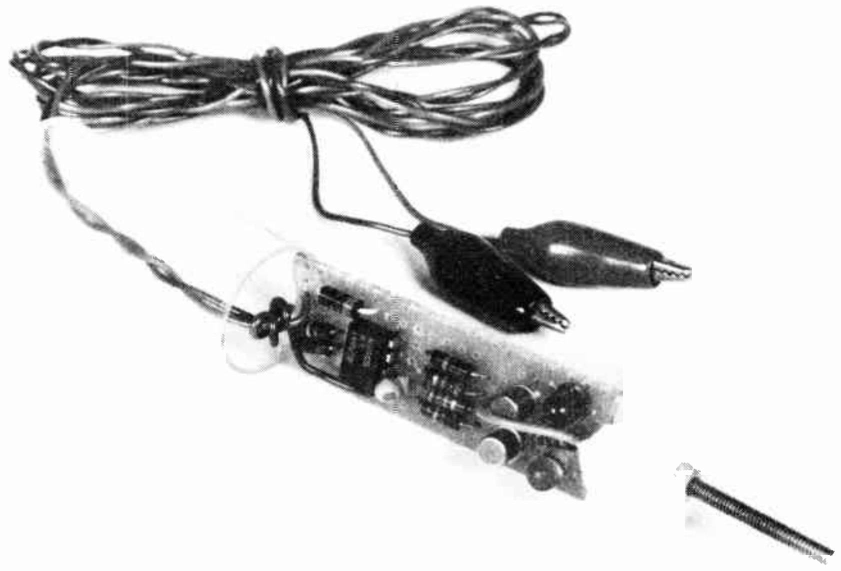
Sorting out the wiring can be a nightmare – especially on motorcycles.

This project gives clear indication of the six conditions one usually finds in an automotive electrical system. These are:

- Short to +ve supply
- Short to -ve supply
- Open circuit
- Connection to +ve supply via an intermediate impedance
- Grounded via an intermediate impedance
- Connection to a fixed, intermediate (low) voltage level

The Auto-probe is smaller, cheaper, easier to interpret and easier to use and read than a multimeter. It is the sort of device that can be left in the tool kit in the boot of your car or stored in the glove box. It is a worthwhile addition to any mechanically-minded handyman's array of gadgets.

The Auto-probe can be used on 6 V or 12 V systems, with minor changes to the circuit values.



The Auto-probe is housed in a common pill bottle. You can construct it either on matrix board, as shown here, or on a printed circuit board(see over the page). It's an amazingly handy gadget !

To get an idea of how it can be used, and how useful it is, let's take a look at a few typical problems encountered in vehicle electrical systems.

## The problem

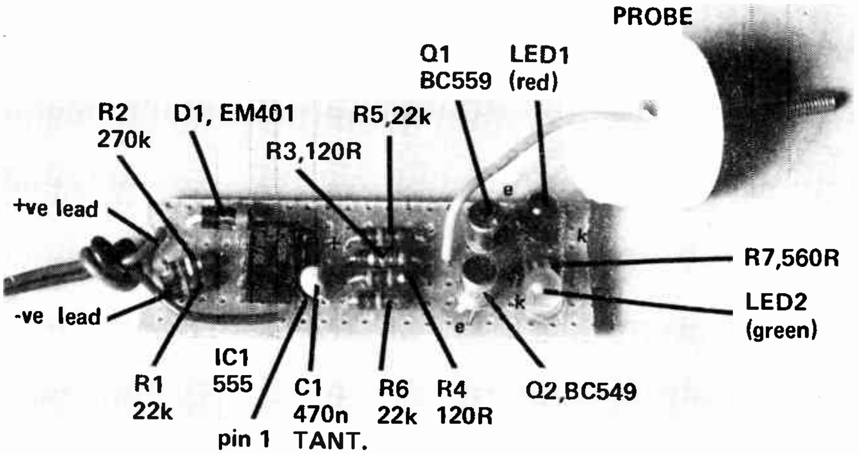
Let us consider the case of a car radio that has 'stopped working'.

Looking at the panel lights, you observe that they aren't lit up when the set's turned on. Obviously, it would seem to be a supply problem. Wriggling, upside down, under the dashboard, you check the fuse and find it intact. Taking the Auto-probe, you attach its supply leads to the rear connection of the cigarette lighter or the ignition switch. Both lights should blink on and off. If they don't then you'd have to reverse the connections and mentally castigate yourself for being a twit. No worries though, it's protected against twits.

Touching the probe on the radio's B+ connection, the red LED glows steadily. Aha! This shows the probe tip is connected to the supply. Touching the probe onto the radio's ground lead results in a blinking red LED. Hmm, it's connected to supply via an impedance. It seems the ground connection isn't grounded.

Some jiggling and scraping at the radio's ground lead earthing point results in a steady green LED and a burst of music . . . well, more likely, commercials.

Suppose you wish to know if your car has an ignition ballast resistor. This is a resistance inserted in series with the ignition coil primary during normal running, but is shorted out when the starter is operated so that the coil receives a voltage 'boost'. The resistor may be a heavy wirewound type mounted somewhere in the engine compartment, or (as is common in ▶




Matrix board construction showing the component positioning and orientation. Note that we used the metal-can type transistors (BC109 etc) in this prototype. R3 and R4 are ½W GLP types.

**PARTS LIST — ETI 325**

| | |
|---|---|
| **Resistors** | all ¼W, 5% unless noted |
| R1, R5, R6 | 22k |
| R2 | 270k |
| R3, R4 | 120R, ½W, 5% (GLP type) see text |
| R7 | 560R |
| **Capacitors** | |
| C1 | 0.47u Tantalum (35V) |
| **Semiconductors** | |
| IC1 | 555 |
| Q1 | BC559, or similar |
| Q2 | BC549, or similar |
| D1 | EM401, or similar |
| LED1 | TIL220R or similar, red |
| LED2 | TIL222 or similar, green |

**Miscellaneous**
Matrix board — 15 mm × 55 mm, or ETI-325 pc board; alligator clips; pill container; wire; 30 mm long 4 BA bolt and nut (for probe).

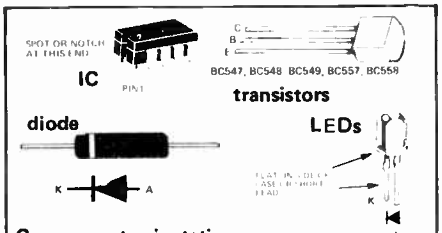
many late-model vehicles) a resistance lead is used – they're hard to spot.

In this case, the probe tip is touched on the coil primary terminal that is not connected to the contact breaker points. With the ignition on, (engine not running) no light will show on the probe, indicating it is connected via an intermediate impedance. When you touch the starter, the red LED should burst into lusty life, indicating the resistor is shorted, as you would expect.

Tracing wiring and switch operation can be a real hassle. Does this motorbike operate its horn by supplying power or a ground connection via the horn switch? If touching the two switch contacts in turn shows first a steady green LED then a blinking red LED, the first contact is grounded and the second is clearly connected to the positive supply via an intermediate impedance, i.e: the horn. If the green LED lights and then both LEDs blink when the probe is touched to the other switch contact, this would indicate that the horn is open circuit.

The circuit will cause both LEDs to blink when the probe tip is connected to an open circuit or to either side of the supply via an impedance greater than about 1000 ohms. In an automotive environment 1000 ohms is a high impedance!

Simple, and easy to use, isn't it?




Component orientations

## Construction

This project may be constructed in either of two ways, depending on your preference: on matrix board, or on a pc board. Both methods are discussed here and overlay photographs are shown also.

If you elect to use matrix board, you will need a piece having holes spaced 0.1" (2.5 mm) apart. Cut the matrix board so that it measures 15 mm wide by 55 mm long – that's about seven holes wide by about 23 holes long (cutting through the 1st and 23rd rows).

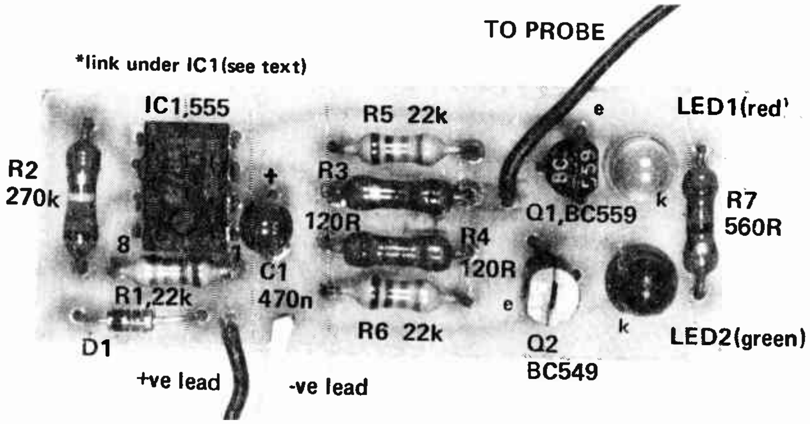
It is probably easiest to commence by mounting the two LEDs and the two transistors. You have to take some care when assembling a project on matrix board as the connections between the components are made under the board, using the component leads. Carefully study the overlay picture to see where the components are located and their orientation.

Make the connections between the components using the circuit diagram to guide you. Take care that no short circuits occur between adjacent leads.

Next assemble resistors R3 to R6, IC1 and C1 onto the board and make the appropriate connections. Take care with the orientation of C1. The positive lead is towards the *centre* of the board. Last of all, add R1, R2 and D1.

We'll get around to testing and assembling the unit into the pill bottle shortly, as this will apply to both sorts of construction.

Constructing the project on a pc board is much simpler. First thing to do is locate the position of IC1. A link is inserted between two pads located between the two rows of holes for the IC pins. Having done that, insert the IC. Take care that you have it correctly oriented. All the other components may now be assembled




Overlay for the printed circuit board model. Plastic pack transistors were used for this one.

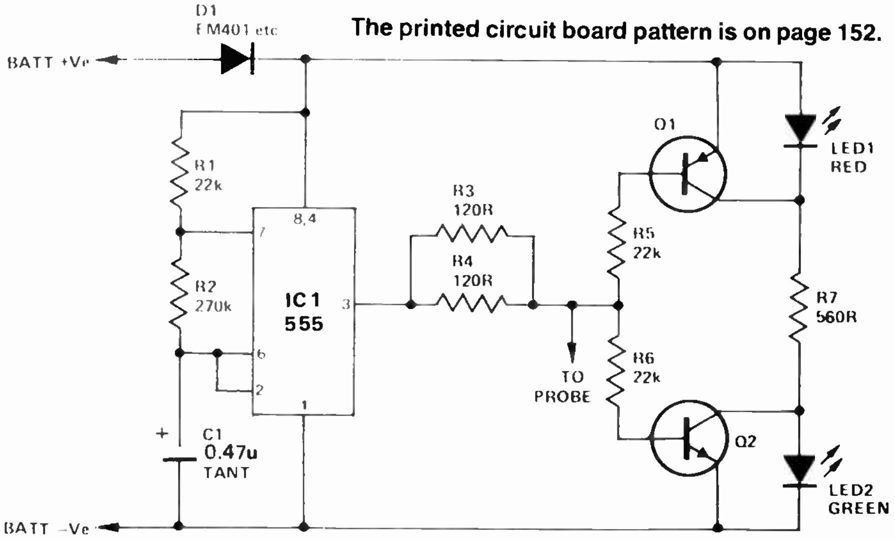
**READERS PLEASE NOTE**
We do not sell kits or components for the projects described in this book. To find out who may be stocking kits or components for the projects featured, please refer to the 'Shoparound' page on page 150.

and soldered into the board. Watch the orientation of Q1 and Q2, the two LEDs and C1. Refer to the overlay picture.

Now comes the testing. This procedure applies to either form of construction. You will need either a 12 V battery or a power supply that can deliver around 12 V to 14 V dc. Temporarily solder battery leads and a probe lead to the board. Connect the battery leads to the 12 V supply. The two LEDs should flash. Shorting the probe lead to the negative of the supply should cause the green LED to flash.

If you cannot obtain the correct indications at this stage, look for incorrect connections or components around the wrong way. To check that IC1 is working, connect a multimeter – set to, say, the 30 V range – between the supply negative and pin 3 of IC1 (positive meter lead to the latter). The meter needle should rise and fall at about four times per second.

The pill bottle used to house this project measured 61 mm overall length (with the cap on) by 21 mm outside diameter. A 25 mm long 6 B.A. bolt was used for the probe. This was bolted through a hole made in the cap somewhat off-centre. The photographs show roughly where this needs to be. Just keep it out of the way of the board. A small solder lug under the bolt head is used to attach the probe lead from




**The printed circuit board pattern is on page 152.**

the board. The battery leads should be colour-coded to avoid confusion. The convention is: red for positive, black for negative. Twist together about one metre of each colour hookup wire.

Connect the appropriate leads to the board and tie a knot close to the board (see photograph).

Drill a hole in the end of the pill bottle, near the edge, and pass the battery leads through it. The knot prevents the leads being pulled out of the board. Attach alligator clips to the ends of the battery leads.

Two small cutouts will have to be made in the lip of the pill bottle's cap so that the LEDs may be seen easily. All these details are clearly shown in the photograph of the completed project.

Once you have the unit assembled, give it a thorough work out.

Once you have this little project working for you, you'll be amazed how quickly electrical problems in your vehicle are sorted out. ▶

**MODIFICATIONS FOR 6 V OPERATION**
Change R3 and R4 to 68 ohms each
Change R7 to 180 ohms
Change R5 and R6 to 10k

## HOW IT WORKS – ETI 325

Consider first the 'idle' state of the device – i.e: with the probe open circuit. Diode D1 protects the whole circuit against accidental reversal of supply polarity. When the battery is connected correctly, the battery voltage (less about 0.7 volts dropped across D1) is applied to the electronics.

IC1 is the familiar 555 timer IC, connected as an astable multivibrator. When C1 charges up to 2/3 of the supply voltage, via R1 & R2, the 'high' level comparator (pin 6) detects this and sends the output high, which also shorts pin 7 to near ground. C1 thus commences to discharge via R2. When it reaches 1/3 of the supply voltage, the 'low' level comparator trips (pin 2) and C1 is allowed to recommence charging as before, since the output is sent low. This cycle repeats indefinitely, with a frequency of

$$F = 1/(0.692 \times C1 \times (R1 + 2R2))$$

With the values chosen, this is about 4 Hz. This may be varied by changing C1 or R2. The output on pin 3 of IC1 oscillates between nearly OV and V+ (less 0.7 volts). It can source about 200 ma.

Consider now the circuitry surrounding the LEDs. Assume at first that the voltage on the junction of R5 and R6 is about half the supply potential. Current will flow through the bases of both transistors via R5 and R6, hence both of these transistors will conduct. Each transistor will short out the LED connected in parallel. Thus neither LED will glow. If the voltage on the resistor junction (the probe connection) were to fall below 0.6 volts, or thereabouts, Q2 would be biased off and would no longer bypass the current flowing through R7 away from the green LED. Thus the green LED would light. Similarly, if the voltage on the probe were to rise to within 0.6 volts of the unit's supply rail (i.e: within 1.3 volts of the battery supply, due to the action of D1) Q1 would be biased off and the red LED would light.

Now let us put the picture together and see what happens in practice. The output of IC1 is connected to the probe and the resistor junction of the LED driver circuit via a 60 ohm resistance made up of two 120 ohm resistors in parallel. There are two resistors rather than one 1W or larger resistor for reasons of physical size.

With no connection made to the probe, the 555 drives the probe alternately to the +ve and -ve rails, with the result that the LEDs flash alternately.

Shorting the probe to either rail of course forces the appropriate LED to stay on continuously. If a resistance is placed between the probe and ground, say, three possibilities occur:

1) The current flowing from pin 3 of the 555, via R3/R4, is insufficient to develop 0.6 volts across the resistance – this looks like a short and the green LED stays on.
2) The current develops sufficient voltage to turn Q2 on and the LED extinguishes on that part of IC1's cycle when its output is high. This allows the appropriate LED (green) to blink.

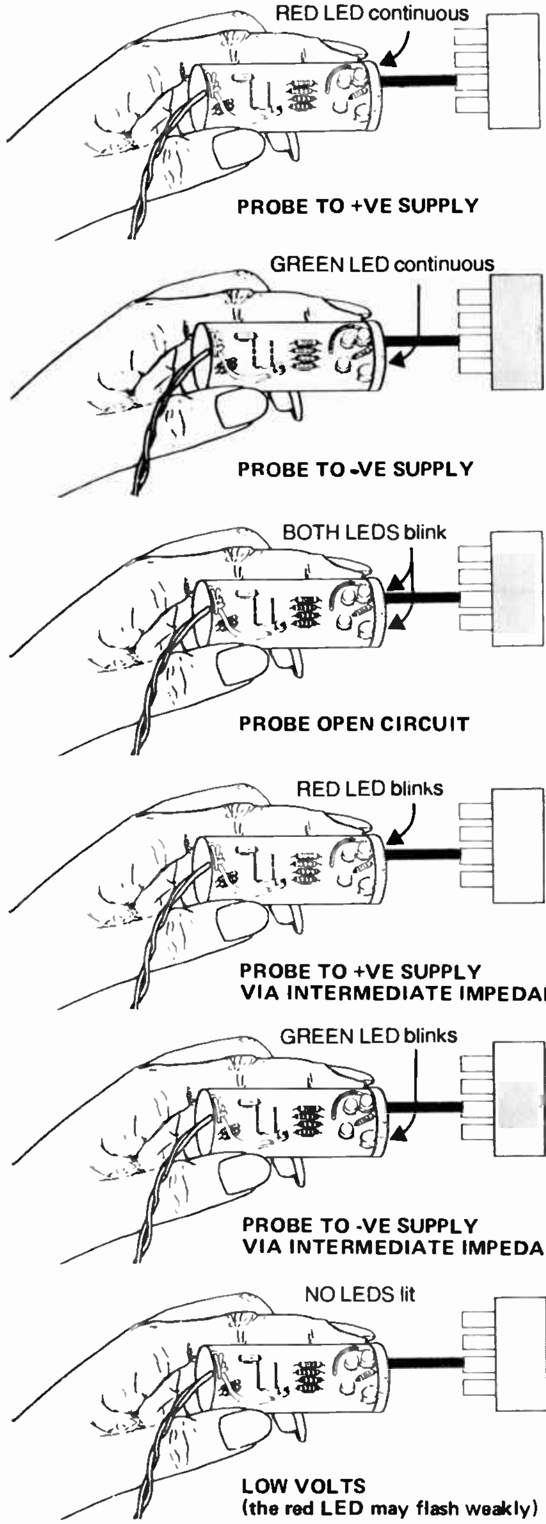
However, if the resistance is not high enough to allow the junction of R5/R6 to go far enough positive the red LED will not turn on. This gives green only blinking.

3) If the resistance is high enough (over 1k) both LEDs blink, giving the open-circuit response.

The same argument applies 'upside down' for a resistance to rail, but the voltage across it must be 1.3 V due to D1 being in the emitter circuit of Q1. If the voltage is fixed midway, neither LED can glow, as first assumed.

Resistor R7 fixes the LED current and R3/R4 limits the 555 output current to a safe level and defines the voltage 'turn-over' points.

## ETI-325 AUTO-PROBE INDICATIONS



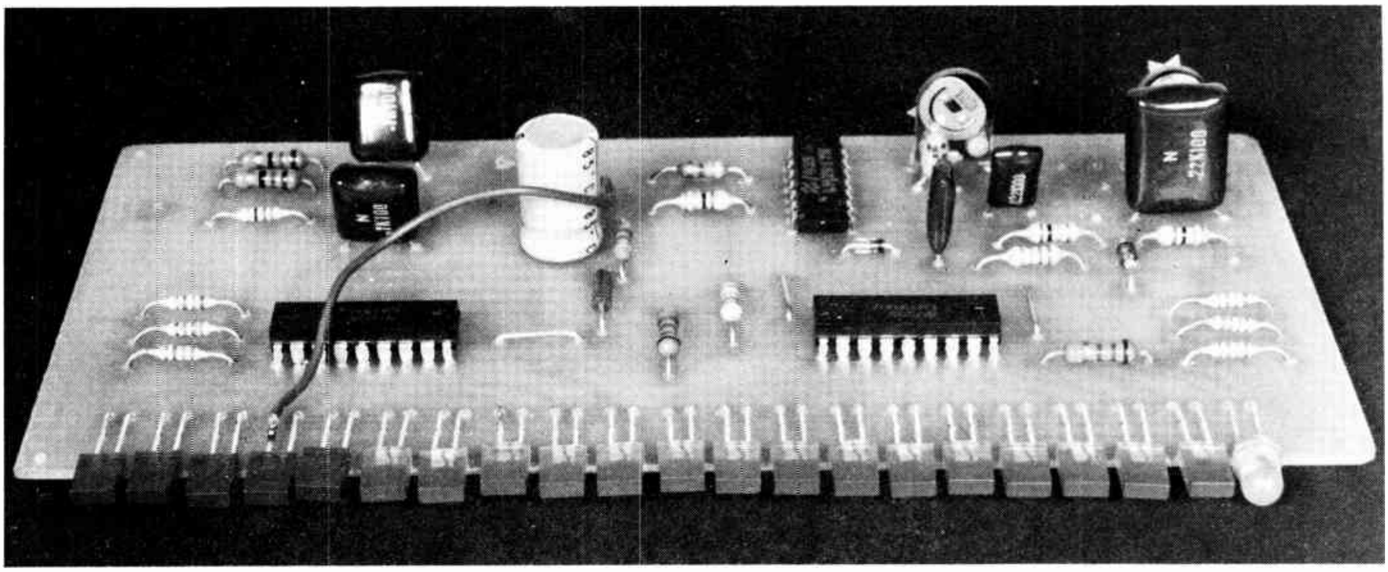

## IMPEDANCE LEVEL CONDITIONS

| | |
|---|---|
| Both LEDs blink | probe sees impedance larger than 1000 ohms |
| Red LED steady | probe to +ve via impedance less than 15 ohms |
| Green LED steady | probe to -ve via impedance less than 6 ohms |
| Red LED blinks | probe to +ve via imp. between 15 & 400 ohms |
| Green LED blinks | probe to -ve via imp. between 6 & 800 ohms |

# Twin range tacho features LED bargraph display

## Staff

Another in our series of projects to "update your car electronically", this tacho has many advantages over conventional types.



FEATURING a bargraph display of 20 rectangular LEDs arranged in a single line, plus one 'zero' LED, this tachometer incorporates an over-rev alarm feature and a high/low range switch. It displays engine speed in an analogue form (as with a conventional tacho) as an illuminated section of the row of LEDs, the length of the 'bar' being proportional to engine speed. This form of display indicates at a glance what your engine is doing, without the necessity of having to mentally interpret a numerical display as you would with a digital tacho — you don't have to take your eyes off the road, nor try to interpret rolling numerals during acceleration or deceleration.

This unit may be used with virtually any type of multi-cylinder petrol engine. The two speed ranges are calibrated by means of preset trimpots to give any full-scale speed range required. The lower range is of great value when setting or checking an engine's ignition and carburation for recommended tick-over speeds. The unit has been designed for use on 12 volt, positive or negative earthed electrical systems. It can be used with conventional (Kettering), capacitor-discharge (CDI) or transistor-assisted ignition systems — where a contact breaker system is used. Only three connections are required to install the unit — one to the positive supply, one to the negative supply and one to the contact breaker points. Protection circuitry has been included to prevent noise on the supply from causing problems and high voltage spikes from the points and coil circuit damaging the electronics.

## Design

The tacho has been designed around a frequency-to-voltage converter IC, the LM2917, driving two LM3914 LED bargraph driver chips. We covered various applications of the LM3914 in 'Lab Notes' in March 1980 issue (page 61).

The LM3914s have an alarm facility which we have incorporated as a feature of the circuit. The triggering point for the alarm is arranged by taking a connection to an appropriate LED in the display. When the engine revs reach the point where this LED is turned on, the alarm will be triggered and the display will flash. An optional audible alarm can also be attached, the better to attract the driver's attention.

We chose a conventional (round) orange LED for the (zero) indicator in ▶

## HOW IT WORKS ETI-324

The circuit consists of a pulse conditioning circuit, R4 - R6, C5 and ZD1, a frequency-to-voltage converter, IC1, and two LED bar display drivers, IC2 and IC3. Each display driver is capable of driving 10 LEDs, giving a total of 20, plus one 'zero' LED. The number of LEDs illuminated is proportional to the output voltage from the frequency-to-voltage converter.

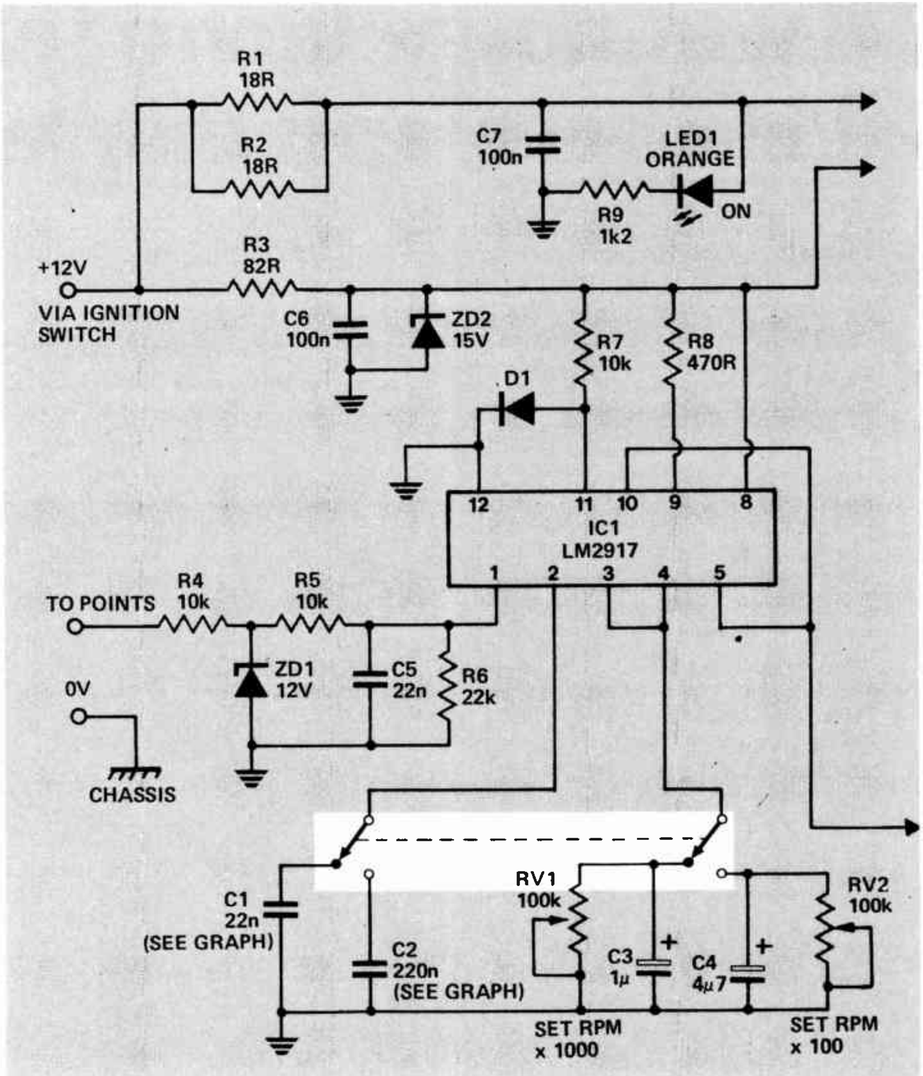
The ignition pulses from the contact breaker points in the vehicle have a repetition rate proportional to the RPM of the engine. The pulses from the points contain high voltage ringing components on the rising and falling edges of the waveform. These can be as high as 250 V at frequencies up to 10 kHz. These pulses would almost certainly damage the electronics so the input to IC1 is preceded by a pulse conditioning circuit. The 12 V zener diode, ZD1, shorts out any voltage spikes above 12 V while any remaining high frequency component is removed by R5 and C5.

The 'cleaned-up' rectangular waveform is fed to pin 1 of IC1. This is a voltage-to-frequency converter, providing an output voltage directly proportional to the frequency of the input waveform. The operating range of the IC is determined by the value of a capacitor connected to pin 2, either C1 or C2, and by a timing resistor and smoothing capacitor connected to pins 3 and 4. (RV1, C3 or RV2, C4). In our application, two preset ranges are provided by the range switch, SW1. The IC contains a constant current charging circuit for the timing capacitors (to ensure an output that is linear with frequency) and an internal voltage regulator. The network of R7 and D1 provides an input threshold level to guard against false triggering from noise.

The dc output of IC1 is fed to the inputs of the display drivers IC2 and IC3. These are LED 'bar' or 'dot' display drivers. Each IC can drive a chain of 10 LEDs and the number of LEDs illuminated is proportional to the output voltage from IC1. Put simply, the ICs act as LED voltmeters. The two ICs are 'cascaded' such that they perform as a single 20-LED voltmeter with a full-scale range of 2.4 volts. The resistors R13 to R18 are wired in series with the display LEDs to reduce the power dissipation in the two ICs. LED1 is permanently illuminated, providing a 'power on' indication and a 'zero' point for the display.

The LM3914 ICs incorporate an alarm facility. The triggering point for the alarm can be connected via a flying lead to any of the LEDs, selecting the trigger point. When the selected LED is turned on, the voltage on its cathode goes low, triggering the alarm. Capacitor C8 discharges, blanking the display. The LED is then turned off and the alarm resets. The capacitor is then re-charged, the display lights, and the alarm is triggered once again. The audible alarm will sound and display flash a few times a second. As soon as the RPM drops so the selected LED does not light, the function of the tacho returns to normal.

Supply line filtering of noise pulses is achieved by R1 - R3, C6 and C7. Reverse polarity and overvoltage protection is provided by ZD2.



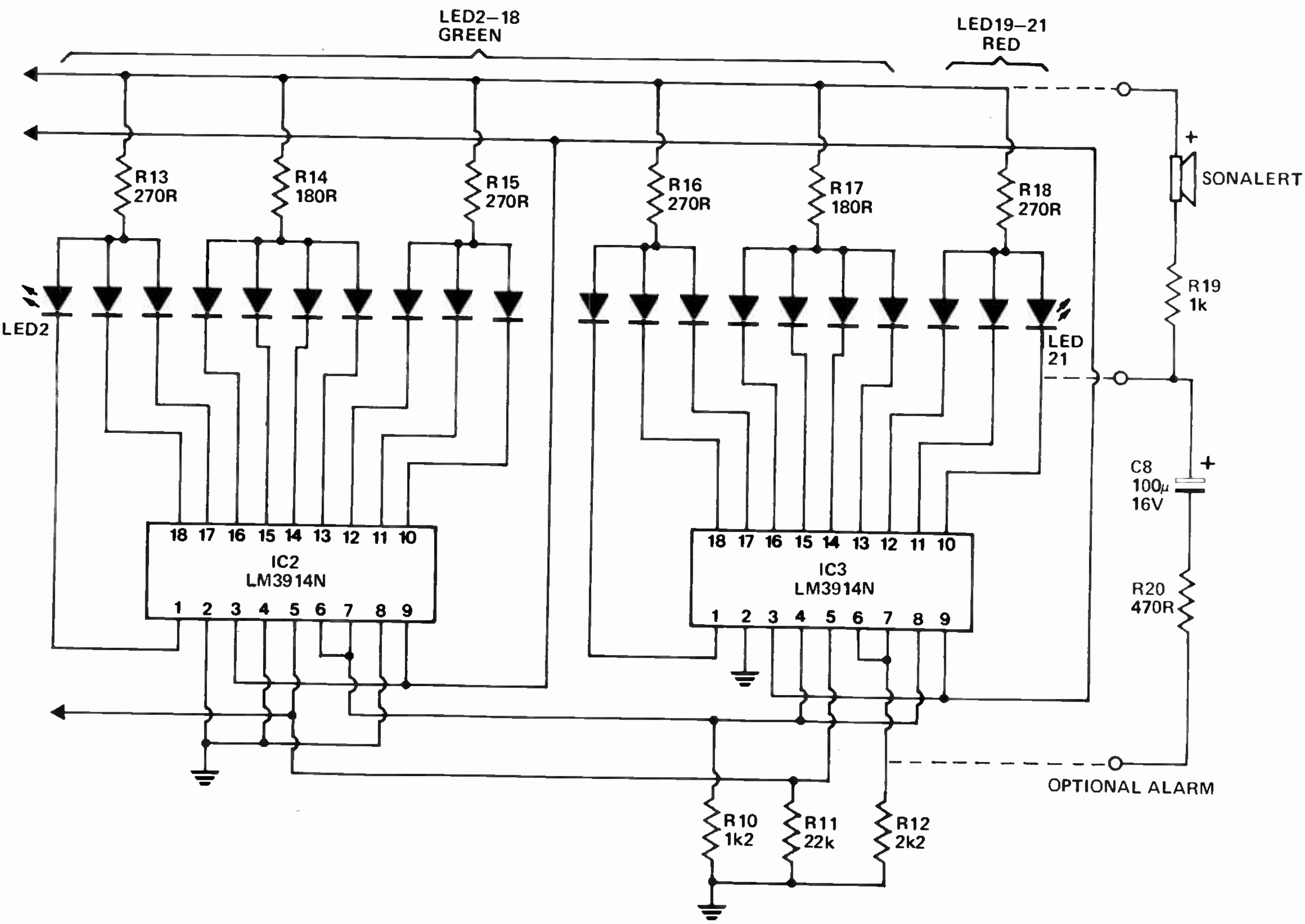

position one (it also indicates power on), rectangular green LEDs in positions 2 - 18 for the normal driving range, and rectangular red LEDs for the positions 19 - 21 giving a 'red line' area of 25% of full display. We thought this was the most convenient arrangement but you may vary it to suit your particular situation. All round LEDs may be used if you wish, but we found the rectangular LEDs provide a better looking display.

## Construction

Our printed circuit board is pretty well essential for constructing this project. The LEDs for the bargraph display are all mounted in a row down the front of the board. As you can see from the accompanying photographs, all the components with the exception of the range switch and audible alarm are mounted on the pc board.

You will find construction easiest if you mount all the ICs, resistors and capacitors first, leaving the LEDs till last. Make sure you have the ICs correctly oriented, as well as the diodes and tantalum and electrolytic capacitors. Refer to the component diagrams and pc board overlay.

When mounting the LEDs it is *most important* that they be placed in the board the right way around. One of the best ways of ensuring this is to first place them on the table or workbench in a row in front of you, with their leads all correctly oriented, just as they would be when mounted on the board. To ensure the leads are the right way around, refer to the overlay and the accompanying




**The printed circuit board pattern is on page 154.**

drawing showing LED orientation. Now comes the hard part — mounting the LEDs so that they're all level! Insert LED2 first and bend it such that it lies flat on the board with the base of the LED flush with the edge of the board — as shown in the pictures. Solder its leads. Bend it back upright and then insert LED3, carefully positioning it such that it is flush with LED2. Solder it in position. Proceed like this until all the LEDs are in place and then bend the whole row over, parallel to the board.

A flying lead is used to connect the alarm circuit to one of the LEDs. This determines when the display will flash and the audible alarm (if used) will sound. This lead should be left floating until the two speed ranges are set up. Attach flying leads for the switch connections, supply and points connection.

## Mounting

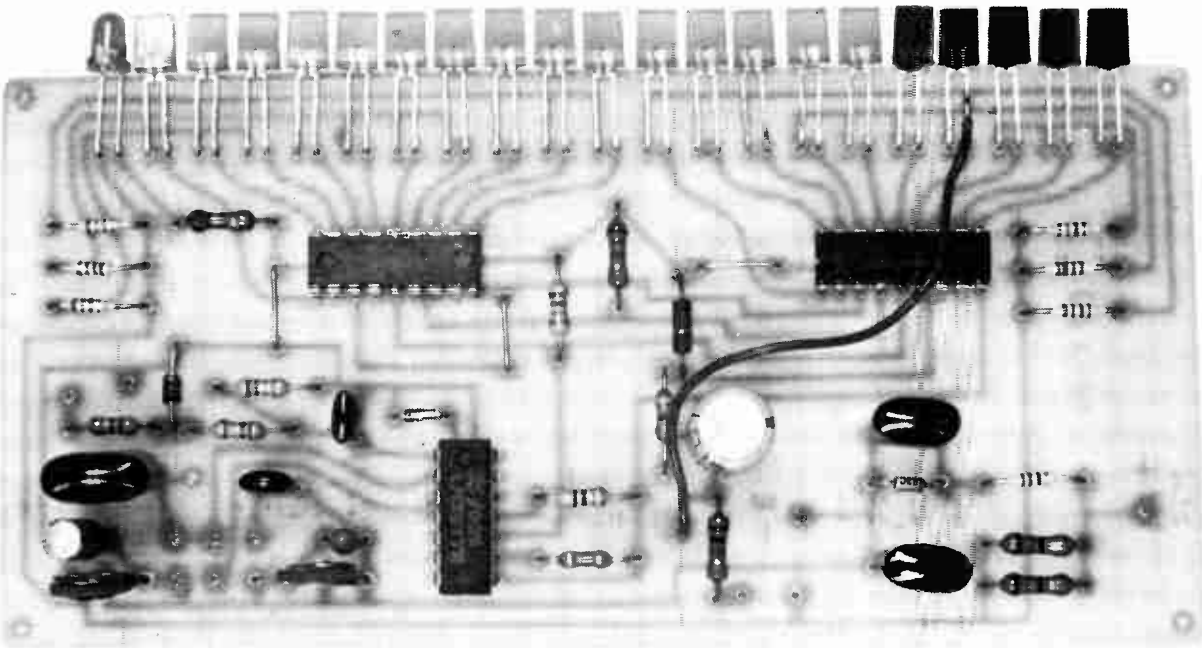
Having built the unit, you'll have to consider where it is to be mounted. In fact, it may be prudent to think about this as your very first step! The tacho can be mounted such that the display is either horizontal or vertical, depending on your preference and available space in the dashboard. It is best mounted not too far from the driver's line of view so that it can be seen without his eyes leaving the road for too long, and to the side of his normal vision.

If you are brave enough, the unit can be mounted behind a slot cut in the vehicle's dash, as near to the speedometer as you can manage. Watch out that there's enough space to accommodate the unit behind the panel before you cut, though!

If that doesn't appeal to you, the unit may be housed in a slim plastic case which is then mounted in a convenient position on the dashboard.

The range switch and audible alarm may be mounted in any convenient position, no matter where or how you mount the tacho itself, as lead length to these components is not at all critical.

Only three connections are made to the vehicle's electrical system: battery +12 V, contact breaker points and chassis (0 V). The battery connection should be taken after the ignition switch so the unit is only on when the ignition is on. The wire to the points will have to be taken through the fire wall to ▶



## PARTS LIST — ETI-324

**Resistors** all ¼W, 5%

| | |
|---|---|
| R1, R2 | 18R |
| R3 | 82R |
| R4, R5, R7 | 10k |
| R6, R11 | 22k |
| R8, R20 | 470R |
| R9, R10 | 1k2 |
| R12 | 2k2 |
| R13,15,16,18 | 270R |
| R14, R17 | 180R |
| R19 | 1k |

**Potentiometers**

| | |
|---|---|
| RV1, RV2 | 100k, miniature vert, mounting trimpots |

**Capacitors**

| | |
|---|---|
| C1 | 22n greencap (see text) |
| C2 | 220n greencap (see text) |
| C3 | 1u, 16V electro. or tant. |
| C4 | 4u7, 16V electro |
| C5 | 22n greencap |
| C6, C7 | 100n greencap |
| C8 | 100u, 16V electro. |

**Semiconductors**

| | |
|---|---|
| IC1 | LM2917N |
| IC2, IC3 | LM3914N |
| D1 | 1N914, 1N4148 or similar |
| ZD1 | 12 V, 400 mW zener |
| ZD2 | 15 V, 400 mW zener |
| LED1 | Orange LED, round or rectangular |
| LEDs 2 - 18 | Green LEDs, round or rectangular |
| LEDs 19 - 21 | Red LEDs, round or rectangular |

**Miscellaneous**

SW1 — DPDT miniature toggle switch, ETI-324 pc board, case (if required), Sonalert (if required).

the points terminal on the outside of the distributor. The easiest way, rather than drilling a hole in the firewall, is to run the wire next to a wiring loom or the speedo cable, through an existing hole. Make sure the wire is well insulated and there is no possibility of the insulation being rubbed off, causing the points to be shorted to the chassis. The chassis connection can be made to any convenient point on the car body under the dash.

## Setting up

All that's left is to set the two RPM ranges by adjusting the two trimpots and to set the point when the alarm triggers.

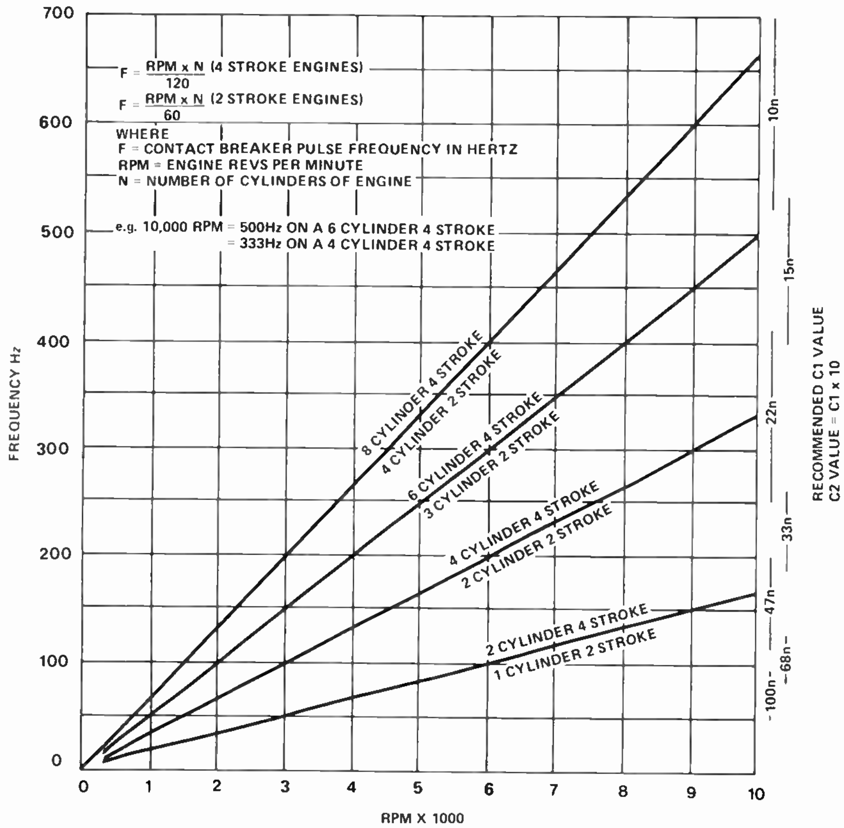
The easiest way to set the RPM ranges is to borrow a friend's tacho. All good dwell angle test meters have an RPM range so it shouldn't be too hard to find a suitable unit.

Run the engine at half the required maximum RPM range and set RV1 so that the *eleventh* LED just lights. Full scale will then be *twice* the engine speed. This technique avoids having to run the engine at full RPM with no load which can be very damaging to your engine as well as you ears!

The low speed range can be set by adjusting RV2 until the *21st* LED just lights at the desired engine RPM. As this is a low speed range there is no danger to the engine.

The alarm triggering point is set by soldering the flying lead directly onto a LED cathode lead. We set ours on the lead of the second red LED. This can be made to trigger at say 6000 RPM by adjusting RV1 for a full range of 7000 RPM. If you don't need the alarm, the flying lead can be left off or the optional components left off the board completely.

That's it — project completed, calibrated and ready to roll! ●




## Setting C1 and C2

The values of the two timing capacitors, C1 and C2 are selected to give the desired full-scale RPM ranges.

The graph gives the value of C1 (right hand scale), for various RPM ranges (bottom scale). As the number of breaker point openings per revolution depends on the number of cylinders and whether it is a two-stroke or four-stroke engine, four lines are drawn on the graph for the eight common engine types.

Select the RPM range over which you want your tacho to operate (i.e: 10 000 RPM full scale) and draw a line upwards from the bottom scale until it intersects the line for your particular engine type. Then, draw a horizontal line across to the capacitor scale and read off the value of C1.

Since the low speed range is one-tenth the scale of the high range the value of C2 will be 10 times C1. i.e: if C1 is found to be 22n, C2 will be 220n.

If your engine is something out of the ordinary, like a five cylinder two stroke diesel (!! . . . Ed), you will have to draw your own line on the graph! This is what the left hand frequency scale and the formulae are for. The formulae give the frequency of the points openings for all engines. Work them out for two RPM values, at say 2000 and 8000 RPM, plot the points on the graph, and draw a straight line between them. You can now work out the values of C1 and C2 as before.

If you have some entirely different use for the tacho, for example: on a piece of rotating machinery, if you know the maximum frequency, or speed, in revolutions per second draw a straight line across the graph from the frequency scale to the capacitor scale and read off the value of C1.

# Expanded-scale LED voltmeter has wide application

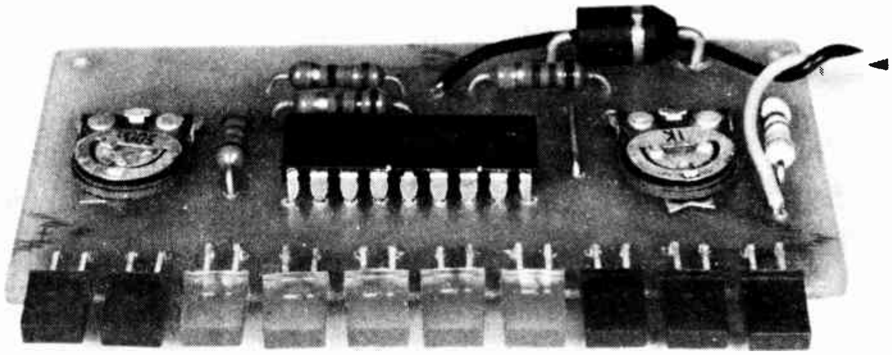
**Phil Wait**
**Simon Campbell**

One of the most useful monitors of battery 'condition' is an expanded scale voltmeter. This novel, but nonetheless useful, project should find applications in vehicles, battery chargers etc.

THE 12 V BATTERY, in its many forms, is a pretty well universal source of mobile or portable electric power. There are lead-acid wet cell types, lead-acid gel electrolyte (sealed) types, sealed and vented nickel cadmium types, and so on. They are to be found in cars, trucks, tractors, portable lighting plants, receivers, transceivers, aircraft, electric fences and microwave relay stations — to name but a few areas.

No matter what the application, the occasion arises when you need to reliably determine the battery's condition — its state of charge, or discharge. With wet cell lead-acid types, the specific gravity of the electrolyte is one reliable indicator. However, it gets a bit confusing as the recommended electrolyte can have a different S.G. depending on the intended use. For example, a low duty lead-acid battery intended for lighting applications may have a recommended electrolyte S.G. of 1.210, while a heavy-duty truck or tractor battery may have a recommended electrolyte S.G. of 1.275. Car batteries generally have a recommended S.G. of 1.260. That's all very well for common wet cell batteries, but measuring the electrolyte S.G. of sealed lead-acid or nickel-cadmium batteries is out of the question.

Fortunately, the terminal voltage is also a good indicator of the state of charge or discharge. In general, the terminal voltage of a battery will be at a defined minimum when discharged and rise to a defined maximum when fully charged. Under load, the terminal voltage will vary between these limits, depending on the battery's condition.



The completed voltmeter. LED1 (10.5 V) is on the right and LED10 (15.0 V) is at far left.

Hence, a voltmeter having a scale 'spread' to read between these two extremes is a very good and useful indicator of battery condition. It's a lot less messy and more convenient than wielding a hydrometer to measure specific gravity of the electrolyte!

Let's look at battery characteristics, before we get into the project's circuitry, to get an understanding of what the project can do.

## Lead-acid batteries

The fully-charged, no-load terminal voltage of a lead-acid cell is between 2.3-2.4 volts. This drops under load to about 2.0-2.2 volts. When discharged, the cell voltage is typically 1.85 volts. The amp-hour capacity is determined from a 10 hour discharge rate. The current required to discharge the battery to its end-point voltage of 1.85 V/cell is multiplied by this time; e.g: a 40 AH battery will provide four amps for 10 hours before requiring recharge. Note however that the amp-hour capacity varies with the discharge current. The same battery discharged at a rate of 10 amps will not last four hours, on the other hand if it is discharged at 1 amp it will last somewhat longer than 40 hours. The typical discharge characteristics of a (nominal) 12 V battery are shown in Figure 1.

The initial charging current for the fully discharged battery (cell voltage under 2.0 V), should be about 20 amps per 100 amp-hours of capacity (i.e: 8 amps for a 40 AH battery). Once the electrolyte begins to gas rapidly, the terminal voltage will be around 13.8 volts and rising rapidly. At this point, the charging current should be reduced to somewhere between 4-8 amps per 100 AH until charging is complete.

At the end of charging, terminal voltage may rise to about 15.6 volts or more but this decreases slowly after the charger is removed, the terminal voltage then usually reading around 14.4 volts per cell (see Figure 2.).

## NiCad batteries

The no-load terminal voltage of a nickel-cadmium cell is typically 1.3-1.4 volts. This drops to about 1.2 volts under load, and to about 1.1 volts when discharged. As the electrolyte does not change during discharge (as it does in lead-acid batteries), the number of amp-hours obtained from a Nicad battery is much less affected by the discharge rate than are lead-acid batteries (see Figure 3.). Ten individual cells are generally used to obtain 12 V.

A number of charging systems can be used to replenish the charge in NiCad batteries. Constant current chargers are well known and quite common (such as the ETI-578 in the June 1980 issue). Fast charging at a high rate, as illustrated in the ETI-563 Fast Charger, is another method while some commercial manufacturers (Christie Electric Asia, for example) employ the "reflex" technique — the battery is alternately charged and discharged at a high rate over a short period. Increased battery life and extremely rapid charging are the claimed features of this method.

The typical charging characteristics of a single cell are illustrated in Figure 4.

For more details on lead-acid and nickel-cadmium batteries, see "Batteries" in ETI, November 1977.

## The voltmeter

This voltmeter uses ten LEDs to provide an 'expanded' voltage scale over the range 10.5 V to 15 V to suit applications with 12 V (nominal) batteries. Heart of the device is an LM3914 LED bargraph driver chip. In this application, we are using it in the 'dot' mode to provide an unambiguous display. The IC has been connected in this circuit such that the first LED (LED1) lights at 10.5 V, the second at 11.0 V and so on at 0.5 V intervals up to 15 V at LED10. Red LEDs have been employed at the extremes of the range to indicate 'problem' conditions. The first three LEDs, covering 10.5 - 11.0 - 11.5 volts, are red to show the discharge condition, while the last two LEDs, covering 14.5 and 15.0 volts, are also red to indicate the overcharge condition. The LEDs covering the 12.0 to 14.0 volts range are all green showing that the battery's within its normal operating voltage range.

An 'idiot' diode (ZD1) and a line fuse protect the instrument in the event of reverse connection or an over-voltage condition. Should the unit be inadvertently wired in reverse polarity, ZD1 will conduct in the forward direction and the line fuse will blow. If a voltage greater than 18 V is applied, which may happen if the unit is installed in a car and a battery terminal comes loose allowing the alternator voltage to rise, then the zener action of ZD1 will cause the line fuse to blow, preventing too high a supply voltage from destroying the unit. ▶

### VEHICLE BATTERY FAULTS

| Symptom | Probable cause |
|---|---|
| ☆ Voltage falls rapidly to low end of green after engine is switched off. | Battery in poor condition or possibly faulty. Check terminals for good connection. |
| ☆ Battery voltage falls considerably overnight | ditto |
| ☆ Voltage falls rapidly from high end of green to low end if lights switched on with engine off. | ditto |
| ☆ Voltage falls more than about one volt when lights are switched on with engine running at moderate speed | Charging system may be supplying low current. Check alternator slip rings, diodes and regulator adjustment. Check battery terminals. |
| ☆ Voltage rises over 14.5 V (LED9) when engine running | Charging system may be overcharging. Check regulator voltage adjustment. |
| ☆ Voltage never rises to top end of green (LED8). | Charging voltage too low. Adjust regulator voltage. |

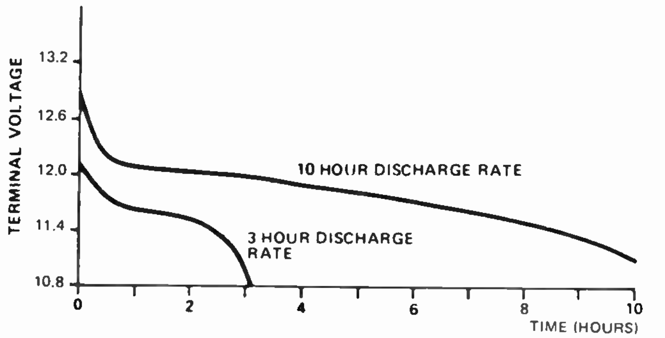



*Figure 1.* **Typical discharge characteristics of a 12 V (nominal) lead-acid battery.**

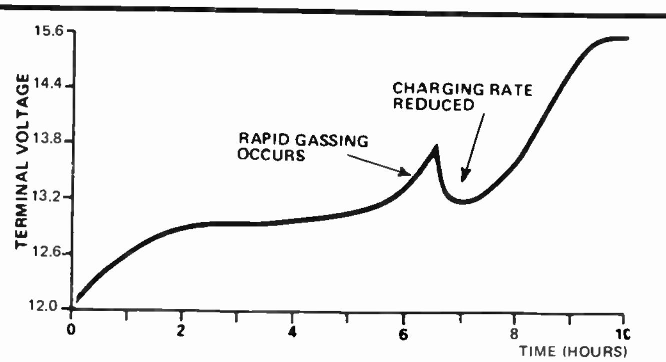



*Figure 2.* **Charging characteristics of a 12 V (nom.) lead-acid battery. The 'kink' in the curve near 6 hrs is explained in the text.**

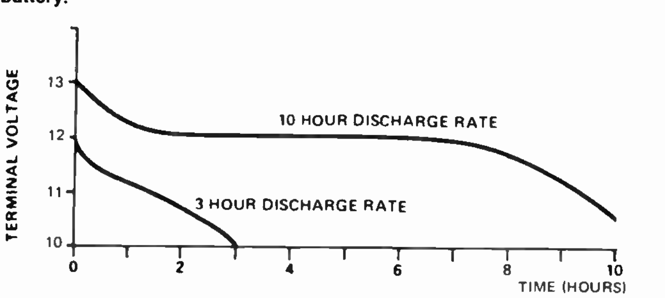



*Figure 3.* **Typical discharge characteristics of a 12 V (nom.) nickel-cadmium battery (usually consisting of 10 cells in series).**

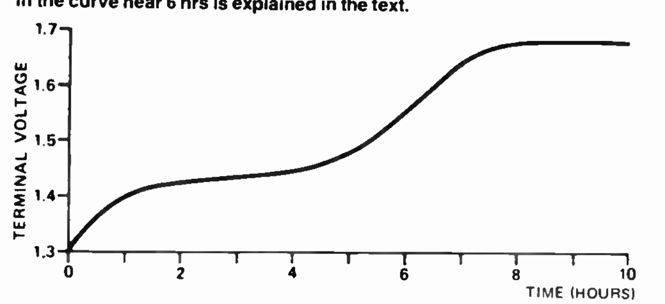



*Figure 4.* **Typical charging characteristics of a single nickel-cadmium cell charged at 1.4 times the discharge rate.**

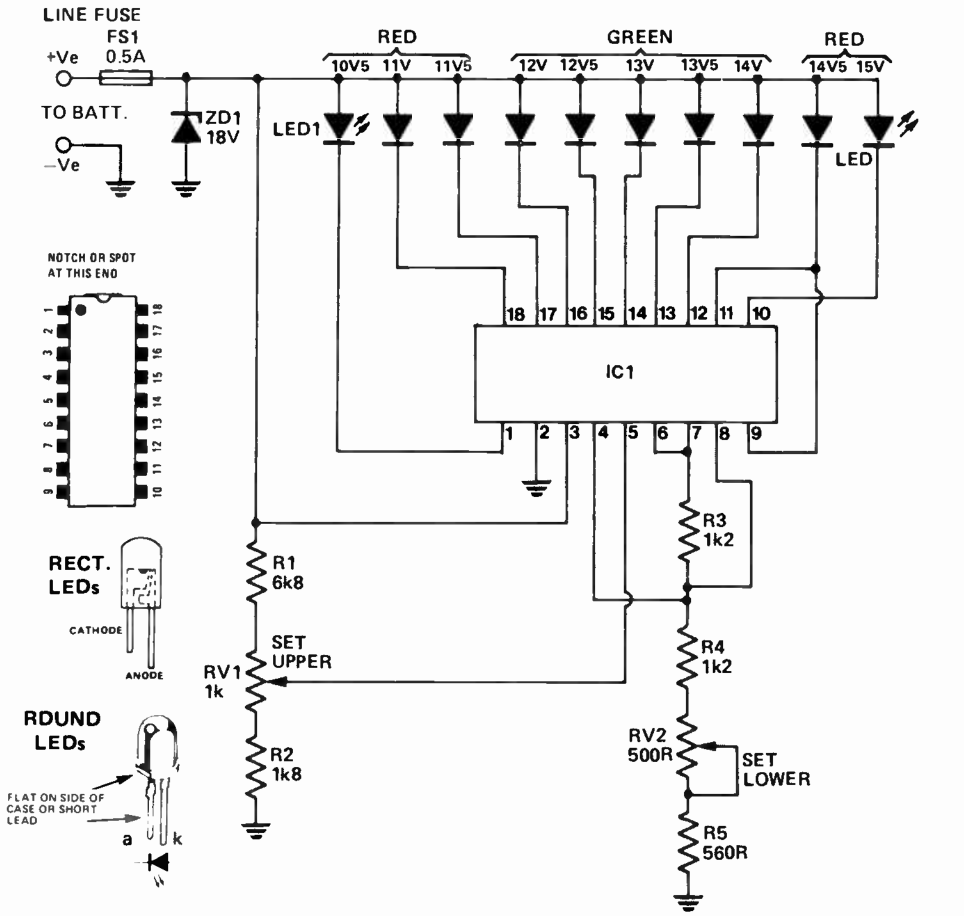
## Construction

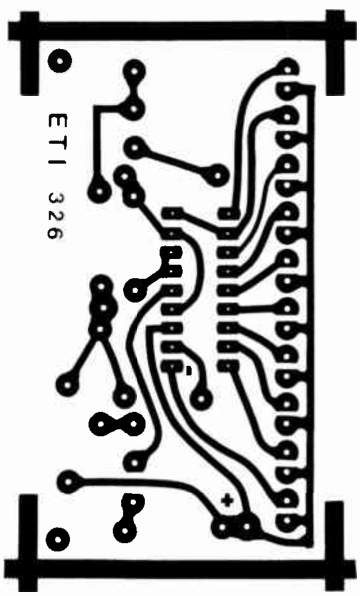
Assembling the project is extraordinarily simple! We recommend you use the printed circuit board — it does make things easier and helps avoid mistakes, although it is not essential.

As with our LED Tacho (ETI-324) we have used rectangular LEDs and mounted them in a row down the front of the pc board. The components may be mounted in any order, but you might find it easier with this project to mount the LEDs first. It is *most important* that they be placed in the board the right way round. About the best way to ensure this is to place them on the table or workbench in front of you with all their leads correctly oriented, just as they would be when mounted in the board. Refer to the overlay and you can't go far wrong. The hard part is getting them all level! Starting at LED1 or LED10 — it doesn't matter which, insert its leads in the board and then bend it over such that it lies flat on the board with the base of the LED flush with the edge of the board. This is clear from the overlay picture. Solder the leads and bend the LED back upright. Insert the next LED carefully positioning it so that it is flush with the first LED and solder its leads. Proceed like this until all the LEDs are in place and then bend the whole row over, parallel to the board.

Note that, although we have used rectangular LEDs, conventional types may also be employed.

If you haven't already done so, the rest of the components may now be mounted. Take care with the orientation of the LM3914 and the zener diode.




## Setting the scale limits

To set the scale limits, you will need a variable power supply capable of delivering 15 volts and perhaps a good multimeter or digital voltmeter — the latter is preferable. Whatever you use, you should be able to read it reasonably well to 0.5 V.

Connect the instrument to the power supply (watch polarity), set the supply to 15 V and switch on. Any of the LEDs may light. Adjust RV1 until LED9 just extinguishes and LED10 lights. Next, set the supply to 10.5 V and adjust RV2 until LED1 just lights. Run the power supply up to 11.0 V and check that LED2 lights and LED1 goes out.

As there is some interaction between the two controls, repeat the process until the unit performs properly. The LEDs should light in turn at each 0.5 V interval from 10.5 V to 15.0 V.

Your LED voltmeter is ready for use!

## Installation

We'll have to leave this pretty much to you as installation details will depend on the individual application. However, if you plan to mount the unit in a vehicle, here are some general hints.

### HOW IT WORKS — ETI 326

**The circuit uses an LM3914 LED bargraph driver arranged as an expanded scale voltmeter with a dot display, in which only one of the ten LEDs is lit at any time. If the voltage is below 10 volts none of the LEDs light, if it is above 15 volts the last LED remains lit.**

**The trimpots RV1 and RV2 set the upper and lower voltages respectively to give a range of 10 to 15 volts in ten steps. Over-voltage and reverse voltage protection is provided by ZD1, an 18 volt zener, and the fuse FS1. If the voltage exceeds 18 volts the zener conducts and blows the fuse, and if the voltage is reversed, the zener acts as a forward-biased diode with the same result.**

The instrument can be mounted in any convenient position in or under the dash, provided the display is shielded from direct light. Seeing as the driver only need glance at it occasionally, it may be mounted away from his normal view, but not such that it's an effort to see the display.

The positive supply lead to the instrument should be taken directly to the battery terminal, or the starter motor connection. This is to avoid any voltage drop in the vehicle's wiring from affect-

## PARTS LIST — ETI 326

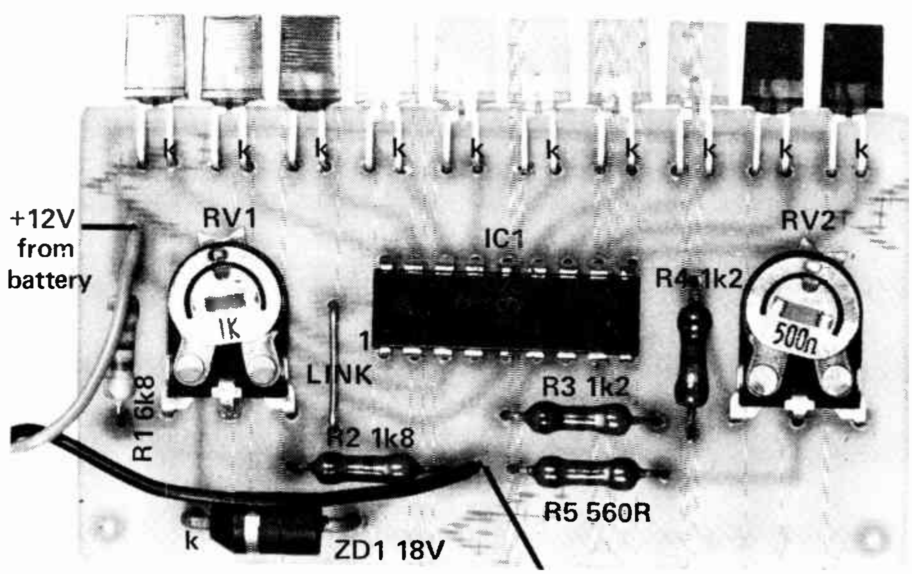
**Resistors** all ¼W, 5%
- R1 ............... 6k8
- R2 ............... 1k8
- R3,R4 ............ 1k2
- R5 ............... 560R

**Trimpots**
- RV1 .............. 1k min. vert. mounting trimpot.
- RV2 .............. 500 R min. vert. mounting trimpot.

**Semiconductors**
- ZD1 .............. 18V, 1W zener diode
- LED1-LED3 ....... red LEDs round or rect.
- LED4-LED8 ....... green LEDs round or rect.
- LED9-LED10 ...... red LEDs round or sq.
- IC1 .............. LM3914N

**Miscellaneous**
ETI-326 pc board; in-line fuse holder with 0.5 A fuse.

ing the reading (such as in the headlight wiring). The chassis connection can be made to the car body under the dash, wherever convenient, or taken to a chassis connection point in the engine bay.




## Use in a vehicle

Say you get into your car in the morning. Before you start the engine, the unit will probably register in the upper range of the green portion of the scale. If you left the lights on overnight the battery voltage will most likely be low. If below 11 volts, you'll probably have to push start the car.

Let's assume you've got the car going. As you drive off, the voltage should rise until it reaches the maximum charging voltage — about 14.0 to 14.5 volts. When you reach your destination and switch off the engine the voltage should fall slightly — maybe 0.5 V - 1.0 V, to about 13.0 or 13.5 volts (LED6 or LED7 should light). The accompanying table may be used as a general guide to battery faults. ●

## THE LM3914 — HOW IT WORKS

The LM3914 is a highly versatile device designed to sense an analogue input voltage and drive a row of ten outputs, usually LEDs or other indicators, in either a 'dot' or 'bar' graph mode.

The IC contains a ten resistor potential divider. Ten voltage comparators in the chip each have their non-inverting (+) input connected to successive taps on the ten-resistor divider. All the inverting inputs of the comparators are tied together and are driven by the output of a buffer from the input. The buffer has unity overall gain, so that for all intents and purposes the voltage on the inverting inputs of the ten comparators is the same as that on the input pin (pin 5). The outputs of the comparators each go to an individual pin on the IC and are capable of driving an LED or other circuitry.

An internal reference voltage source provides a highly stable 1.2 volts between pins 7 and 8. Since this reference is 'floating', the voltage between pins 7 and 8 always remains at 1.2 volts, irrespective of whether pin 8 is tied to ground or held at some voltage above ground.

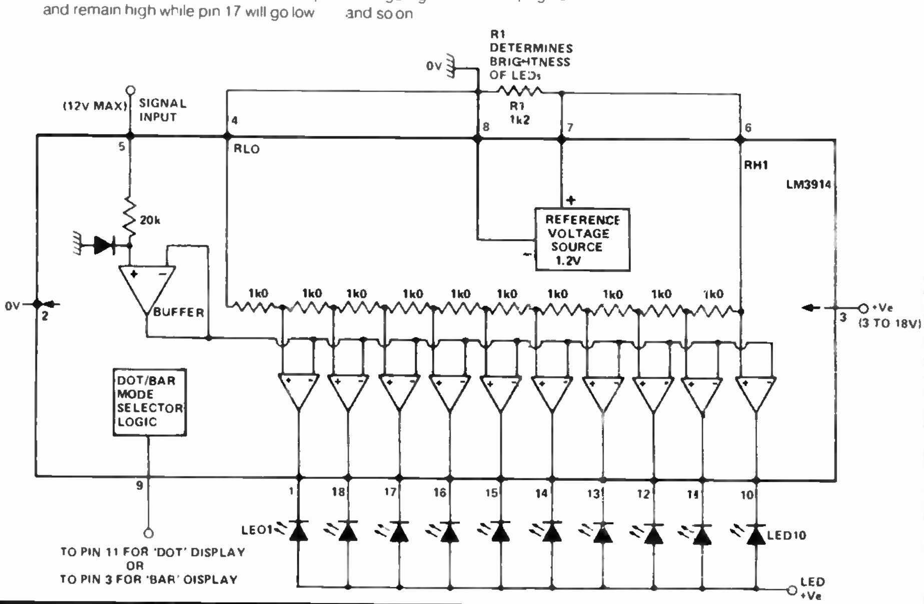
Finally, the IC also contains an internal logic network that can be externally programmed to provide either a 'dot' or 'bar' display from the outputs of the ten voltage comparators. When the dot mode is selected, only one of the ten outputs will be 'active' as the input voltage varies. When the bar mode is selected, each output becomes 'active' in succession as the input voltage increases, and vice versa.

If the reference voltage (1.2 V) is connected across the internal resistive divider, by connecting pin 7 to pin 6 and pin 8 to pin 4, 0.12 volts is applied to the non-inverting input of the lowest voltage comparator, 0.24 V to the next 'up' the divider line, 0.36 V to the next, and so on.

When the input voltage on pin 5 is zero, all the comparator outputs are high. As the input voltage is increased, the buffer output will increase. When it passes 0.12 V, the first comparator in the string (output on pin 1) will switch and its output will go low and remain low. If the input continues to rise, the next comparator will switch over and pin 18 will go low and remain low when the input passes 0.24 V. Pin 17 will go low and remain low when the input passes 0.36 V etc. pin 10 (output of the tenth comparator) will go low and remain low when the input reaches or exceeds 1.2 V. This is what happens when the bar mode is selected. For the dot mode, pin 1 will go low when the input reaches 0.12 V. When the input reaches 0.24 V, pin 1 will go high and remain high and pin 18 will go low. When the input reaches 0.36 V, pin 18 will go high and remain high while pin 17 will go low ... and so on.

The output currents from the comparators may be programmed by a connecting resistor across the reference supply, between pins 7 and 8. Each comparator output current is approximately ten times the output current of the voltage reference source. This can supply about 3 mA maximum, so the maximum output current from each comparator is 30 mA.

A detailed explanation of the operation and applications of the LM3914 appeared in the March 1980 issue of ETI, page 61.



Project 320

# BATTERY CONDITION INDICATOR

Ever been caught by a battery that went flat at an embarrassing moment — like when you've just offered a friend a lift? The conversation goes a little flat when you're both riding the bus to work, 20 minutes late. Jonathan Scott found a solution . . .

THE OLD, RELIABLE lead-acid battery may be way ahead of what ever is in second place for vehicle electrical systems, but they do need a 'weather eye' kept on them. Particularly if they're out of warranty. The same applies to 'reconditioned' batteries, so often found in secondhand vehicles of some age.

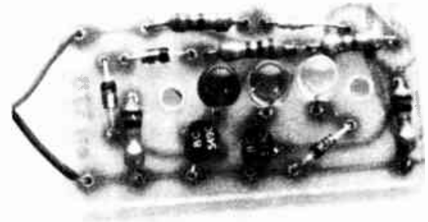
That's the problem with cars — running out of petrol and running out of battery produces the same heart-rending result. Immobility.

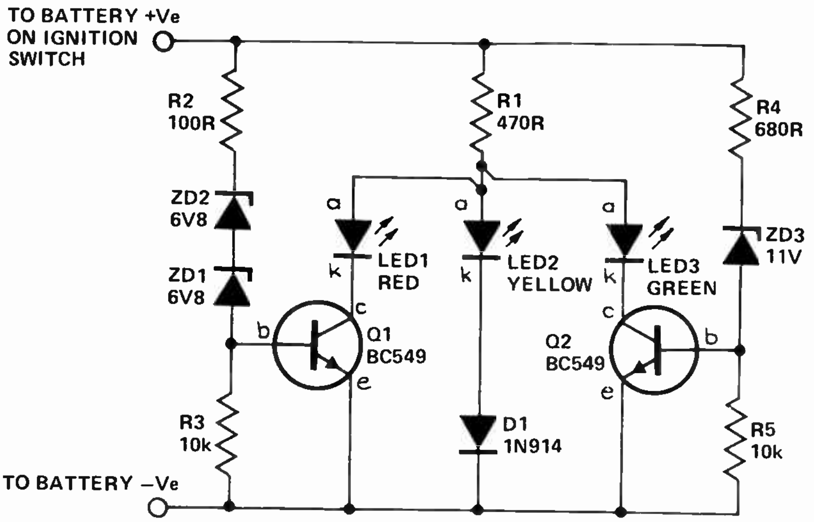
Most vehicles have a petrol gauge. Few have an equivalent for the battery. Many 'older' cars included a 'charging current' meter. This told you something about the car's generator-regulator and required some interpretation to figure out whether the battery was in good health.

Probably the best way to check on the state of your battery is to use a hydrometer. However, hydrometers have a number of drawbacks. Being made of glass, they're fragile and can't be used while a car is in motion. The small amount of battery acid that remains on them presents a storage problem — the drips and fumes attack most metals and materials. They're okay for the corner garage but justifying their cost, for the occasional use they get in home workshops, is not always possible.

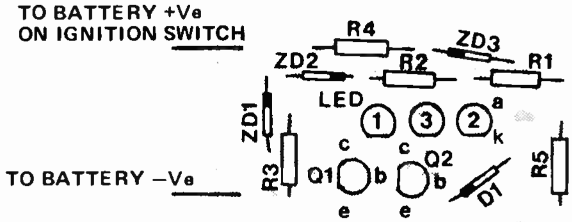
Another method of testing battery condition is by checking the voltage 'on load'. A lead-acid vehicle battery in a reasonable state of charge will have a terminal voltage under normal working load somewhere between 11.6 and 14.2 volts. When a battery shows a terminal voltage below 11.6 volts its capacity is markedly decreased and it will discharge fairly quickly. Like as not, it won't turn the starter motor for very long! On the other hand, if the voltage on load is above 14.5 volts then the battery is definitely fully charged! However, if it remains that way for any length of time while the car is on the road, the vehicle's alternator-regulator system is faulty and the battery may be damaged by overcharging.

Reading the battery voltage can be done in a number of ways. You could use a digital panel meter, set up as a voltmeter. Their drawback is that they cost nearly ten times as much as a hydrometer! The next best method is to use an 'expanded-scale voltmeter'. Reading the voltage range between 11 and 15 volts on a meter face calibrated 0-16 volts is a squint-and-peer exercise. On a 0-30 volts scale, as used on many modern multimeters, it's worse. A meter which reads between 11 volts at the low end of the scale and 16 volts at the high end is ideal. Hence, the term 'expanded-scale'.






*The circuit diagram and component overlay (below). During construction, make sure all of the diodes and LEDs are the right way round.*




## HOW IT WORKS – ETI 320

This circuit depends for its operation upon the different voltage drops across different colour LEDs.

At 20 mA the voltage drops across red, yellow and green LEDs are typically 1.7, 3.0 and 2.3 volts respectively. When the vehicle battery voltage is too low to cause either ZD1/ZD2 or ZD3 to conduct, Q1 and Q2 are held off by R3 and R5. Under these conditions the yellow LED is forward biased and conducts via D1 producing a potential of about 3.7 volts at point A (see circuit diagram). When the supply rises above about 11.6 volts ZD3 conducts, biasing Q2 on. By virtue of its lower voltage requirements the green LED conducts, reducing the voltage at point A to approximately 2.6 volts. This is not enough to bias D1/LED3 on, so the yellow LED goes off. The green LED 'steals' the bias from the yellow LED. When the supply rises above about 14.2 volts, Q1 is biased on and the red LED 'steals' the bias from the green. The potential at point A falls to two volts and only the red LED conducts.

R1 limits the current through the LEDs. R2 and R4 limit the base currents into Q1 and Q2.

## PARTS LIST – ETI 320

**Resistors all ¼W, 5%**

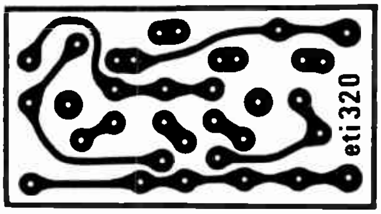
| | |
|---|---|
| R1 | 470R |
| R2 | 100R |
| R3, R5 | 10k |
| R4 | 680R |

**Semiconductors**

| | |
|---|---|
| D1 | 1N914 |
| ZD1, ZD2 | 6V8 400 mW zener |
| ZD3 | 11V 400 mW zener |
| Q1, Q2 | BC547,8,9 or BC107, 8, 9 or common silicon NPN type |

**Miscellaneous**

pcb ETI 320
Aluminium angle bracket for under-dash mounting.




*The printed circuit board pattern*

However, you don't want to be peering at a meter on the dash board when you're driving through traffic. The range of voltage over which your battery is healthy is some two volts. An indicator which simply requires the occasional glance, and needs no 'interpretation', is what is really needed.

With this project, that's exactly what we've done.

### Go, caution, stop

We have devised a simple circuit that indicates as follows:

| | |
|---|---|
| Yellow: | battery 'low' |
| Green: | battery okay |
| Red: | battery overcharging |

When the battery voltage is below 11.6 volts, a yellow indicator lights. This indicates the battery is most likely undercharged or a heavy load (such as high power driving lights) is drawing excess current. When it is between 11.7 and about 14.2 volts the green indicator lights, letting you know all is sweet. If the red indicator lights, as it will if the voltage rises above 14.2 volts, maybe the vehicle's voltage regulator needs adjusting or there is some other problem.

### The circuit

The circuit is ingeniously simple, having barely a handful of parts. Reliability should be excellent.

We actually started out with a somewhat complex circuit. It used only two indicators and required you to 'interpret' what was happening. In trying to convert that to a yellow-green-red style of indication it sort of grew like topsy. This circuit had four transistors, a dozen resistors etc and didn't look at all attractive as a simple project that the average hobbyist or even handyman could build one Saturday afternoon and get going immediately. A rival circuit was devised by another staff member using a common IC. This sparked a controversy as to which was the better! Certainly, both did the job required . . . but maybe there was a simpler method.

It was discovered that different coloured light emitting diodes (LEDs), which we had decided to use for the indicators in the project, had different voltage drops when run at the same current. Seizing on this idea, the original circuit (four transistors, a dozen resistors . . . ) was modified to exploit this characteristic and the simple circuit you see here was the result.

### Construction

Construction is straightforward. If you haven't soldered electronic components before – and this project was designed for the motorist/handyman as well as electronics enthusiasts – then we suggest you practice on something before tackling this project. Soldering is one of those things like swimming or riding a bicycle, or sex – it's okay once you've done it once or twice but you don't practice out on the street!

We recommend you use the printed circuit board designed for this project. The actual layout of the components themselves is not critical but a printed circuit board reduces the possibility of errors.

It is best to mount and solder the resistors first. Follow this by soldering in the diodes D1 and the zener diodes ZD1, ZD2 and ZD3. Carefully follow the accompanying component overlay making sure the diodes are all inserted the correct way around. Next, mount the transistors, again referring to the overlay, checking to see they are inserted correctly before soldering.

Finally, mount the light emitting diodes. These too may only be inserted one way. Check with the component overlay and connection diagrams. Make sure they are in the correct sequence. On the component overlay, LED 1 is the red LED, located at the left. The yellow LED is on the right, marked with a '2'. The green LED, marked '3' is between them.

The circuit could be tested at this stage if you have a variable power supply, or access to one. Simply vary the voltage across the range between 11 and 16 volts and note whether the LEDs light up in the correct sequence and close to the voltages indicated.

## Mounting

As vehicles vary so much in dash panel layout, we can only make general suggestions.

Clearly, the indicator should be mounted such that the three LEDs are not in direct sunlight. A low part of the dash, but make sure it's readily visible from your normal driving position, will pretty well ensure the display may be easily read during the daytime. Alternatively, if you have an 'overhung' dash, or a portion which overhangs (usually where the instruments are mounted anyway), then a suitable position will generally suggest itself.

Exact mechanical details will have to be determined according to your particular situation. Two holes are provided in the pc board for mounting bolts. Alternatively, the whole assembly may be mounted from the LEDs. Three LED holders inserted through part of the dash panel, or an escutcheon plate mounted on the dash, will hold the LEDs quite securely. Providing the leads on the LEDs are fairly short, the pc board will place little strain on them and the assembly should be mechanically secure.

## Connection

The indicator may be installed in vehicles having positive or negative earth electrical systems.

The component overlay shows the connection for a **negative** earth vehicle. The 'battery +ve' lead goes to the ignition switch – the indicator only operates when the vehicle is being used – the battery negative lead should be taken to a good 'earth' point on the vehicle frame.

For a **positive** earth vehicle, the lead marked 'battery –ve' goes to the ignition switch connection, while the 'battery +ve' lead goes to the vehicle frame.

# "The Rocker" — 140W of rich, warm valve sound!

We have had so many requests for a valve power amplifier in the last year or so, from readers and project suppliers alike, that we finally succumbed. Turn back the clock, heat up your 100 watt iron and read on . . .

**Phil Wait**

**Ron Keeley**

FASHIONS CHANGE, styles come and go, but some things remain the same ... one of the constants is the preference of many musicians for the warm, deep-throated sound of an old-fashioned valve amplifier.

The "valve vs transistor" argument may never be settled conclusively. Despite all the obvious advantages of solid-state, musicians prefer valves because, they say, valve amps simply sound 'better', subjectively – like the preference of some people for an old Harley-Davidson or Triumph motorbike, rather than a modern, high-revving performance machine. On the other hand, there are definite technical reasons why a valve amp will sound 'different'.

The reason most often advanced is that valves produce predominantly second harmonic distortion, whereas transistor amp distortion is mainly third harmonic. While this is true, it is not the whole truth; the distinctive sound of valves is caused by the synergy of many factors, and the spectral balance of the distortion components is just one of them. Other important factors are the shape of the distortion/power curve, the fact that valve amps are transformer-coupled to the load (which affects the overall response of the amp), the high output impedance of valve amps (resulting in reduced damping of the loudspeaker and a more 'colourful' sound), and the higher 'dynamic output' capability of valve amps (the ability to deliver relatively constant power to a varying load, i.e: a speaker).

If all these factors could be built into a transistor amp, then possibly it would sound, subjectively, like a valve amp. Many have tried to do this – most have failed. We've taken the opposite approach, and built a good, old-fashioned, high power valve amplifier, the "Rocker".

## Circuit design

This amplifier circuit is the result of many hours of experimentation and


incorporates suggestions from many people, staff and friends of both ETI and sister magazine Sonics, and particularly John Burnett of the School of Electronics, whose suggestions prompted quite a few changes, especially around the input stage. Overall, the circuit uses a triode voltage amplifier stage followed by a phase splitter, a pair of drivers and the output stage, consisting of four valves in push-pull-parallel. The amplifier is ▶

**SPECIFICATIONS OF PROTOTYPE – ETI 456 VALVE AMPLIFIER**

| Power Bandwidth | - 1 dB | - 3 dB |
|---|---|---|
| 140 watts | 22 Hz to 12 kHz | 18 Hz to 17 kHz |
| 50 watts | 18 Hz to 22 kHz | 14 Hz to 27 kHz |

Distortion at 1 kHz

| | 100 mW | 5 watts | 50 watts | 100 watts | 140 watts |
|---|---|---|---|---|---|
| open loop: | 1% | 0.7% | 1.9% | 3% | 15% |
| closed loop: | 0.4% | 0.22% | 0.65% | 1% | 5% |

Power output for 5% THD
140 watts (8 ohm load)

Maximum power output
200 watts (8 ohm load)

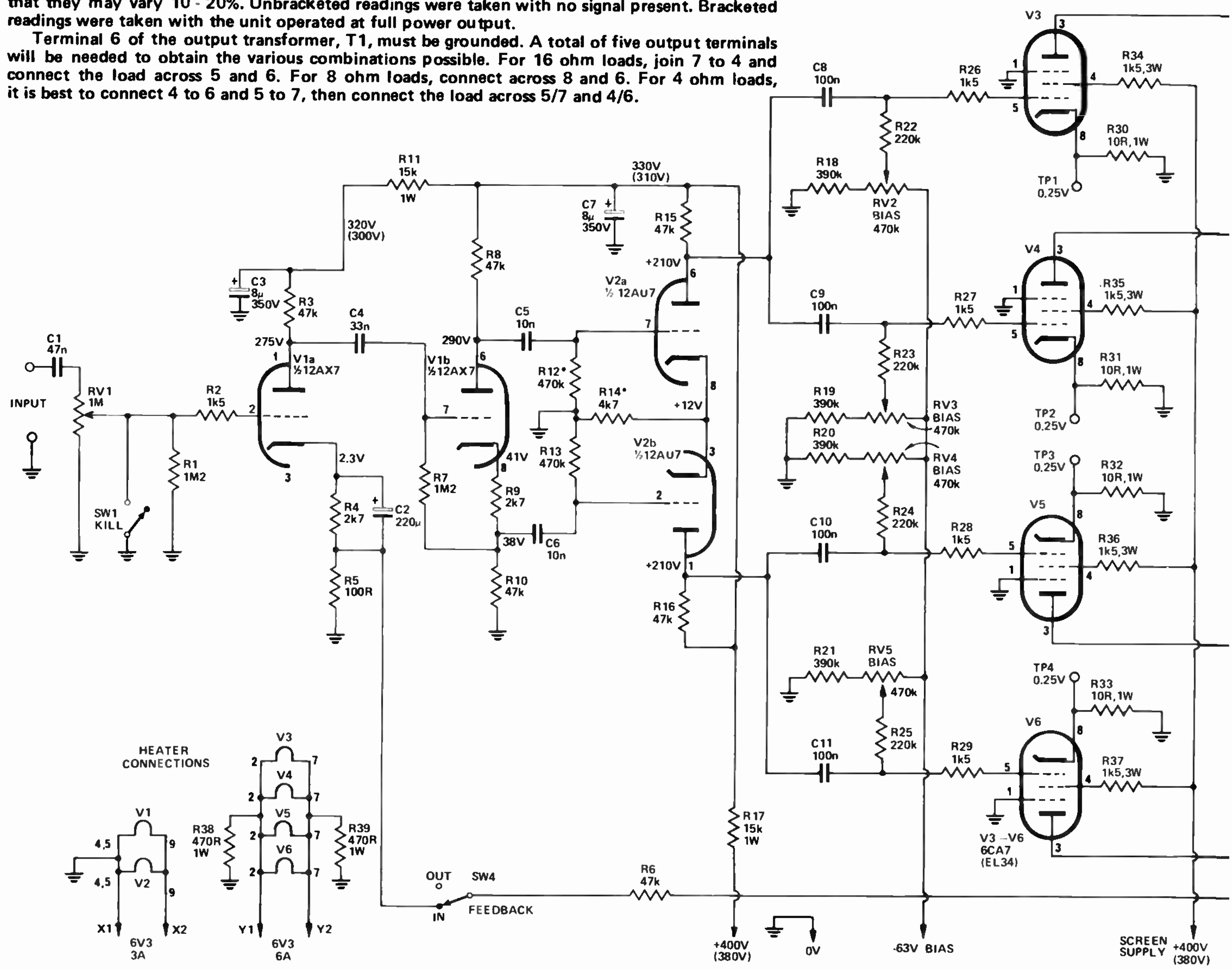
Hum and Noise
- 62 dB with respect to 140 watts output

Input Sensitivity
with feedback: 200 mV (adjustable)
without feedback: 80 mV

Feedback Ratio:
10 dB

NOTES: Various voltage readings are given on this drawing as a guide to constructors, but note that they may vary 10 - 20%. Unbracketed readings were taken with no signal present. Bracketed readings were taken with the unit operated at full power output.

Terminal 6 of the output transformer, T1, must be grounded. A total of five output terminals will be needed to obtain the various combinations possible. For 16 ohm loads, join 7 to 4 and connect the load across 5 and 6. For 8 ohm loads, connect across 8 and 6. For 4 ohm loads, it is best to connect 4 to 6 and 5 to 7, then connect the load across 5/7 and 4/6.




## HOW IT WORKS — ETI 456

The amplifier has four separate stages: the input voltage amplifier, a phase-splitter, a push-pull driver stage and a push-pull power output stage.

The input stage, V1a, uses one section of a 12AX7 of a high-u twin triode. The input enters via a dc-isolating capacitor, C1, and the gain control, RV1. The 'grid stopper' resistance, R2, is placed directly in series with the grid to reduce susceptibility to RF interference.

The phase-splitter uses the other half of V1 (V1b), its grid being coupled to the anode of the input stage by C4. This stage has no gain. The signal at the grid of V1b appears at the anode inverted, i.e.: 180 out of phase. The signal also appears at the junction of the cathode bias resistors R9 and R10, in the same phase. Thus, the signals coupled to the push-pull driver stage via C5 and C6 are 180 out of phase. Grid bias for the phase-splitter is obtained by returning the grid resistor, R7, to the junction of the cathode bias resistors, R9 and R10, effectively placing the grid at about −3 V with respect to the cathode.

The driver stage consists of a 12AU7 low-u twin triode. Resistor R14 provides common cathode bias, while R12 and R13 are the two grid returns. The anode supply for this stage comes from the 400 V supply (screen voltage supply for the output stage) via a decoupling network consisting of R17 and C7. Each driver (V2a and V2b) has a gain of 10, defined by the ratio of R15 to R14 and R16 to R14.

The output stage consists of four valves in a push-pull parallel arrangement. V3 and V4 are in parallel and V5 and V6 are in parallel, the two pairs connected in push-pull via the output transformer. The anode of V2a drives the grid circuits of V3-V4 while the anode of V2b drives the grid circuits of V5-V6. The output stage is operated in class AB, which affords good gain, low distortion and good power output.

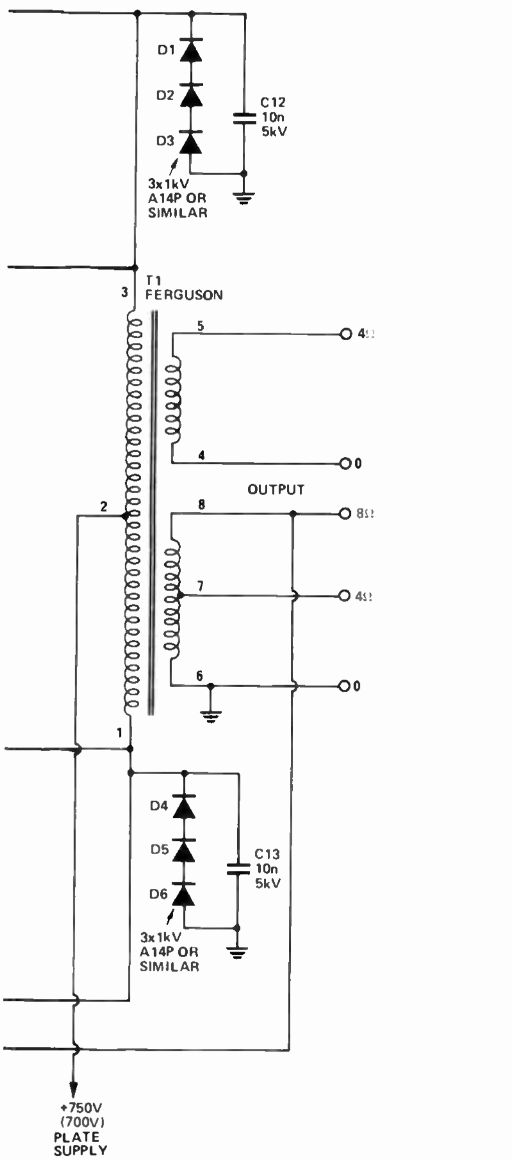
Bias for output stage is provided from a common bias supply from the power transformer, the bias for each valve being individually adjusted. As the characteristics of the 6CA7 output valves can vary widely, this adjustment is provided to ensure proper operation from unit to unit.

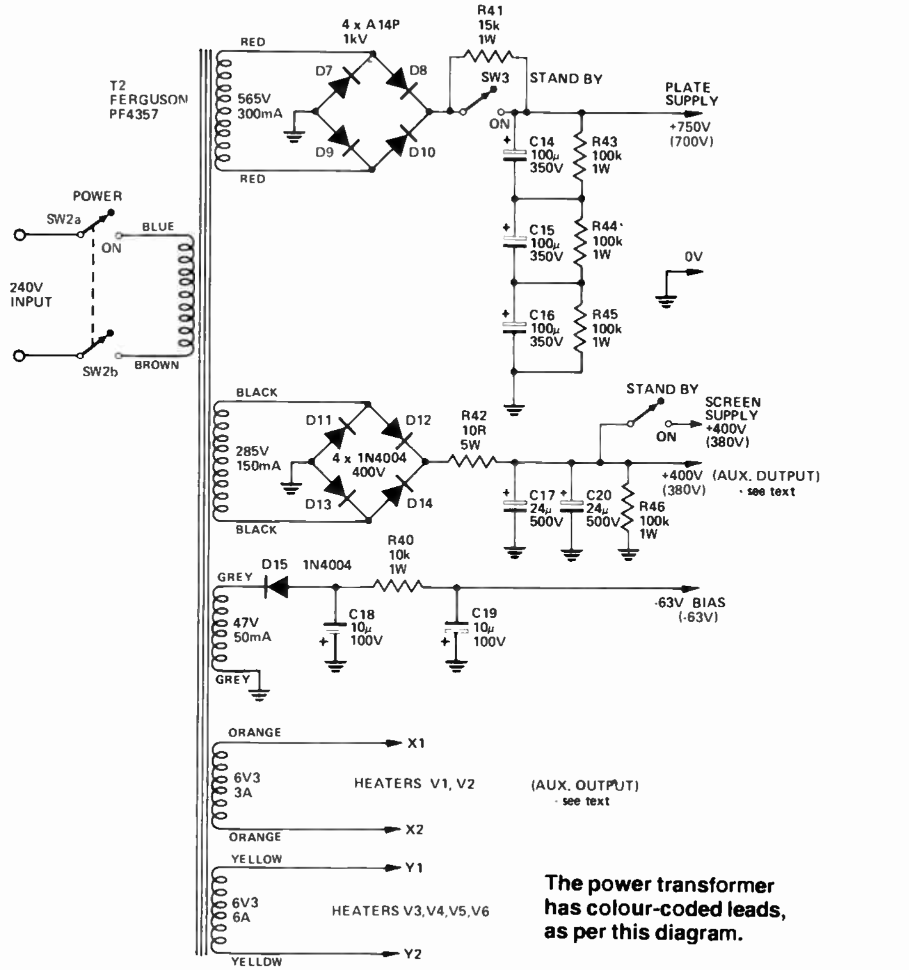
The output transformer matches the plate-to-plate impedance of the push-pull output pairs, about 5500 ohms, to the low impedance speaker load. Several output windings are provided: a single 4 ohm winding and an 8 ohm winding, tapped at 4 ohms. Feedback to the cathode of the input stage is taken from one end of the 8 ohm winding, the other end being grounded.

During each half cycle of the signal waveform, one 'side' of the output stage (i.e.: V3-V4 or V5-V6) will 'turn off'. This will allow that side of the output transformer primary to develop enough back emf to cause arcing across the valve socket pins. To prevent this, the reverse cycle emf is shunted via a set of diodes to ground — D1 — D3 and D4 — D5.

The power supply is fairly conventional. The power transformer has five secondary windings: one 6.3 V/3A heater winding, one 6.3 V/6A heater winding, one 47 V/50 mA bias winding, one 285 V/150 mA HT winding and one 565 V/300 mA HT winding.

Bridge rectifiers with capacitor-input filters are used to provide the appropriate HT voltages: 750 V for the output stage anodes, 400 V for the output stage screens and HT for the driver stages. A half-wave rectifier and pi-section filter is used to derive the −63 V bias supply.




**The power transformer has colour-coded leads, as per this diagram.**

capable of driving four, eight or sixteen ohm loads, or two four ohm loads simultaneously.

Overall feedback is taken from the eight ohm winding of the output transformer to the cathode of the input stage, and is wired via a front panel switch, allowing the feedback to be switched out if desired. This will increase the impedance looking back into the output terminals, reducing the damping factor so that the speaker cone is more influenced by the back emf of the voice coil. Normally, hi-fi amps are designed to have very low output impedance – a high damping factor – to suppress the effect of the back emf and reduce the colouration which would otherwise be introduced by the speaker.

With the feedback in, the 'Rocker' is quite clean, and suitable for PA, bass guitar or even as a hi-fi amp; switching the feedback out, however, makes the amp that much 'dirtier' and will also give it a more 'live' sound. Other front panel controls are provided for the usual functions – power, standby and input gain. The 'kill' switch shorts the input to ground, and is an effective way of temporarily 'switching off' without generating any transients or unwanted thumps.

All inputs and outputs are mounted on the rear panel. Although we have used a phone-jack input socket and a single pair of binding post output terminals, there is sufficient room behind the chassis for Cannon/Switchcraft inputs and multiple binding post or phone jack outputs, if required.

At the input stage, we had a choice between a triode-pentode, such as the 6BL8, or a 12AX7 twin triode. Triodes have the disadvantage of large plate to grid capacitance which, together with the plate resistor and the voltage gain of the stage, introduces a phase shift at high frequencies, called the Miller Effect. The degree of phase shift depends on the capacitance, gain and value of the plate resistor. All phase shifts add through the amplifier, the first stage having the largest effect, and when feedback is applied from the output to the input, the amplifier may oscillate. The feedback ratio (and the possible reduction in distortion) is therefore limited by the phase change through the amplifier, and must be kept low if a triode is used in the input stage.

Our first design used a 6BL8 pentode which worked well with about 20 dB of feedback, allowing a good stability margin, and looked very promising. Then we started talking to people in the audio business who had experience with valve amplifiers, who all said that a triode-pentode tube was internally fragile and would fail after a few months on the road. Back to the 12AX7 then, and lower amounts of feedback to preserve stability.

We wanted the amplifier to be useful for hi-fi and bass guitar ▶

applications as well, so we had to design it carefully for good performance but with a good stability margin, too. Conventional circuits usually drive the output stage directly from the phase splitter, which is inherently high in distortion when run at high signal levels and so requires large amounts of feedback to clean it up. Since the amount of feedback we could apply was limited by stability considerations, we followed the phase splitter with a pair of driver amplifiers, allowing the splitter stage to operate at a lower level for less distortion.

The output stages run in push-pull parallel using 6CA7 power pentodes. We chose four of these tubes, rather than two of the more powerful KT88s, because they are less than one quarter the price and are readily available.

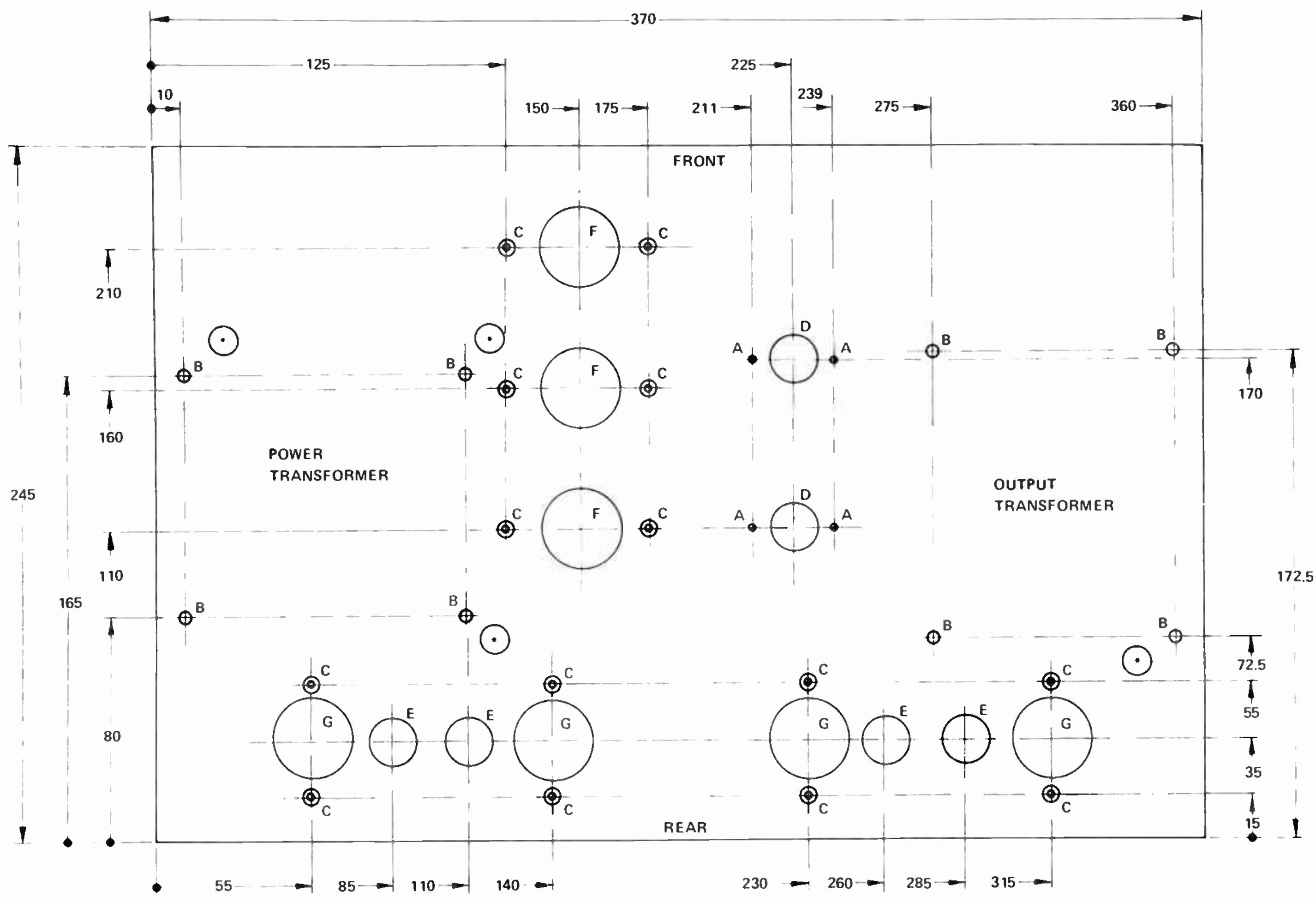
The bias for class B operation is set individually on each tube; this was found to be necessary because of the large spread in the parameters of unmatched tubes bought over the counter. The bias is set by monitoring the voltage across 10 ohm resistors, in the cathode of each valve, which also help reduce the effects of bad matching.

The life of the output valves is increased by placing lk5 resistors in each of the screen leads to reduce the peak screen dissipation, and parasitic oscillation is avoided by lk5 resistors on the grids. The possibility of socket flashover is reduced by using diodes and capacitors from each side of the output transformer primary to earth. The back emf from the transformer, when each half of the output stage turns off, is conveniently shunted to ground via the diodes. Three are connected in series to obtain a PIV rating of 3 kV.

The output transformer is probably the most important component affecting the performance of the amplifier. It must have sufficient winding inductance for good bass, but low leakage inductance for good high frequency performance. These are conflicting requirements and the transformer must be well made to achieve both.

In this transformer, the secondary windings are placed either side of the primary, sandwich fashion, to reduce leakage inductance. For maximum flexibility, the output transformer has two separate secondary windings, an eight ohm winding tapped at four ohms and a separate four ohm winding. A 16 ohm load can be run from the two four ohm windings in series (linking pins 4 and 7, taking the output from 5 and 6), an eight ohm speaker is run from the eight ohm winding, and either one or two four ohm speakers can be run by connecting the four ohm windings in parallel for one speaker, or independently for two.

Throughout the circuit, the values




HOLES MARKED A 6BA x 4
" " B 4BA x 8
" " C 6BA x 14 or 3mm pop rivet
" " D 18mm x 2
" " E 9mm x 4
" " F 28mm x 3
" " G 30mm x 4

ALL DIMENSIONS IN MILLIMETRES UNLESS OTHERWISE SPECIFIED
MATERIAL 1–1.5mm ALUM. OR STEEL

• DRILL AND INSULATE TO SUIT FOR THROUGH WIRING FROM TRANSFORMER

**Drilling details for the chassis, looking down from the top. Refer to the picture on the page opposite.**

of coupling capacitors have been kept as low as possible. If the capacitors are large and if the preceding stage is driven into clipping, there will be a time delay while they discharge, causing a short drop-out in the sound.

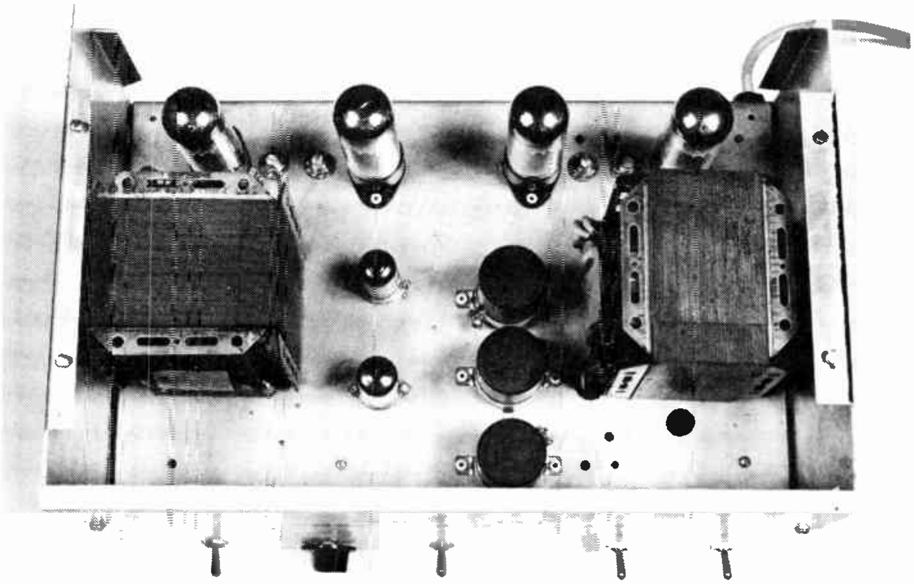
When you look at the power supply circuit, it may seem a little large. It is! It must be, to allow the amplifier to run into hard distortion, especially when used for bass guitar amplification.

The bias supply must be both free from ripple, and must reach its normal value immediately after turn on. If the power to the amplifier is momentarily interrupted (somebody tripping over a cord then quickly plugging it back in) the heaters in the tubes will still be hot; if the bias supply then takes time to come up to value, the output tubes will draw excessive current and may destroy themselves. The bias supply filter capacitors should be quite small and used with a fairly small value reistor in a pi-section filter to remove ripple. Regulation of the screen supply is ensured by using a separate transformer winding for the 400V (screen supply) rail.

One of the heater lines should be earthed to reduce the risk of hum caused by heater to cathode leakage, but you will notice that the output stage heater lines are earthed through two 470 ohm resistors, rather than having one side connected directly to earth. Why? Imagine this: an output tube goes short circuit; the cathode resistor won't last long, and the tube will arc over internally from cathode to heater, and then to earth through the heater line.

Now the output transformer has the full supply voltage across it and the current is limited only by the dc winding resistance, with the result that the output transformer burns up! The same thing will happen if a valve socket arcs over from pin 3 to pin 2. If resistors are placed from either side of the heater line to earth, however, they act as fuses protecting the output transformer while still preventing hum problems.

As in any amplifier, the mechanical design is just as important as the electrical. Looking at the layout, you will notice that the two transformers are the same size and are placed at either end of the chassis for correct weight distribution, and the four output valves are spaced along the back of the chassis for good ventilation — an important consideration to ensure them a long life. All power supply components are at the power transformer end of the chassis, while amplifier components are at the other. Bias controls are situated next to each output valve so that all wiring is short and direct.



**Looking into the unit. WARNING: keep all the covers on in use as lethal voltages are present. The multimesh cover fits under the front panel lip and is secured by the PK screws at either side.**

## Construction

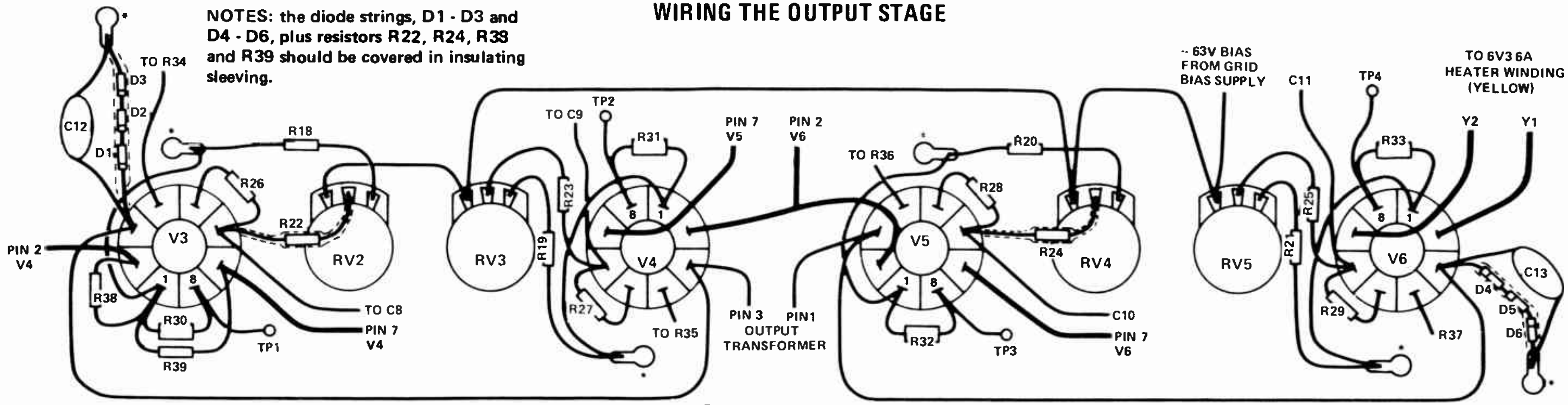
Since most of the components are mounted either on the chassis or on the valve sockets, a pc board is of little advantage. The method we used requires some care in wiring, however, and careful cross checking with the circuit diagram to ensure you haven't made any mistakes! Remember that the unit has lethal voltages present and if you make a mistake you may not have the chance to make another.

As the amplifier will be a relatively expensive project, you may wish to save a few dollars by making your own chassis. Hence we have produced a complete set of metalwork drawings. If you have the patience, the tools and the skill, quite a professional-looking unit can be produced. Many component suppliers sell sheets of aluminium, as well as useful things like hole-punch tool sets. Aluminium sheet and expanded aluminium may also be obtained from hardware stores, don't forget.

Examine the photos and the wiring diagrams and note carefully the positions of the components. The layout should be followed exactly, and all wiring should be of the highest standard. The power supply circuitry is located around the power transformer while the voltage ▶

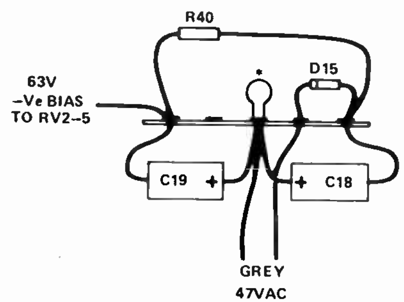
## WIRING THE OUTPUT STAGE

NOTES: the diode strings, D1 - D3 and D4 - D6, plus resistors R22, R24, R38 and R39 should be covered in insulating sleeving.



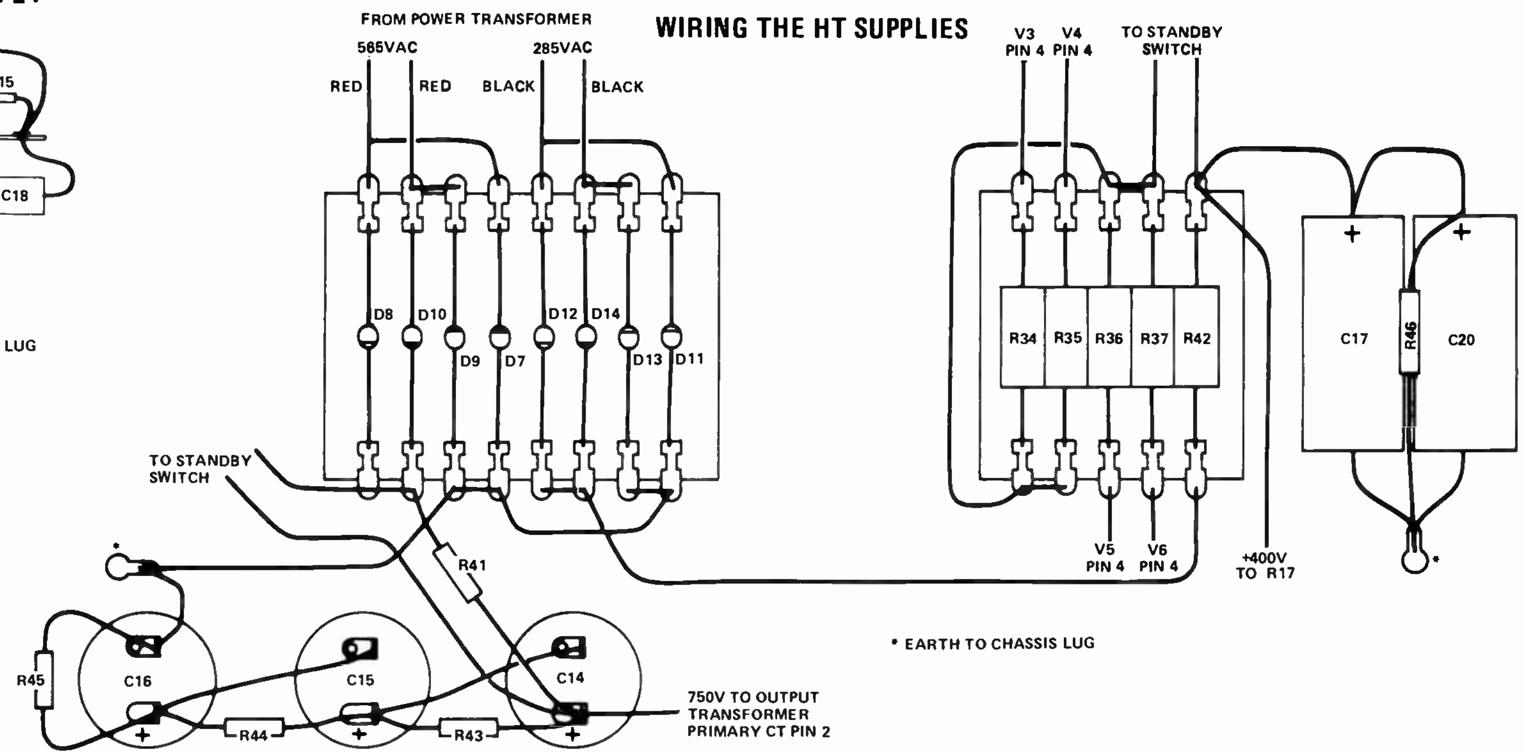

* EARTH TO CHASSIS LUG

## WIRING THE BIAS SUPPLY



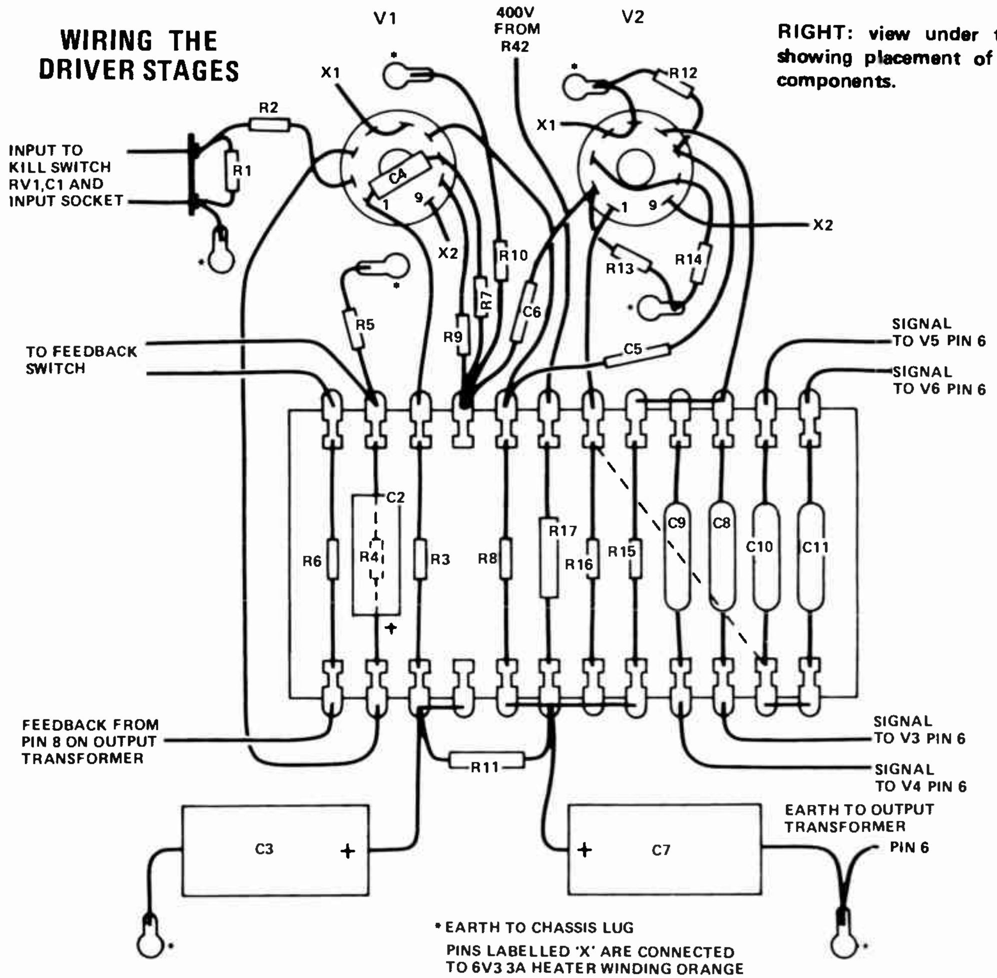

* EARTH TO CHASSIS LUG

## WIRING THE HT SUPPLIES

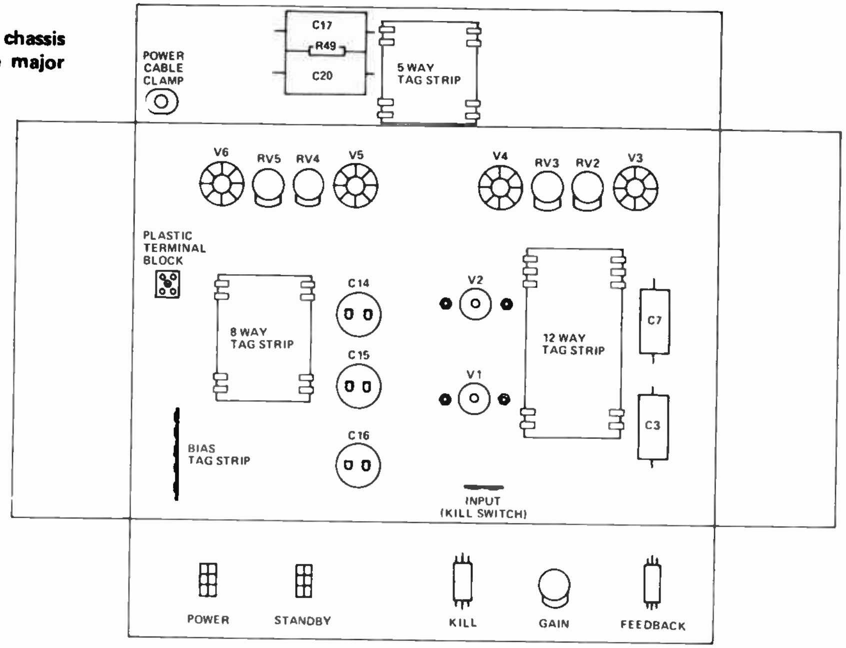


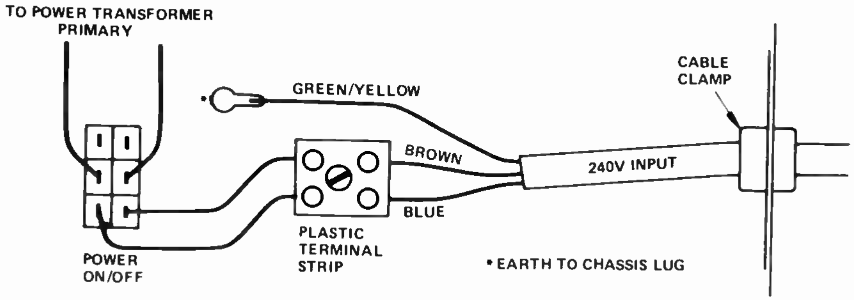

* EARTH TO CHASSIS LUG

## WIRING THE DRIVER STAGES




**RIGHT: view under the chassis showing placement of the major components.**




**MAINS INPUT WIRING**

## PARTS LIST — ETI 456

**Resistors** all ½W, 5% unless noted

| | |
|---|---|
| R1,R7 | 1M2 |
| R2,26,27,28,29 | 1k5 |
| R3,6,8,10,15,16 | 47k |
| R4,R9 | 2k7 |
| R5 | 100R |
| R11,R41 | 15k, 1W, 5% |
| R12,13 | 470k |
| R14 | 4k7 |
| R17 | 15k, 1W, 5% |
| R18,19,20,21 | 390k |
| R22,23,24,25 | 220k |
| R30,31,32,33 | 10R, 1W, 5% |
| R34,35,36,37 | 1k5, 3W, 10% |
| R38,39 | 470R, 1W, 5% |
| R40 | 10k, 1W, 5% |
| R42 | 10R, 5W, 10% |
| R43,44,45,46 | 100k, 1W, 5% |
| RV1 | 1M, log. pot. (GAIN) |
| RV2,3,4,5 | 470k, lin. pot. (BIAS) |

**Capacitors**

| | |
|---|---|
| C1 | 47n greencap |
| C2 | 220u, 16V electro. (pigtail) |
| C3,7 | 8u, 350V electro.(pigtail) |
| C4 | 33n greencap |
| C5,6 | 10n greencap |
| C8,9,10,11 | 100n greencap |
| C12,13 | 10n, 5kV ceramic disc or mica |
| C14,15,16 | 100u, 350V electro.(can) |
| C17,C20 | 24u, 500V electro.(pigtail) |
| C18,19 | 10u, 100V electro.(pigtail) |

**Valves**

| | |
|---|---|
| V1 | 12AX7 |
| V2 | 12AU7 |
| V3,4,5,6 | 6CA7 (EL34) |

**Semiconductors**

| | |
|---|---|
| D1 to D10 | A14P or similar |
| D11 to D15 | 1N4004 |

**Transformers**

| | |
|---|---|
| T1 | PF4357, Ferguson power transformer (see circuit) |
| T2 | OP603, Ferguson output transformer; 5k5 p-p impedance to 4 ohm + 8/4 ohm, 200 W. |

**Miscellaneous**

| | |
|---|---|
| SW1, SW4 | SPST toggle switch |
| SW2, SW3 | DPDT, 250 Vac rated toggle switch |

Four octal valve sockets; two nine-pin valve sockets; 6.5 mm input jack; binding post (or other) output terminals; 55 - 60 mm wide double tagboards (one 12 pair, one 8 pair, one 5 pair) with insulated backs; one five-lug tagstrip; one three-lug tagstrip; solder lugs; power cord and plug; chassis as per dimensions given plus panel, side plates and mesh top; base plate with rubber feet; 10 mm grommets; nuts, bolts etc.

NOTES: Greencap capacitors should be 630 V rated types or use polycarbonate types rated at 400 V or more.

amplifier, phase splitter and driver stages are next to the output transformer.

The first step is to mount the major components on the chassis. Locate the transformers, valve sockets, can electrolytic capacitors and bias pots in their correct positions.

Cut three lengths of double-sided tag board, twelve, eight and five tag pairs respectively, making sure the strips are capable of insulating the very high voltages used in this amplifier. We used wide-spaced bakelite tag boards with a bakelite backing piece, so that they can be mounted directly on the chassis without standoffs. Ours came from David Reid Electronics but similar types are widely available. Turn the chassis upside down and mount the tag boards in the appropriate positions. We used the transformer mounting bolts to mount the power supply and amplifier tagstrips. Mount a five-lug single tagstrip for the bias components and a three-lug tagstrip for the input to V1 as shown in the diagrams.

Once the tagstrips and tag boards are mounted, drill holes in the chassis for the leads from the two transformers. We used 10 mm holes with grommets for this, one for the output transformer, and three for the power transformer leads. (The holes for the leads are drilled after the tagstrips are mounted to avoid drilling holes under the tagstrips!). Start the wiring with the power supply components and the heater lines. The heavier (six amp) winding supplies the output tubes and the three amp winding supplies V1 and V2 the 12AX7 has a 12 volt centre-tapped heater, and for six volt operation, the two ends of the heater (pins 4 and 5) are joined together and the voltage applied between pins 9 and pins 4/5. All heater wiring is twisted and run above the sockets to keep it away from other wiring. One side of the 3A heater wiring is earthed at the socket of V2 and the 6A winding is balanced with respect to earth, as already discussed.

Solder the diodes onto the power supply tagstrip and wire the electrolytic capacitors, standby switch, screen resistors, power switch and bias supply. When the power supply wiring is complete check it thoroughly and re-check the polarity of all the diodes and electrolytic capacitors and the connections of the 100k bleed resistors.

Turn the unit on without any valves inserted. If everything seems to be OK (no smoke!) take a meter, with well insulated test probes, and check all the voltages across the electrolytic capacitors. The three electrolytics in series should have equal voltages across them. OK? Turn the unit off and wait for a minute. Then take a screwdriver and short out all the capacitors. If the bleed resistors are working the capacitors should already be discharged. Even so, always repeat this operation when you are working on the amplifier, as bleed resistors sometimes fail and the capacitors can give you a very nasty shock. Now insert the valves and turn on again to check that the heaters are working. Turn it off (and short the capacitors).

If all is well with the power supply, start wiring the circuitry around V1 and V2. The input blocking capacitor, C1, is wired between the gain control and the input socket while the resistor, R2, should be placed as close as possible to the grid pin to reduce the possible pick up of RF interference. We found it unnecessary to use shielded cable between the valve socket, gain pot, kill switch and input socket but if your wiring is longer than ours it may be required to avoid hum pickup. However, the feedback wiring should be kept well-away from the input wiring, or HF instability may occur when the feedback is switched out.

Wire the bias circuitry to each of the output valves, making sure that there is no possibility of components shorting together. Use plastic sleeving over the component leads for insurance, because if the bias supply to any tube fails the result is very dramatic! The lk5 resistors in the grids of the output valves are wired between pins 5 and 6 of the valve sockets.; pin 6 is not internally connected and is used as a terminal – and also places this resistor nearest the grids for best supression of parasitic oscillation.

The 10 ohm resistors in the cathodes are wired across the sockets and it is a good idea to wrap the body of the resistor in tape or plastic tube; in the event of a short in one of the valves this resistor will certainly burn up and deposit carbon over the valve socket and surrounding circuitry, which would then have to be replaced. Using the tape to shield the fallout will minimise the damage, should a fault occur.

Be careful not to cross the two out-of-phase signals from the phase splitter; the signal from the cathode must go to the grid of V2b and the signal from the anode must go to the grid of V2a. Also be careful not to cross the primary windings of the output transformer; pin 3 goes to the V3 and V4 anodes and pin 1 goes to V5 and V6 anodes. If these connections are crossed, the phase of the output will be reversed, the beedback will become positive and the amplifier will become a higher power oscillator!

The power supply is quite capable of powering auxiliary equipment such as a valve pre-amplifier, and a power output socket can be mounted on the rear panel. The 400 V rail will be able to supply about 70 mA and the three amp heater winding will supply 2.4 amps.

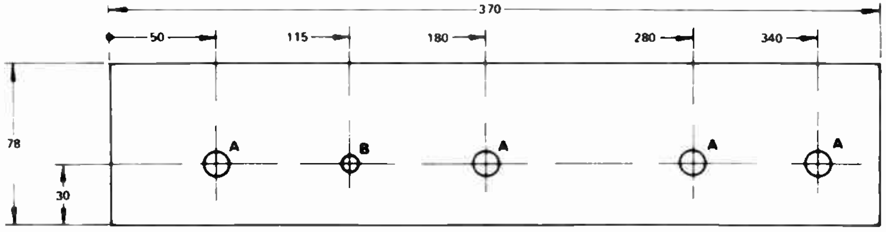
## Powering up

There's one good thing about valve circuitry – it's very obvious if something's wrong – but re-check everything thoroughly in any case.

Turn the amplifier on without any valves inserted first, and check the power supply voltages. To check the bias on pin 5 of each output valve, set all pots for maximum bias (counterclockwise), turn down the gain pot, then connect a speaker and plug in the valves. Turn on the amplifier and set each bias pot for 0.25 volts across each of the 10 ohm cathode resistors. If anything unusual happens turn off the amp immediately and re-check the wiring! If not, connect a signal to the input, advance the gain pot and you're ready to rock!

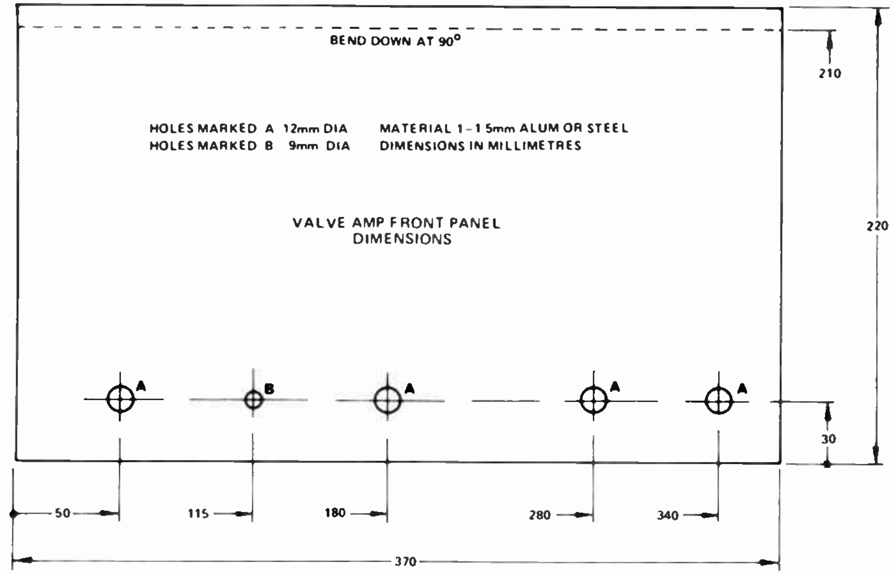
## A note on speakers

If you plan on using the "Rocker" as a guitar amplifier, we strongly recommend using loudspeakers specifically designed for the purpose, rated to at least 200 watts. These speakers are extremely rugged, with aluminium voice coils designed to withstand the very high power levels generated by guitarists. If you use the amplifier for hi-fi reproduction, be careful not to drive it into clipping. The onset of clipping will not be as harsh and as evident as it would be with a transistor amplifier and you may be doing irrepairable damage to your speakers without knowing it. We strongly recomend the ETI-455 speaker protector for any application, as we very quickly blew up a set of 250 watt speakers when the amplifier was overloaded. ●

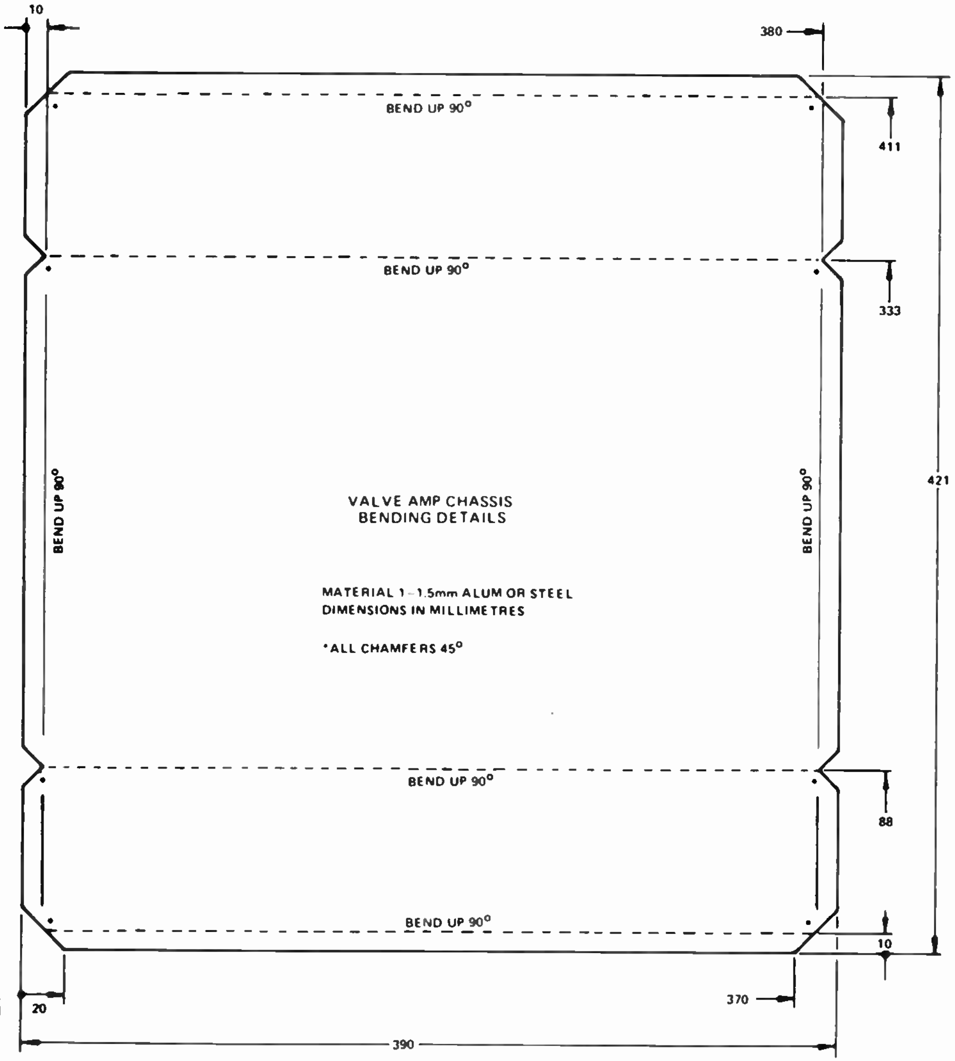


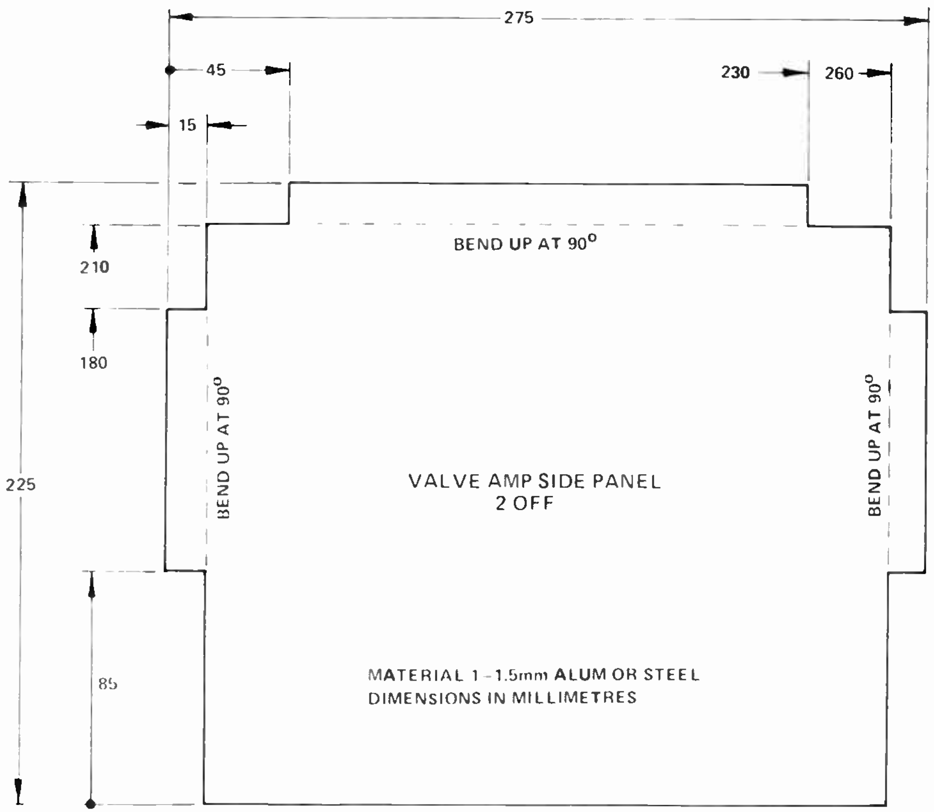

VALVE AMP CHASSIS FRONT LAYOUT DIMENSIONS

DIMENSIONS IN MILLIMETRES HOLE MARKED B 9mm DIA HOLES MARKED A 12mm DIA




**NOTES: a base plate, measuring 370 x 245 mm is necessary. Suitable rubber feet may be mounted on it. The top cover is made from Lysaght 'Multimesh' expanded aluminium. It covers the top of the unit and folds down the rear to the chassis top.**



# Series 4000 four-way loudspeaker

David Tilbrook

This project is the first in a series of loudspeaker projects designed to complement our Series 4000 range of quality hi-fi projects.

LOUDSPEAKERS still remain the weakest link in the hi-fi chain and the total sound of any system will depend more on the loudspeakers than any other single hi-fi component. So it is important to get the best loudspeakers, even if this means accepting a slightly lower performance amplifier or turntable. In most systems the performance of the cartridge, turntable and amplifier greatly exceeds that of the loudspeakers so an improvement in the loudspeaker department will often yield a radically improved system.

Unfortunately, there are very few really good kit loudspeakers. This project is an attempt to rectify that situation by providing a loudspeaker suitable for home construction that rates amongst the best available. This is not an inexpensive project – the driver and crossover cost being around $400 – but the finished project will rival commercial units at three times the price.

## Choosing the drivers

In order to build a good loudspeaker it is obviously important to use good drivers, but availability is just as important a criterion as performance. For this reason we had a close look at the drivers commonly available in Australia and finally decided to use drivers from the huge range of Philips loudspeakers, some of which were not available in this country at that time. Philips agreed to stock the drivers we decided on and these form the basis of the 4000 series of loudspeakers.

The 4000/1 is a four-way sealed enclosure loudspeaker using 12 dB/octave crossover slopes. The original design for our prototype used an 18 dB/octave M-derived crossover (see 'Principles and problems in loudspeaker design' in Jan '80 and Feb '80 ETI issues) but it was enormously expensive and complex and would have contributed little to the overall sound finally achieved with the 12 dB/octave crossover. The four-way approach allows closer control over the final frequency response than does a three-way. More importantly a major part of the mid-range normally handled by the woofer can be dedicated to a separate mid-range driver. The basic design idea was to use the woofer only up to 150 Hz. A separate mid-range driver would then take over up to 750 Hz where a second mid-range would come in. The lower mid-range driver, crossing in at 150 Hz needs a usable response down to around 60 Hz (i.e. one octave) so that the crossover region will have a reasonably flat response. Similarly, the woofer crossing out at 150 Hz needs to have a usable response to at least 300 Hz.

After a great deal of testing it was finally decided to use the Philips AD12250/W8 unit for the woofer. This is a 100 watt driver with a free air resonance of 26 Hz. When mounted in the enclosure the fundamental resonance rises to around 31 Hz, an excellent figure. This driver seems to have a bad hole in its response at 350 Hz but this is unimportant in this loudspeaker.

The AD70601/W8 unit was chosen as the lower mid-range as it has a free air resonant frequency at 45 Hz. This driver is actually a woofer and does not have the integral sealed enclosure common to many mid-range drivers. The enclosure must be provided by the cabinet construction and the volume chosen in the 4000/1 increases the 45 Hz fundamental resonance of this driver to around 55 Hz, which is ample.

The response between 750 Hz and 3 kHz, where the tweeter takes over, is handled by the latest Philips dome (AD02161/SQ8) mid-range. This driver has a 50 mm textile dome giving a good frequency response and wide dispersion at higher mid-range frequencies.

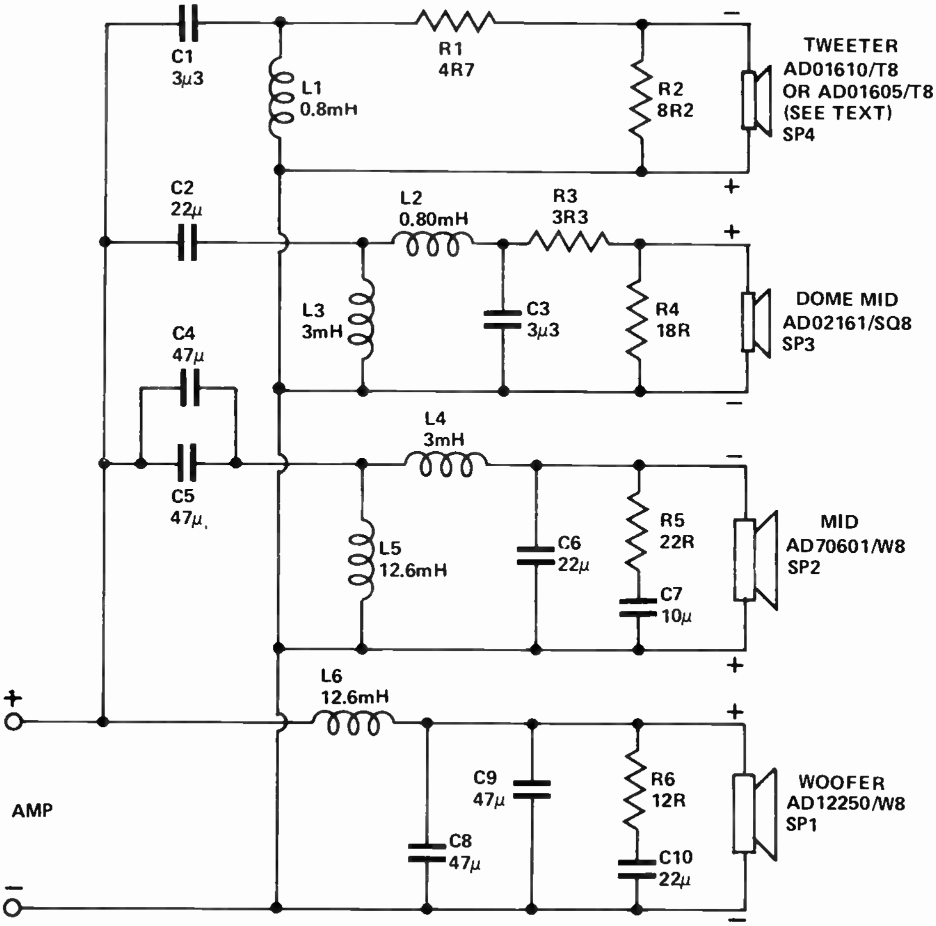
Above 3 kHz the AD01610/T8 tweeter is used. We tested a large range of Philips tweeters and this was the best, followed closely by the AD01605/T8, which suffered a little from roll-off of the frequencies above 10 kHz.

The 4000/1 loudspeaker, without the front grille, showing the drivers. It stands about one metre tall.

## Construction

If you are constructing the boxes yourself start by assembling the sides, top, bottom and back of the cabinet. The bottom panel is placed 100 mm above the bottom of the box and the cavity formed under the box can be used to mount the crossover instead of putting it inside the box as is the usual practice. Now insert the two pieces of timber that form the mid-range enclosure. It is essential that there is a perfect seal between the bass and mid-range chambers, as well as between these two chambers and the outside air. Line every joint carefully with caulking compound

> **HOW IT WORKS.**
> The input signal from the output of the amplifier is fed to the 4 way crossover that divides the signal into the 4 different frequency bands covered by each of the drivers. The loudspeaker cabinet is divided into two sections, the larger one forming the bass chamber for the woofer and the smaller one forming the midrange chamber. These two chambers are sealed from each other so that interactions cannot occur between the back radiations of the woofer and lower midrange. The other two drivers have their own enclosures as an integral part of the driver. For a detailed account of the design approach and the problems that occur in loudspeaker design, read 'Principles and problems in loudspeaker design' in Jan '80 and Feb '80 issues of Electronics Today International.




**Circuit diagram for the four-way system. Driver polarity is important. Note that the "dome mid" driver, AD02161/SQ8, is available in two models, the other being AD02160/SQ8, which is different in appearance but electrically equivalent.**

or glue so that no possiblity of an air leak exists. This is probably the best stage of the construction to drill the holes for the wiring to the loudspeakers. I used two cores of 240 volt three-core mains cable for this purpose, mainly because a round hole could be drilled and the cable squeezed through it to make a reasonable seal. Three holes need to be drilled in the bottom of the midrange chamber to allow for cables for the two midrange drivers and the tweeter. Cut suitable lengths of 240 V mains cable and insert these through the holes. Seal between the cables and the holes with sealing compound or a glue like Silastic. If the crossover is to be mounted under the loudspeaker, drill four holes through the bottom of the box and run the cables exactly as with the mid-range enclosure. Drill the holes so that they are closer to the rear of the box to allow ample room for mounting of the crossover. The input terminals should be mounted on the back of the enclosure, below the bottom panel if the crossover is mounted under the loudspeaker.

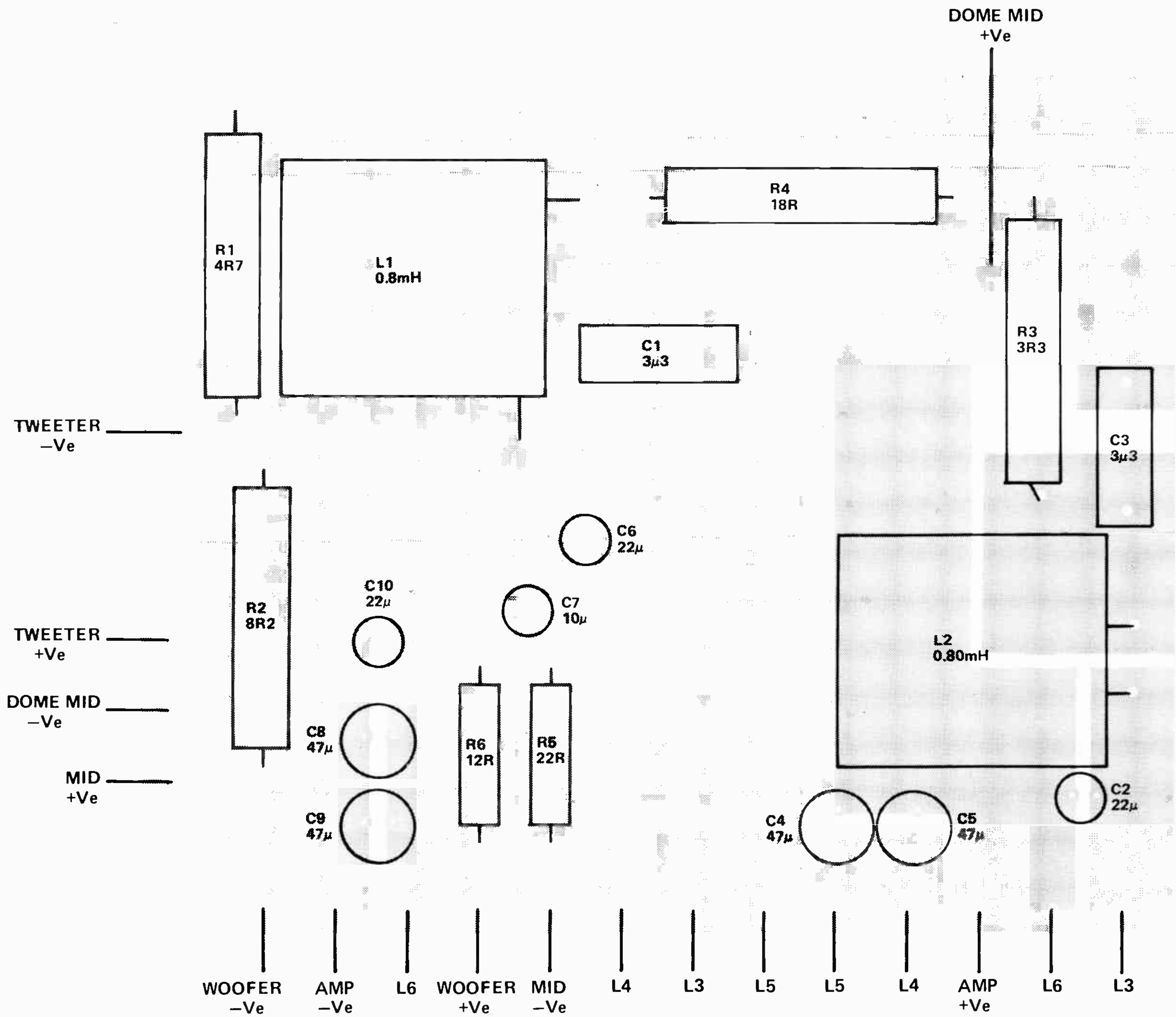
It is not necessary to have the front baffle removable since the drivers are external mounting types. It is probably easier to cut the holes for the drivers before mounting the baffle onto the front of the cabinet. The base panel and midrange enclosure panel should have been cut so that 38 mm remains between these and the front edge of the side and top panels. When the front panel is fitted, 19 mm should remain between the front of the baffle and the front edge of the sides and top. This space will be taken up by the grill cloth frame. Seal the remaining joints between the front baffle and the rest of the box. The only remaining part of the box construction is to attach the small 100 mm high wooden panel to the bottom of the box. The front grill is made by constructing a rectangular frame that fits into the remaining cavity on the front of the baffle. Stretch the grill cloth (use proper speaker grill material to avoid absorption of the treble) tightly over the frame.

If you have purchased a kit of ready made boxes it will still be necessary to drill the holes for the cables and to seal the box thoroughly with some sealing compound. If the slightest leak exists between the bass and mid-range chambers the large pressure increases created in the bass chamber will force the mid-range to vibrate, causing distortion.

The last stage before mounting the drivers is to line the box with 25 mm thick loudspeaker innerbond. Line the back, sides, top and bottom of both the bass and mid-range chambers. Attach the innerbond firmly to the sides of the box using tacks or thin nails and glue.

The tweeter and dome mid-range drivers are supplied with mounting washers so that good seals can be made between the drivers and the baffle. Use adhesive foam tape available from most hardware stores, to make a good seal around the lower mid-range unit and the woofer. Stick the tape to the front of the baffle around the edge of the holes cut for the woofer and mid-range so that when the drivers are mounted a good seal results.

Solder the wires to each of the drivers making sure you know which wire is connected to the positive terminal on the loudspeaker. This terminal is marked on the driver either by a red terminal or a red dot near one of the terminals. Mark the other ends of the cables so that it is clear which cables connect to which drivers. *This is important;* if the outputs of the cross-over are connected to the wrong drivers ▶

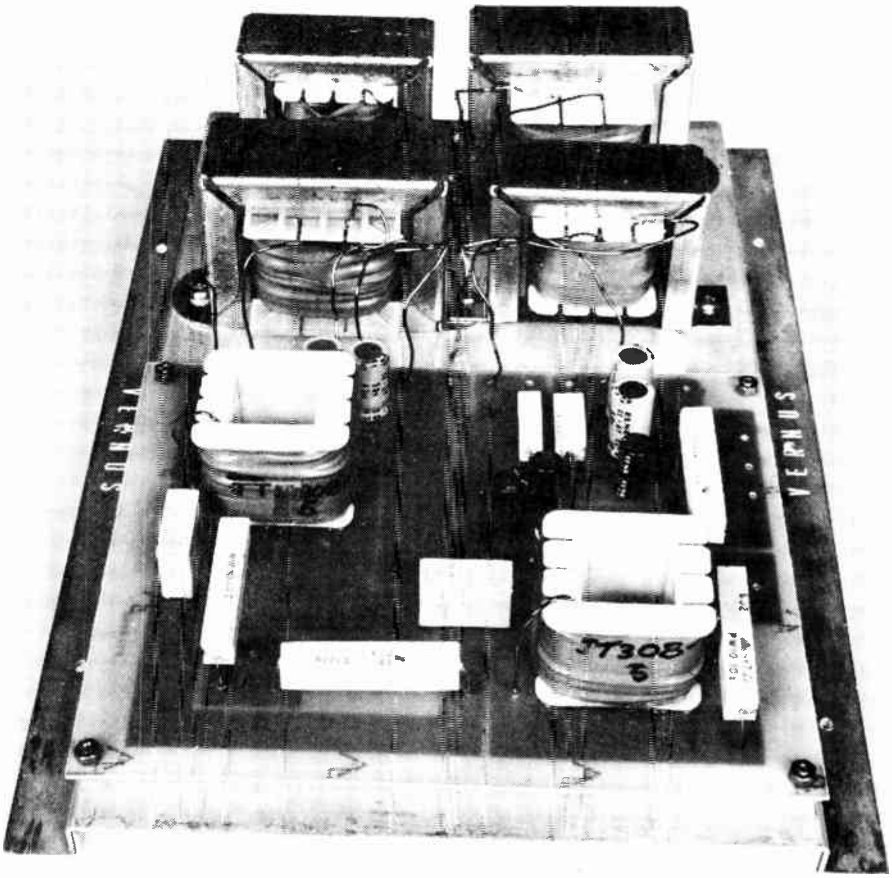


DOME MID +Ve
R1 4R7
L1 0.8mH
R4 18R
C1 3μ3
R3 3R3
C3 3μ3
TWEETER –Ve
R2 8R2
C6 22μ
C10 22μ
C7 10μ
L2 0.80mH
TWEETER +Ve
DOME MID –Ve
MID +Ve
C8 47μ
C9 47μ
R6 12R
R5 22R
C4 47μ
C5 47μ
C2 22μ
WOOFER –Ve
AMP –Ve
L6
WOOFER +Ve
MID –Ve
L4
L3
L5
L5
L4
AMP +Ve
L6
L3

this could result in damage to the drivers.

Once all of the drivers are mounted the final stage is the construction and mounting of the crossover. If the cross-over is mounted inside, instead of under the box it will be necessary to leave mounting of the woofer until last. After all of the drivers have been mounted connect a 1.5 volt battery to the woofer wires and watch the lower mid-range cone. If it moves, the seal between the bass and mid-range chambers is not complete.

The inductors used in the crossover are too big to be mounted on the pc board. All the other crossover components are on the pc board. Start construction of the crossover by



We mounted the crossover network assembly on an aluminium plate, bent as shown. The whole assembly was then screwed to the bottom of the loudspeaker and each driver connected as per the overlay.

### PARTS LIST - ETI 496

**The following is a parts list for one only loudspeaker so two of every component will be needed for a stereo pair.**

**Drivers**
SP1 . . . . . . . Philips AD12250/W8
SP2 . . . . . . . Philips AD70601/W8
SP3 . . . . . . . Philips AD02161/SQ8
Philips AD02161/SQ8 or AD02160/SQ8
SP4 . . . . . . . Philips AD01610/T8 or AD01605/T8, see text.

**Inductors**
L1, L2 . . . . . 0.8 mH max dc resistance 0.5 R
L3, L4 . . . . . 3.0 mH max dc resistance 0.5 R
L5, L6 . . . . . 12.6 mH max dc resistance 0.7 R

**Capacitors**
C1. . . . . . . . 3μ3 polycarbonate
C2. . . . . . . . 22μ bipolar electrolytic 50 V
C3. . . . . . . . 3μ3 polycarbonate
C4, C5 . . . . . 47μ bipolar electrolytic 50 V
C6. . . . . . . . 22μ bipolar electrolytic 50 V
C7. . . . . . . . 10μ bipolar electrolytic 50 V
C8, C9 . . . . . 47μ bipolar electrolytic 50 V
C10. . . . . . . 22μ bipolar electrolytic 50 V

**Resistors**
R1 . . . . . . . 4R7 10 W 5%
R2 . . . . . . . 8R2 10 W 5%
R3 . . . . . . . 3R3 10 W 5%
R4 . . . . . . . 18R 10 W 5%
R5 . . . . . . . 22R 5 W 5%
R6 . . . . . . . 12R 5 W 5%

**Miscellaneous**
pc board . . . . ETI 496
Wire, one pair of spring terminals, particle board, screws, glue, etc.
Speaker grill cloth, innerbond.

mounting and soldering the capacitors to the pc board. Next solder the resistors into place spacing them approximately 10 mm off the board. This is necessary to prevent charring the pc board should these resistors get hot when the speaker is used with high power amplifiers. The remaining two inductors should be glued onto the pc board and then the leads soldered.

The prototype crossover was mounted on a sheet of aluminium 200 mm by 330 mm, but this is optional. If you elect to use this method of construction screw the remaining four inductors onto the aluminium sheet and solder the leads from these onto the pc board. Solder the leads from the drivers and input terminals onto the pc board and mount the pc board onto the aluminium base using 6 mm spacers. Finally, the whole cross-over can be screwed to the bottom of the loudspeaker box. If you are not using the aluminium base the pc board and inductors are mounted directly to the bottom of the loudspeaker box. The advantage of using the aluminium base is so that the crossover can be handled as one complete unit.

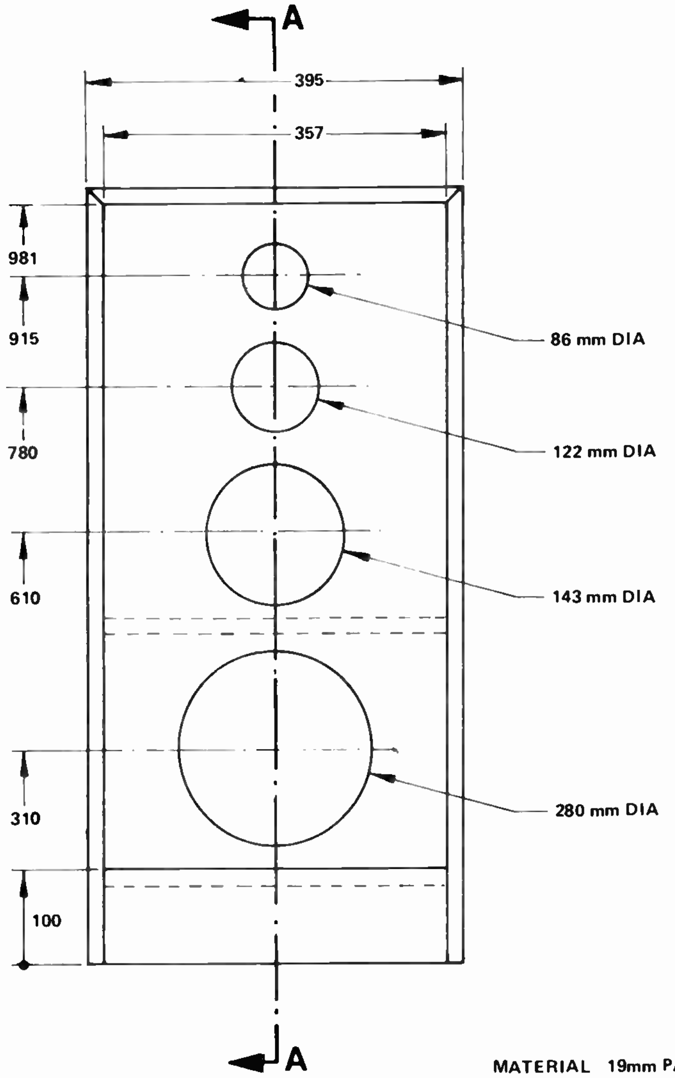
## Powering up

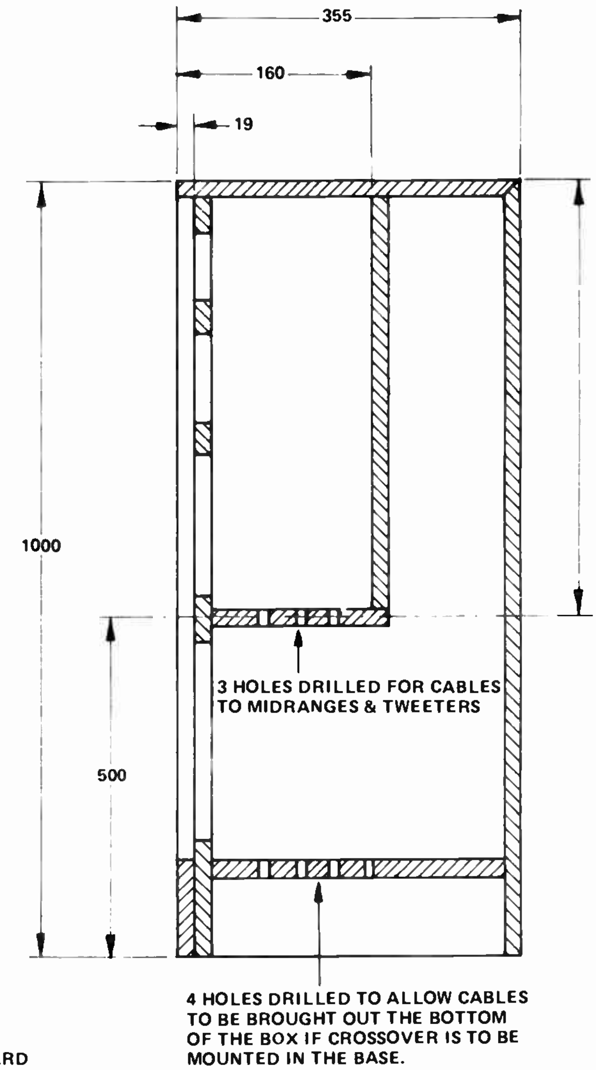
Before connecting the loudspeaker to an amplifier touch the input of the loud-speaker to a *single 1½ volt* penlight battery. With the positive of the battery connected to the positive input (red terminal) of the loudspeaker the woofer cone should move forward and the loud-speaker should make a loud thump. Listen to all the drivers separately while connecting and disconnecting the battery to check that all of the drivers are operating. Don't use a battery any bigger than 1½ volts for this test or you could damage the woofer.

If all is well, connect the speakers to an amplifier and turn the volume up slowly.

## Performance

Power handling figures for loudspeakers ▶




**Complete cutting and assembly details for the four-way loudspeaker box. It is important that all joints be well sealed.**

MATERIAL 19mm PARTICLE BOARD

ALL DIMENSIONS ARE IN MILLIMETRES

NOT TO SCALE

SECTION AA

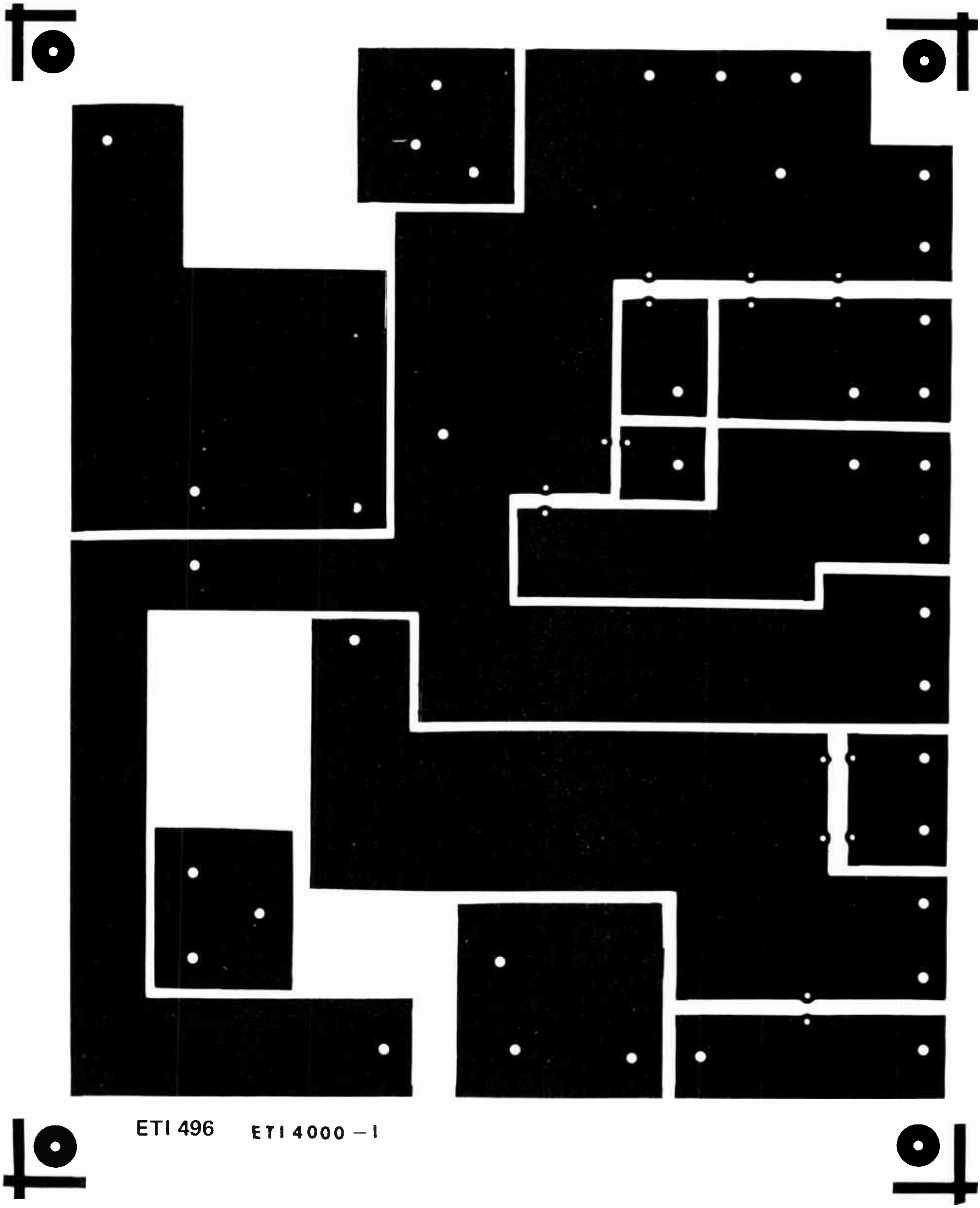
are a very dubious quantity. Some manufacturers (not many) quote continuous sine wave power handling at a particular frequency, but it is doubtful that this is a really meaningful figure. Probably the best way of measuring power handling is with pink noise. This is a type of noise which contains equal energy per octave over the entire audio range. Using this technique, these loudspeakers are rated at 100 watt power handling. The bipolar electrolytic capacitors used in the crossover are rated at 50 volts. This corresponds to 156 watts into an 8 ohm load so this should be considered the *absolute maximum* power for the loudspeaker. It is sometimes mistakenly thought that the power handling figure represents the power below which the loudspeaker cannot be damaged. The most dangerous condition for any loudspeaker is a heavily clipping amplifier. In this state the output of the amplifier approaches dc and even a 20 watt amplifier can do irreparable damage if operated incorrectly.

Your ears are the best indication that the loudspeakers are operating safely. If the sound becomes distorted or unpleasant at higher power levels, turn down your amplifier. Nine times out of ten it will be the amplifier and not the loudspeaker that is running out of power.

The 4000/1 loudspeaker has been designed in accordance with extensive tests that reveal the "ideal" frequency response characteristics for most listening environments. This response is not flat but has a tapered top end, so that the extreme treble is attenuated slightly with respect to the mid-range and bass.

The subjective test revealed just how good the loudspeakers are. The frequency response is smooth and extended and the bass and treble are present only when they should be!

Above all, the sound is clean and easy to listen to for extended periods, even at very high listening levels. I hope you get as much enjoyment from your 4000/1 speakers as I have. ●


ETI 496
ETI 4000 — I


# Series 3000 compact stereo amplifier

**Phil Wait**

"Small is beautiful" when you have a premium on space, but there's no need to sacrifice performance. This amp delivers 20 W/channel, has low distortion and costs less than $90!

THE TREND to living in 'compact' accommodation such as units, town houses and inner city terraces, has led to a demand for appropriately sized household goods and furniture — including hi-fi equipment. The major hi-fi manufacturers all leapt into this market last year, releasing various combinations of separate components and integrated arrangements generally tailored to a size to stack conveniently on a shelf or bench top and not take up precious space.

This project is aimed at those readers who want something to fill that requirement but want to 'roll their own' to save money or just to gain the satisfaction of having done it themselves.

Apart from that, this project is ideal for the beginner with a little construction experience who wants a 'meaty' project to tackle. This unit is quite simple to build as the majority of components are mounted on a single printed circuit board and the interwiring has been simplified with the use of 'ribbon' cable.

Despite the low price, compared to other such projects around, this unit is not a 'cheap' amplifier. The performance is demonstrably better than similar amplifiers that cost a great deal more and it can be teamed with some of

## SPECIFICATIONS

**Power output**
25 W RMS, one channel driven
20 W RMS, both channels driven

**Distortion** (refer to graph)
1 kHz: 0.03% @ full power
0.013% @ 12W RMS
10 kHz: 0.08% @ full power

**Frequency response**
Phono: within 1 dB, RIAA
Other inputs: within ±0.5 dB
from 10 Hz to 20 kHz; −3 dB @ 40 kHz

**Hum**
Phono: −60 dB w.r.t. 10 mV input
Other inputs: −70 dB w.r.t. 200 mV input

**Noise**
Phono: −80 dB w.r.t. 10 mV input
Other inputs −86 dB w.r.t. 200 mV input

**Tone controls** (see text)
Bass: ±10 dB @ 50 Hz
Treble: ±10 dB @ 12 kHz

**Slew rate**
15 V/μs

**Separation**
Phono: 46 dB
Other inputs: 40 dB

**Sensitivity**
Phono: 2.5 mV for full output
Other inputs: 200 mV for full output

**Tape output level**
200 mV

our previously published hi-fi projects to obtain quite a respectable hi-fi set up.

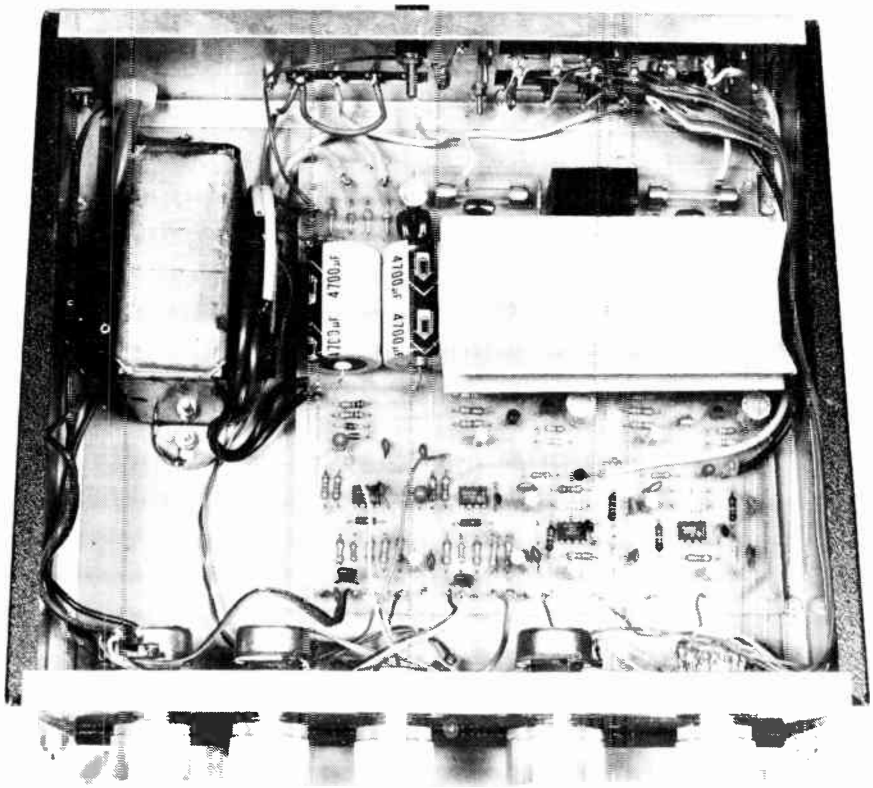
## The design

Overall design is fairly conventional, except for the output stage, but we have paid attention to such details as transient intermodulation and slew limiting distortion as well as keeping total harmonic distortion within acceptably low limits.

The preamp stages employ common integrated circuits op-amps. The power amplifiers employ a differential input stage driving a complementary-symmetry class-B power stage. The output devices are TIP31C/TIP32C 'flatpack' transistors arranged such that a simple heatsink can be mounted on the pc board — which can be seen in the internal photograph. A conventional transformer/bridge rectifier power supply is used and speaker anti-thump circuitry is provided too.

The output stage of each channel is capable of delivering 25 watts (single channel) into an 8 ohm load. If you're building the amplifier as a Christmas present for your kids, in the interest of tranquillity, family relations and the sanity of the family cat(/dog/budgie/goanna) the power output might seem 15 - 20 watts too much. By the simple expedient of using a lower voltage transformer and changing a few resistors, the amp will deliver only five watts(*). This also reduces the heatsink requirement and the overall price (as the transformer's less expensive). The two different types of transformer are given in the parts list.

*Psst — kids. If the old fella has built you a five watt amp you can make it up to a 20 W/ch amp without much fuss. Read on.

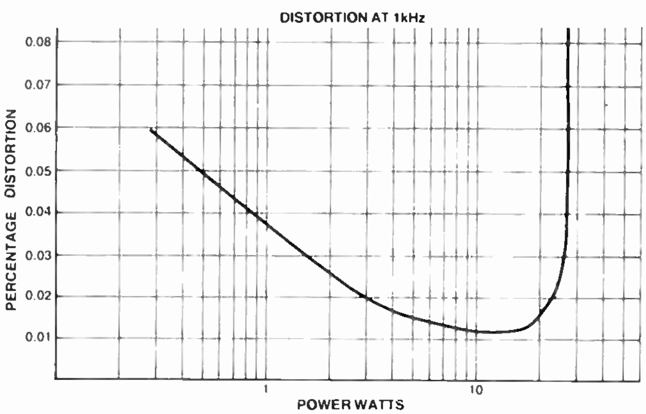


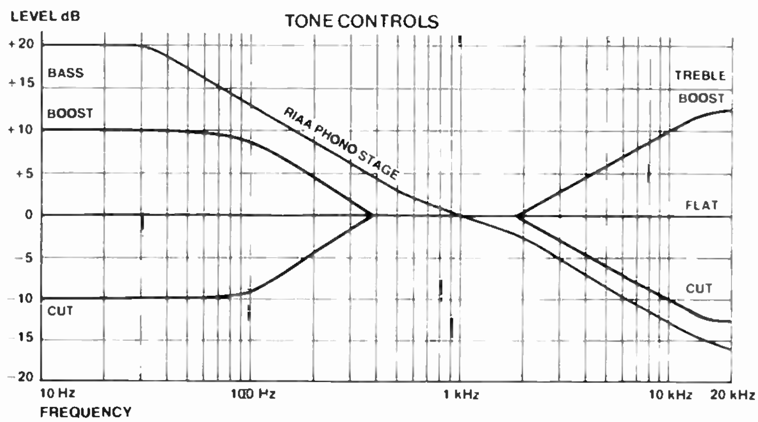
**Internal view of the completed project shows the general layout and obvious simplicity — almost everything's on the pc board. We haven't anything much to say about the external appearance as it speaks for itself! Scotchcal transfers for the front and rear panels will be available from suppliers — see Shoparound on page 150.**

When you turn an amplifier on or off, a loud thump may come from the speaker. This transient may have sufficient energy to destroy the speaker! It is caused by the supply line voltage rising (at switch-on) or falling (at switch-off) at different rates. This may cause the output to the speaker to swing wildly between the positive and negative supply rails under the worst-case conditions — spectacular, but costly if your speakers can't handle it. Consequently, we have provided an anti-thump circuit which only connects the speakers after a short delay whenever the amplifier is turned on. When the unit is turned off, the speakers are immediately disconnected, before the supply rails have a chance to fall appreciably.

## Construction

We chose to assemble the amplifier in a Horwood instrument case measuring 255 mm by 255 mm by 78 mm overall. These are supplied with black, vinyl covered steel top and side panels and plain aluminium front and rear panels. Handles are attached either side of the ▶



## HOW IT WORKS — ETI 476

This amplifier employs common IC op-amps in the phono and preamp stages driving a class-B power amplifier employing discrete circuitry. The power supply is conventional, employing a transformer and bridge rectifier with capacitor-input filters to derive positive and negative supply rails and incorporating a speaker anti-thump circuit.

The following description applies to one channel only as both channels are identical, except for component numbering. Components are numbers IC1, R1, C1 etc in one channel, IC101, R101, C101 etc in the other. Ganged controls are labelled SW1a, b or RV1a, b etc.

### PHONO STAGE

The phono input, from a moving magnet turntable cartridge, is applied to the input of IC1, an LM301, via an R-C network (C1, R1) which provides a roll-off at subsonic frequencies. The feedback network for IC1 (R3, R4, R5, R6 and C4, C5) provides the correct RIAA compensation. Output from this stage goes to the Source switch, SW1, via C7/R7.

Resistor R7 maintains the negative side of C7 at 0 V to prevent speaker thump when operating the Source switch. The purpose of C6 is to reduce the gain of IC1 to unity at dc so that the dc offset at its output is maintained at a low value.

Capacitor C3 provides stability compensation for IC1. Resistor R2 and capacitor C2 provides RF interference immunity for the input of IC1.

Overall gain of the phono amp is about 300 and is designed to provide full power output with 2.5 mV RMS input at 1 kHz.

### PREAMP-TONE CONTROL

The Source Switch selects the various inputs, applying them to the Volume Control, RV1, via the Tape Monitor Switch, SW2.

Output from the Volume Control passes to the input of the preamp-tone control stage via C8. Conventional tone control circuitry around the feedback of IC1 provides boost and cut at 12 kHz for Treble and 50 Hz for Bass. However, unlike conventional controls we have only provided a range of +/− 10 dB for reasons explained in the text.

General gain for this stage is around 10, and input sensitivity is 200 mV RMS for full power output. The slew rate for this stage has been set at 15 V/us so that it is slower than the power amplifier. This has been done by selecting the value of the compensation capacitor, C11 to limit the speed to that required. The R-C network formed by R15 and C12 provides additional slew rate limiting at the output of the tone control stage. This technique avoids transient intermodulation distortion developing in the power amplifier.

### POWER AMPLIFIER

Keen-eyed readers will recognise similarities between this circuit and the ETI-452 Guitar Practice Amplifier (Jan 1980) and the ETI-453 General Purpose Amplifier Module (April 1980). There's no need to re-invent the wheel!

Ten transistors are employed (Q1 to Q10) in a discrete component design. Transistors Q1 and Q2 form a differential input stage. Q4 provides a constant current source for the input stage emitters, biased by R24 and LED1.

Output from the preamp-tone control stage is applied to the Balance control, and thence to the input of the power amplifier stage via C13 to the base of Q1. The collector of Q1 is directly coupled to the base of Q3, an emitter follower which is directly coupled to the base of the pre-driver, Q5. Diodes D1, D2 and D3 maintain about 1.8 V between the bases of Q7 and Q8. Each of these transistors will drop about 0.6 V across their base-emitter junctions. This leaves a total of 0.6 V to be dropped across the two 100 ohm resistors R27 and R28. Since these are of equal value, each drops 0.3 V and holds this across the base-emitter junctions of Q9 and Q10, the output transistors. As these two transistors require 0.6 V to be biased on, they will remain off until the applied signal raises the voltage on the bases above 0.6 V (with respect to 0 V). Only a little more than 10 mA through R27 and R28 will supply the extra 0.3 V to turn on the output transistors.

Transistor Q6 provides a constant current sink (or source, depending on your point of view) for the collector current of Q5, increasing the gain of the drive stage, Q5, and decreasing distortion. There is approximately a one volt drop across R26 (and incidentally, R19).

Emitter ballast resistors are included in the output stage, these being resistors R29, 30 and R31, 32. Their main purpose is to help prevent thermal runaway in this application and stabilise the gain of each output transistor. They play a secondary role as fuses in the event of a fault condition causing heavy conduction in the output devices. Hence, the text advises these resistors be mounted up off the pc board on their leads.

Negative feedback is supplied by the potential divider formed by resistors R23 and R20. The capacitor C3 represents a short circuit to the common rail (0 V) for ac signals in the audio range. Gain of the stage across the audio range is thus the ratio of R23 to R20, about 12 in this case. At very low frequencies the impedance of C3 increases, decreasing the gain of the power amplifier by increasing the amount of negative feedback. Capacitor C16 increases the speed of the ac feedback at high frequencies.

The base of Q1 is tied to 0 V and as the whole amplifier is dc-coupled, the quiescent output voltage will be held to a value less than about 50 mV.

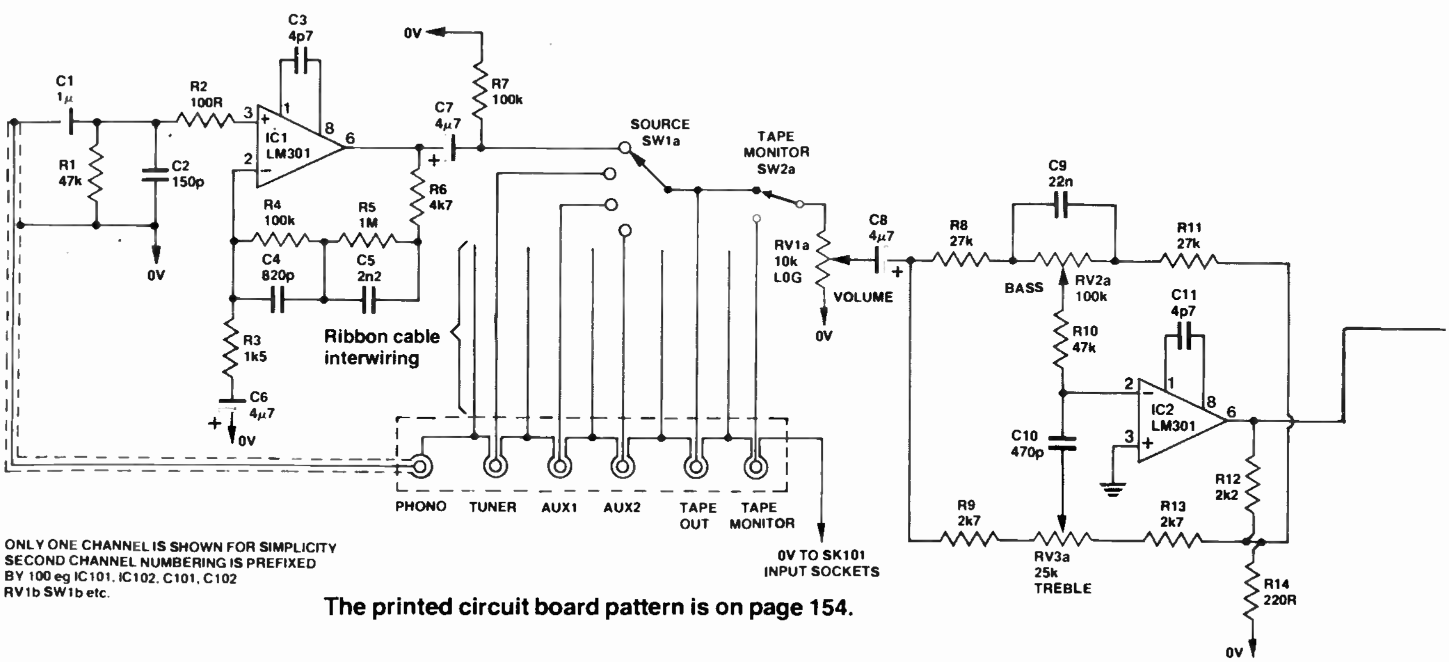
Output from the power stage is taken via a set of contacts on the anti-thump relay and a 2 A fuse, for speaker protection. The R-C network R33 and C17 provides output phase lage compensation.

The output stage devices — a TIP31C and complementary TIP32C — operate in pure class-B, the effects of crossover distortion being reduced by the feedback arrangements. These devices will deliver 25 W into an 8 ohm load. Only a modest heatsink is required as quiescent dissipation is low. The output devices are operated close to their SOAR limit under certain conditions, but no problems should arise. Lower power output can be arranged by reducing the supply rail voltage (see text).

### POWER SUPPLY

The 240 Vac mains input is applied to the primary of the power transformer via the power switch, SW3, which isolates both active and neutral leads. A 'spike' suppression capacitor (C26) is connected on the mains input side of the power switch.

The secondary of the mains transformer consists of two windings connected in series, the 'centre tap' providing the 0 V return line. A bridge rectifier comprising diodes D4 to D7 provides positive and negative supply rails. The main supply rail voltages will depend on the transformer chosen for the desired power output as per the text.




The printed circuit board pattern is on page 154.

Smoothing for each supply rail is provided by C20 and C21. Capacitors C22 and C23 reduce the supply rail impedances at high frequencies. The phono and preamp-tone control stages require +/− 12 Vdc supply rails and these are derived by conventional shunt zener regulators involving R36, R37, ZD1 and ZD2. Capacitors C24 and C25 provide bypassing for these supply rails. LED2 is a 'power on' indicator.

## ANTI-THUMP

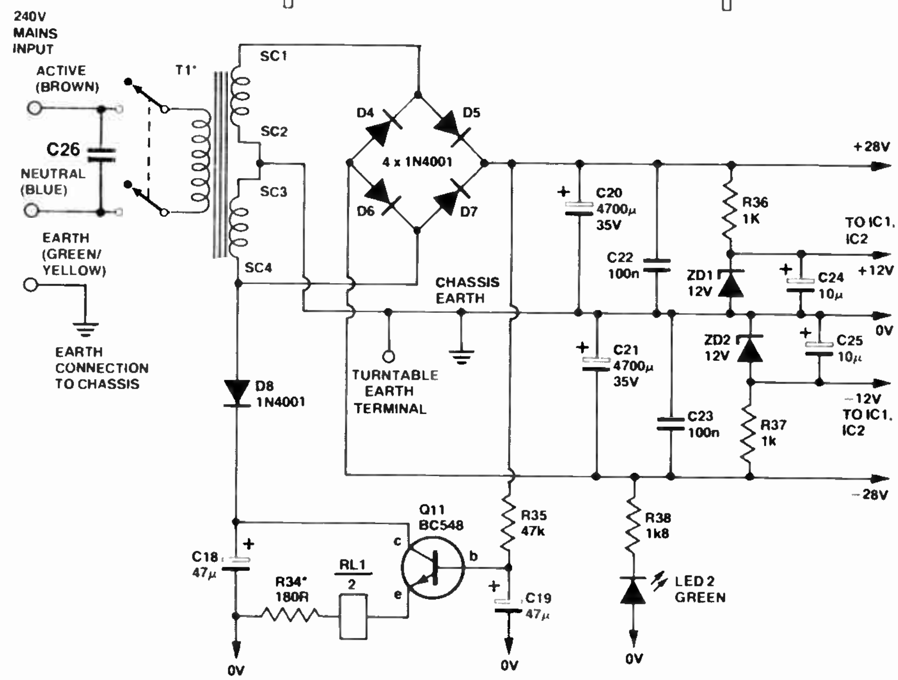
The anti-thump circuit involves D8, Q11, C18 and C19, R34 and R35 plus RL1. The object is to isolate the speakers from the power amplifier until the supply rails have stabilised following switch on and to isolate the speakers once again when the amplifier is turned off, before the supply rails have decayed.

The relay RL1 has two sets of contacts which are connected normally open. These contacts are in series with each channel's speaker output line, between the power output stage and the speaker protection fuse.

At switch on, D8 rectifies one side of the transformer secondary, rapidly charging C18, establishing collector supply for Q11 before the bridge rectifier smoothing capacitors have time to charge to a significant voltage. Until such time as C20 charges to 12 volts, Q11 has no base bias and is turned off. Thus, relay RL1 remains unoperated. As the voltage on C20 rises, capacitor C19 will charge via R35. When the voltage on C19 rises to about 12 V, Q11 will turn on and RL1 will operate, connecting the speakers. The R-C network formed by R35/C19 provides a time delay such that the voltage on C19 will only reach about 12 V after the voltage across C20 has risen to the full supply voltage. The delay is several seconds.

When the unit is switched off, C18 will rapidly discharge and the current through RL1 will drop below that required to hold it operated well before the supply smoothing capacitors (C20 and C21) discharge.

Resistor R34 limits the current through the relay to a safe maximum value when Q11 is on. Note that it is not required if the lower voltage transformer is used.

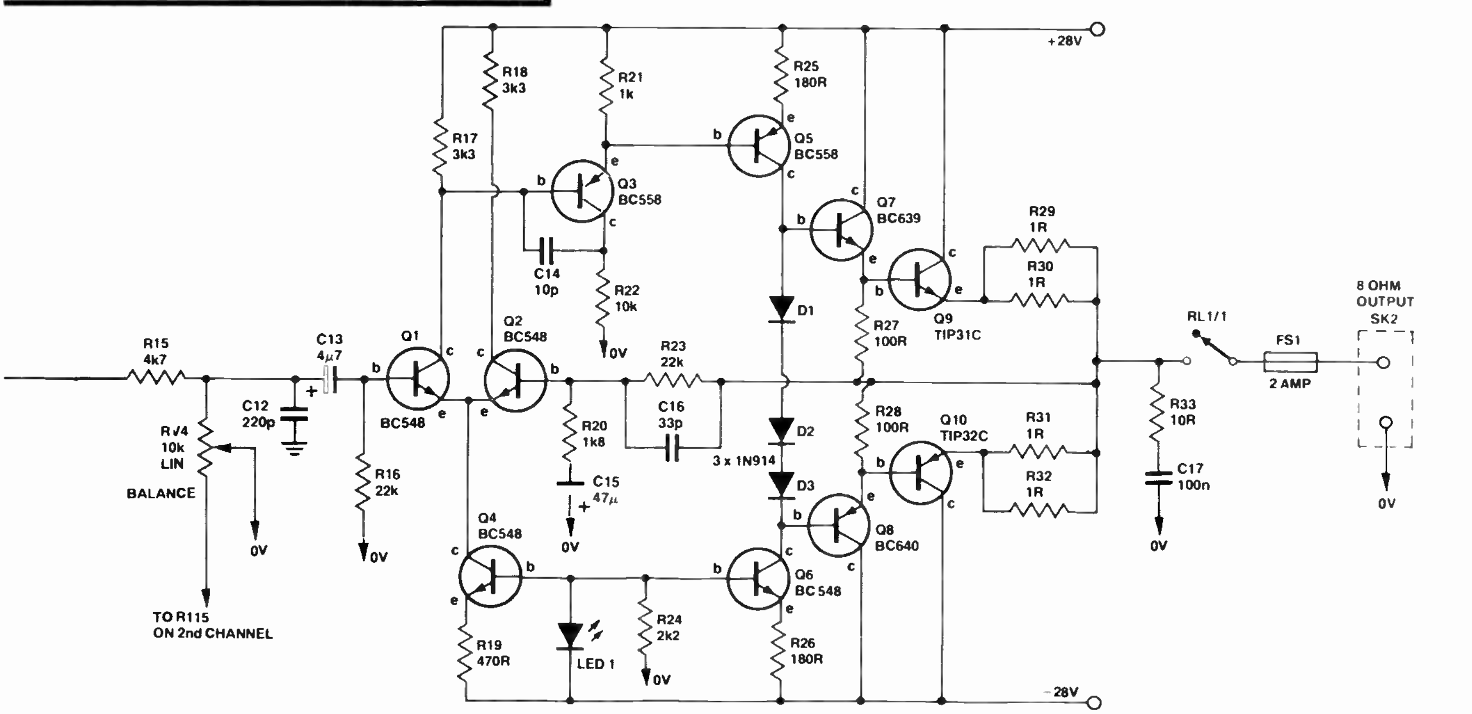



Power supply and speaker anti-thump circuit. A transformer with a secondary rated at 20 - 0 - 20 V at 1.5 A will provide 20 W per channel. For 5 W per channel operation, a 12 - o - 12 V at 0.8 A transformer is required. In the latter case, reduce the values of R36 and R37 to 390 ohms each and short out R34.

front panel and these can be obtained in plain aluminium or black anodised. We made up a black Scotchcal label with white lettering (i.e: 'reverse') for the front panel and used brushed satin aluminium knobs.The whole effect is quite attractive.

The layout of the controls on the front panel is kept quite simple. There are only two toggle switches — power and tape monitor. A stereo/mono switch was thought unnecessary as it would add to the cost and clutter up the simple front panel layout. They are rarely used these days in any case. The rear panel holds the input and output connectors, power cord and an earth terminal for other equipment such as a turntable, headamp or whatever.

We used an internally-mounted heatsink for the four output stage devices, made from a sheet of 16 gauge aluminium. This heatsink is the minimum recommended for 20W/channel opera-▶



tion. If you wish, the output transistors can be mounted on the rear panel, in the space above the speaker output terminals. Their leads may be connected to the pc board with hookup wire or ribbon cable in this case.

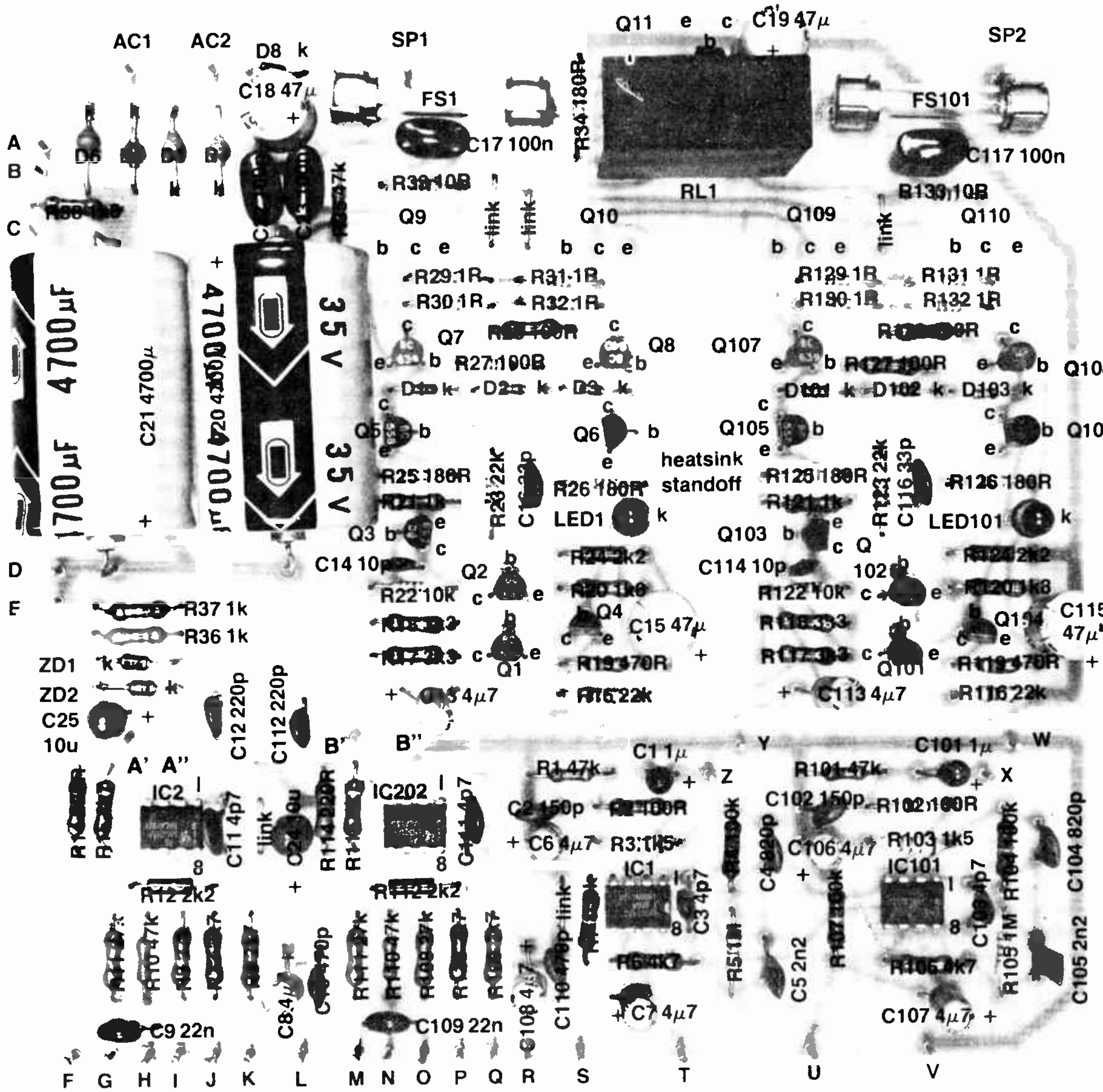
You will notice from the internal photographs that the phono input connection to the pc board is made with shielded cable, but the other inputs are made via a length of 20-wire ribbon or rainbow cable. This cable is wired in a signal-earth-signal-earth fashion so that each signal wire has an earth either side to provide some shielding. This we tried as an experiment and found it very successful. It simplifies the wiring enormously compared to using individual shielded cables. There was only a slight degradation in the crosstalk between channels and no increase in hum levels.

Construction is best commenced by loading the components on the pc board. The overlay photograph shows all the details. Insert the four link wires first. Note that a link should replace R34 if you intend using the lower voltage power transformer. This ensures that 12 V appears across the anti-thump relay coil at the lower voltage, ensuring correct operation.

Next mount all the resistors. Note that, if you're using the lower voltage power transformer, resistors R36 and R37 should be reduced to a value of 390 ohms each. Resistors R27 to R32 and R127 to R132 should be stood about 4 - 5 mm above the board to protect the pc board in the unfortunate event of a fault in the driver or output stages causing overheating of these resistors.

The capacitors can be mounted next. As usual, take care with the polarity of the electrolytic and tantalum capacitors. The lead length on the low value ceramic capacitors C3, C11, C14 and C103, C111, C114 should be kept as short as possible. Mount them so that the body of the component is right down on the pc board. The mains transient suppression capacitor is mounted off the pc board, but this is discussed later.

Now you can mount all the semiconductors, except the output transistors. Here too, take care with the orientation of the devices. The pinouts of the BD639s and BD640s do not have the base lead between the emitter and collector leads like most small signal transistors, so take care with these devices. Pay particular attention to the orientation of the diodes D1 to D3 and D101 to D103 as these set the voltages on the bases of the output transistors. If they are inserted the wrong way round



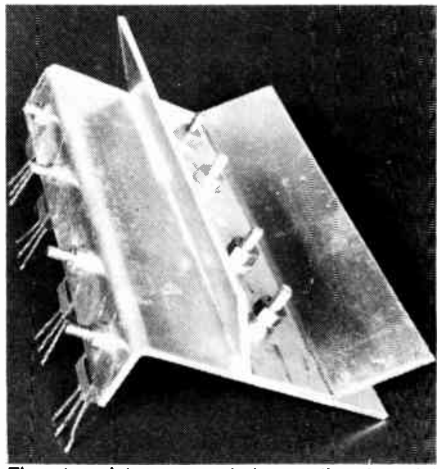
(or are open circuit for some reason) the output transistors won't last long, as we found out to our detriment! Apart from the disappointment, the smell is dreadful! If in doubt, use a multimeter to check the diode. Remember that the *positive* lead of an ohmmeter has the internal battery *negative* connected to it. Thus, this lead will be connected to the *cathode* of the diode when the ohmmeter indicates a low resistance (i.e: diode conducting).

Mount the relay, fuse clips and fuses next. Some fuse clips are hard to solder so to prevent overheating the pc board, first file the plating off the edge of the pins on each clip before you attempt to solder them in.

For all the external connections to the board we used pc board pins. They aren't essential, but they do make it considerably easier to wire the board to the other components. These pins are mounted at this stage.

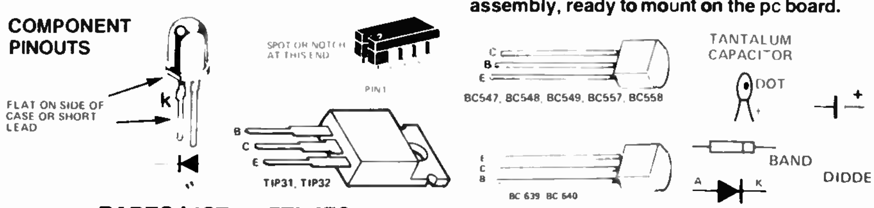
If you haven't already noticed, there are two pads on the board, just above IC2 and IC102, that appear to have no purpose. Circuit-wise, these pads are located at the input to the power stage of each channel and are marked A' and B' on the overlay photograph. By breaking the track between the points marked A' and A", and B' and B", the preamp output and power amp input can be separated to provide connections for "preamp out — main in" sockets so that equipment such as a graphic equaliser may be used in conjunction with this unit. For those readers including this provision, the output impedance of any equipment used to drive the power stages of this unit should be between 4k and 10k.

The output stage transistors are mounted on the board last of all. If you mount them as we have done, drill and bend up the aluminium heatsink first. The accompanying drawing gives all the details. The 'fin' mounts on top of the L piece and the two are held tightly together with four nuts and bolts. Smear thermal compound between the two mating surfaces and insert the bolts with their heads on the side that will face the pc board. Make sure that the surface on which the transistors mount is both smooth and flat. Smooth the surface with emery paper if necessary. By the way, don't paint the heatsink. We painted ours to experiment with colour photographs inside the completed unit and found it adversely affected the thermal capacity of the heatsink. ▶



**The transistors mounted on the heatsink assembly, ready to mount on the pc board.**

**COMPONENT PINOUTS**




## PARTS LIST — ETI 476

**Resistors** all ½W, 5%

| | |
|---|---|
| R1, 10, 35, 101 | 47k |
| R110 | 47k |
| R2, 27, 28, 102 | 100R |
| R127, 128 | 100R |
| R3, 103 | 1k5 |
| R4, 7, 104, 107 | 100k |
| R5, 105 | 1M |
| R6, 15, 106, 115 | 4k7 |
| R8, 11, 108, 111 | 27k |
| R9, 13, 109, 113 | 2k7 |
| R12, 24 | 2k2 |
| R112, 124 | 2k2 |
| R14, 114 | 220R |
| R16, 23, | 22k |
| R116, 123 | 22k |
| R17, 18 | 3k3 |
| R117, 118 | 3k3 |
| R19, 119 | 470R |
| R20, 120, 38 | 1k8 |
| R21, 36, 37, 121 | 1k |
| R22, 122 | 10k |
| R25, 26, 125, 126 | 180R |
| R34 | 180R see text |
| R29 - 32 | 1R |
| R129 - 132 | 1R |
| R33, 133 | 10R |

**Capacitors**

| | |
|---|---|
| C1, 101 | 1u electro or tantalum |
| C2, 102 | 150p ceramic |
| C3, 103, 11, 111 | 4p7 ceramic |
| C4, 104 | 820p ceramic |
| C5, 105 | 2n2 greencap |
| C6, 7, 8, 13, 106 | 4u7, 16V electrolytic |
| C107, 108, 113 | 4u7, 16V electrolytic |
| C9, 109 | 22n greencap |
| C10, 110 | 470p ceramic |
| C12, 112 | 220p ceramic |
| C14, 114 | 10p ceramic |
| C15, 115 | 47u, 16V electrolytic |
| C16, 116 | 33p ceramic |
| C17, 22, 23, 117 | 100n greencap |
| C122, 123 | 100n greencap |
| C18, 19 | 47u, 35V electrolytic |
| C20, C21 | 4700u, 35V electrolytic |
| C24, 25 | 10u, 16V tantalum |
| C26 | 10n to 100n, 240VAC Rated capacitor (value not critical) |

**Semiconductors**

| | |
|---|---|
| IC1, 101 | LM301 |
| IC2, 102 | LM301 |
| Q1, 2, 4, 6, 11 | BC548, BC108 |
| Q101, 102, 104, 106 | BC548, BC108 |
| Q3, 5, 103, 105 | BC558, BC178 |
| Q7, Q107 | BC639 |
| Q8, 108 | BC640 |
| Q9, 109 | TIP31C |
| Q10, 110 | TIP32C |
| D1 - D3, D8 | 1N914, 1N4148 |
| D101 - 103 | 1N914, 1N4148 |
| D4, 5, 6, 7 | 1N4001, A14A or sim. |
| ZD1, 2 | 12V, 400mW zener diode |
| LED1, 101 | red LED, TIL220R or sim. |
| LED2 | green LED TIL220G or sim. |

**Potentiometers**

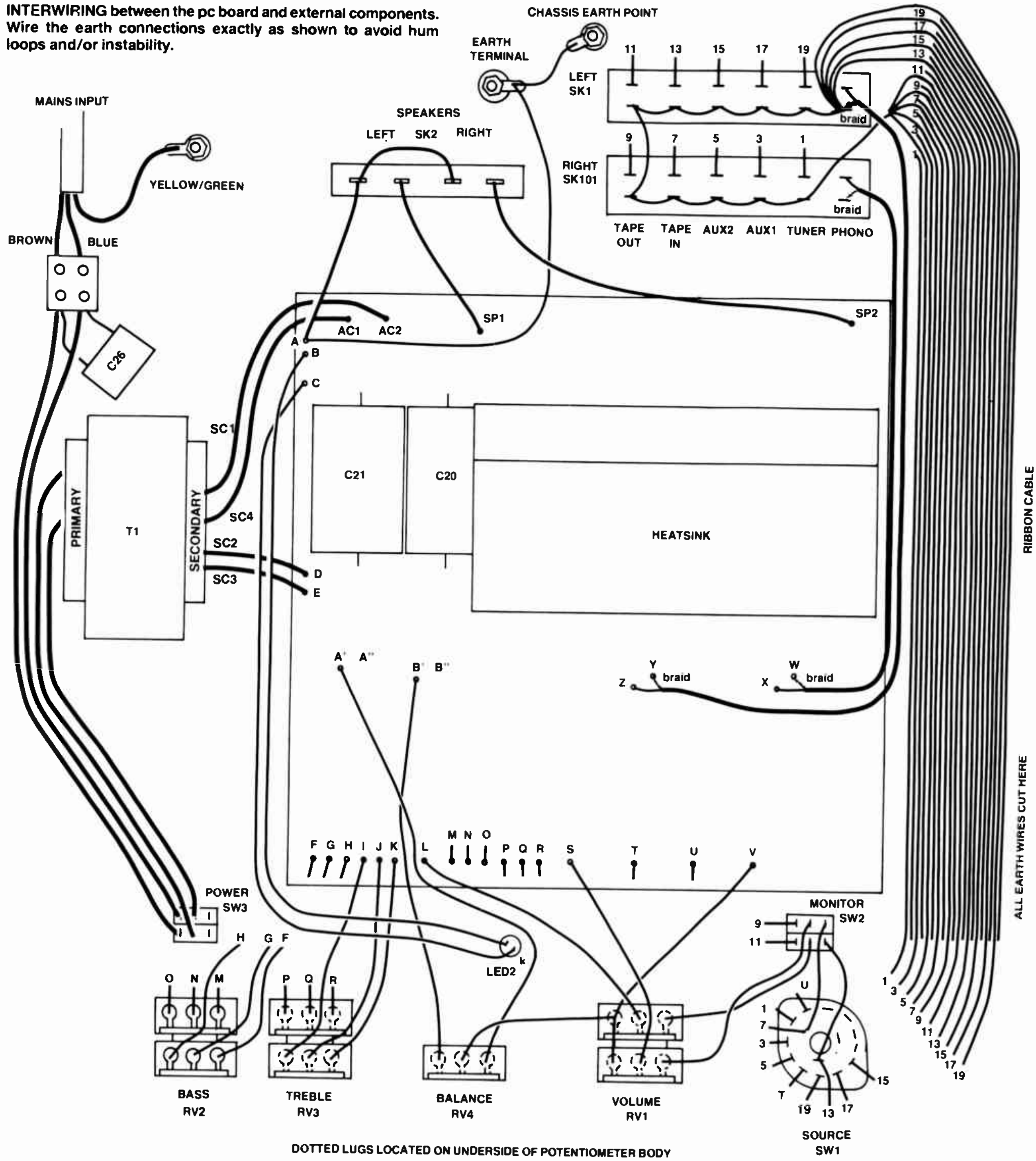
| | |
|---|---|
| RV1 | 10k dual gang log. |
| RV2 | 100k dual gang lin. |
| RV3 | 25k dual gang lin. |
| RV4 | 10k single gang lin. |

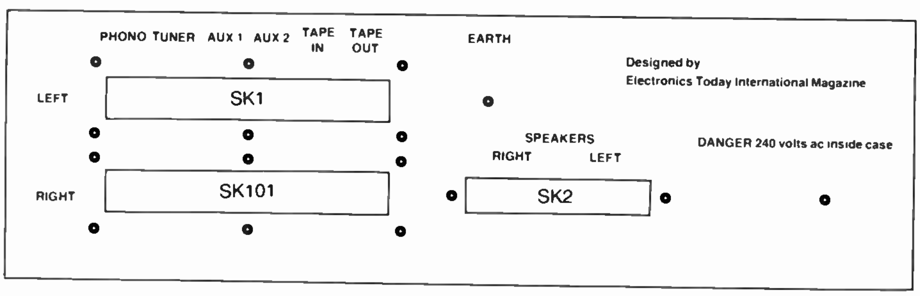
**Miscellaneous**

| | |
|---|---|
| SW1 | two pole, four position wafer switch |
| SW2 | DPDT miniature toggle switch |
| SW3 | DPST 240V rated miniature toggle switch |
| SK1, 101 | six RCA sockets on insulated panel |
| SK2 | set of spring contact speaker terminals on insulated panel |
| T1 | For 25 Watts output 20 - 0 - 20V secondary at 1.5 amps Ferguson type PF3993 or similar For 5 Watts output 12 - 0 - 12V secondary at 800mA Ferguson type PL24/20VA or sim. |
| FS1, 101 | 2 Amp. 3AG fuses with pc board mounting clips |
| RL1 | DPDT pc board mounting relay with 12 Volt coil, Takamisawa type VB 12 STAN or Pye 265/12/G2V |

ETI 476 pc board, heatsink (see text), black screw terminal for turntable earth connection, Horwood case type 93/10/V (255 mm wide x 255 mm deep x 76 mm high), power cord and 3 pin plug, four 12 mm pc board standoffs, clamping grommet for power cord, nuts, bolts, length 20 wire ribbon cable, length shielded cable.

**INTERWIRING between the pc board and external components. Wire the earth connections exactly as shown to avoid hum loops and/or instability.**




◄ REAR PANEL

| SW1 | POSITION FUNCTION | LEFT | RIGHT |
|---|---|---|---|
| 1 | PHONO | U | T |
| 2 | TUNER | 1 | 19 |
| 3 | AUX 1 | 3 | 17 |
| 4 | AUX 2 | 5 | 15 |
| — | TAPE OUT | 9 | 11 |
| — | TAPE IN | 7 | 13 |

Source and monitor tape switches wiring legend.

Mount the output transistors as shown in the accompanying diagram. Note that a mica or plastic washer and insulating bush must be used with each one. Smear a small amount of thermal compound on both sides of the mica or plastic washer before you mount and screw the bolts down firmly to get good thermal contact between the transistor body and the heatsink.

Check that you have the transistors in the correct order and check also that there are no shorts between the collector pins and the heatsink.

Before the heatsink/transistors assembly can be mounted, bolt a 25 mm standoff pillar on the pc board as indicated on the overlay photograph. This is to secure the heatsink and relieve stress on the transistor leads.

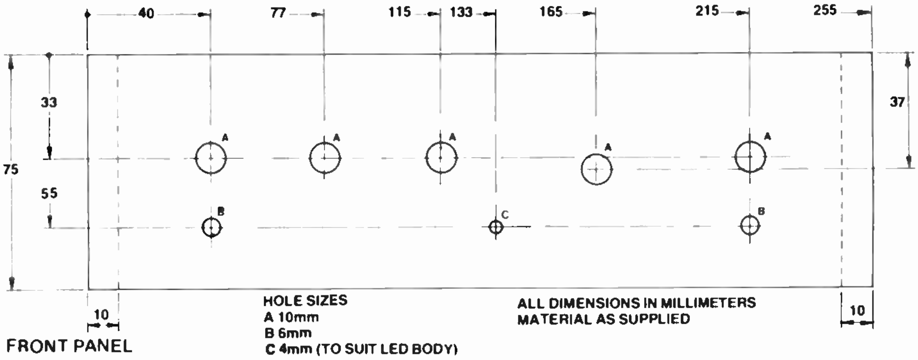
Once you have the heatsink and output transistors all together, bring the assembly to the pc board and insert the leads of the transistors in the appropriate holes. A small pair of needle-nose pliers helps here. Push the transistor leads through the board such that they protrude about 2mm on the copper side of the board. Bolt the heatsink to the standoff and then solder the transistor leads.

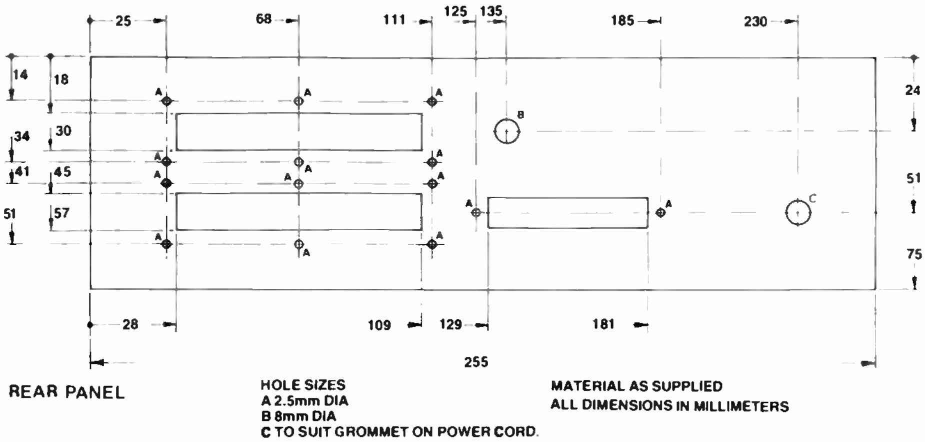
That completes the pc board assembly.

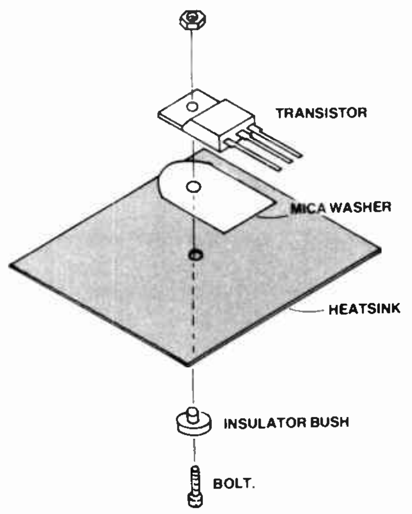
Next step is the metalwork. If you have purchased a pre-drilled case, just check that all fits and there are no burrs. If you've purchased an undrilled case, first thing to do is to disassemble it and scribe the hole positions on the front and rear panels as per the metalwork drawings. If you're going to use a Scotchcal front panel, this may be used as a template for drilling with the added assurance that all will fit when the holes are drilled. Don't take the backing off the Scotchcal at this stage as once it is stuck down to anything, you can't remove it without damaging the panel.

Carefully drill and de-burr all the holes. Slots are cut in the rear panel to accommodate the strips of RCA input/output connectors and the speaker connector strip. These can be cut using a 'nibbling' tool, which requires a single hole to be drilled, or by drilling a succession of holes and filing the edges of the slot straight.

With the front panel drilling completed, the Scotchcal can be positioned and stuck down. Take care, making sure that it is properly aligned. With the Scotchcal in position, mount the front panel components, noting the potentiometers are slightly angled to ensure the centre of their range corresponds to



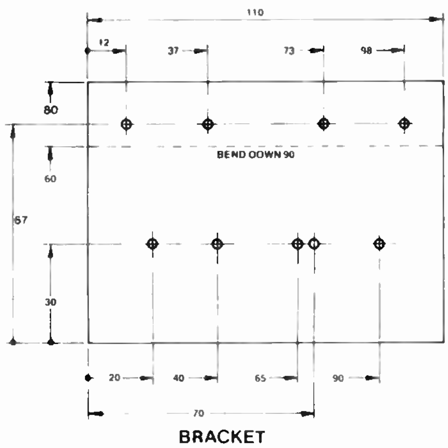



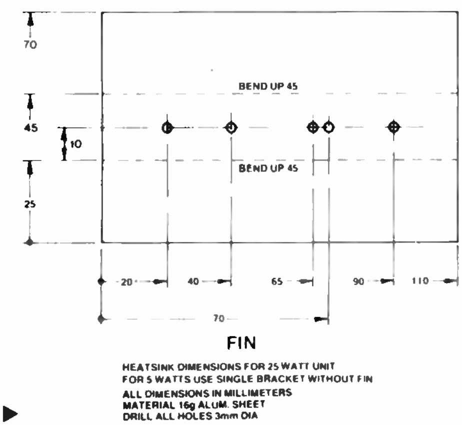

Assembling a flatpack transistor to a heatsink.

the centre of the knob pointer. The bass control faces upside down to the other controls so that its terminals face away from the power switch. Note that the power and tape monitor toggle switches are sideways operating.

Mount the rear panel components next, making sure there are no shorts between the terminals and the chassis.

The bottom panel of the case needs to be drilled to suit the transformer mounting holes, mains terminal block ▶



and the pc board standoff mounts. With this done, assemble the case leaving the top panel off for the moment. Note that the handles mount over the Scotchcal on the front panel, and that the bottom and top plates of the case overlap the front panel, protecting its edge and improving the overall appearance.

The bottom panel is normally held in place by four self-tapping screws but, owing to the weight of the transformer, we used four small nuts and bolts.

To protect the surface of whatever the equipment may stand on, we attached four 'stick-on' rubber feet to the bottom panel of the case.

Mount the transformer and pc board as shown in the internal photograph. The transformer is mounted in the rear left hand corner, furthest away from the phono stages which are sensitive to hum pickup from its field. The pc board is held in place by four 12 mm plastic push-in standoff mounts.

Now all the interconnecting wiring can be completed. The wiring diagram shows how this is done. Best place to start is with the ribbon cable between the function switch and the input/output RCA sockets. We also used ribbon cable to wire the potentiometers as it makes quite a neat job.

The high level inputs are connected to the source switch via the ribbon cable in which each second wire is connected to earth at the input sockets. The earth wires are then cut off neatly near the source switch. A bit of care in installing the ribbon cable will make a big difference in appearance if not performance.

The two phono inputs are connected to their respective input sockets with shielded cable. Both shields are connected to the pc board and their input socket. One of the shields is then extended to the earths on the high level inputs, but not to the other phono input.

Wire the earth wiring *exactly* as shown in the wiring diagram. The earth for the speakers is returned to the *power supply* end of the pc board and the earth for the inputs returns down one of the phono lead shields. The only connection to the chassis is made near the earth terminal on the rear panel, and this is returned to the earth connection adjacent to the power supply section on the pc board.

Take care with the mains wiring. We used a clamp grommet to secure the cable where it enters the case and the wires are terminated at a two-way terminal block. The earth lead (green/yellow) should be longer than the other two and secured to a solder lug mounted under a nut and bolt. The ac noise suppression capacitor mounts on this terminal block, on the side where the wiring leads to the power switch on the front panel. If your transformer comes with terminals, the suppression capacitor can be mounted there. All the 240 Vac wiring is passed along the left hand side of the chassis. Use spaghetti sleeving or heatshrink tubing on the power switch wiring to protect the exposed connections.

That just about finishes it. The only thing left to do is to carefully check your wiring and then give the unit a test run.

With no inputs and no speakers connected, turn the unit on. The LED on the front panel should light as should the two LEDs on the pc board. With a sensitive multimeter, check the voltage on the output terminals of each channel. You should read no more than 100 mV. Because the output stage operates in class-B there is no bias adjustment.

If all is well, turn the unit off, connect loudspeakers and a turntable or tape deck and you're ready to rock!

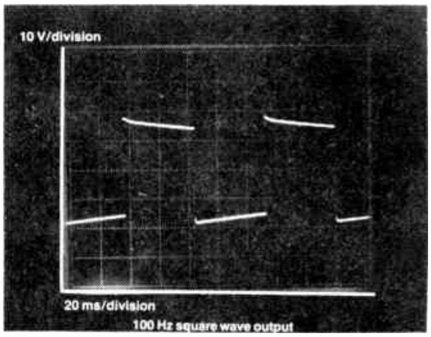
## Trials

We gave the unit a thorough trial, running it into 'odd' loads etc, running it heavily into clipping and conducting extensive listening tests. The accompanying photographs taken from the oscilloscope in our lab show how the amplifier performs with square wave drive at different frequencies throughout the audio range plus one shot showing the amplifier's output when driven into clipping with a sine wave input. Performance of the unit is clearly very good.

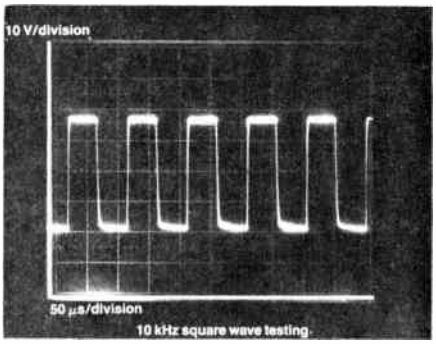
Just to convince ourselves, and you skeptics amongst the readers, we have also included a photograph taken from the screen of a Hewlett Packard model 3580A spectrum analyser we have on loan from Tech-Rentals for some development work (you'll be seeing more about it in the months to come — keep reading!). As you can see, this amplifier has quite a creditable performance.

For listening tests we used a pair of our Series 4000/2 three-way loudspeakers in an average sort of domestic environment with a Sansui turntable and Shure M91 cartridge. Overall sound is very clean, with well defined bass and crisp top end and it was obvious that any sonic 'faults' were not contributed by the amplifier. The unit drove the Series 4000/2 speakers effortlessly to levels liable to raise neighbour complaints!

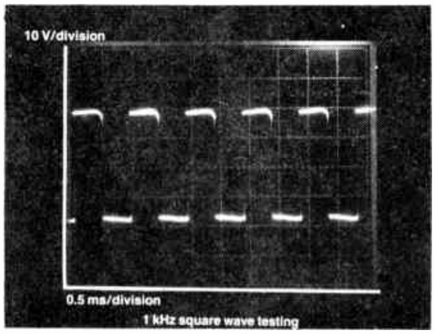
We think you'll be as pleased with the Series 3000 Compact Stereo Amplifier as we are. ●



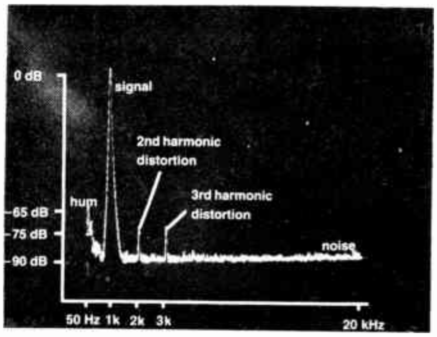
100 Hz square wave output

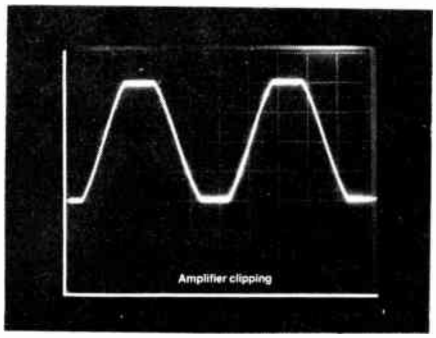


10 kHz square wave testing



1 kHz square wave testing





Amplifier clipping

# AM Tuner features wide bandwidth and low distortion


## Design: Ken Woods
## Article: Staff

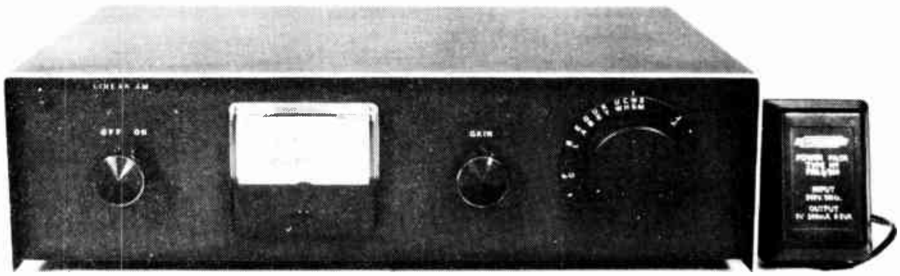

Now the 'FM boom' has arrived, the AM stations are fighting back with wide bandwidth, good quality sound. This tuner, though simple to build and get going, provides extraordinarily good performance.

WE WERE SURPRISED to learn recently that many of the AM broadcast stations have been transmitting 'full bandwidth' signals for quite some time, it seems they're 'fighting back' at the recent boom in FM with all the new stations coming on to the VHF band.

This tuner has been designed to take advantage of this situation. Broadcast stations are permitted to transmit an audio bandwidth that rolls off at 15 kHz. That means an AM broadcast station will have a nominal bandwidth of 30 kHz. At first glance this seems a little out of kilter as frequency spacing in the 530 - 1650 kHz AM broadcast band is 9 kHz. However, stations serving a particular area are generally allocated frequencies no closer than 54 kHz. Hence, a wideband tuner may be used to exploit the good quality reception possible from stations transmitting 'full bandwidth' programme material.

## Design

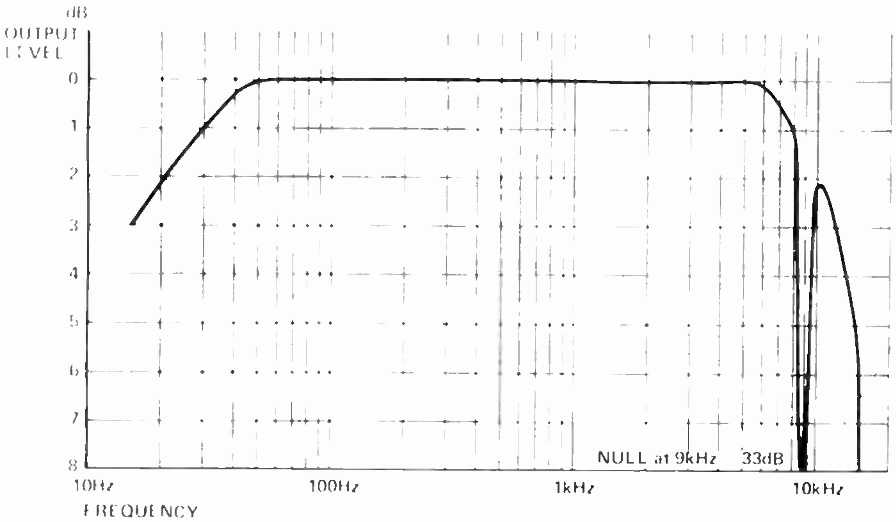
The designer, Ken Woods, has chosen to employ a 'tuned radio frequency' design to achieve low intermodulation distortion, low phase distortion and good transient response. There are only two tuned circuits. The overall selectivity is determined solely at the front end, at the frequency selected. The parameters of the input double-tuned circuit have been arranged to provide the required bandpass selectivity with good attenuation outside the passband, to reduce unwanted noise and interference. This circuit arrangement provides low phase distortion as it has a slowly varying phase change across the pass band and no phase reversals. Transient response of this particular arrangement is also good as there is minimum signal delay from input to output and the Q has been carefully 'tailored' to reduce the 'fly-wheel effect' of multiple tuned circuits (ringing).



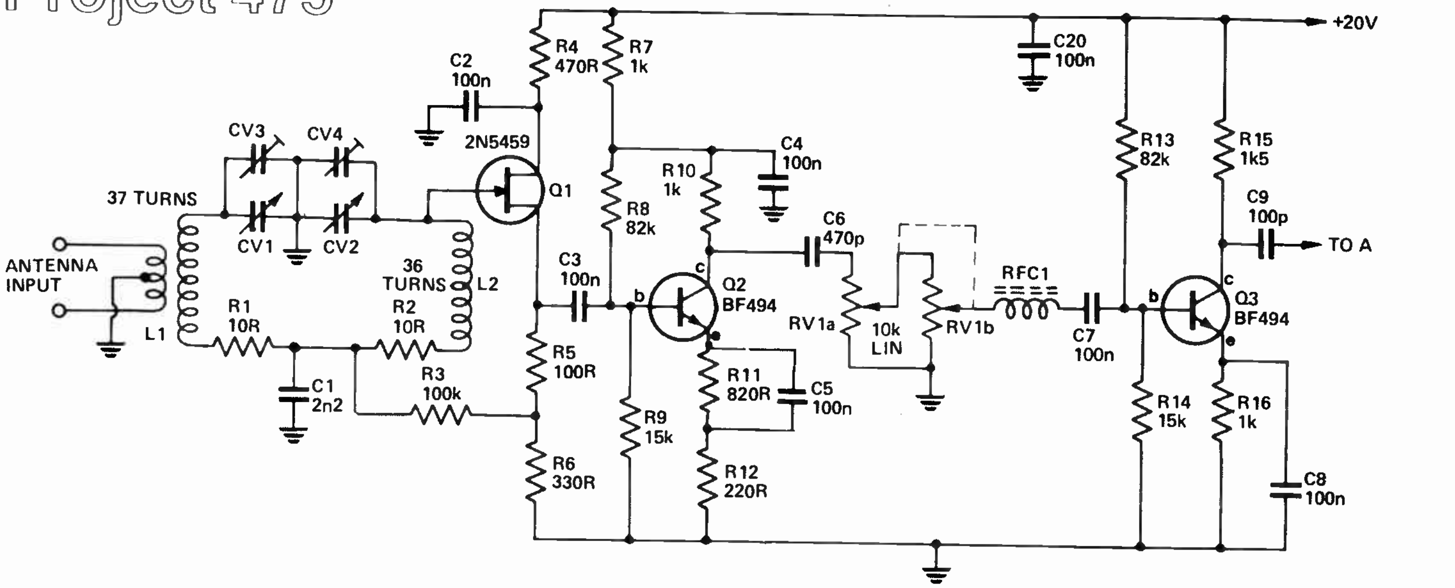
The tuner is housed in a simple, yet attractive, case. A plugpack is used to power the unit.

In addition, the circuit has a virtually constant bandwidth characteristic right across its tuning range. It's a little too complex to go into here, but readers looking for a good reference could hardly do better than consult "The Radiotron Designer's Handbook", by F. Langford-Smith, published by AWV-RCA, Chapter 8, section (iii) 'Complex Coupling' (Page 420 in ours, the Fourth Edition).

The tuner has a manual RF gain control and no AGC so that the evil of AGC distortion, prevalent with conventional superhet AM tuners, is eliminated. Actually, rather than varying the gain of one or more of the amplification stages, the RF gain control is an attenuator, ▶




Overall frequency response of the receiver. The response is 3 dB down at 15 Hz and 12 kHz. The whistle filter provides 33 dB of attenuation at 9 kHz and is 3 dB below midband response at just over 8 kHz and just below 10 kHz.




## HOW IT WORKS — ETI 475

The tuner employs a TRF design where all the amplification and selectivity is achieved at the actual frequency of reception, prior to the detector.

The required selectivity characteristics are provided by the input tuned circuit which is arranged to tune the whole broadcast band, from 530 kHz to 1650 kHz. Several stages of untuned RF amplification follow the tuned circuit. A low distortion diode detector removes the audio programme information from the selected station's RF carrier and this is fed to a 9 kHz whistle filter — which provides a deep 'notch' to remove interstation heterodynes — followed by an audio output stage.

For best, low noise reception, a balanced antenna input is provided. Antennas are discussed in the text. The two tuned circuits, comprising L1, L2 and the dual-gang tuning capacitor CV1/2, are mutually coupled by C1. Individually, each tuned circuit has quite a high Q by virtue of the totally 'closed' magnetic field provided by the pot core. The reactance of C1, whilst small, is sufficient to overcouple the two tuned circuits, providing a 'double-humped' response (see the accompanying diagram). To remove the 'dip' in the middle of the response, the overall circuit Q is 'damped' by two, low value resistors — R1 and R2.

A FET source follower, Q1, isolates the input tuned circuits from the first RF amplifier stage, Q2. The input impedance to the gate of Q1 is quite high and this avoids loading the coupled tuned circuits which would reduce the Q. Gate bias dc return is via R3, R2 and L2. The source of Q1 is coupled to the base of Q2 via C3. This first stage of RF amplification has a gain of about five and is stabilised by having part of the emitter bias resistance unbypassed (R12).

An RF gain control is placed between the first and second RF amplifier stages. A dual-gang potentiometer, RV1a and RV1b, connected in a cascade configuration, provides very smooth control over the signal level.

The input stage FET has its drain decoupled from the supply rail by R4 and C2 while Q2 has its collector circuit and base bias decoupled by R7 and C4.

The third stage of amplification is provided by Q3 which operates at full gain. To prevent VHF parasitic oscillation in this amplifier, a wideband RF choke, RFC1, has been inserted in series with the input to the base.

A further two stages of amplification follow, before the detector. Transistors Q4 and Q5 are direct-coupled and the collector of Q5 drives the diode detector via C11.

The detector is a voltage-doubling type with degeneration to reduce distortion. In addition, there is negative feedback from the detector to the emitter of Q4 via C12, further reducing distortion. A signal strength meter has been provided as a tuning aid. It measures the dc output level from the detector. Capacitor C14 provides smoothing for the meter, removing any audio signal influence.

RF 'smoothing' from the output of the detector is provided by R24 and C15 forming a low pass filter that passes audio (3 dB down at 28 kHz) but bypasses the RF. The output of this is coupled to the input of the audio output stage via the 9 kHz whistle filter. This is a parallel tuned circuit made up by L3 and C16. This provides a 'notch' in the audio response, attenuating any 9 kHz interstation whistles by more than 30 dB. The coil is constructed in a pot core which ensures high Q and a narrow bandwidth notch.

The audio output stage consists of a Darlington pair emitter follower stage, Q6 and Q7. This has a high impedance input, so as not to load the whistle filter, and a low impedance output suitable to drive the 'tuner' input of an amplifier. The collectors of Q6 and Q7 are decoupled from the supply rail by R29 and C18.

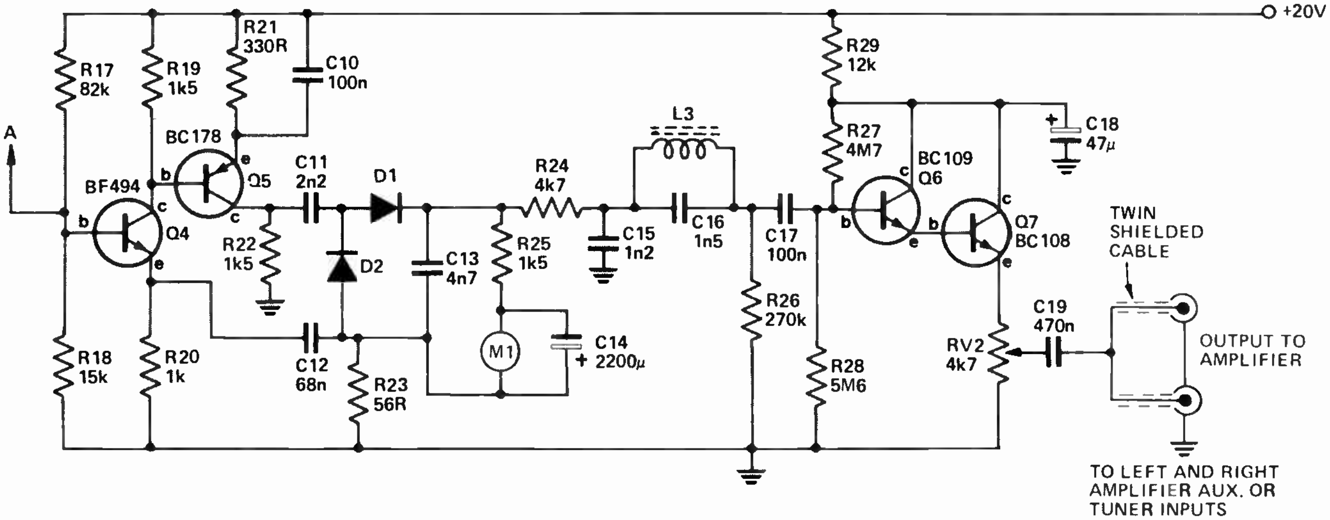
Power is supplied from a plug back, thus removing a possible source of hum pickup, and a voltage-doubler rectifier involving D3, D4, C21 and C22. Extra supply filtering is provided by R31 and C23. A front panel LED power indicator, LED1, is supplied directly from the rectifier output. Switch SW1 is used to turn the tuner on and off.

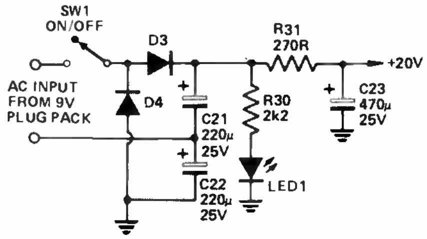
located between the first and second stages of RF amplification. Its purpose is to allow adjustment of the signal level so that at no time is the detector overloaded.

The detector employed features some signal degeneration, via R23, to reduce distortion and negative feedback to one of the RF amplifier stages to further reduce distortion. The overall distortion

## PARTS LIST — ETI 475

| **Resistors** | all ½W, 5% |
|---|---|
| R1,R2 | 10R |
| R3 | 100k |
| R4 | 470R |
| R5 | 100R |
| R6,R21 | 330R |
| R7,10,16,20 | 1k |
| R8,13,17 | 82k |
| R9,14,18 | 15k |
| R11 | 820R |
| R12 | 220R |
| R15,19,22,25 | 1k5 |
| R23 | 56R |
| R24 | 4k7 |
| R26 | 270k |
| R27 | 4M7 |
| R28 | 5M6 |
| R29 | 12k |
| R30 | 2k2 |
| R31 | 270R |
| **Potentiometers** | |
| RV1 | 10k linear dual pot. |
| RV2 | 4k7 flat mounting large trimpot. |
| **Capacitors** | |
| C1,C11 | 2n2 greencap |
| C2,3,4,5,7, 8,10,17,20 | 100n greencap |
| C6 | 470p ceramic or styroseal |
| C9 | 100p ceramic or styroseal |
| C12 | 68n greencap |
| C13 | 4n7 greencap |
| C14 | 2200u/16V electro |
| C15 | 1n2 greencap |
| C16 | 1n5 see text |
| C18 | 47u/25V electro, axial lead type |
| C19 | 470n greencap |
| C21,C22 | 220u/25V electro |




C23 .............. 470u/25V electro

**Variable Capacitors**

CV1,CV2 .......... 415p dual gang variable capacitor (Roblyn RMG —2), see text

CV3,CV4 .......... 40p film dielectric trimmer, Philips type 2222 808 01027 (grey case) or similar.

Inductors .......... see coil winding details

**Semiconductors**

D1,D2 ............ AA119, OA95, see text

D3,D4 ............ 1N4004, A14A or sim.

Q1 ............... 2N5459

Q2-Q4 ............ BF494

Q5 ............... BC558, BC178

Q6 ............... BC549, BC109

Q7 ............... BC548, BC108

LED1 ............. red LED, TIL220R or sim.

**Miscellaneous**

SW1 .............. one pole, two position rotary switch

M1 ............... 1 mA meter, University TD48, Minipa MU45 or similar

Planetary dial drive with flange (Watkin Wynne type 4511 DAF or similar); large black knob 40 mm dia., aluminium disc 55 mm dia. for scale plate (see text); two small black knobs; two antenna terminals: one black, one red; two-pin plug and socket for power input; 9V plug pack, Ferguson type PPA9 - 500 or similar; length of twin shielded cable with two RCA plugs on one end; five pc board standoffs, box to suit (see text); ETI-475 pc board.

RFC1 — Philips VK200 wideband choke or six-hole ferrite bead (type 4312-020-31550) with a length of 22 swg tinned copper wire passed through it five times.

of this tuner proved to be significantly lower than that of our Wavetek laboratory signal generator, so we are unable to present a reliable distortion measurement. Listening tests confirm the low distortion characteristic of this tuner.

As some interference may be experienced in particular areas from distant stations propagating via the ionosphere (this generally occurs at night), a 9 kHz whistle filter has been incorporated. It provides an attenuation in excess of 30 dB at 9 kHz and the notch bandwidth is about 2 kHz maximum. If you do not experience any difficulties with this sort of interference, the whistle filter may be dispensed with.

A tuning or signal strength meter has been provided and it has several functions:

(a) To provide a positive tuning indication.
(b) To facilitate optimum signal strength control.
(c) To indicate when signal overload occurs.

It's a very handy aid when adjusting antennas or when setting the RF gain control.

Instruments are not absolutely necessary to align the tuner, although a signal generator makes it somewhat quicker.

An inexpensive plug back is used to provide power to the tuner. This has the advantage of removing the transformer from the tuner's chassis, eliminating a possible source of hum.

## Construction

The tuner is housed in a chassis made from a 240 x 290 mm sheet of 16 gauge aluminium bent into a U-shape measuring 290 mm wide by 180 mm deep and 80 mm high. The lid was made from a 205 x 455 mm sheet of 16 gauge aluminium. It is bent and mounted so that it overhangs the front panel of the chassis by 10 mm and the rear by 15 mm. This results in quite a neat, professional-looking unit.

The power switch, power LED, signal strength meter, gain control potentiometer and planetary reduction drive are all mounted on the front panel. The antenna terminals and two-pin power input socket are mounted on the rear panel. The output lead passes through a rubber grommet.

Commence by marking out and drilling the holes in the chassis. This is probably best done before bending it up. Mark out accurately, as per the metalwork drawings. The size of hole required for the meter depends on the meter used. The one on our prototype is a Minipa MU-45 type. It fits neatly on the front panel and has a pleasing appearance. However, other types may be used, such as the University type TD48. This is a little smaller than our meter, but will do equally well.

Two lengths of aluminium angle are bolted to each side of the chassis and the lid is secured to these with either bolts (which mate with tapped holes in the angle pieces) or self-tapping screws. The aluminium brackets are cut from a single 320 mm length of 13 mm (½") angle. This is readily obtainable in hardware stores. Mark and drill the lid, then bend it carefully to shape. The aluminium angle pieces are best marked up and drilled using the chassis, and then the lid, as a template.

At this stage, the chassis and lid could be sprayed matt black inside and out, or anodised — if you're willing to go to that expense.

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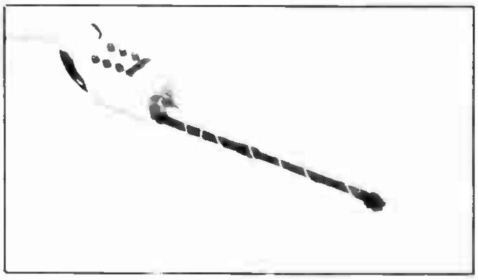

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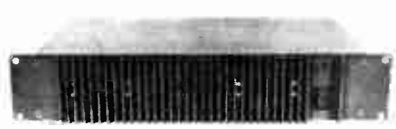

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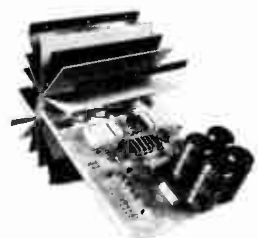

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## COIL DETAILS ETI-475

**L1**

Primary: two turns wound bifilar with thin plastic insulated hookup wire (wound last).
Secondary: 37 turns pile wound, 34 SWG enamelled wire (wound first).

**L2**

36 turns, 34 SWG enamelled wire (0.23 mm).
*L1 and L2 are wound on Philips P18/11 pot core assemblies, 3D3 material, ue = 68, with adjusters.*

**Philips part numbers**

| | |
|---|---|
| **Pot core** | 4322/022/24454 |
| **Adjuster** | 4322/021/32170 |
| **Former** | 4322/021/30270 |
| **Washer** | 1811/HWI |
| **Clip** | 1811/HPC |

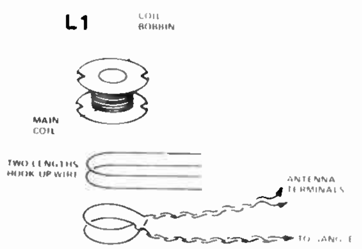
**L3**

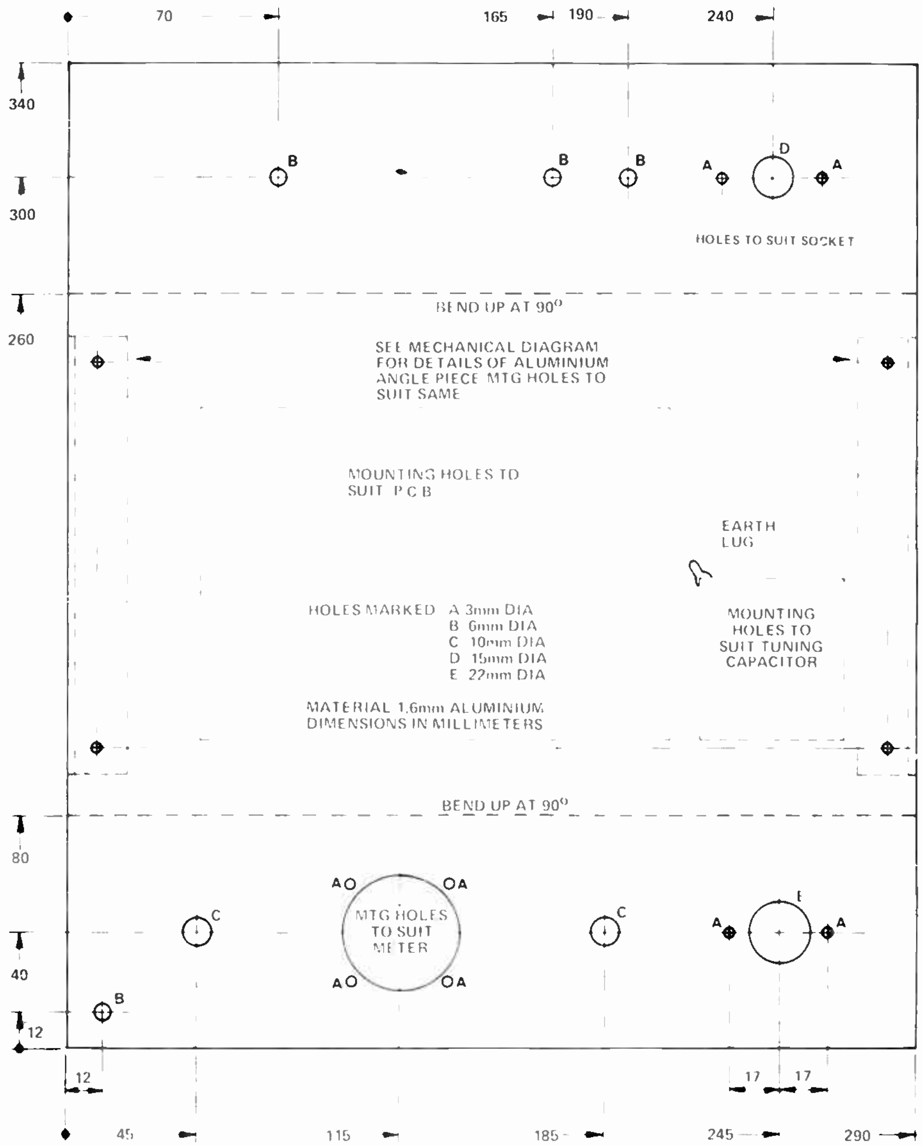
540 turns 36 SWG enamelled wire (0.2 mm).
*L3 is wound on Philips P26/16 pot core assemblies, 3B7 material ue = 220, with an adjuster.*

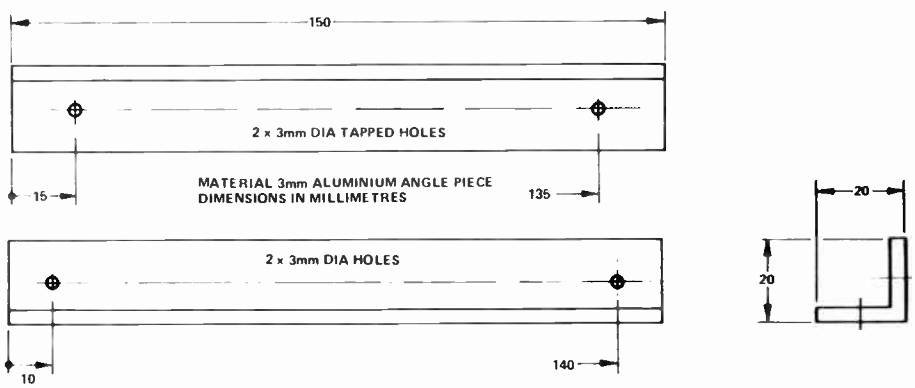
**Philips part numbers**

| | |
|---|---|
| **Pot core** | 4322/022/28294 |
| **Adjuster** | 4322/021/30810 |
| **Former** | 4322/021/30330 |
| **Clip** | 2616/HPC |

No washer is used with the large pot core.




When the chassis is completely prepared, the major components can be mounted on it. The planetary drive should be mounted first. It is best to mount it on adjustable standoff pillars, as shown in the photographs, to allow the position of the dial flange to be adjusted. This should protrude from the front panel about one or two millimetres.

The dial was made up from a disc of 18 gauge aluminium (though 16 gauge or even a thinner gauge would be OK. The local stations were marked on the dial with white rub-down lettering (such as Letraset or Geotype). This disc is attached to the planetary dial flange by two screws supplied with the dial drive. The complete assembly is shown in the exploded-view diagram.

Since it will probably be difficult for most readers to cut a clean circle from aluminium, without the facilities of a machine shop, we have reproduced a suitable dial from which a Scotchcal copy may be made. If you use the metal Scotchcal, you can leave the backing paper on it and attach that as your dial.

The tuning knob on the prototype is a little special. It consists of a large diameter knob with a turned-up aluminium 'cup' pushed over it (the inside diameter forms a snug fit to the knob). We'll leave the knob to your ingenuity. A large knob is recommended as it provides smooth control of the tuning, a good grip and enhances the appearance.

The next step is to mount the tuning gang. It is very important that no strain is placed on the planetary drive from the shaft of the tuning gang. Careful, correct alignment will ensure this. The tuning capacitor is mounted on small standoff nuts and the shaft is carefully aligned, using washers or something ▶

similar, to pack the standoffs so that it mates with the planetary drive properly.

The rest of the chassis-mounted components may now be secured in place.

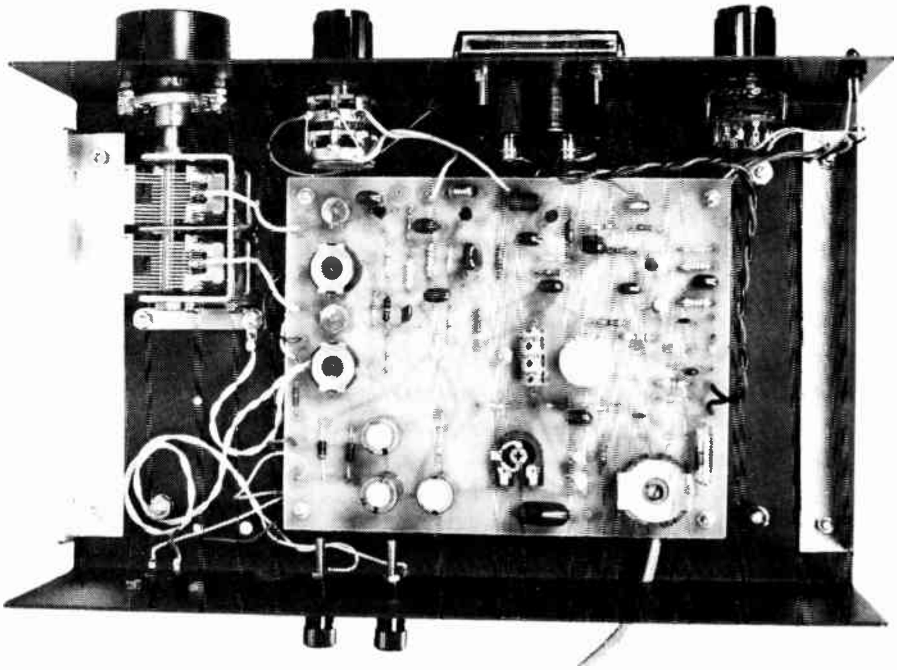
Assembling the pc board comes next. Mount all the components with the exception of the three pot cores. Take care with the orientation of the electrolytic capacitors, diodes and transistors. The BF494 transistors have an unusual lead configuration — the emitter lead is in the centre. When soldering the trimmer capacitors in place, don't use too much heat or strain the leads while soldering them. This avoids possible distortion of the plastic case and problems when adjusting them.

All components should be mounted right down on the pc board using minimum lead length. The transistors should have leads no longer than 5 mm.

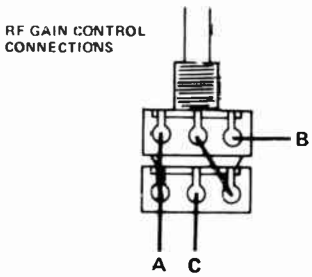
The detector diodes can either be gold-bonded germanium types like the AA119s recommended, or germanium types such as the OA47. The gold-bonded diodes will give lower detector distortion but may be difficult to obtain. We tried both types and could not detect any audible difference.

The resonating capacitor for the whistle filter, C16, should be either a styroseal or mica type to avoid drift in the tuning as this is a high-Q circuit.

The two input tuned circuits use 18 mm diameter pot core assemblies. Each assembly contains two ferrite halves, an adjustor, former, washer and clip. When assembled, the clip solders into the pc board and holds everything together. L1 has two windings while L2 has only one. Wind the secondary (37 turns) of L1 first. This should leave sufficient room on the former so wind the link over the top.



The link is bifilar wound with two lengths of thin, plastic insulated hookup wire. With the two wires parallel, wind a single turn around the former, over the top of the secondary winding. The start lead of one wire is then twisted together with the finish lead of the other. These two leads are twisted together for 150 mm or so and will connect to the antenna terminals after the coil is assembled. The other two leads are also twisted together, for 100 mm or so, and will be joined and soldered to an earth lug under the tuning gang mounting bolt adjacent to the coil locations on the pc board.



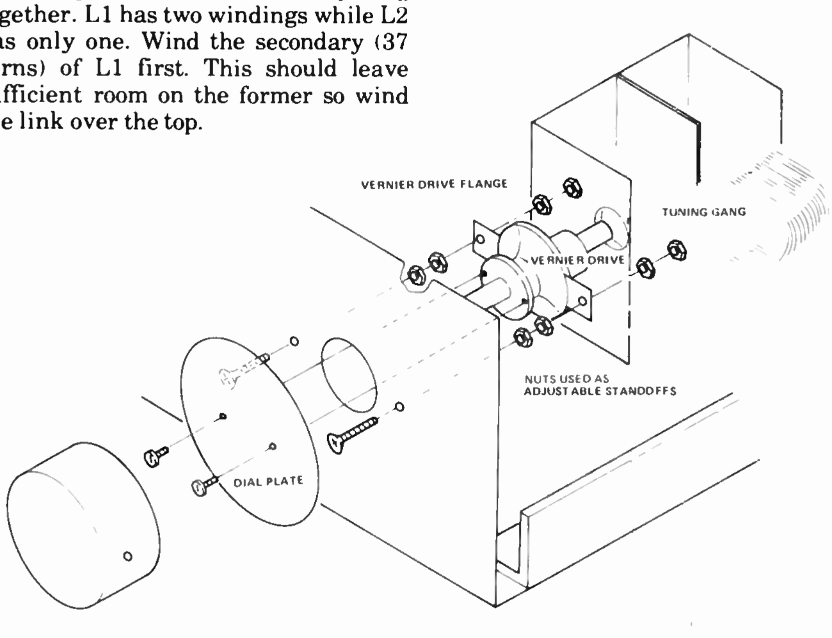

The accompanying exploded diagram should make the assembly of this link winding clear.

Arrange the wires so that all the link wires come out one side of the bobbin and the secondary wires come out the other.

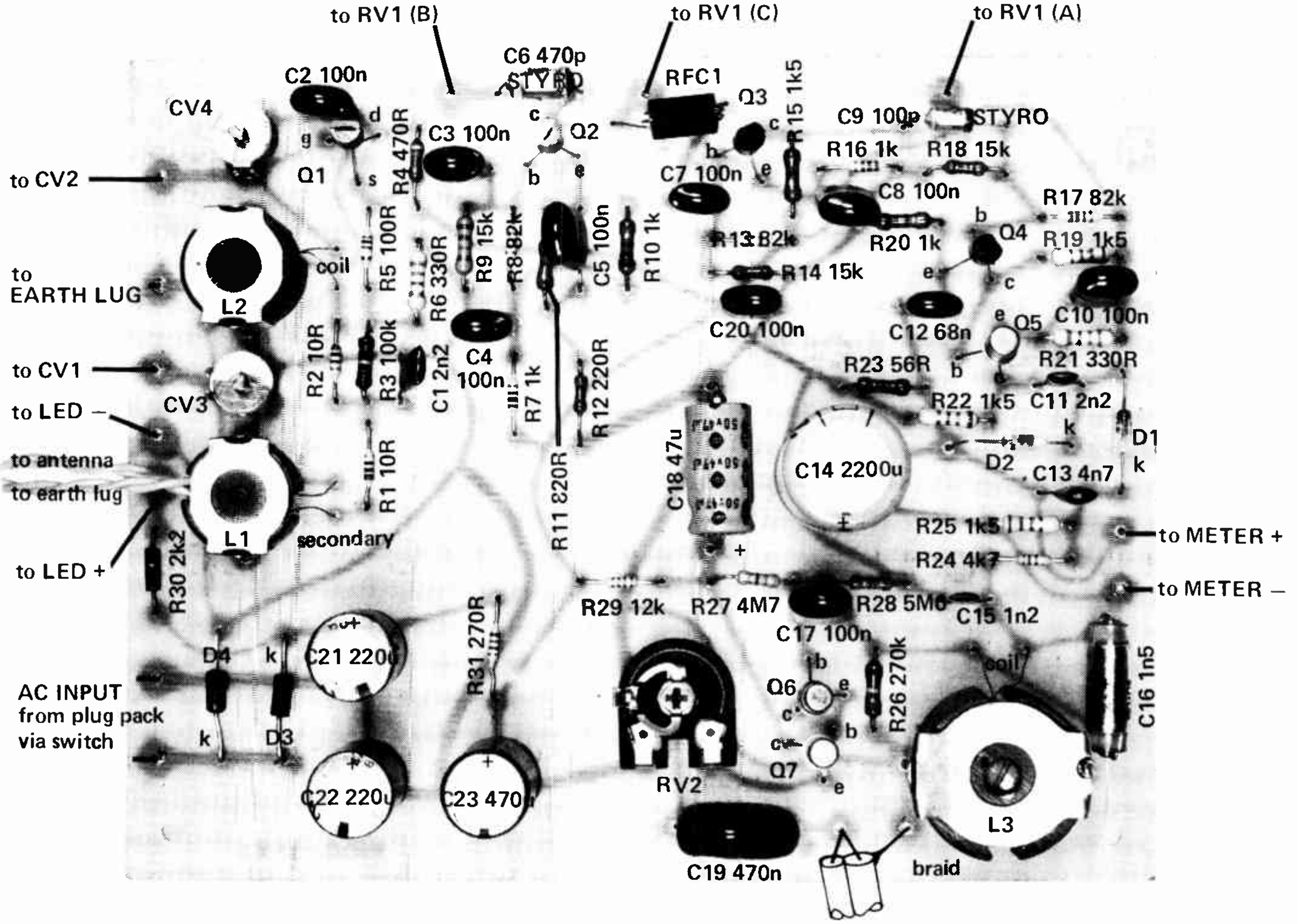
Assemble the two ferrite pot core halves over the former, place the washer on top of the assembly and slip on the clip. The washer ensures an even pressure is transmitted from the clip to the ferrite assembly and should always be used with these small pot cores. Insert the adjuster carefully into the centre hole of the core using a small aligning tool. Take care as it cuts its own thread in the nylon insert and any forcing can damage this.

Solder the complete assembly into the pc board (before everything falls apart!) orienting the assembly with the link connections facing the edge of the board and the secondary connections toward the centre.

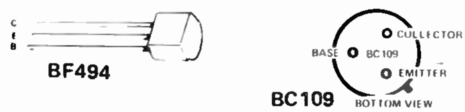
The second front end pot core, L2, is assembled in a similar way but note




EXPLODED DIAGRAM OF VERNIER DRIVE AND DIAL ASSEMBLY




The printed circuit board pattern is on page 153.




that it has no link.

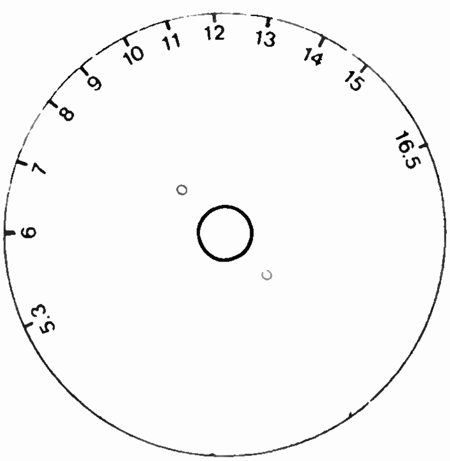
The whistle filter, L3, uses a 26 mm diameter pot core which is assembled in a similar fashion to the other two except that it does not require a washer under the clip. Wind the wire on the bobbin as detailed in the accompanying box. The wire should almost fill the former, so be careful to wind it firmly, laying the turns neatly on the bobbin.

## Tuning up

Turn the unit on and connect it to your stereo amp. Turn trimpot RV2 on the pc board fully clockwise. Connect an antenna and turn the RF gain control fully clockwise. Set the two trimmer capacitors at mid range (you can see the plates), and the ferrite adjusters in L1 and L2 at half depth. Tune over the range and you should hear some stations. Select a station at the high frequency end of the range. By adjusting the two trimmers in turn, and the tuning capacitor, bring the station to its correct position on the dial. This requires a little juggling with the three adjustments. Next, find a station at the low frequency end of the dial and repeat the procedure, this time tuning in the station using the two ferrite pot core adjusters and the tuning capacitor. You now have the receiver roughly aligned.

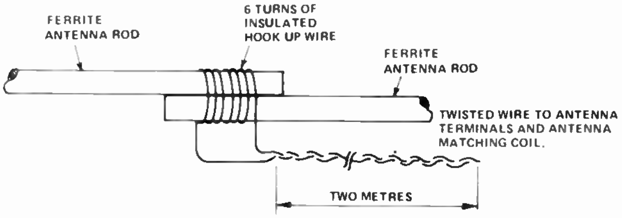
Repeat the process but this time you can set the dial to where a station should be located on the dial (according to the markings) and tune the two trimmers for maximum signal on the meter. Repeat for a low frequency station, adjusting the pot cores.

Repeat once more, just to make sure, ▶




Full-size reproduction (negative) of the dial.

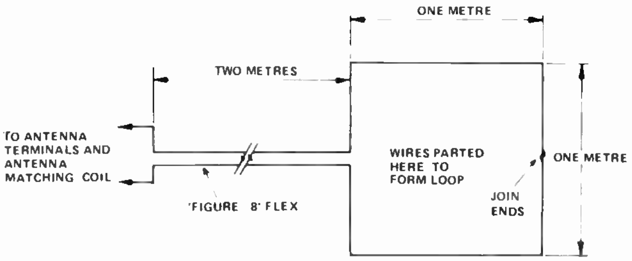
## SUGGESTED ANTENNAS




### For strong signal areas

This antenna is constructed of two 13 mm diameter ferrite rods. We suggest Neosid types, of F8 material, 12.7 mm diameter by 100 mm long. Most ferrite rods intended for broadcast band 'loopstick' antenna applications will probably suffice though, as construction is not all that critical; performance may vary though.

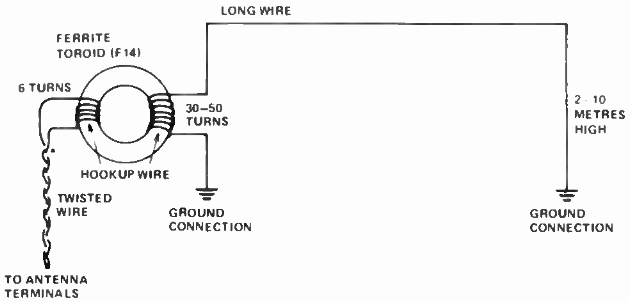
Six turns of hookup wire are wound firmly around the two rods and twisted leads two metres long connect to the tuner's antenna terminals. The two ferrite rods may be extended as illustrated or pushed together so that they overlap over more of their length. As shown, the antenna provides maximum sensitivity and least directivity. The rods should be oriented for best reception for the station or stations of interest.




### For medium to weak signal areas

A loop antenna can provide very good results where signals are not too strong. The loop illustrated is made by taking a length of 'figure-8' flex, parting the wires over a length of two metres, joining the free ends and forming a loop of one metre per side. The feedline should be about two metres long. It can be longer but performance may deteriorate. The plane of the loop should be oriented towards the transmitters for best results.

A larger loop may be constructed to improve pickup. Note that a rectangular loop may also be used, if more convenient. Experimentation will indicate which arrangement provides satisfactory results. A matching coil, as shown, may improve results.



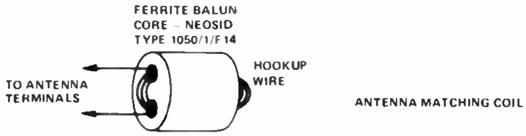

### For weak signal areas

If you live in a weak signal area, or want to 'chase the DX', this antenna should provide good results. Run a long, straight wire as high above the ground as you can reasonably manage and as long as will fit in your property (but less than 5 km !). Connect the furthest end to a ground stake. The opposite end connects to the primary of a 'matching' transformer wound on a ferrite toroid. The illustration shows the main details.

The toroid should be of a material having an initial permeability of about 200 to 300, t least, and an $A_L$ factor of around 100 to 150. A Neosid toroid of F14 material, 25.4 mm outside diameter, 19.05 mm inside diameter and 9.5 mm high should do nicely. It's not too critical, and some experimentation may be in order.

### Note

The impedance of the antenna will have some effect on the tuning of L1. This may necessitate minor re-alignment of the adjuster in L1 if you change antennas or change the position of the antenna. Check the alignment at the low frequency end of the band.




For use with small loops 6-8 turns
For use with large loops 2 turns

and you should notice that all the stations are in their correct positions on the dial. If you change antennas you may need to make a slight re-adjustment to L1.

The whistle filter can be adjusted by tuning across the dial until you find a 9 kHz whistle between two stations. Wind the ferrite adjuster on L3 in until the tone disappears. If no whistles are found, wind the adjuster all the way out.

An alternative method is to use a signal generator with external AM modulation. Set the modulation to 9 kHz, at about 80%, and tune in the signal. Use the ferrite adjuster on L3 to null the audio from the speaker.

Always use proper adjusting tools (these are available from most suppliers) to avoid breaking the adjusters or affecting their correct operation. The pot core adjusters are delicate and should be treated with kindness. Overzealously screwing them in and out will almost certainly result in permanent damage.

This fairly simple alignment technique yielded an overall bandwidth, at the −3 dB points, extending from 15 Hz to 12 kHz. For those readers with a little more perseverance, this can be improved with judicious adjustment of the tuned circuits.

## Operation

With the unit aligned you can connect an antenna and enjoy sounds from an AM tuner you never thought possible!

The output level to your stereo amplifier may be set by adjusting RV2, a trimpot on the pc board. The setting will depend on the signal strengths of the different stations at your location and the tuner input sensitivity of your amplifier. It is best set by experiment.

The antenna required will depend, again, on the signal strengths of the various stations at your location. It is a wise move to spend a bit of effort here as it pays off. The accompanying box shows a variety of antennas that will generally provide more than satisfactory performance under different conditions.

We tried the tuner in different areas of metropolitan Sydney and were quite impressed with the performance. At a location on the north side, where local stations are quite strong, we used a simple ferrite rod antenna with good results. At our offices in the eastern suburbs, where some stations are relatively weak we used a small loop antenna with excellent results. Sound quality is remarkable — you have to hear it to believe it! ●

Cut the crackle and get rid of the rumble with our

# Scratch and rumble filter

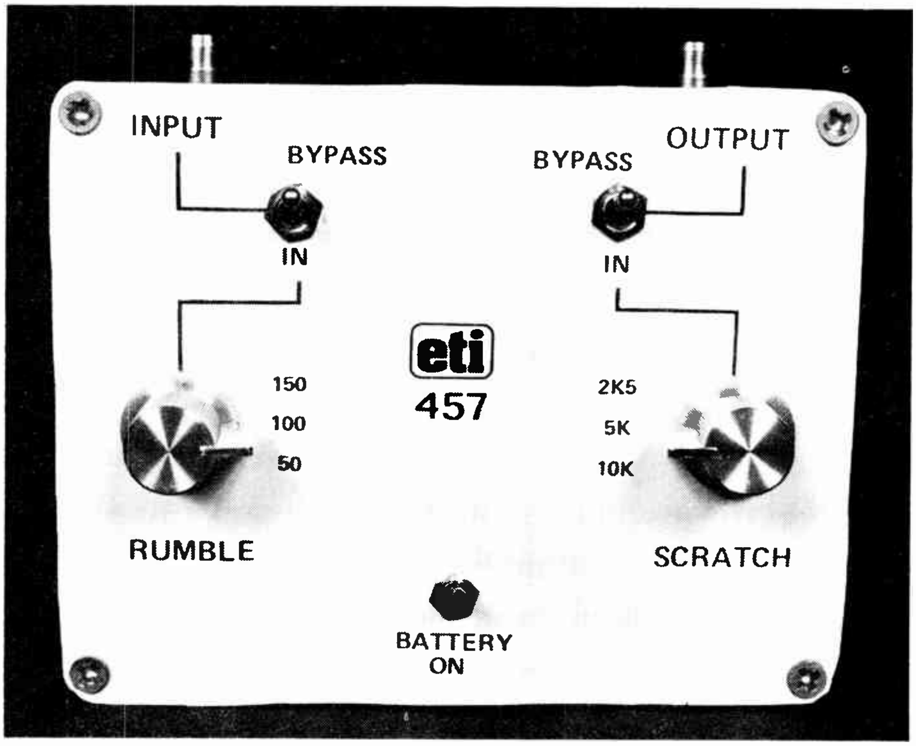
Staff

If many of your cherished older recordings are showing signs of old age and long use, or if you wish to transcribe your collection of 78s onto tape, this scratch and rumble filter project should help improve the sound quality.

SO YOU SAY you look after your records, but you probably have some that are scratched? Perhaps you lent them to someone who didn't care for them or they might be cherished rarities you picked up in a secondhand shop. Some of the best 'original' recordings are still on 78s especially if you're into jazz, bluegrass, blues or country music. Whatever the cause, clicks, pops and severe surface noise can spoil your listening pleasure, no matter how enthusiastic you are about the artist or the item recorded.

One other source of unwanted sound comes from the turntable in the form of rumble — a low frequency sound which can make your teeth grind in sympathy! If you look at the speaker cone whilst playing a turntable suffering from rumble, you may see it move in and out, although you may not hear anything. This is subsonic rumble and can be detrimental to the performance of the speaker system. The main cause of rumble is a less than perfect turntable transmitting vibration from the motor and bearings to the stylus. Rumble has almost been cured with the introduction of belt drive and good direct-drive turntables but these can suffer from wow and flutter. That's another story, though. Low frequency acoustic feedback from the speakers to the turntable can also occur if the acoustic mounting of the turntable is not up to scratch.

The high frequency surface noise on a recording can be removed with a 'high cut' filter. This will also cut the highs on the recording but on old records this will not be so noticeable. Likewise, low frequency noise can be removed with a 'low cut' filter and again, some of the low frequency information is lost.




It is desirable to only modify enough of the amplifier's frequency response to reduce the problems, therefore we have included switchable cutoff frequencies for each filter. High frequency hiss can usually be removed with the 10 kHz filter while cracks will probably need a lower frequency cutoff.

The unit uses two active filters in series, one a low cut for the rumble filter, the other a high cut for the scratch filter. The filters provide an attenuation of 12 dB per octave at frequencies past the cutoff point and can be switched in and out independently. The unit is battery operated and designed to go between the turntable and the preamplifier on older stereo systems, or between the preamplifier and the main amplifier on modern systems. We have built each channel on a separate pc board to allow the unit to be used for either mono or stereo systems. We have shown only one channel for simplicity. If you wish to build a stereo version you will need to duplicate all components except the switches and batteries, and of course, the box ▶

## PARTS LIST — ETI 457

**Resistors** all ½W, 5%

| | |
|---|---|
| R1 | 27k |
| R2 | 12k |
| R3 | 2k7 |
| R4,R5 | 15k |
| R6 | 220k |
| R7,R8 | 4k7 |
| R9 | 10k |
| R10 | 820R |

**Capacitors**

| | |
|---|---|
| C1,C4 | 68n greencap |
| C2,C5 | 100n greencap |
| C3,C6,C9 | 220n greencap |
| C7,C8,C16 | 1u tantalum |
| C10,C13 | 10n greencap |
| C11 | 22n greencap |
| C12, C15 | 4n7 greencap |
| C14 | 2n2 greencap |

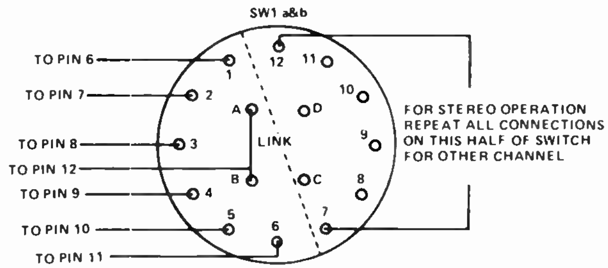
**Semiconductors**

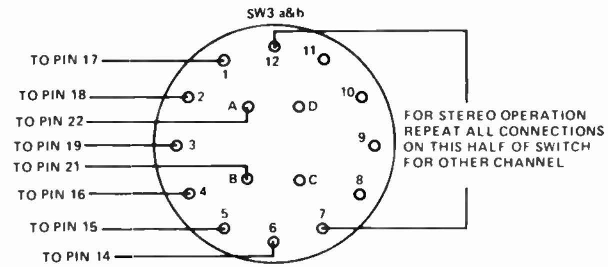
| | |
|---|---|
| Q1,Q2 | BC549, BC109 or sim. |
| LED1 | red LED TIL220R or sim. |

**Miscellaneous**

| | |
|---|---|
| SW1,SW3 | four pole, three-way wafer switches |
| SW2,SW4,SW5 | DPDT miniature toggle switches |

ETI-457 pc board; two RCA phono sockets; box to suit (120 mm × 95 mm × 55 mm): knobs; 9V No. 216 battery and battery clip.



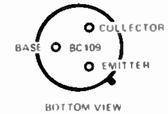



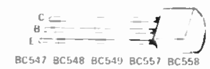

**SW1 LOWCUT RANGES**

| | |
|---|---|
| 1. | 150 Hz |
| 2. | 100 Hz |
| 3. | 50 Hz |

**SW3 HIGH CUT RANGES**

| | |
|---|---|
| 1. | 10 kHz |
| 2. | 5 kHz |
| 3. | 2.5 kHz |



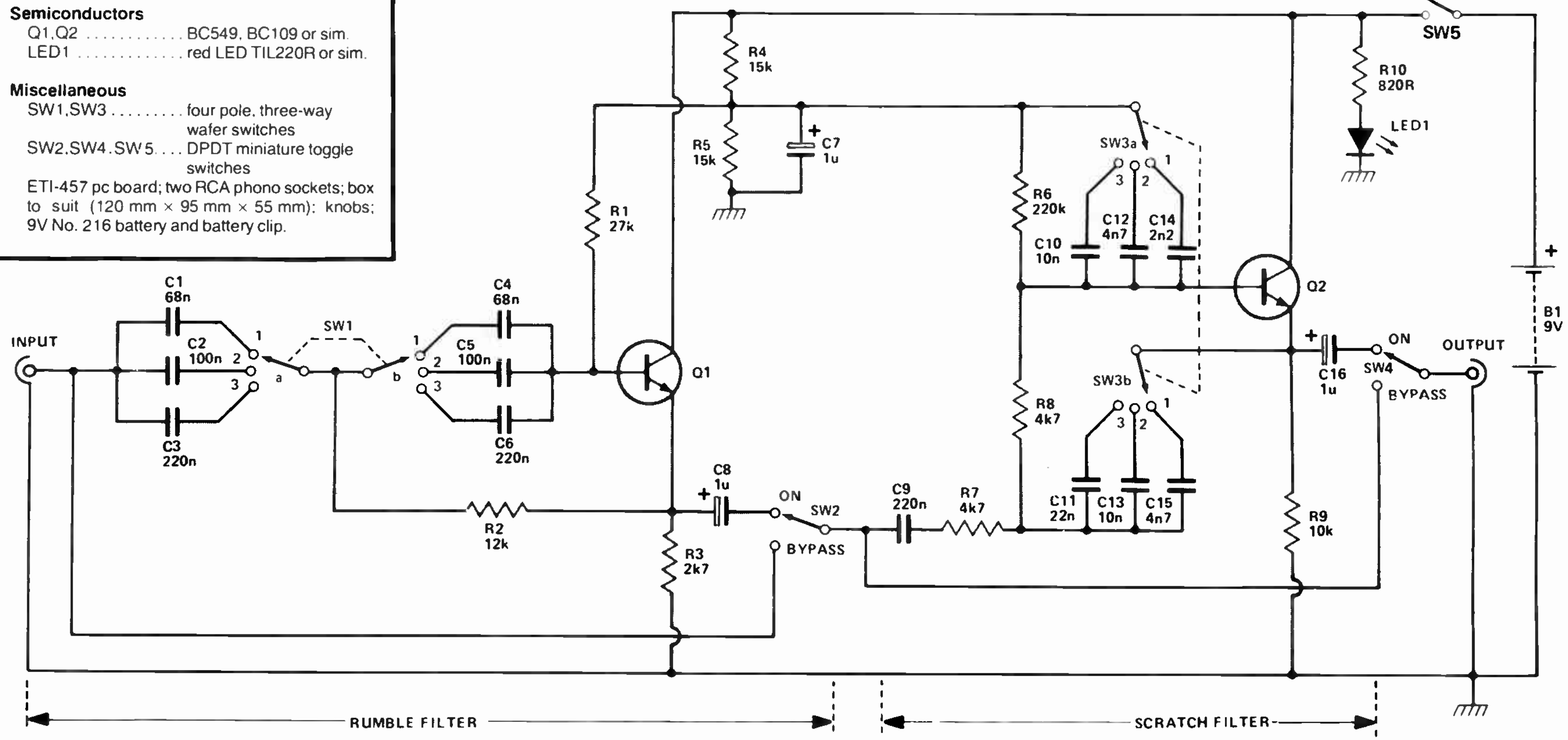



Figure 1 shows the block diagram of the mono version of the scratch and rumble filter. The input signal (from the turntable pick-up) is first fed through a high-pass filter, which rejects unwanted low-frequency rumble signals, and is then fed through a low-pass filter which rejects unwanted high-frequency scratch signals. Each filter can be bypassed via a simple switch if required, so the input signal can be passed through either one, both, or neither of the filters.

Figure 2 shows the circuit (a) and performance graph (b) of a simple single-stage passive high-pass filter. At low frequencies, capacitor C1 presents an impedance that is high relative to R1 so a lot of signal attenuation occurs between the input and output terminals. At high frequencies C1 presents an impedance that is low relative to R1, so negligible signal attenuation occurs between input and output.

The frequency at which the output signal is 3 dB down on the input signal is conventionally known as the BREAK frequency.

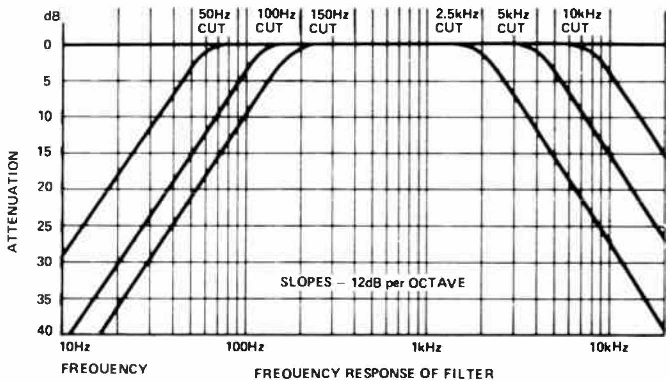
Note in Figure 2(b) that the graph shows a smooth roll-off or slope up to the break frequency point: a single stage filter has a slope or roll off of 6 dB/octave, i.e: the signal output level doubles if the input frequency is doubled.

A number of filter stages can be cascaded to give a roll-off of greater than the basic 6 dB/octave: usually, some kind of electronic buffering or feedback is used between the individual sections of a multi-stage pass filter system.

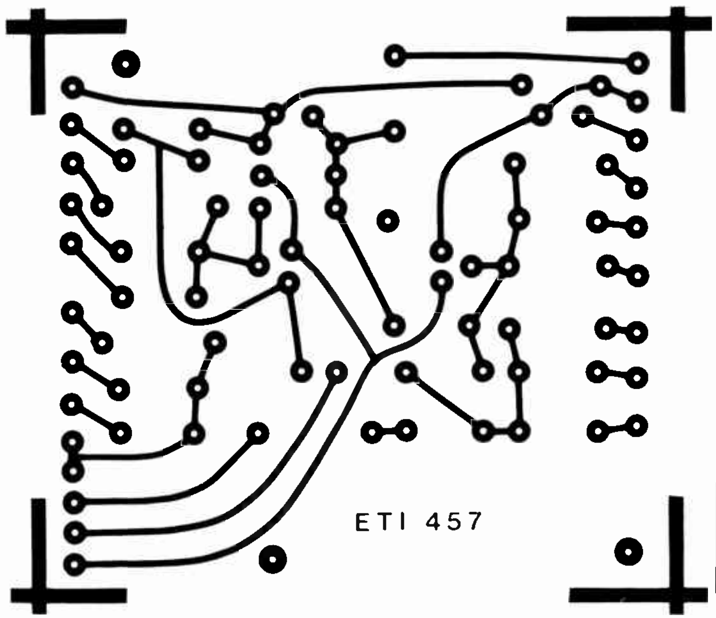
Figure 3 shows the circuit (a) and performance graph (b) of a two-stage high-pass filter. This design is known as a Butterworth filter, and is the type used as the rumble filter section of our project: It has a sharp break frequency, and gives a slope or roll-off of 12 dB/octave.

The basic high-pass filter of Figure 2 can be made to act as a low-pass type by simply transposing the positions of C1 and R1, as shown in Figure 4. Figure 5 shows the two-stage (second order) Butterworth version of the low-pass filter. This is the design that is used as the scratch filter in our project.

In the complete project (see main diagram) the high-pass or rumble filter is designed around Q1 and R1, R2 and C1 - C6, and the low-pass or scratch filter is designed around Q2 and R6 - R8 and C10 - C15. Resistors R4, R5 and bypass capacitor C7 provide the low-Z bias point for the two transistors. The low-frequency break point of the rumble filter can be varied via three-way switch S1, and the high-frequency break point of the scratch filter can be varied via S3.




FREQUENCY RESPONSE OF FILTER



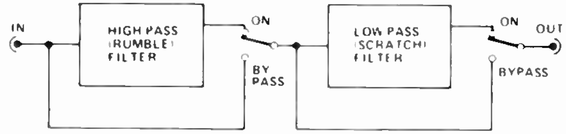




*Figure 1.* **Block diagram, scratch and rumble filter.**

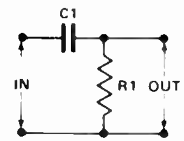



*Figure 2 (a).* **Simple passive high-pass filter.**

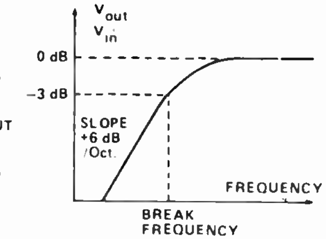



*Figure 2 (b).* **Frequency response.**

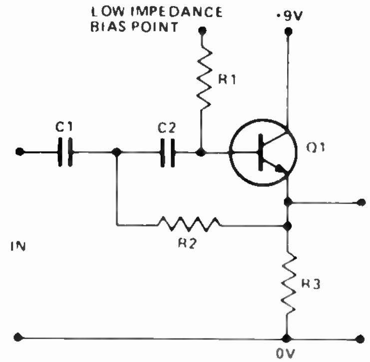



*Figure 3 (a).* **Two-stage active high-pass filter.**

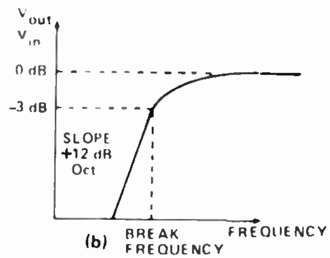



*Figure 3 (b).* **Frequency response.**

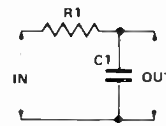



*Figure 4 (a).* **Simple passive low-pass filter.**

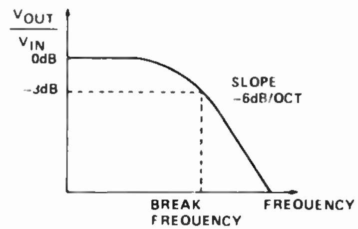



*Figure 4 (b).* **Frequency response.**

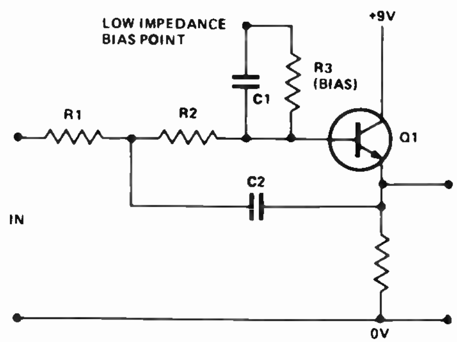



*Figure 5 (a).* **Two-stage low-pass filter.**

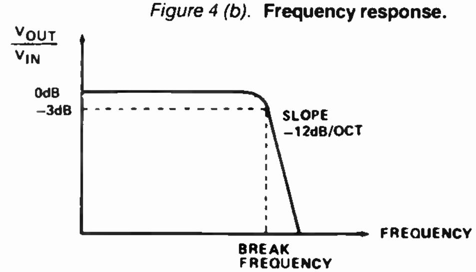



*Figure 5 (b).* **Frequency response.**

## Construction

This description is confined to the mono version. A stereo version is readily assembled from two pc boards. As the switches are all available with a complete extra set of poles and contacts, these components need not be duplicated in a stereo version. Wiring will follow much the same course as described here.

We built our filter into a diecast box, but you may have something else in mind. A diecast box is very robust and provides generally good shielding, although a steel box would further reduce possible hum pickup.

All the switches are mounted on the lid of the diecast box. The pc board is 'hung' off the rotary switches and supported by tinned copper wire from the switch tags. This makes quite a rigid assembly and ensures short wiring to the switches. For a stereo version, the second channel pc board may be mounted behind the first, wired to the switches in a similar fashion.

The input and output sockets are mounted on one wall of the box and wired to the pc board with shielded cable. The bypass toggle switches are wired with hookup wire.

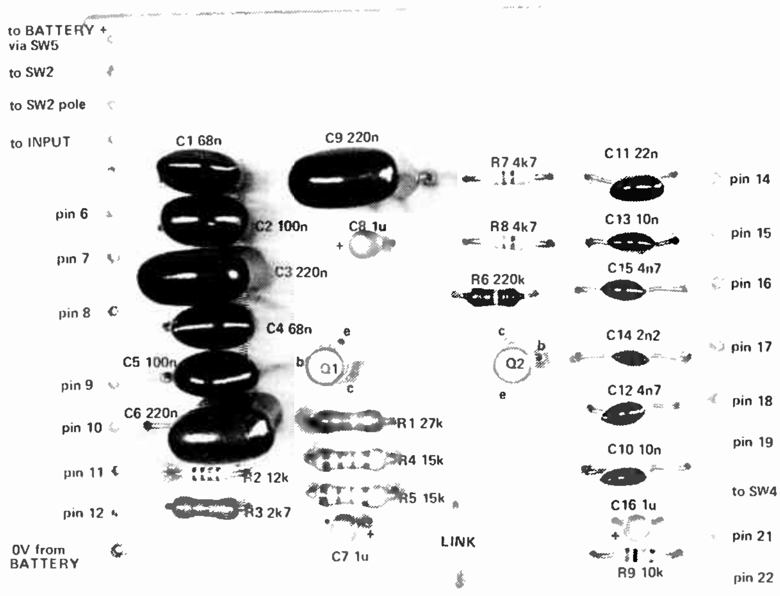
When assembling the pc board, watch out for the polarity of the tantalum capacitors and the orientation of the transistors, otherwise assembly is quite easy. With the components mounted in the board, the next step is to solder 50 mm lengths (longer for the second channel in a stereo version) of tinned copper wire to the lugs on the rotary switches.

Solder suitable lengths of insulated hookup wire to the points on the pc board that lead out to the toggle switches SW2, SW4 and SW5.

Carefully insert the tinned copper wires into their respective holes on the pc board and push the board up the wires to within about 15 mm or so of the switches. Take care not to bend any of the wires. Solder all the wires in place and cut off the excess. If building a stereo version, repeat this, taking care not to get the two channels' switch wiring tangled, pushing the second channel board to within 15 mm of the first.

Wire all the toggle switches input and output leads and you're ready to try it out.

We used a No.216 9 V battery. This is quite sufficient for the mono or stereo versions as current drain is only two milliamps per channel.




**Component overlay for the pc board. Note that pin numbers 1 to 5, plus 13 and 20, are not used. Resistor R10 and the indicator LED1 are mounted off the pc board (we have not used these).**

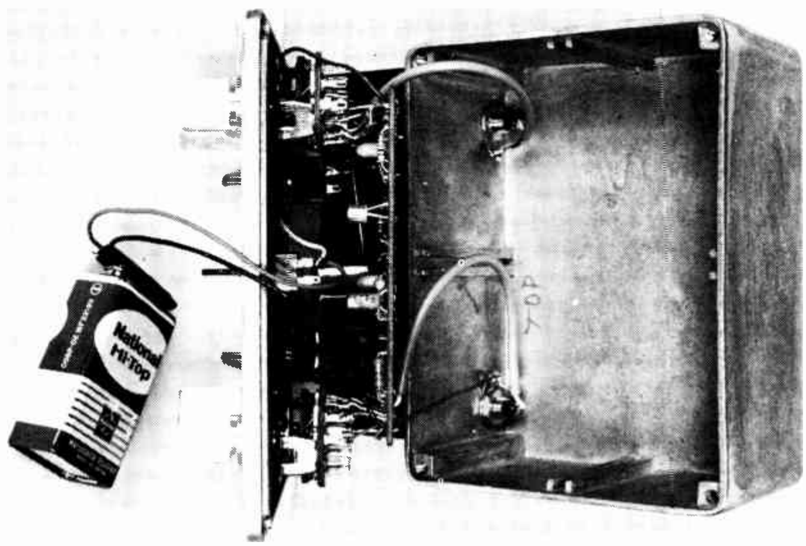
## Operation

Operation is quite simple. With the unit's switches set for bypass, put on a record known to suffer from surface noise problems. Switch the unit on and put the scratch filter in circuit. Adjust the rotary switch and note the effect of the different filter frequencies. Do the same for the rumble filter.

A little experimentation should show up the best setting for each recording. It's worthwhile keeping a note of the setting with each record. The Scratch and Rumble filter is also a great aid when making tape recordings of old discs, particularly 78s.

With this unit, those old discs will find a new lease of life! ●

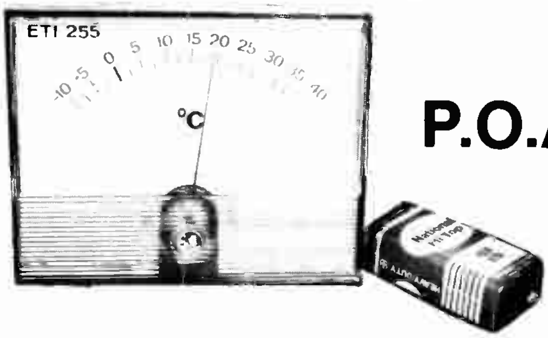
**Internal view of the completed project showing the location of the input and output RCA sockets and the pc board 'hung' from the rear of the switches. Note that this is a mono version.**



# ROD IRVING ELECTRONICS

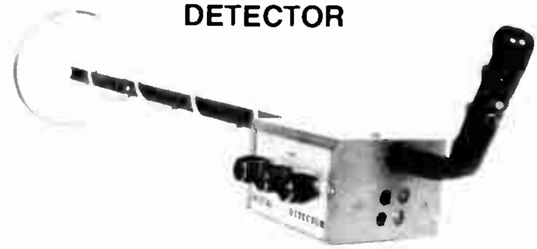
425 HIGH STREET, NORTHCOTE 3070. MELBOURNE. PH (03) 489-8131

## ETI 255 ELECTRONIC THERMOMETER




P.O.A.

## ETI 561 SIMPLE METAL DETECTOR



$34.50

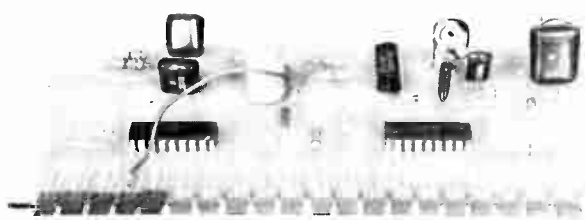
## ETI 325 AUTO PROBE

P.O.A.

## ETI 476 SERIES 3000 COMPACT STEREO

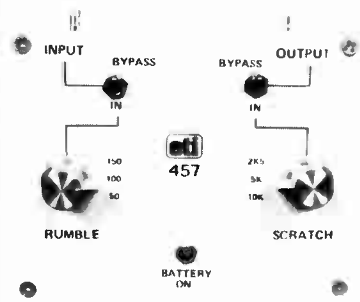

$84.50

## ETI 324 LED TACHO



$34.50

## ETI 457 SCRATCH AND RUMBLE FILTER




P.O.A.

326: Expanded scale LED voltmeter........P.O.A.
320: Battery condition indicator........P.O.A.
496: Series 4000 speakers........$699.00
475: AM tuner........$89.00
131: General purpose power supply........P.O.A.
142: DC power supply........P.O.A.
pH the acid test........P.O.A.
572: pH meter........$97.50
562: Geiger counter........P.O.A.
724: Microwave oven leak detector........P.O.A.
546: GSR monitor........P.O.A.
250: Simple house alarm........P.O.A.
558: Masthead strobe........P.O.A.
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Experimenting with ultrasonics........P.O.A.
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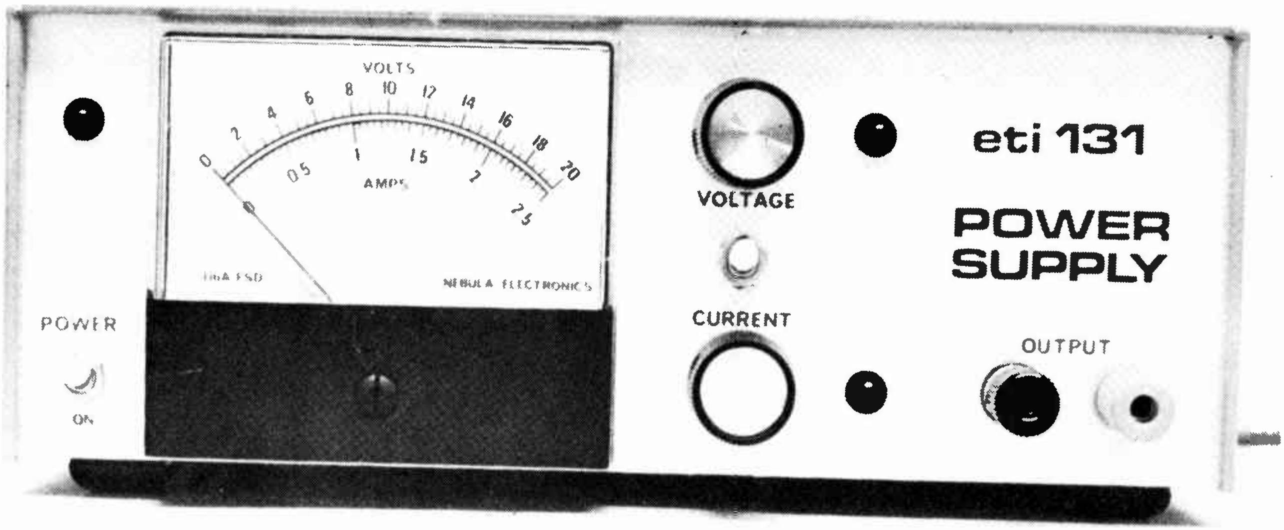
# General purpose power supply

This versatile general purpose supply produces up to 2.5 amps from zero to 20 volts – or up to 1.25 amps from zero to 40 volts. Current limiting is adjustable over the entire range for either output option.




**SPECIFICATION – ETI 131**

| | | |
|---|---|---|
| **20 VOLT VERSION** | | |
| VOLTAGE | | |
| | Output | 0–20 volts |
| | Regulation | <20 mV (0–2.5A) |
| | Ripple and noise | < 1 mV at 2.5A |
| CURRENT | | |
| | Output | 0–2.5A (up to 18 V) |
| | | 0–2.0A (up to 20 V) |
| | Limit | 0–2.5A |
| | Regulation | <10 mA (0–20 V) |
| **40 VOLT VERSION** | | |
| VOLTAGE | | |
| | Output | 0–40 V |
| | Regulation | <20 mV (0–1.25A) |
| | Ripple and noise | <1.5 mV at 1.25A |
| CURRENT | | |
| | Output | 0–1.25A |
| | Limit | 0–1.25A |
| | Regulation | <10 mA (0–40 V) |

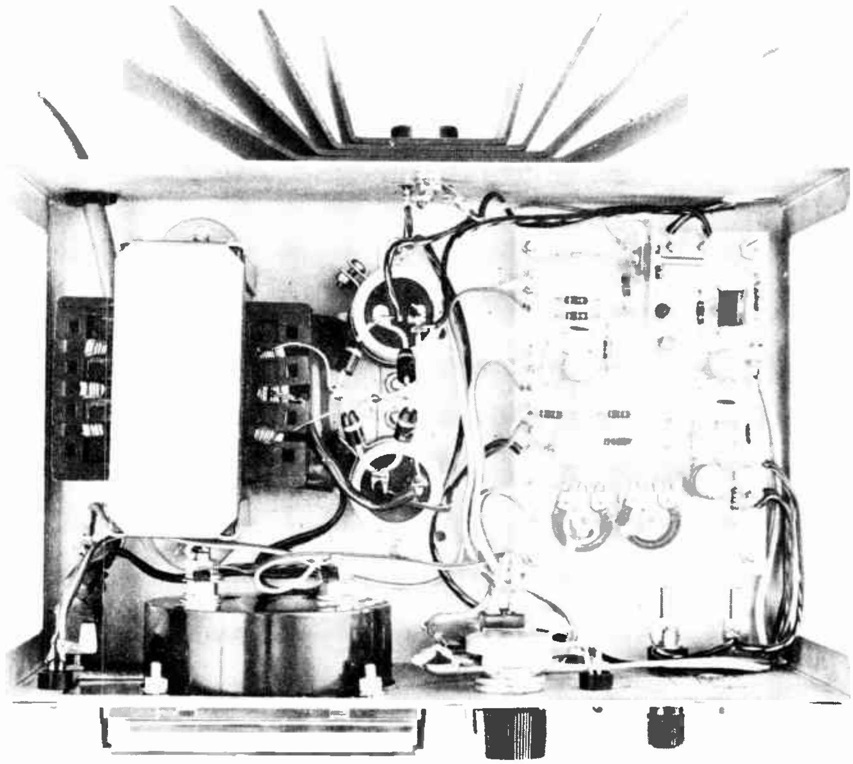
In both versions LEDs indicate voltage or current modes and the meter is switchable to read voltage or current.

AN IDEAL POWER SOURCE should supply a voltage which is adjustable over a wide range, and which remains at the set voltage regardless of line voltage or load variations. The supply should also be undamaged by a short circuit across its output and be capable of limiting the load current so that devices are not destroyed by fault conditions.

Two such supplies have previously been described in ETI. The first was a simple supply providing 0 to 15 volts at up to 750 mA. The second was a dual tracking supply providing ± 20 volts at up to one ampere. Both these supplies have been extremely popular, especially the simple one, and are still being built by many people. However there have been many requests for a supply having a greater output current capability than either of these previous designs could provide.

This project describes a supply that will provide 2.5 amperes at up to 18 volts (up to 20 volts at lower currents).

Alternately a few simple changes can make the supply provide up to 40 volts at 1.25 amperes. The supply voltage is settable between zero and the maximum available, and current limiting is also adjustable over the full range.
The mode of operation of the supply is indicated by two LEDs. The one beside the voltage control knob indicates when the unit is in normal voltage-regulation mode and the one beside the current limit control indicates when the unit is in current-limit mode. In addition a large meter indicates the current or voltage output as selected by a switch.



*Inside view of the completed 40 volt power supply. Note how the heatsink is mounted to the rear of the unit.*

## DESIGN FEATURES.

During our initial design stages we looked at various types of regulator and the advantages and disadvantages of each in order to choose the one which would give the best cost-effective performance. The respective methods and their characteristics may be summarized as follows.

**The shunt regulator.** This design is suitable mainly for low-power supplies – up to 10 to 15 watts. It has good regulation and is inherently short-circuit proof but dissipates the full amount of power it is capable of handling under no-load conditions.

**The series regulator.** This regulator is suitable for medium-power supplies up to about 50 watts.. It can and is used for higher power supplies, but heat dissipation can be a problem especially at very high current with low output voltages. Regulation is good, there is little output noise and the cost is relatively low.

**SCR regulator.** Suitable for medium to high power applications, this regulator has low power dissipation, but the output ripple and response time are not as good as those of a series regulator.

**SCR preregulator and series regulator.** The best characteristics of the SCR and series regulators are combined with this type of supply which is used for medium to high-power applications. An SCR pre-regulator is used to obtain a roughly regulated supply about five volts higher than required, followed by a suitable series regulator. This minimizes power loss in the series regulator. It is however more expensive to build.

**Switching regulator.** Also used for medium to high-power applications, this method gives reasonable regulation and low power dissipation in the regulator but is expensive to build and has a high frequency ripple on the output.

**Switched-mode power supply.**
The most efficient method of all, this regulator rectifies the mains to run an inverter at 20 kHz or more. To reduce or increase the voltage an inexpensive ferrite transformer is used, the output of which is rectified and filtered to obtain the desired supply. Line regulation is good but it has the disadvantage that it cannot easily be used as a variable supply as it is only adjustable over a very small range.

## OUR OWN DESIGN

Our original design concept was for a supply of up to 20 volts at 5 to 10 amps output. However, in the light of the types of regulator available, and the costs, it was decided to limit the current to about 2.5 amps. This allowed us to use a series regulator – the most cost-effective design. Good regulation was required, together with variable-current limit, and it was also specified that the supply would be useable down to virtually zero volts. To obtain the last requirement a negative supply rail or a comparator that will operate with its inputs at zero volts is required.
Rather than use a negative supply

*Rear view of the heatsink showing how it and the transistor are mounted.*

## HOW IT WORKS – ETI 131.

The 240 volt mains is reduced to 40 Vac by the transformer and, depending on which supply is being built, rectified to either 25 or 50 Vdc. This voltage is only nominal as the actual voltage will vary between 29 volts (58 volts) on no-load to 21 volts (42 volts) at full load. The same filter capacitors are used in either case. They are connected in parallel for the 25 volt version (5000 μF) and in series for the 50 volt version (1250μF). In the 50 volt version the centre tap of the transformer is connected to the centre tap of the capacitors thus ensuring correct voltage sharing between the capacitors. This arrangement also provides a 25 volt supply for the regulator IC.

The voltage regulator is basically a series type where the impedance of the series transistor is controlled in such a way that the voltage across the load is maintained constant at the preset value. The transistor Q4 dissipates a lot of power especially at low output voltages and high current and is therefore mounted on the heatsink on the rear of the unit. Transistor Q3 adds current gain to Q4, the combination acting as a high-power, high-gain, PNP transistor.

The 25 volts is reduced to 12 volts by the integrated-circuit regulator IC1. This voltage is used as the supply voltage for the CA3130 ICs and is further reduced to 5.1 volts by zener diode ZD1 for use as the reference voltage. The voltage regulation is performed by IC3 which compares the voltage as selected by RV3 (0 to 5.1 volts) with the output voltage as divided by R12 and R13. The divider gives a division of 4.2 (0 to 21 volts) or eight (0 to 40 volts). However at the high end the available voltage is limited by the fact that the regulator loses control at high current as the voltage across the filter capacitor approaches the output voltage and some 100 Hz ripple will also be present. The output of IC3 controls transistor Q2 which in turn controls the output transistor such that the output voltage remains constant regardless of line and load variations. The 5.1 volt reference is supplied to the emitter of Q2 via Q1. This transistor is in effect a buffer stage to prevent the 5.1 volt line from being loaded.

Current control is performed by IC2 which compares the voltage selected by RV1 (0 to 0.55 volts) with the voltage generated across R5 by the load current. If say 0.25 volts is set on RV1 and the current drawn from the supply is low, the output of IC2 will be near 12 volts.

This causes LED 2 to be illuminated as the emitter of Q1 is at 5.7 volts. This LED therefore indicates that the supply is operating in the voltage-regulator mode. If however the current drawn is increased such that the voltage across R5 is just above 0.25 volts (in our example) the output of IC2 will fall. When the output of IC2 falls below about 4 volts Q2 starts to turn off via LED 3 and D5.

The effect of this is to reduce the output voltage so that the voltage across R7 cannot rise further. When this happens the voltage comparator IC3 tries to correct for the condition and its output rises to 12 volts. IC2 then takes more current to compensate and this current causes LED 3 to light, indicating that the supply is operating in the current-limit mode.

To ensure accurate regulation the voltage sensing leads are taken to the output terminals separately from those carrying the load current.

The meter has a one milliamp movement and measures the output voltage (directly across the output terminals) or current (by measuring the voltage across R5) as selected by the front panel switch SW2.

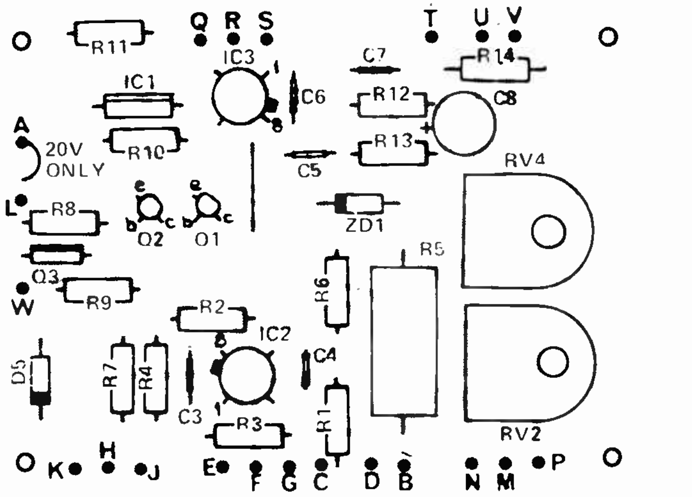
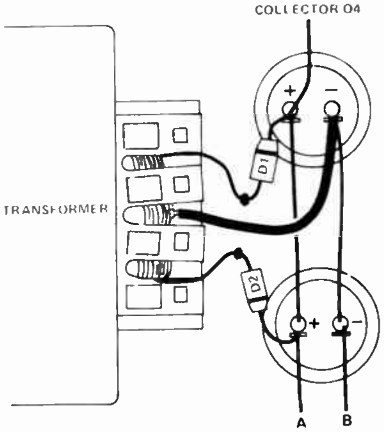
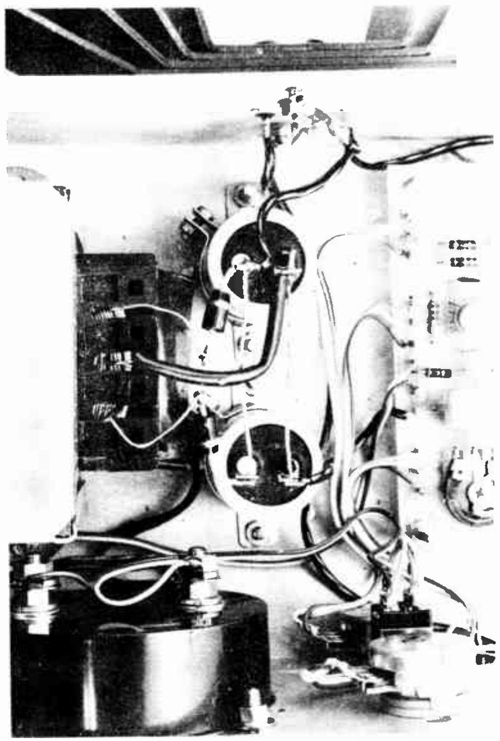



*Fig. 3. Component overlay for the printed-circuit board assembly.*

*Fig. 4. How the supply is wired for the 20 volt 2.5 ampere version.*



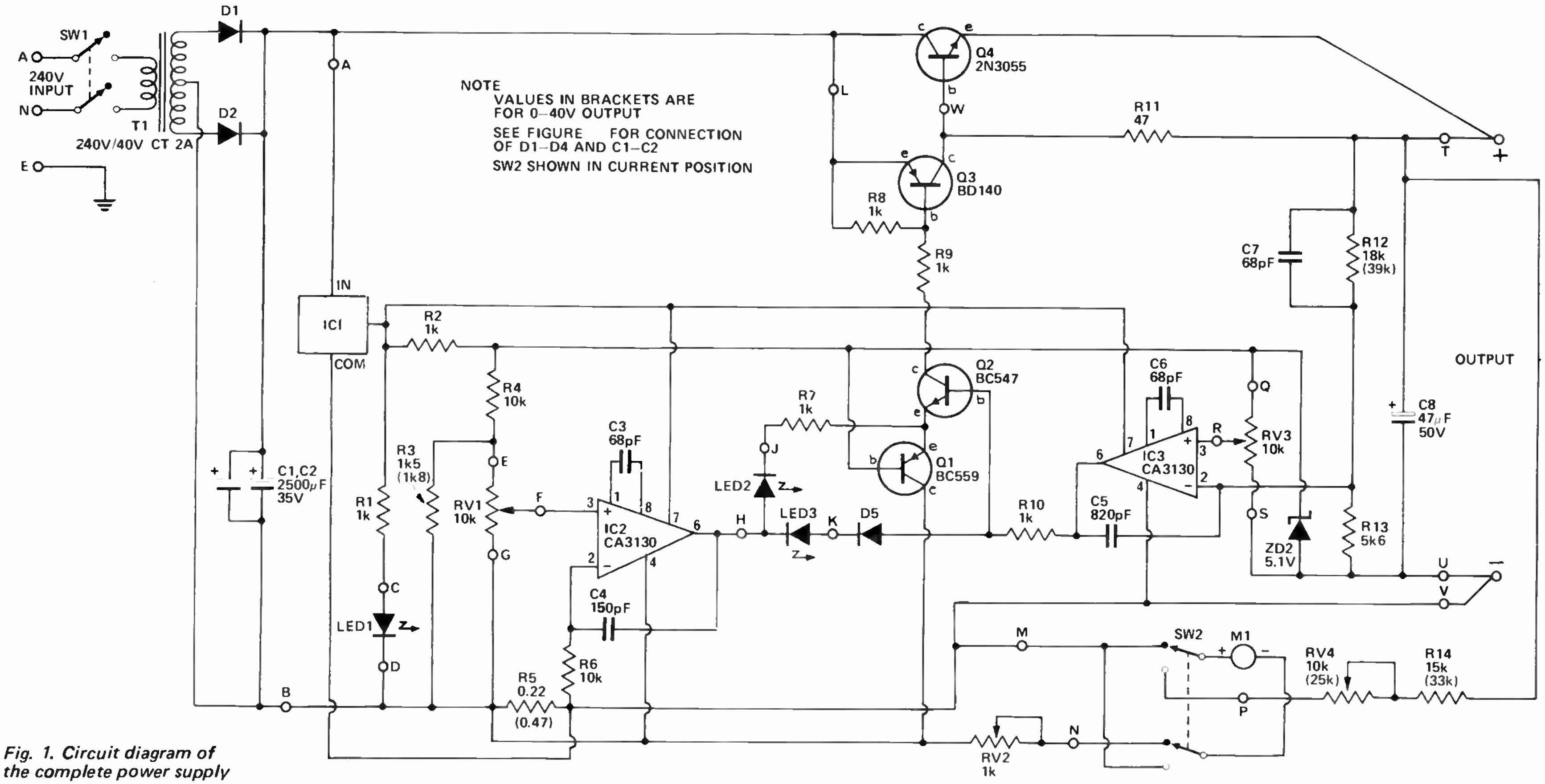



*Fig. 1. Circuit diagram of the complete power supply 20 volt 2.5 ampere version.*

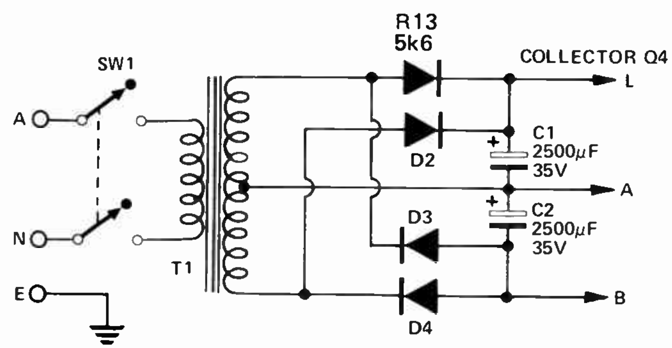
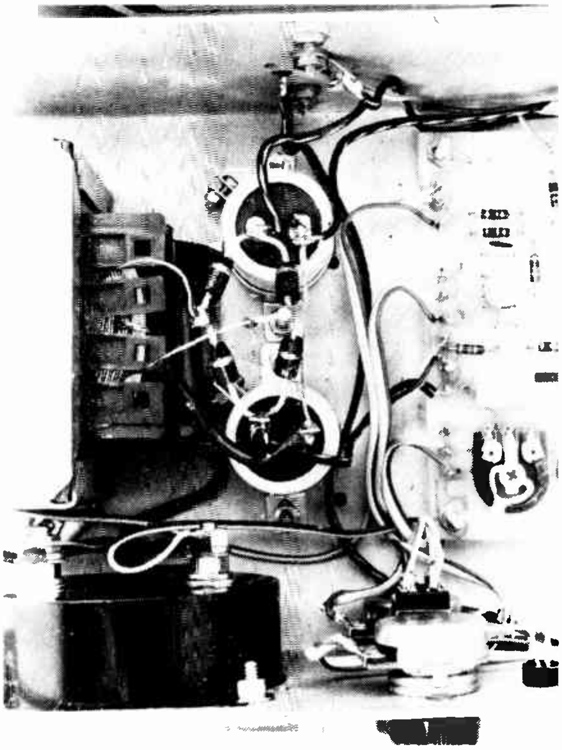



*Fig. 2. Alternative rectifier and filter capacitor connections required for 40 volt, 1.25 ampere version.*

RECONNECTEDPOWER SUPPLY FOR 40V 1.25A SUPPLY

# General purpose power supply



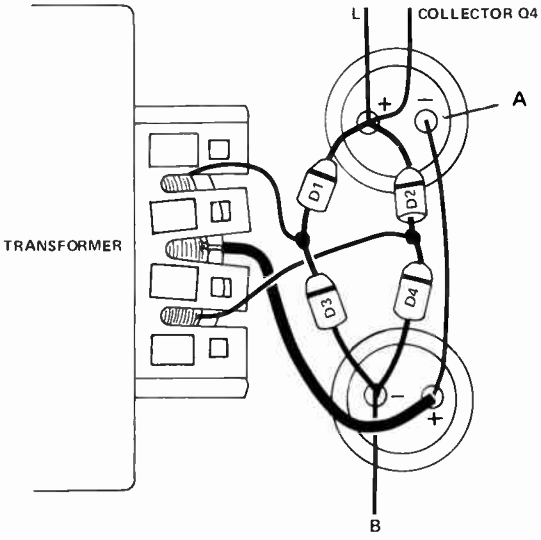



*Fig. 5. How the supply is wired for the 40 volt 1.25 ampere version.*

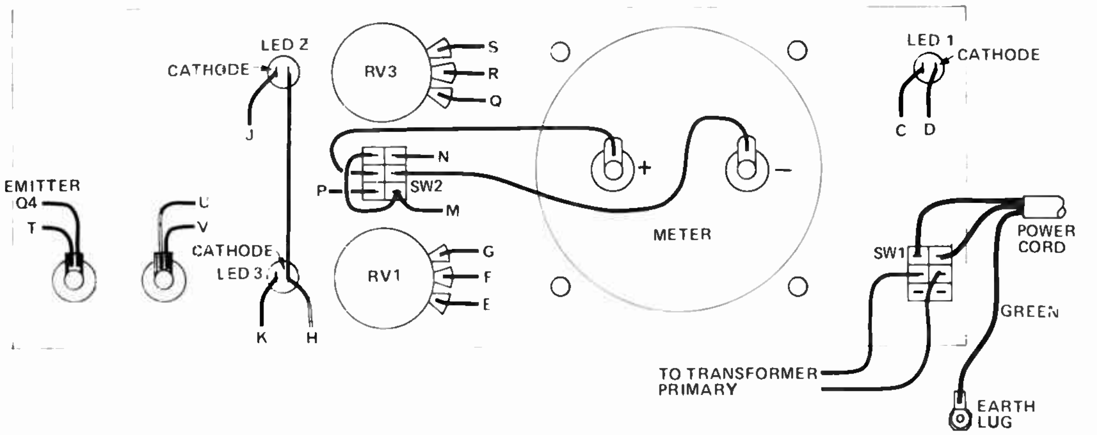



*Fig. 6. Front panel wiring diagram.*

rail we chose to use a CA3130 IC operational amplifier as the comparator. The CA3130 requires a single supply (maximum of 15 volts) and, initially, we used a resistor and 12 volt zener to derive a 12 volt supply. The reference voltage was then derived from this zener supply by another resistor and a 5 volt zener. It was felt that this would have given sufficient regulation for the reference voltage but in practice the output from the rectifier was found to vary from 21 to 29 volts and some of the ripple and voltage change that occurred across the 12 volt zener, as a consequence, was reflected into the 5 volt zener reference. For this reason the 12 volt zener was replaced by an IC regulator which cured the problem.

With all series regulators the series-output transistor by the nature of the design, must dissipate a lot of power especially at low output voltage and high current. For this reason an adequate heatsink is an essential part of the design. Commercial heatsinks are very expensive and sometimes difficult to mount. We therefore designed our own heatsink which was not only cheaper but worked better than the commercial version we had been considering — being easier to mount. However at full load the heatsink still runs hot as does the transformer, and under high-current low-voltage conditions the transistor may even be too hot to touch. This is quite normal as the transistor under these conditions is still operating within its specified temperature range.

With any highly regulated supply, stability can be a problem. For this reason in the voltage-regulation mode of operation, capacitors C5 and C7 are incorporated to reduce the loop gain at high frequencies and thus prevent the supply from oscillating. The value of C5 has been chosen for best compromise between stability and response time. If the value of C5 is too low the speed of response is greater — but there is a higher chance of instability. If too high the response time is unduly increased.

In the current-limit mode the same function is performed by C4 and the same remarks apply as for the voltage case.

As the supply is capable of fairly high current output there is inevitably some voltage drop across the wiring to the output terminals. This is overcome by sensing the voltage at the output terminals via a separate pair of leads.

Whilst the supply was primarily designed for 20 volts at 2.5 amps it was suggested that the same supply could be used to supply 40 volts at 1.25 amps and that this would be of more value to some users. This may be done by changing the configuration of the rectifier and by changing a few components. Some thought was given to making the supply switchable but the extra complication and expense were such that it was not considered to be worthwhile. Thus you should simply decide which configuration suits your need and build the supply accordingly.

The maximum regulated voltage available is limited either by the input voltage to the regulator being too low (at over 18 volts and 2.5 amps) or by the ratio of R12/R13 and by the value of the reference voltage.

$$(\text{Output} = \frac{R12 + R13}{R13}\ \text{V ref})$$

Due to the tolerance of ZD1 the full 20 volts (or 40 volts) may not be obtainable. If this is found to be the case R12 should be increased to the next preferred value.

Single turn potentiometers have been specified for the voltage and current controls because they are inexpensive. However if precise setability of voltage or current limit is required ten-turn potentiometers should be used instead.

## CONSTRUCTION

The recommended printed-circuit board layout should be used as construction is thereby greatly simplified. Printed-circuit board pins should also be used for the 20 wire connections to the board. These should be installed first. The rest of the components may now be assembled onto the board making sure that the polarities of diodes, transistors, ICs and electrolytics are correct. The BD140 (Q3) should be mounted such that the side with the metal surface faces towards IC1. A small heatsink should be bolted onto the transistor as shown in the photograph.

If the metalwork as described is used the following assembly order should be used.

a) Mate the front panel to the front of the chassis and secure them together by installing the meter.

b) Fit the output terminals, potentiometers and meter switch on to the front panel.

c) The cathodes of the LEDs (that we used) were marked by a notch in the body which could not be seen when the LEDs were mounted onto the front panel. If this is the case with yours, cut the cathode leads a little shorter to identify them and then mount the LEDs into position.

d) Solder lengths of wire (about 180 mm long) to the 240 volt terminals of the transformer, insulate the terminals with tape and then mount the transformer into position in the chassis.

f) Install the power cord and the cord retaining clip, wire the power switch,

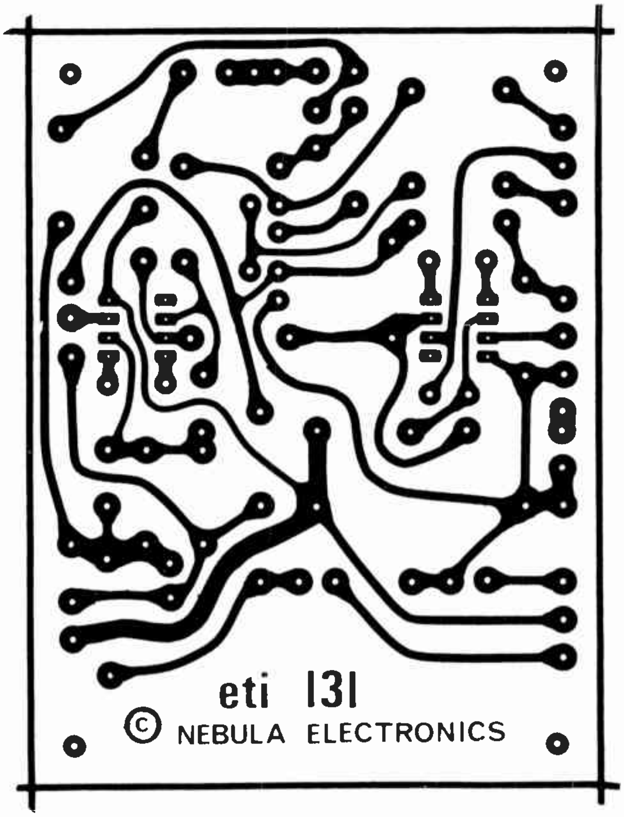



*Fig. 7. Printed-circuit board layout for the power supply. Full size 100 x 75 mm.*

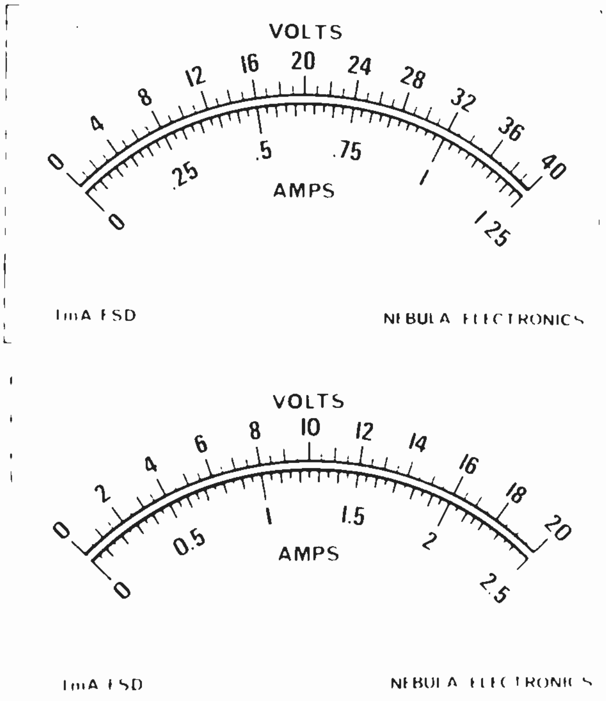



*Fig. 8. Scales for the alternative meters for the unit shown full size.*

# General purpose power supply

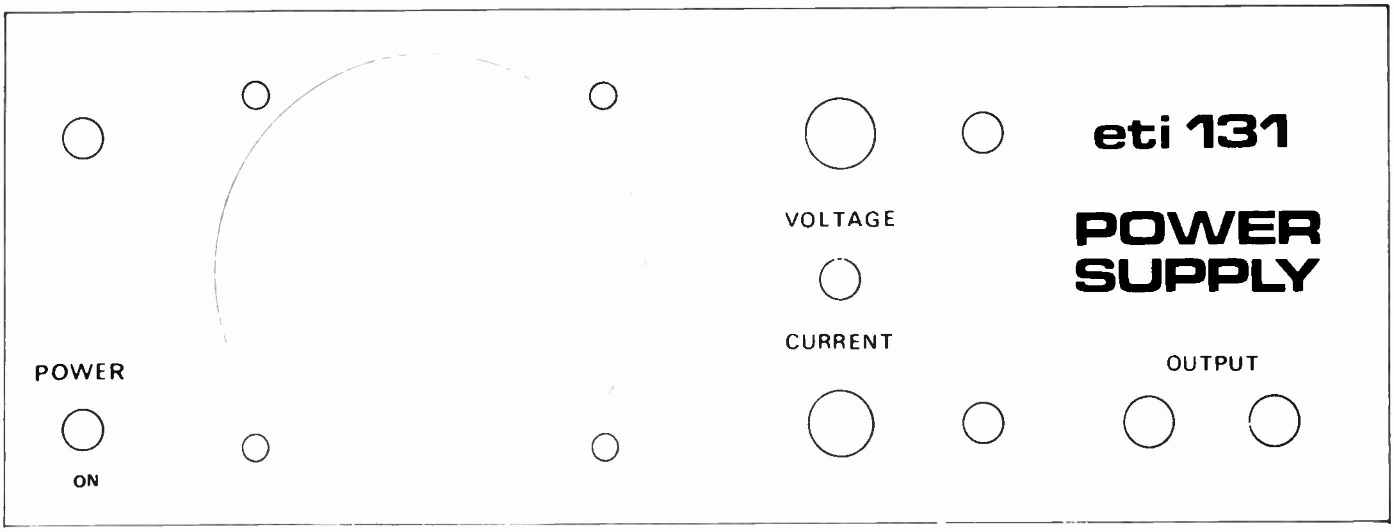



*Fig. 9 Artwork for the front panel. Full size 224 x 82 mm.*

insulate the terminals and then mount the switch onto the front panel.

g) Assemble the heatsink and screw it onto the rear of the chassis via two bolts — then mount the power transister using insulation washers and silicon grease.

h) Mount the assembled printed-circuit board to the chassis using 10 mm spacers.

i) Wire the transformer secondary, rectifier diodes and filter capacitors. The diode leads are stiff enough not to need any additional support.

j) The wiring between the board and the switches may now be made by connecting points with corresponding letters on the front panel diagram and component overlay diagrams.

The only setting up required is to calibrate the meter. Connect an accurate voltmeter to the output terminals and wind up the voltage control of the power supply until the external meter reads 15 volts (or 30 volts on the alternate arrangement). Switch the internal meter to read volts and adjust RV4 to obtain the same reading.

To set up the current reading first wind the supply voltage down to zero and connect an accurate ammeter across the output. Wind up the voltage control and observe that the current limit LED is on. Now adjust the current limit control so that the external meter indicates two amps (or one amp on the alternative unit). Now adjust RV2 so that the same reading is obtained on the internal meter when it is switched to the current position.

## PARTS LIST — ETI 131A

**Resistors**

| | | | | |
|---|---|---|---|---|
| R1 | — | 1 k | ½ W | 5% |
| R2 | — | 1 k | " | " |
| R3 | — | 1 k5 | " | " |
| R4 | — | 10 k | " | " |
| R5 | — | 0.22 ohm 5 W | | |
| R6 | — | 10 k | ½ W | 5% |
| R7 | — | 1 k | " | " |
| R8 | — | 1 k | " | " |
| R9 | — | 1 k | " | " |
| R10 | — | 1 k | " | " |
| R11 | — | 47 | " | " |
| R12 | — | 18 k | " | " |
| R13 | — | 5 k6 | " | " |
| R14 | — | 15 k | " | " |

**Potentiometers**

| | | |
|---|---|---|
| RV1 | — | 10 k lin rotary |
| RV2 | — | 1 k trim |
| RV3 | — | 10 k lin rotary |
| RV4 | — | 10 k trim |

**Capacitors**

| | | |
|---|---|---|
| C1 | — | 2500 µF 35V electro |
| C2 | — | 2500 µF 35V electro |
| C3 | — | 68 pF ceramic |
| C4 | — | 150 pF " |
| C5 | — | 820 pF " |
| C6 | — | 68 pF " |
| C7 | — | 68 pF " |
| C8 | — | 47 µF 50V electro |

**Complete kits of components for this project can be obtained from Nebula Electronics Pty Ltd, 4th Floor, 15 Boundary St, Rushcutters Bay (telephone 33-5850).**

**Transistors**

| | | |
|---|---|---|
| Q1 | — | BC559 |
| Q2 | — | BC547 |
| Q3 | — | BD140 |
| Q4 | — | 2N3055 (with insulation kit) |

**Diodes**

| | | |
|---|---|---|
| D1,2 | — | IN5404 |
| D5 | — | IN914 |

**Other Semiconductors**

| | | |
|---|---|---|
| ZD1 | Zener Diode | 5.1V 400 mW |
| LED 1,2 | LED | 5023 or similar |
| IC1 | Integrated Circuit | LM341P-12 |
| IC2,3 | " " | CA3130 |

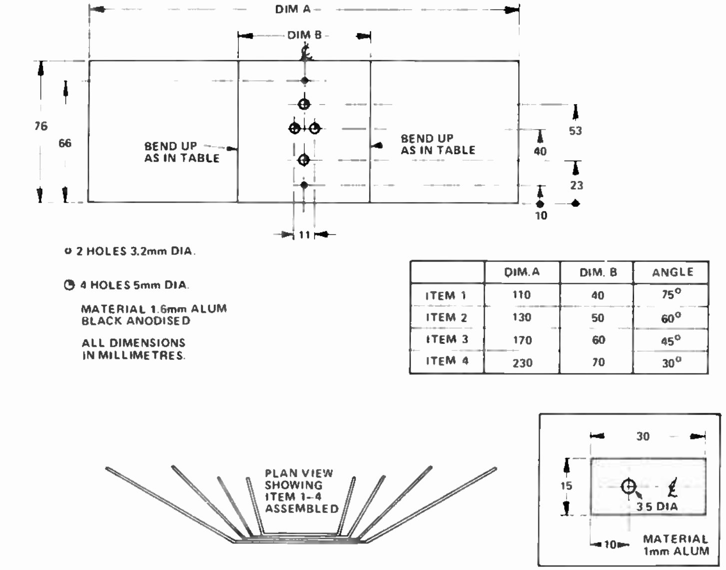
**Miscellaneous**

PC board ETI 131
Transformer 40V CT 2A A&R 5755
SW1,2 switch DPDT toggle
Meter 1 mA FSD scaled 0-20V, 0-2.5A
Chassis to Fig. 11
Cover to Fig. 13
Heatsink to Fig. 10
Front panel to Fig. 9
Two terminals
Power cord & clamp
Two knobs
Four 10 mm long spacers
20 PC board pins
Four rubber feet
nuts, bolts, washers etc.

## PARTS LIST — ETI 131B

**All parts for ETI 131A except**

| | | | |
|---|---|---|---|
| Change | R3 | to | 1 k8 |
| | R5 | to | 0.47 ohm |
| | R12 | to | 39 k |
| | R14 | to | 33 k |
| | RV4 | to | 25 k |




| | DIM. A | DIM. B | ANGLE |
|---|---|---|---|
| ITEM 1 | 110 | 40 | 75° |
| ITEM 2 | 130 | 50 | 60° |
| ITEM 3 | 170 | 60 | 45° |
| ITEM 4 | 230 | 70 | 30° |

Fig. 10. Heatsink detail.

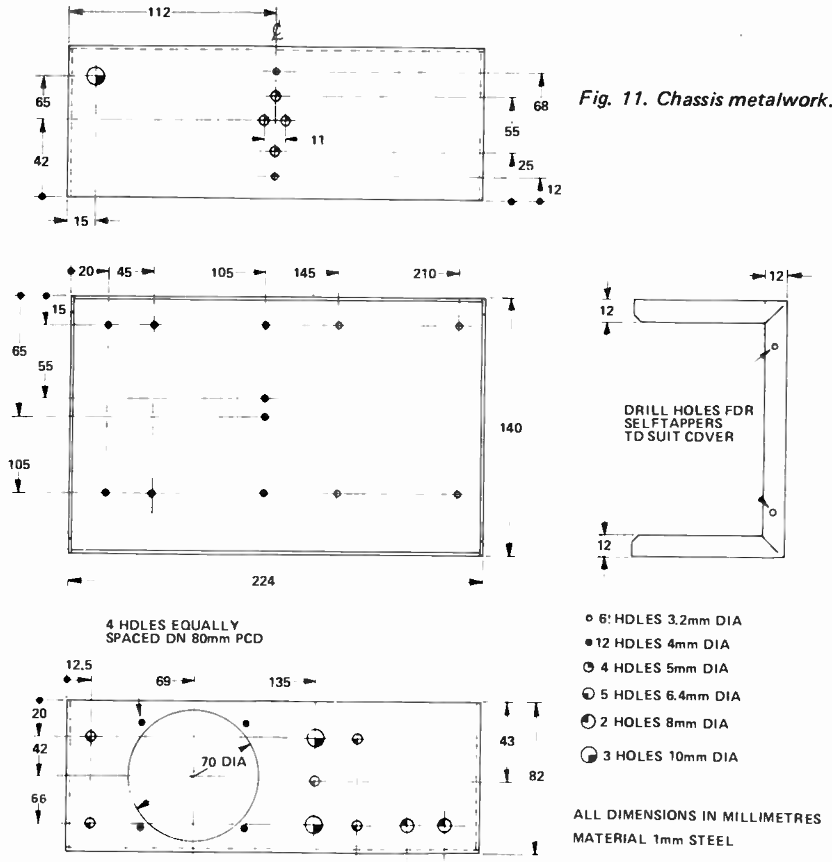



Fig. 11. Chassis metalwork.

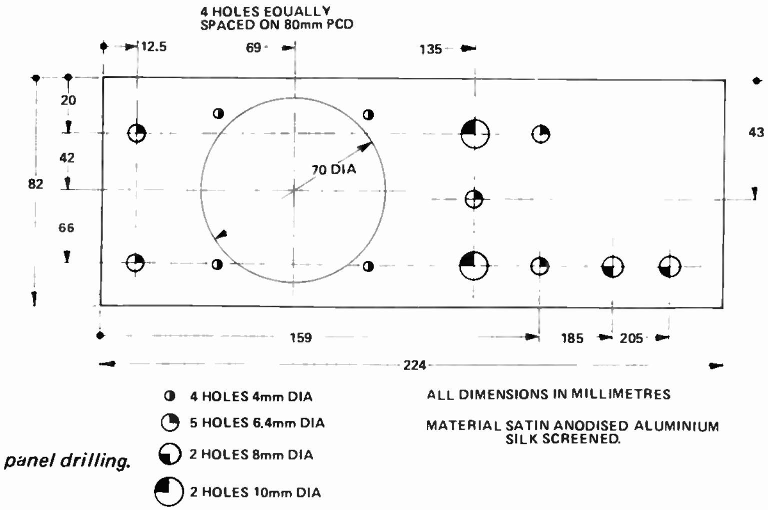



Fig. 12. Front panel drilling.

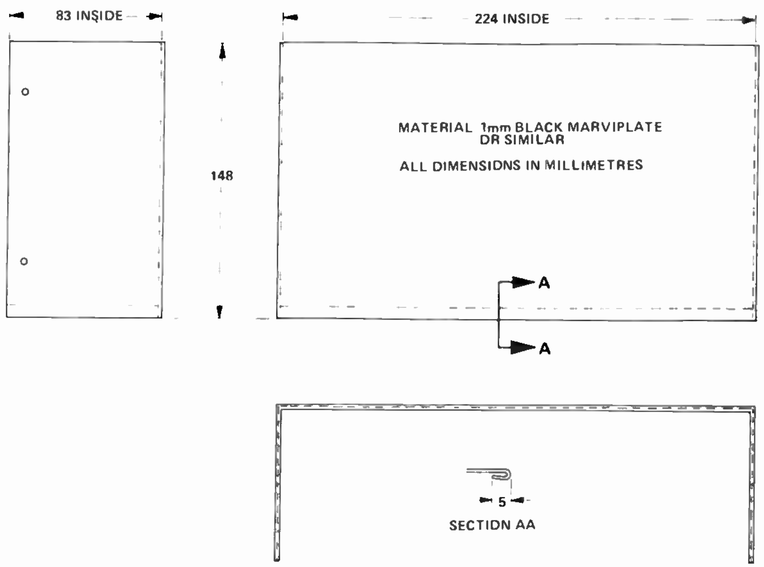
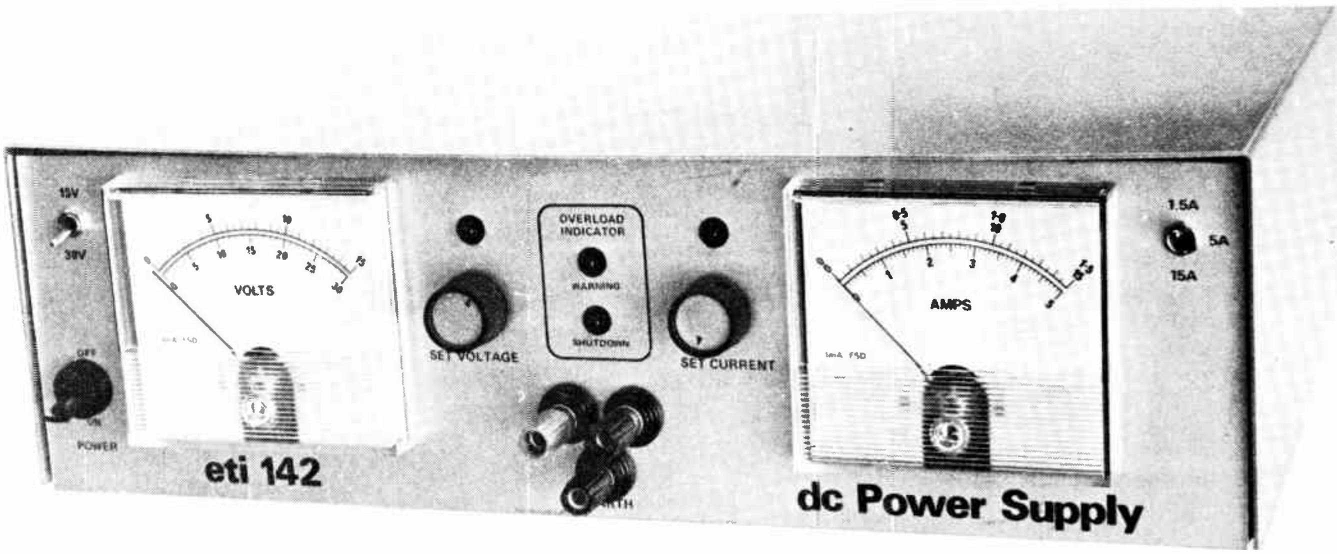



Fig. 13. Detail of metal cover.

# dc Power Supply

This new power supply has high current, high voltage capability.




## SPECIFICATION - ETI 142

| | |
|---|---|
| Output voltage | 0 - 30V |
| Output current | 0 - 15A |
| Regulation | 20mV (0 - 15A) |
| Ripple and noise | 10mV |
| Metering | |
| Voltage | 0 - 15V, 0 - 30V |
| Current | 0 - 1.5A, 0 - 5A, 0 - 15A |

| | |
|---|---|
| Overload indication | |
| Warning | if run continuously in this mode supply may shutdown. |
| Shutdown | if transformer gets too hot due to a continuous overload the supply will shut down until it has cooled. |
| Maximum output (not continuously) | 24V 15A<br>26V 12.5A<br>28V 11A<br>30V 8A |

THIS POWER SUPPLY was designed to extend the range of dc supplies we have published over recent years. It is capable of supplying voltages from zero to 30 volts and current up to 15 amps. The techniques used allow a high power output while retaining a small physical size.

## Design Features

Once again, as with all power supply designs, there is a choice to be made as to the technique of regulation to be used. Starting from the most efficient we have:

### The switched-mode power supply

With this system the mains voltage is rectified to give 340 volts dc and an inverter using an inexpensive ferrite transformer gives the low voltage required. While regulation against line and load changes can be built in, it is not suitable where the output voltage has to be variable over a large range.

### Switching regulator

This utilizes a conventional transformer/rectifier but the regulation is done by switching the output at about 20 kHz with a variable markspace ratio. The output is filtered by an LC network with a diode protecting the switching transistor. This system is efficient but is fairly complex where good regulation is needed and some 20 kHz ripple appears on the output.

### SCR regulator

This simply uses two SCRs in the rectifier circuit with the phase angle of their firing controlling the output voltage. This scheme has the disadvantage of having a slow response time and normally a choke input rectifier/filter is necessary.

### Series regulator

This is the most common regulator in use today and has good response time, ripple rejection and regulation. Power dissipation however is high when drawing high currents at low voltages on a variable output unit. It is usually used up to about 100 watts with other systems used above this.

### Shunt regulator

This is normally limited to about 10 watts, for, while the performance is very good, the dissipation is more than the maximum output on no load.

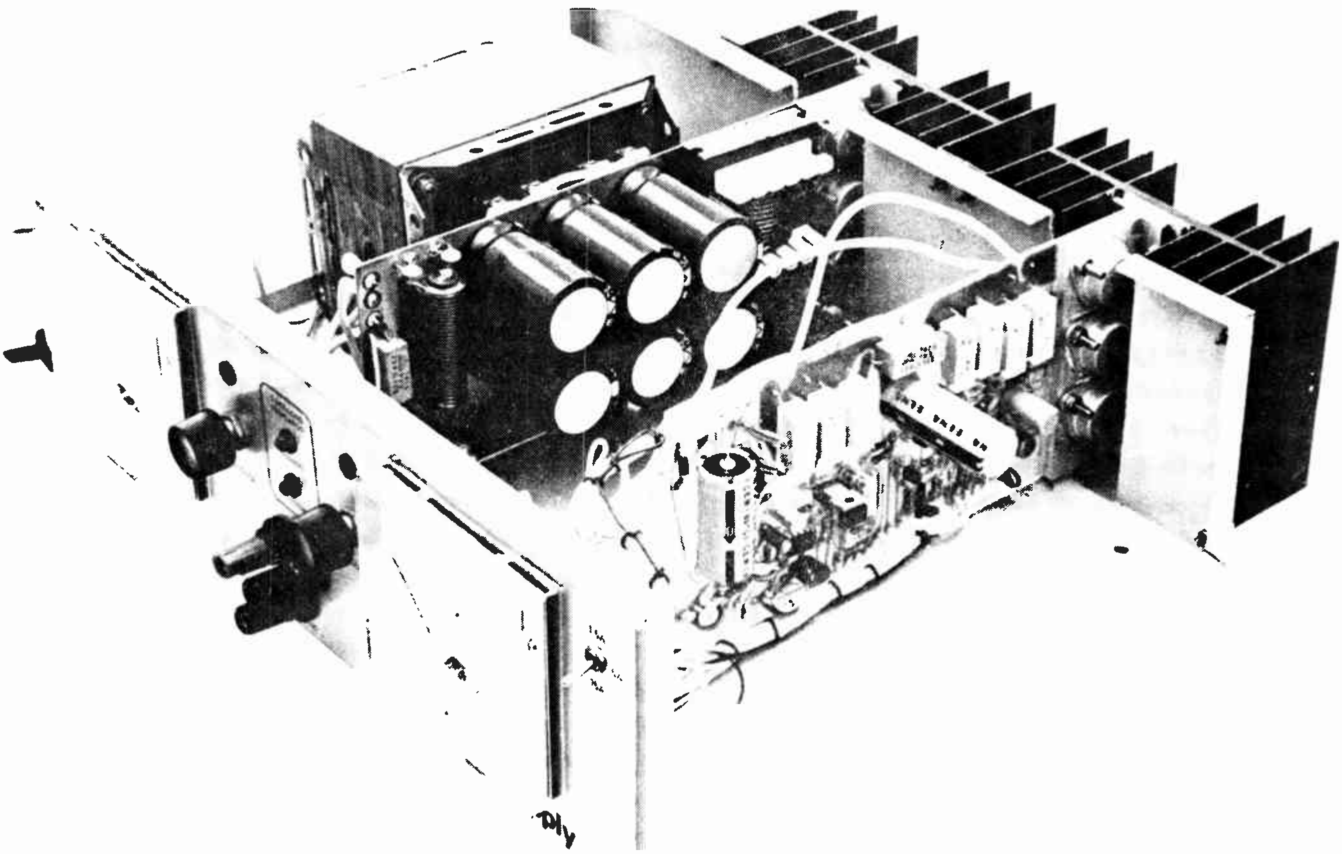
When we originally built the unit we intended using an SCR pre-regulator followed by a series final regulator. The SCR pre-regulator was to give an output about 5V above the required output. To reduce cost and size we chose not to use a choke input filter. While we could regulate the output the transformer became hot with low (dc) output voltage. The reason soon became apparent when some maths was done.

At low voltages a very short SCR conduction time is used and as the current out times time must equal current in times time for the main capacitor the input current can be 5 or 10 times the dc load current. As heating of the transformer is due to the current in the windings and not the thru-power it got hot.

We then changed to a switching pre-regulator with a series final regulator. With this design the transformer output is rectified and filtered before being regulated. This system allows higher load currents to be taken at lower output voltages without the necessity of a range switch.

Problems arising from the use of a switching regulator are mainly due to the high current and fast voltage transients generating radio frequency interference (RFI) and voltage transients in the output. The RFI problem was solved mainly by the use of an earthed shield on one side of the pc board and the addition of input and output filters.

Initially we intended to vary the mark-space ratio to compensate for the 100 Hz ripple making it easier on the series regulator. However the prototype exhibited a tendency to oscillate at around 1 kHz due to the delays in the output filter; either a more complicated control circuit would be needed or we should let the series regulator get rid of the 50 Hz ripple. We chose the second approach.



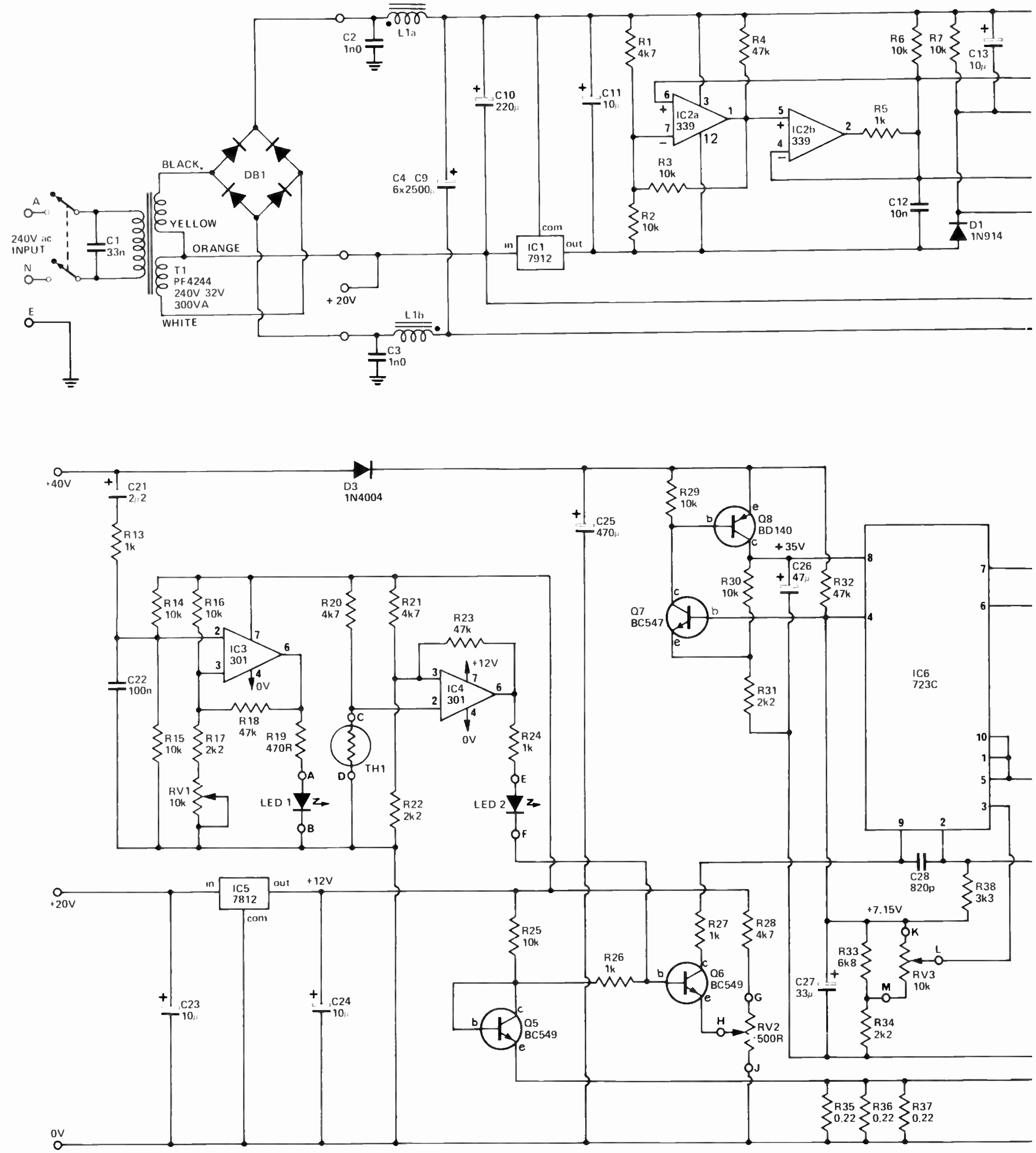
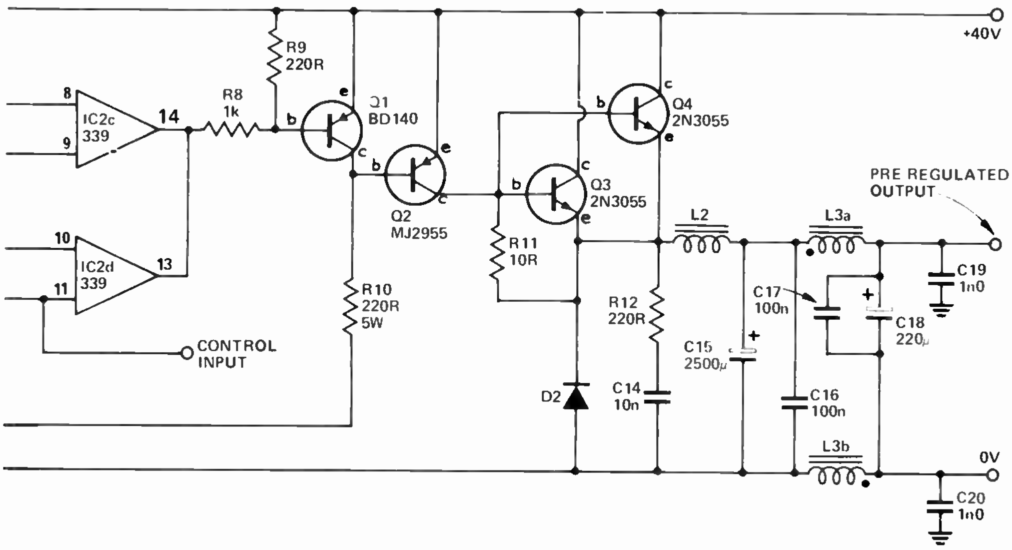
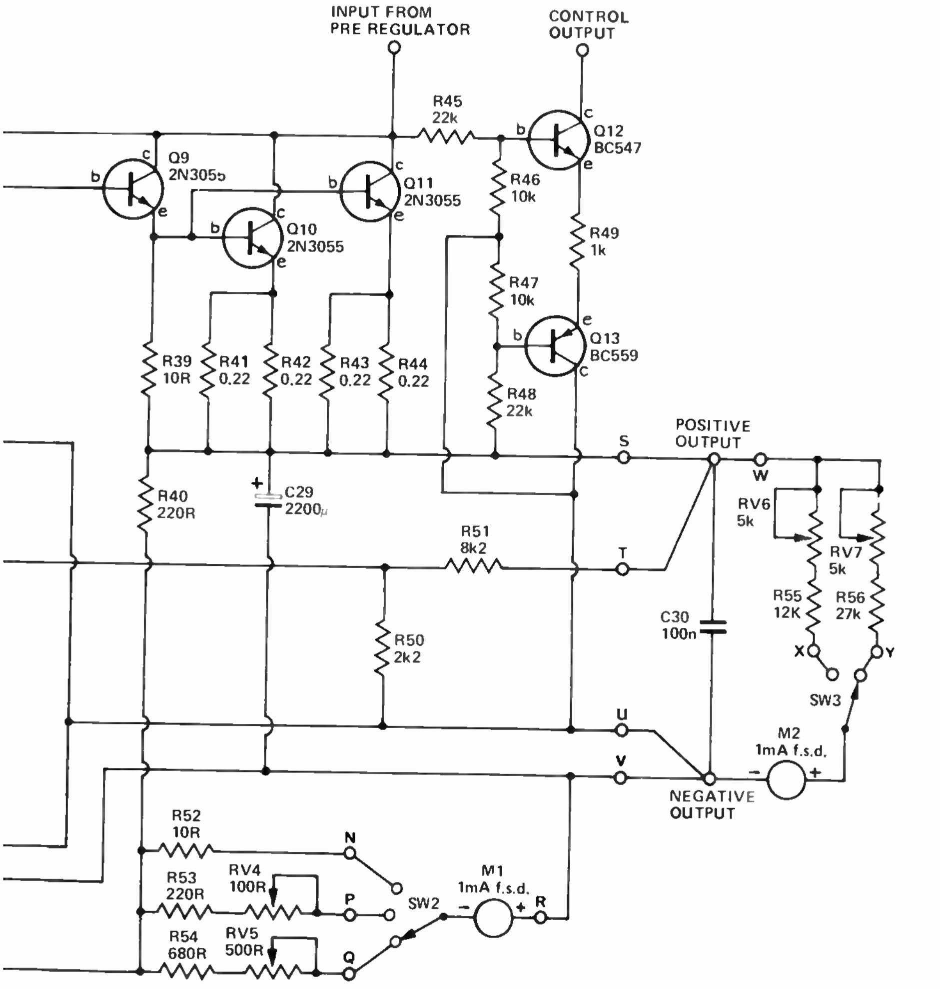



*Fig. 1. The circuit diagram of the switching pre-regulator (top) and the series regulator (lower).*




*Owing to space limitations, it is not possible for us to print the printed circuit patterns or the metalwork drawings. However, these are available directly from ETI on receipt of a large, stamped self-addressed envelope. Send it to: PSU Drawings, Electronics Today, 15 Boundary Street, Rushcutters Bay, NSW 2011.*

## Construction

The two chokes on the ferrite rods can be wound according to table 1, and the appropriate diagram. Note that the two layers are wound in *opposite* directions and that the start and finish of each coil occurs on diagonal corners. After winding the first layer it is best to smear epoxy cement over it so that it will stay in place.

The main choke can now be wound with four close-wound layers of wire. Bring the start and finish out through the slots in the bobbin. Smear some epoxy over the outer layer to prevent movement and, after it has set, break the ends of the bobbin off as shown in the photograph. This is to enable the coil to be fitted through the hole in the pc board. Break the ends on the *opposite* side to the start/finish.

In the switching regulator the only emitter resistor used with the output transistors is a length of pc board track. It is necessary to ensure that the two transistors used have reasonably close base-emitter voltages. A selection can be made from the five used in the unit by joining the base and collector with a lead and passing 2 to 3 amps from collector to emitter (unless a current source is available it may be simplest to use a 12V battery with a 24-32W globe in series). The two which have the closest base-emitter voltages should be used.

Begin assembly of the switching pre-regulator board by mounting the board on the heatsink brackets with the transistors. As the current passes through the mounting screws it is recommended that 4BA or 4 mm brass screws be used. Also, tin the area where the screws contact the board. Some insulating tubing should be inserted in the holes to prevent the screws touching the sides. Mica insulation washers should be used under the transistors with silicon grease on *both* sides of each washer and also between the two brackets. Before tightening up, temporarily mount the brackets onto the heatsink to ensure that the mounting surface mates well. Tighten a couple of the screws holding the brackets onto the board remove the bracket from the heatsink, then tighten the rest of the screws on the board. As it takes the silicon grease some time to spread out it is best to re-tighten these screws again just before the unit is finally mounted on to the heatsink.

Check that the insulation washers are doing their job and solder the base and emitter leads of the transistors. The diode can also be mounted onto the heatsink using mica and insulation around the stud.

The rest of the components can now be mounted with the exception of the main choke, L2. Be careful that none

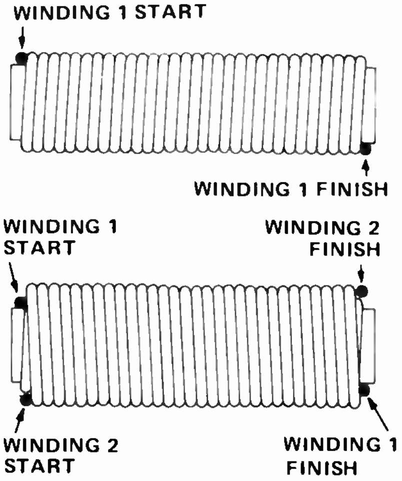
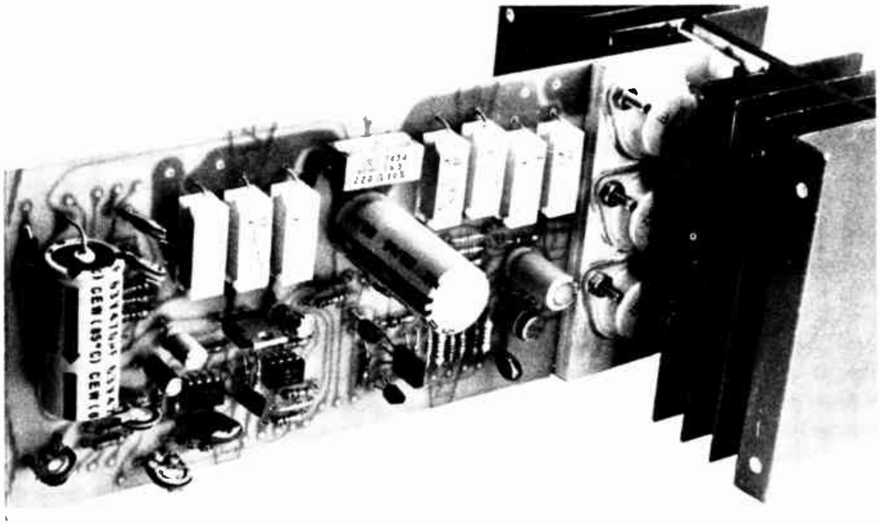
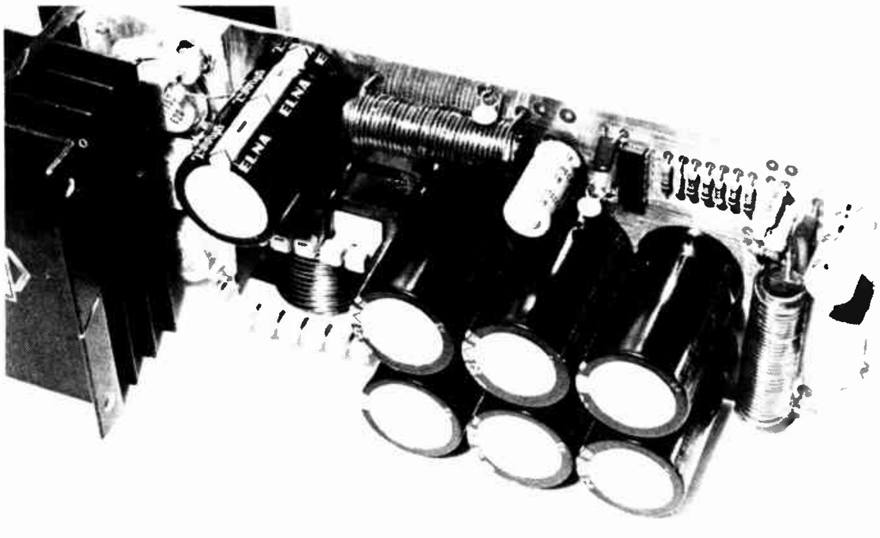



*Fig. 2. L 1, 3 with the first layer wound (top) and with both layers wound (lower).*

**Choke Winding Data    Table 1**

| | |
|---|---|
| **L1, L3** | |
| Core | 50mm long, 10mm dia. ferrite rod |
| Winding 1 | single layer, close wound, 1.25mm dia. copper wire |
| Winding 2 | single layer, close wound, 1.25mm dia. copper wire |
| Note that the two windings are wound in opposite directions. See diagram. | |
| **L2** | |
| Core | Philips FX3740/4322 020 52520 (2 required) |
| Bobbin | Philips DT2740/DT2743 |
| Winding | 48 turns 1.6 mm copper wire |
| Gap | 5mm |





of the components touch the earth screen (with the exception of C2, 3 and C19, 20 which go to ground).

## Mounting the Core

Cut two pieces of card or some other non-ferrous material, about 10 mm x 10 mm with a thickness of about 5 mm. These are glued onto the outer legs of one half of the core of L2. Several pieces can be laminated to give the required thickness if required. Slide both halves of the core into the former and bend the leads into such a position that the assembly will fit into the holes provided with no stress on the leads. Lift the coil out, clean the insulation off the leads where needed, place some epoxy on the side of the cores which contact the pc board and refit to the board. When the epoxy is set, the leads can be cut and soldered.

The start of the assembly of the series regulator board is similar to the first board with the exception that there is no power diode used. The board can be assembled according to the overlay — the only point to watch being that the 5 watt resistors should be mounted off the board by 1 or 2 mm, especially if anything but a fibreglass pcb is used (the resistors get warm!).

Start wiring by cutting 17 pieces of

hookup wire about ½ meter long, baring one end and soldering them into the lower row of holes in the series regulator board. Add similar wires to the switching regulator board for the +40V and control input connections. To the output pads on this board, add about 200 mm of wire capable of handling 15A.

Mark the ends of all these wires with the letter on the overlay (a small square of paper held on with tape is easiest). The two boards can now be mounted onto the appropriate heatsinks using silicon grease on the contact area.

Before fitting the pc board to the chassis, mount the transformer, rectifier DB1, 3 core flex, front panel and front panel components. The pcb/heatsink assemblies can now also be added. On our prototype unit the transformer had lugs on the transformer but others will have leads. Note that the wiring that carries the power must be capable of carrying 15 amps or more.

The front panel can now be wired in accordance with fig. 3. Note that C30 is mounted directly across the output terminals on the front panel and similarly C1 is mounted on the power switch. Insulate the bare connections of the power switch with insulation tape to prevent accidental contact.

The thermistor should be soldered onto the appropriate leads (C and D), initially cutting the leads to about 5 – 6 mm long. It should then be epoxied onto the side of the coil in the power transformer. Use the 'slow dry' type of epoxy as this normally works better at elevated temperatures.

## Testing and calibration

With a power supply as big as this one, initial power-up is always nerve-wracking and sometimes dramatic. If one is available use a variac to bring up the voltage. If a variac is not available set both the voltage and current limit adjustments to about mid position and switch on.

The voltmeter should now read about 15 volts and it should be adjustable using the voltage control. Measure the voltage between the input and output of the series regulator – this should be about 6 volts. This checks the operation of the switching regulator.

Add a load to the unit to check the operation of the series regulator. If it is correct the meters can now be calibrated. For the low current range (1.5A) it is necessary to select R52 to calibrate the meter (the value is too low for a trim potentiometer).

To set the trim pot for the "warning" LED it is necessary to adjust the unit to 12V output and to load it to 10 amps. The potentiometer can now be adjusted until the led just lights.

## HOW IT WORKS - ETI 142

### Rectifier

The 240V AC is transformed to 32 V AC by T1 with DB1 rectifying it to give about 45V DC. On full load this voltage will fall to about 35 volts. For the purposes of this description we will refer to this as +40 volts (nominal value). The centre tap of the transformer is used to derive a centre tap DC voltage, reducing power dissipation in some of the electronics.

### Switching pre-regulator

In this section, IC1 is used to generate a supply voltage 12 volts *below* the positive supply rail and this powers IC2. This IC has two functions: IC2a and IC2b form a triangular wave generator and IC2c and IC2d a comparator. The voltage on pins 8 and 10 of IC2 is the triangular waveform, varying from -3.6V to -6.3V (referred to the positive rail) with the rising part taking about 50 µs and the falling edge being about 4 µs. This gives a frequency slightly less than 20 kHz.

The comparators IC2c and d are connected in parallel simply to give additional drive capability. The output stage of the 339, for those unfamiliar with it, is simply an open-collector NPN transistor with the emitter joined to the negative supply rail. If the voltage on the control input is within 3.6V of the positive supply rail, the comparator output will be high and so Q1 will be off, Q2 on and Q3 & 4 on. Transistors Q3 and Q4 are in parallel to give additional drive and current sharing is helped by emitter resistance made up of about 60 mm of copper track on the pc board. These transistors should however be the same brand and selected to have similar base-emitter voltages.

If the control voltage is more than 6.3V from the supply rail the comparator output will be low, turning on Q1. This turns Q2, 3 and 4 off. The control voltage oscillates between -3.6V and -6.3V and so the transistors will be turned on and off at 20 kHz, the mark to space ratio being controlled by the control voltage. This effectively varies the output voltage.

The output of Q3, 4 is filtered by L2 and C15 to give a smooth DC voltage. A flyback diode, D2, is necessary and must be a fast recovery type to reduce power dissipation in the transistors. While the choke has an AC voltage across it the current is DC with an AC ripple. For this reason a substantial air gap is used to prevent the core saturating when the current rises to around 15 amps.

### Series Regulator

The basis of the regulator is the familiar 723 monolithic regulator IC. The output of this IC is buffered by Q9-Q11 giving the required 15 ampere capability. Normally this IC cannot regulate to below 2V because of the limitations of the comparator. To get around this problem resistor R38 provides some bias current such that when the output voltage is zero the comparator input (pin 2) is above the 2V lower limit. Similarly the potentiometer which controls the output voltage varies not from zero, but from about 2 volts up to the reference voltage from the IC (pin 4) at 7.15 volts.

For those not familiar with the IC, it compares the voltage at pins 2 (inverting) and pin 3 (non-inverting) and adjusts the output on pin 6 to compensate. While this IC can vary the output voltage to within 3 volts of the positive supply rail, it does have a maximum supply of 40V. With this circuit, on no load the supply rises to about 45 volts, too high for the IC. To overcome this we have used a two transistor regulator (Q7, 8) using the reference voltage in the 723 IC to give about 35V on pin 8 of the 723. On full load the regulator ceases to operate as the ripple on the supply rail drops below the 35 volts required. An additional isolation diode and storage capacitor are used to maintain as high a voltage as possible.

Control of the preregulator is done by Q12 and Q13. The voltage from the preregulator and the actual regulated output voltage are both divided by three; if the differential voltage is greater than about 3.6 volts Q12 and Q13 will start to conduct. The collector of Q12 goes to the control input of the preregulator card to vary the voltage from the preregulator. The action of these transistors is to maintain about 5-6V differential between the desired output voltage and the preregulator output.

Current limiting is done by measuring the voltage across R35-37 using Q6. A second transistor Q5 is used to compensate for the 0.5-0.6 volt base-emitter voltage of Q6 and also to compensate for any temperature variations, in the base-emitter voltage.

If the current exceeds the preset value Q6 will start to conduct pulling current out of pin 9 of the 723 IC. This will reduce the output voltage to prevent the current rising above the preset limit.

Current measurement is done simply by measuring the voltage across R35-37. Three ranges are provided. Voltage measurement is done directly across the output terminals with two ranges provided.

The supply is capable of delivering high currents at high voltages for short periods; overload indication is provided by IC3 and IC4. The first of these, IC3, measures the amplitude of the ripple voltage on the main filter capacitors. This effectively gives an indication of the current being drawn from the transformer. When it exceeds a preset level, IC3 changes state, lighting up LED1.

The second indication is given by IC4 which measures the resistance at a thermistor glued onto the transformer. If the resistance drops below about 2.2k ohms the output of IC4 will go high, lighting LED2 and also shutting down the output by overriding the current limiting.

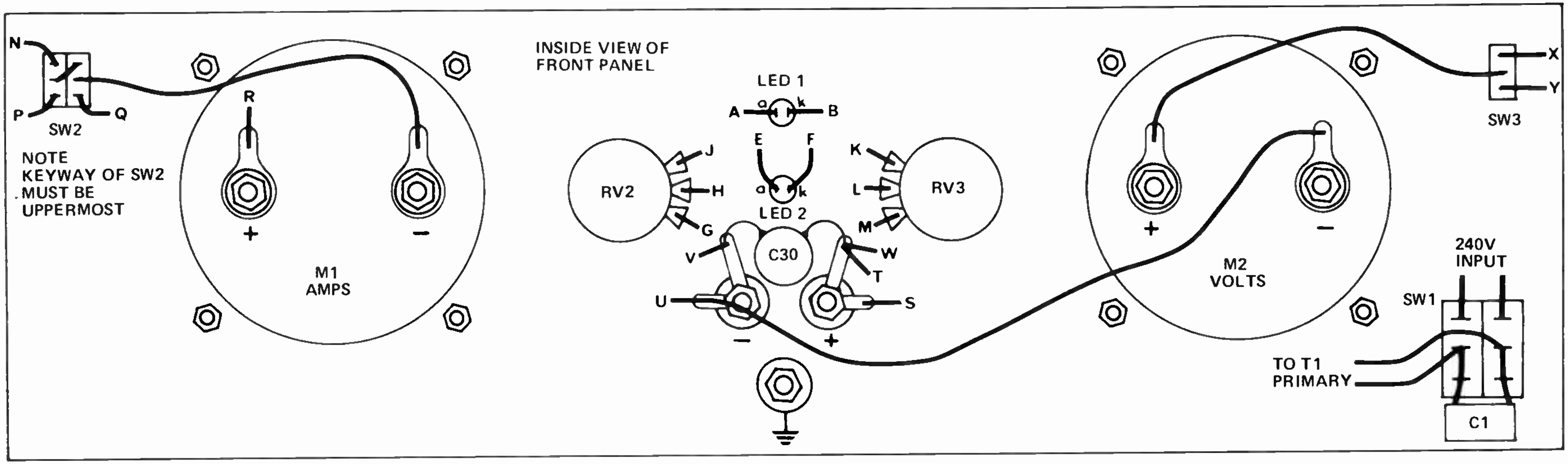



*Fig. 3. The front panel wiring diagram.*

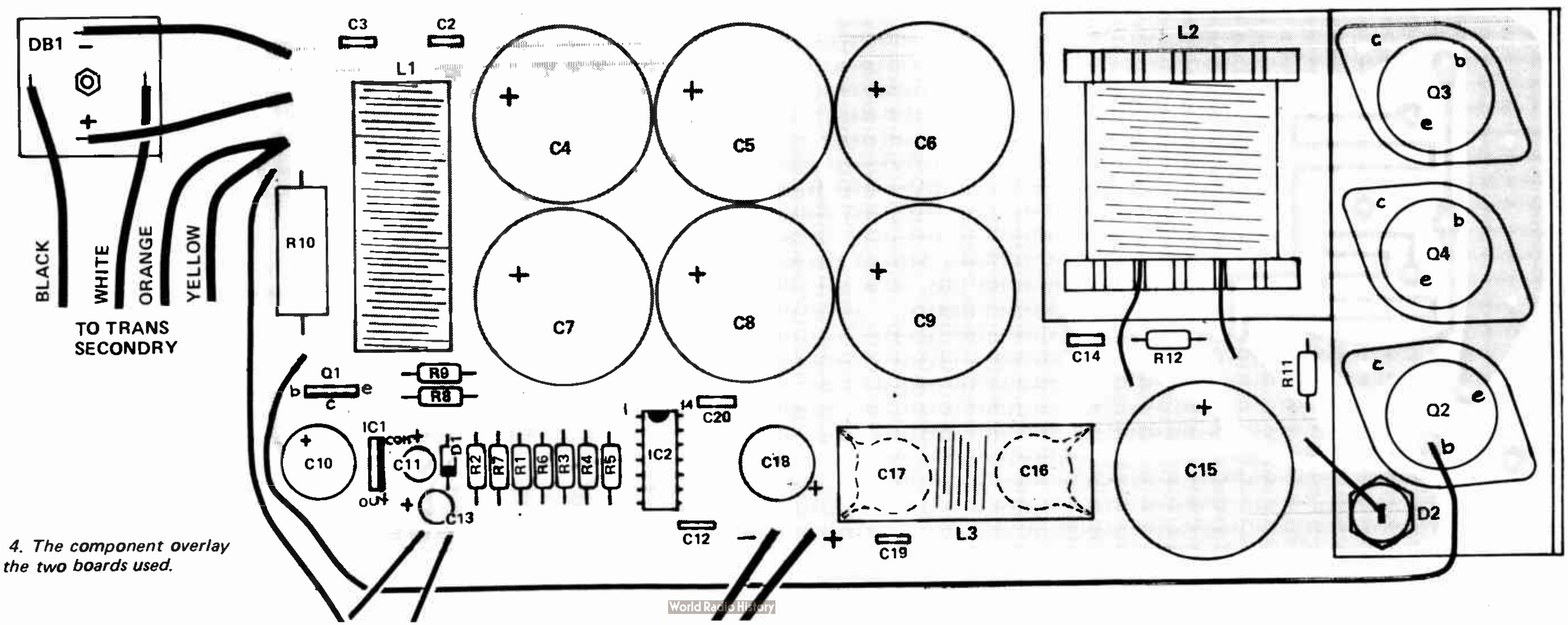



*Fig. 4. The component overlay for the two boards used.*

## PARTS LIST – ETI 142

**Resistors** all ½W, 5% unless stated

| | |
|---|---|
| R1 | 4k7 |
| R2,3 | 10k |
| R4 | 47k |
| R5 | 1k |
| R6,7 | 10k |
| R8 | 1k |
| R9 | 220R |
| R10 | 220R, 5W |
| R11 | 10R |
| R12 | 220R |
| R13 | 1k |
| R14–R16 | 10k |
| R17 | 2k2 |
| R18 | 47k |
| R19 | 470R |
| R20,21 | 4k7 |
| R22 | 2k2 |
| R23 | 47k |
| R24 | 1k |
| R25 | 10k |
| R26,27 | 1k |
| R28 | 4k7 |
| R29,30 | 10k |
| R31 | 2k2 |
| R32 | 47k |
| R33 | 6k8 |
| R34 | 2k2 |
| R35–R37 | 0.22Ω, 5W |
| R38 | 3k3 |
| R39 | 10R |
| R40 | 220R, 5W |
| R41–R44 | 0.22Ω, 5W |
| R45 | 22k |
| R46,47 | 10k |
| R48 | 22k |
| R49 | 1k |
| R50 | 2k2 |
| R51 | 8k2 |
| R52 | 10R |
| R53 | 220R |
| R54 | 680R |
| R55 | 12k |
| R56 | 27k |

**Thermistor**

| | |
|---|---|
| TH1 | Philips 2322 640 90004 |

**Potentiometers**

| | |
|---|---|
| RV1 | 10k trim |
| RV2 | 500R lin rotary |
| RV3 | 10k lin rotary |
| RV4 | 100R trim |
| RV5 | 500R trim |
| RV6,7 | 5k trim |

**Capacitors**

| | |
|---|---|
| C1 | 33n 250Vac |
| C2,3 | 1n0 disc ceramics |
| C4–C9 | 2500µ 63V RP electro |
| C10 | 220µ 35V RB electro |
| C11 | 10µ 35V RB electro |
| C12 | 10n polyester |
| C13 | 10µ 35V RB electro |
| C14 | 10n polyester |
| C15 | 2500µ 63V RP electro |
| C16,17 | 100n disc ceramics |
| C18 | 220µ 50V RB electro |
| C19,20 | 1n0 disc ceramics |
| C21 | 2µ2 63V RB electro |
| C22 | 100n polyester |
| C23,24 | 10µ 35V RB electro |
| C25 | 470µ 63V RT electro |
| C26 | 47µ 63V RB electro |
| C27 | 33µ 16V tantalum |
| C28 | 820p ceramic |
| C29 | 2200µ 35V RB electro |
| C30 | 100n disc ceramic |

**Inductors**

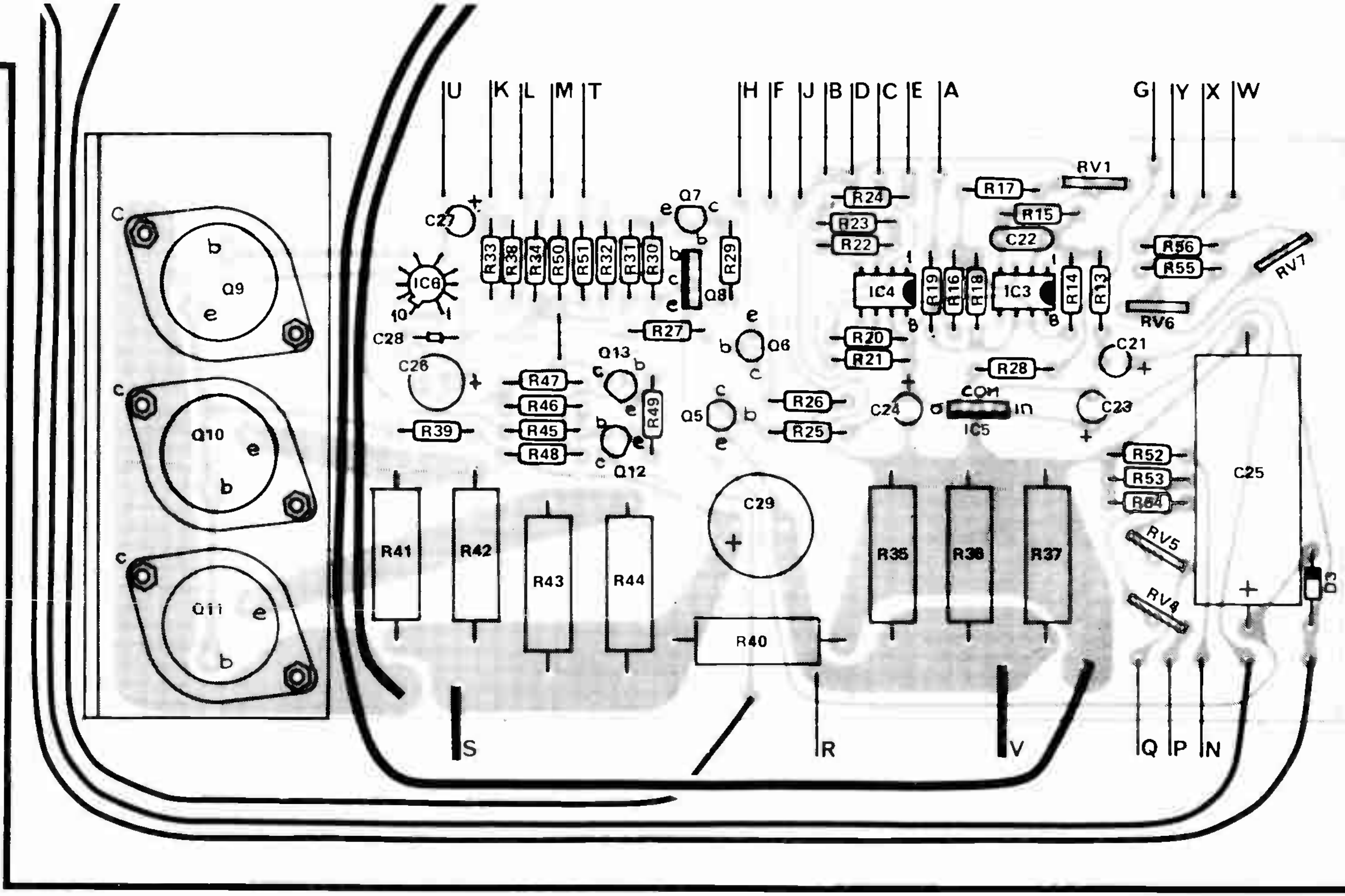
| | |
|---|---|
| L1 | see table 1 |
| L2 | see table 1 |
| L3 | see table 1 |

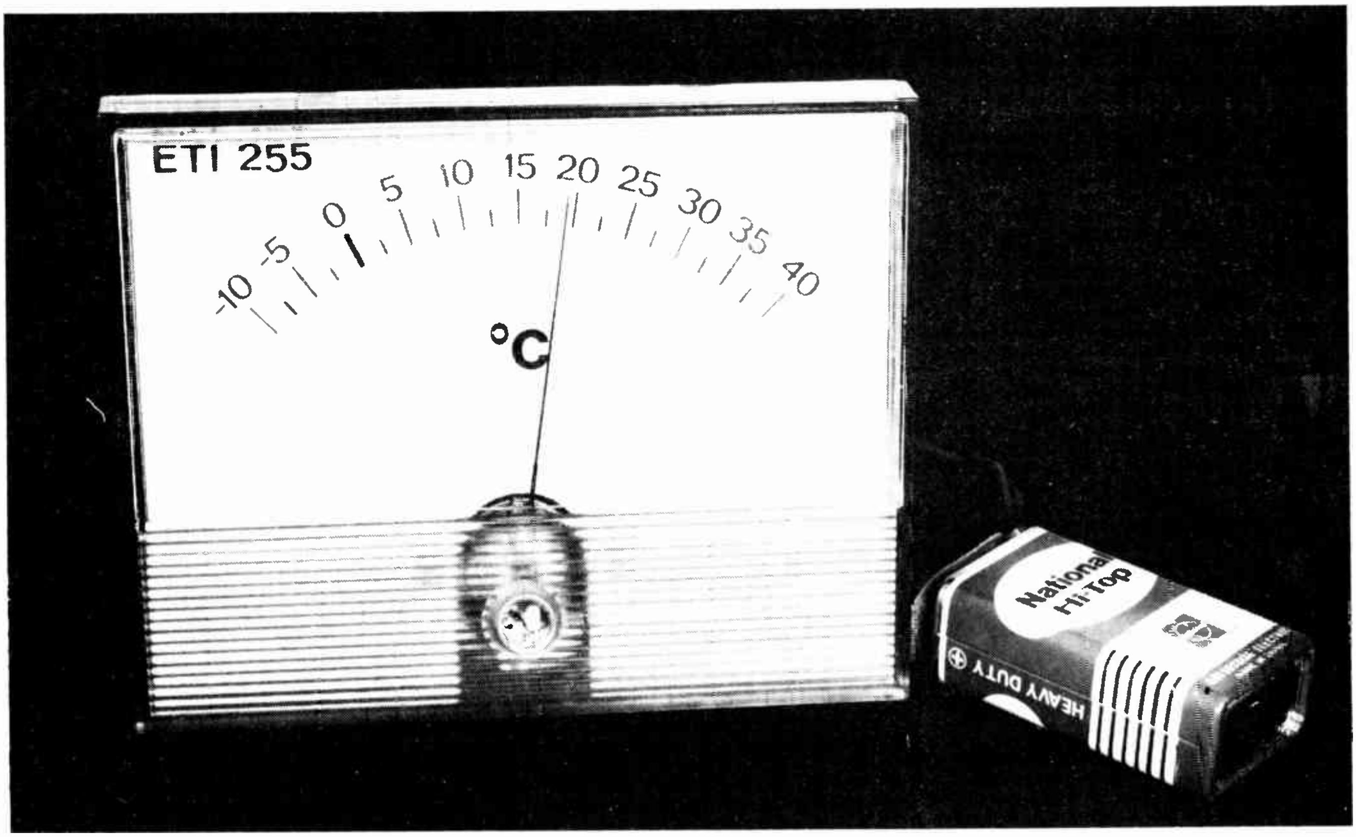
**Semiconductors**

| | |
|---|---|
| IC1 | 7912 |
| IC2 | LM339 |
| IC3,4 | 301A |
| IC5 | 7812 |
| IC6 | 723C (metal pack) |
| Q1 | BD140 |
| Q2 | MJ2955 |
| Q3,4 | 2N3055 |
| Q5,6 | BC549 |
| Q7 | BC547 |
| Q8 | BD140 |
| Q9–Q11 | 2N3055 |
| Q12 | BC547 |
| Q13 | BC559 |
| D1 | 1N914 |
| D2 | 1N3891R,BYX30-200R |
| D3 | 1N4004 |
| DB1 | MDA3502 or similar |
| LED1,2 | Red LED with mounting |

**Miscellaneous**

- PCBs ETI 142A, ETI 142B
- Transformer PF4244 (16+16V@300W)
- Two 1mA TD86 meters scalled to fig.5
- One 10A two pole power switch
- One 7101 toggle switch (SPDT)
- One 7211 toggle switch (SP3T)
- Three terminals posts (red, black, green)
- Two knobs
- Two 45D4CB heatsinks
- Two each, heatsink brackets
- Metal box and cover
- Front panel
- 3 core flex and plug
- Cable clamp
- Rubber feet etc.






# Electronic temperature meter is easy to read and easy to build

Jonathan Scott

This handy little thermometer can be used for local or remote indication of temperatures.

THIS TEMPERATURE meter project can stand alone or you can mount it in a desk top or even in the dash of your car if you don't mind cutting a hole for it. (If you've built all the ETI projects for motorists your dash must look like a piece of swiss cheese by now, so one more hole won't matter!)

Why an electronic thermometer, you may ask? What's wrong with the ordinary mercury-in-glass type that's been with us for hundreds of years? It's hard to read, that's what. You have to go right up close to see the scale. And mercury thermometers are fragile, too.

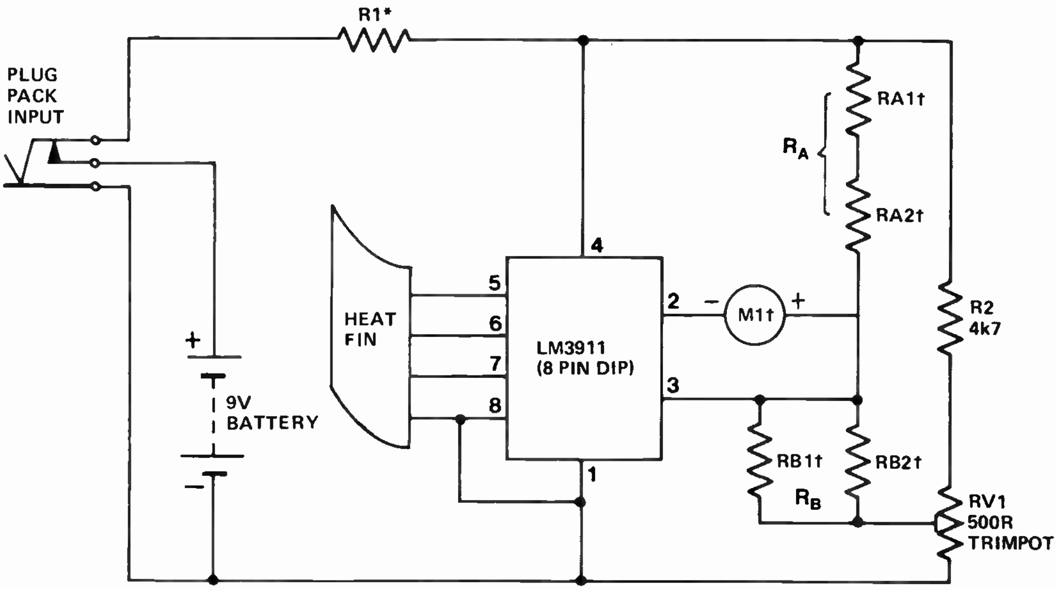
If you want to be able to read off temperature on a nice clear dial you need some kind of electric or electronic sensing element. There are several kinds of sensors you might use, including thermocouples, thermistors and diodes, all of which have their own advantages and drawbacks.

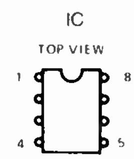
We chose to use a temperature sensing IC, the LM3911, recently introduced by National Semiconductor. There's a more detailed description of it on page 92, but basically it relies on the well-known fact that a transistor's base-emitter voltage varies with temperature — the warmer the transistor gets the greater the b-e voltage.

Because the LM3911 chip includes its own amplifer, it's very easy to use it to drive a meter. Apart from the IC and the meter, the only components in this project are five resistors and a trimpot. By choosing different values of resistors, you can build this temperature meter so that it indicates any temperature range you choose as long as it's between −25°C and +85°C.

We've specified resistor values to make the meter read from −10°C to +40°C, which should be fine for most locations, but in case you live somewhere like Birdsville we've also given values for a temperature range of −10°C to +90°C. But you don't have to stick to the ranges we suggest. Opposite you'll find formulae for calculating the necessary resistance values for any temperature range.

One more useful feature of this project ▶




*R1 = 470R (¼W or ½W) for 9 V operation; 1k8 for 12 V battery (11 - 15 V) operation.
†See table below for resistor values to suit different meter ratings.

The printed circuit board pattern is on page 152.

## HOW IT WORKS — ETI 255

Almost all the functions take place inside the LM3911 chip. Pins 5 - 8 are thermally connected to an internal temperature sensor circuit and transmit the external temperature from a small sheet of copper. The copper fin will generally be at air temperature.

An internal voltage reference, connected between pins 1 and 4, regulates the supply rail to 6.8 volts for the chip and external circuitry. The dropping resistor R1 sets the current to about 3.5 mA, maintaining about 1.2 mA to the IC and about 2.5 mA to the external circuit. It is desirable to keep the current into the IC as low as possible to prevent excessive temperature rise in the chip giving rise to inaccurate readings.

An internal op-amp sinks current from pin 2 in order to hold the voltage on pin 3 at a level which is linearly proportional to the temperature on the sensing pins. The meter, M1, monitors the current into pin 2 giving a reading which is directly proportional to temperature. The resistors $R_A$ and $R_B$ are calculated to give the required zero reading and full-scale temperatures. We have included a table with suitable values as well as formulae so you can roll your own.

The meter reading is linear with temperature and is calibrated to cover the desired range.

The trimpot RV1, compensates for variations between different ICs as well as compensating for temperature rise within the chip.

## SUGGESTED VALUES

| Range (°C) | Meter F.S.D. | $R_{A1}$ | $R_{A2}$ | $R_{B1}$ | $R_{B2}$ |
|---|---|---|---|---|---|
| 0 to +100 (note: 85 max.) | 100 μA | 10k | 6k8 | 27k | 270k |
| 0 to +50 | 50 μA | 10k | 6k8 | 27k | 270k |
| −10 to +90 | 100 μA | 8k2 | 8k2 | 27k | 480k |
| −10 to +40 | 50 μA | 8k2 | 8k2 | 27k | 480k |
| −10 to +40 | 100 μA | 8k2 | zero | 82k | 15k |

**NOTE: maximum rated temperature is 85°C; minimum is −25°C.**

Other temperature ranges can be covered, within the specified limitations of the LM3911, the required range resistor values being calculated from these formulae:

$$R1 = \frac{V_s - 6.9}{0.0035} \quad \ldots\ldots (1)$$

$V_s$ = supply voltage

$$R_A = R_{A1} + R_{A2} \quad \ldots\ldots (2)$$

$$R_B = \frac{1}{1/R_{B1} + 1/R_{B2}} \quad \ldots\ldots (3)$$

$$\text{Let } T_1 = T_0 + 5 \quad \ldots\ldots (4)$$

using equation (4), calculate 'M'

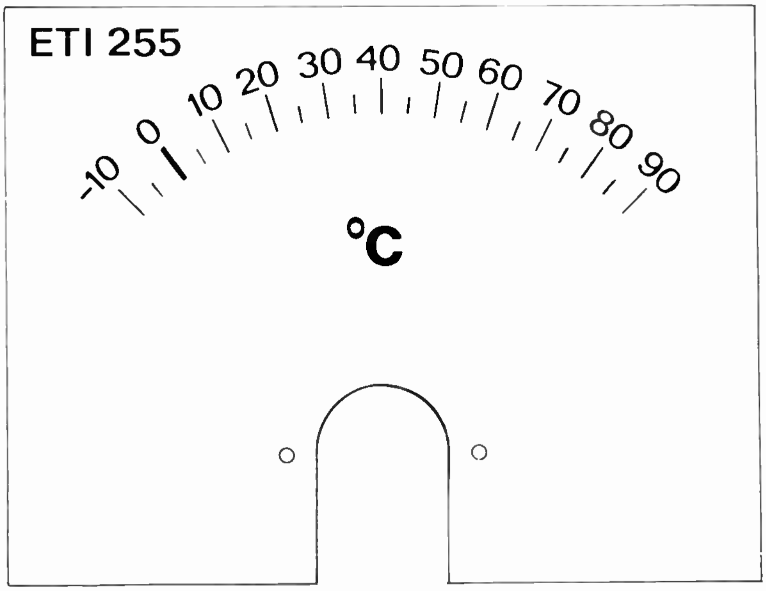
$$M = \frac{T_1}{685} \quad \ldots\ldots (5)$$

where $T_0$ = zero scale reading in °K
and T (°C) = T(°K) − 273 . . . . . . (6)

$$\text{then } R_B = \frac{10^4}{M.s} \quad \ldots\ldots (7)$$

$$\text{and } R_A = \frac{10^4}{s(1-M)} \quad \ldots\ldots (8)$$

where s = meter sensitivity in μA/°C
(For example; if you choose a 100 μA meter and wish to cover a range of 50°C, then s = 2 μA/°C)




**Full size artwork for meter scale covering −10°C to +90°C. Note that the limit for the LM3911 is +85°C.**

## THE LM3911 — HOW IT WORKS

The LM3911 is a highly accurate temperature measurement IC for use over a —25°C to +85°C temperature range. Fabricated on a single chip it includes a temperature sensor (pins 5 — 8), stable voltage reference (pins 1 and 4) and an operational amplifier.

The output voltage on pin 2 is directly proportional to temperature in degrees Kelvin having a sensitivity of 10mV/°K. By using the appropriate external resistors with the internal op-amp, any temperature range can be selected.

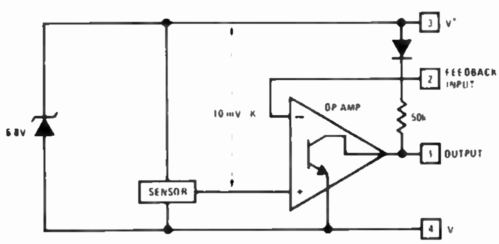
An active shunt regulator across the supply pins provides a stable 6.8 volt reference for the sensing circuitry, and allows the use of any supply voltage with the correct dropping resistor.

The input bias current is low and relatively constant with temperature to ensure high accuracy when a high source impedance is used. The output pin can be returned to a supply up to 35 volts to allow the circuit to drive lamps or relays.

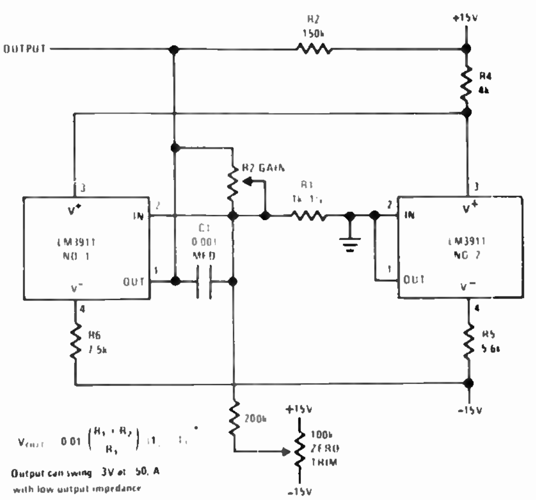
The temperature sensing element uses the difference in base-emitter voltages of two transistors operating at different current densities. Since this output depends only on transistor matching, very good stability and reliability can be obtained.

The op-amp can either be connected as an amplifier to give a linear temperature/voltage output or as a comparator to switch the output at a preset temperature. Therefore, the device can be used either as a measuring instrument or as a temperature controller.

The output can be calibrated for degrees Celsius, Fahrenheit or Kelvin.




**Internal block diagram of the LM3911.**




*The 0.01 in the above equation is in units of V/°K or V/°C and is a result of the basic 0.01 V/°K sensitivity of the transducer

**Two LM3911s can be configured as a differential thermometer.**

is that the meter doesn't need to be closely connected to the IC and the rest of the circuitry. You could, for example, have the electronics outside the house and the meter inside, so you could find out how cold it is outside without having to open the door and get chilled. Or less frivolously, suppose you're trying to grow exotic plants in a controlled temperature hothouse, you could use our project as a remote indicating thermometer to keep a check on their environment.

## Construction

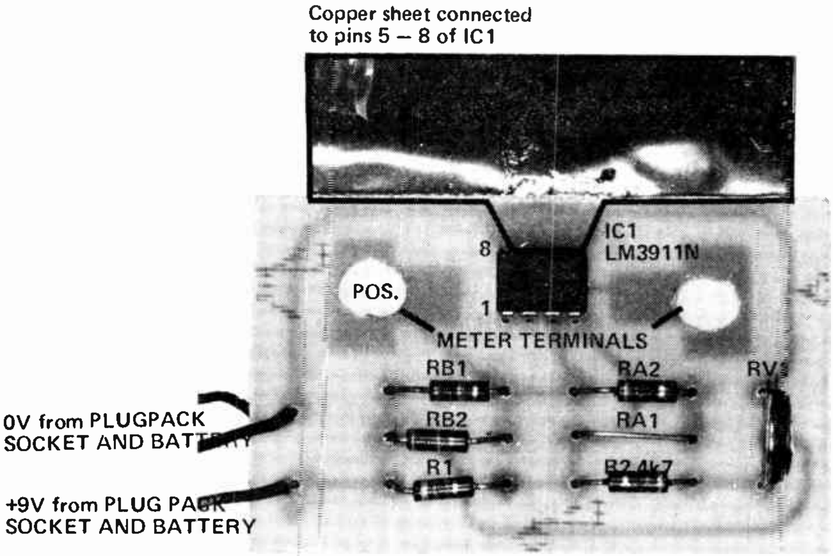
The entire circuit, including the heat fin, is assembled on a small pc board which is then mounted onto the rear of a moving coil meter. Connection to the meter is made by large copper pads on the pc board which can accommodate a variety of meters with different terminal sizes and spacings.

The thermometer can be mounted in a small plastic box, fitted into a car dash or perhaps built into a neat, desk-top unit for the 'shack'. Whichever you choose, be sure to leave a large enough hole in the box to allow free air flow across the heat fin so the meter reads the room air temperature and not that inside the box. If a remote reading unit is required the pc board can be mounted away from the meter.

The first job is to drill the holes into the pc board to suit the type of meter you have. Next fit all the components as shown in the overlay, taking care with the orientation of the IC and the polarity of the battery or power supply connections. The value of R1 is different depending on whether the unit is operated from a 9 V supply (battery or plugpack) or a 12 V supply (vehicle battery or plugpack). Values are beneath the circuit. The values of $R_A$ and $R_B$ are selected from the table for the required temperature range and meter used. Note that $R_A$ consists of two resistors in series ($R_{A1}$ and $R_{A2}$), while $R_B$ consists of two resistors in parallel ($R_{B1}$ and $R_{B2}$). Either 2% tolerance or selected 5% tolerance metal film resistors should be used for the sake of accuracy.

Power from a plugpack is applied through a shorting type socket so the unit can be battery operated when the plugpack lead is removed.

The 50 mm by 20 mm heat fin is cut from a small piece of 0.25 mm thick copper shim. Solder it to the pc board track connected to pins 5 - 8 of the IC (see overlay photo). A larger size fin may be used, but we found this one works nicely. In fact, the circuit will work well without any heat fin, but has a longer response time. Make sure the



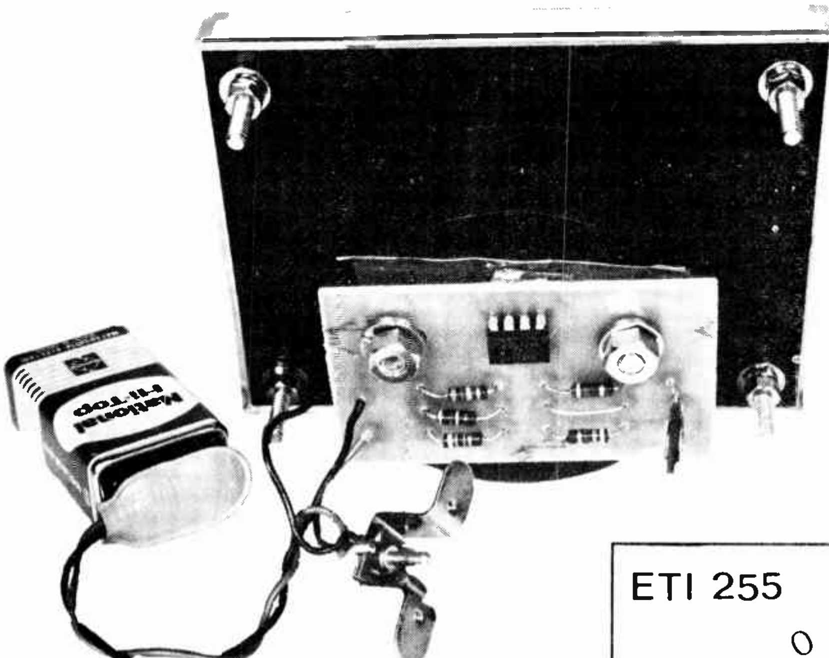

## PARTS LIST — ETI 255

| | |
|---|---|
| IC1 | LM3911N |
| R1 | 470R or 1k8 |
| RA1 | See table |
| RB1 | " |
| RA2 | " |
| RB2 | " |
| R2 | 4k7 |

All resistors should be 2% or selected 5%, ¼W or ½W metal film types.

| | |
|---|---|
| RV1 | 500R miniature vertical mounting trimpot |
| M1 | 50 or 100 microamp meter (to suit range). University TD 106 or similar. |

ETI-255 pc board; case (if required); plug pack adaptor socket and 9V Plug Pack (Ferguson PPA-9/500 or similar); 9V battery (No. 216) and battery clip if required; small piece of 0.25 mm shim copper.



Rear view of the instrument showing general assembly. You may prefer to use a rechargeable NiCad type, rather than the dry battery shown, for battery operation of the unit.

fin is not touching any other part of the circuit.

Finally, fit the meter after cleaning the meter pads on the pc board. The spring washer supplied with the meter should be assembled on the copper side of the board so it digs into the surface of the copper for good contact. If this is not done the meter connections may become a high resistance when the copper tarnishes after use.

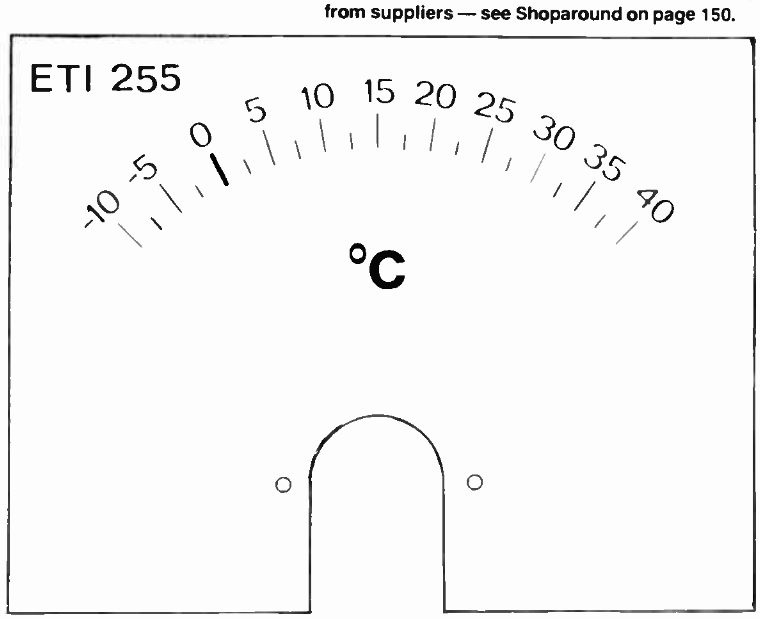
Apply power and adjust the zero set trimpot which should be capable of adjusting the reading about +/−10°C.

## Calibration

Place the unit and a reference thermometer (choose a good one) in a cool place close together and after a few minutes note the difference in readings. Adjust the trim pot for the correct reading.

Two different meter face scales have been included for two temperature ranges, −10°C to 40°C and −10°C to 90°C. Values have also been calculated for 0°C to 50°C and 0°C to 100°C scales to allow standard scales on 50 μA and 100 μA meters to be used. ●

Full size artwork for meter scale covering −10 C to +40 C. Scotchcal meter scales will be available from suppliers — see Shoparound on page 150.



# pH — the acid test

Many chemical and biological systems depend critically on a parameter known as pH. This article explains what pH means, outlines how it is measured and investigates some areas where it is important.

**Elaine Ray &**
**William Fisher**

THE IMPORTANCE of acids and alkalis is well known, as is the fact that some acids and alkalis are stronger than others — that is, they react more vigourously with other substances. But what is it that makes sulphuric acid, for example, stronger than acetic acid? And how can we quantify their strengths?

## Dissociation

All acids have at least one hydrogen atom that tends to break away from the molecule when the acid is dissolved in water. In doing so it leaves behind an electron and becomes a positively charged hydrogen ion. It is these free hydrogen ions that are responsible for the chemical properties of acids, and their relative numbers determine the strength of the acid in question.

For example, acetic acid ($CH_3COOH$) dissolved in water tends to partly dissociate into positive hydrogen ions ($H^+$) and negative acetate residues ($CH_3COO^-$), thus:

$$CH_3COOH \rightleftharpoons CH_3COO^- + H^+$$

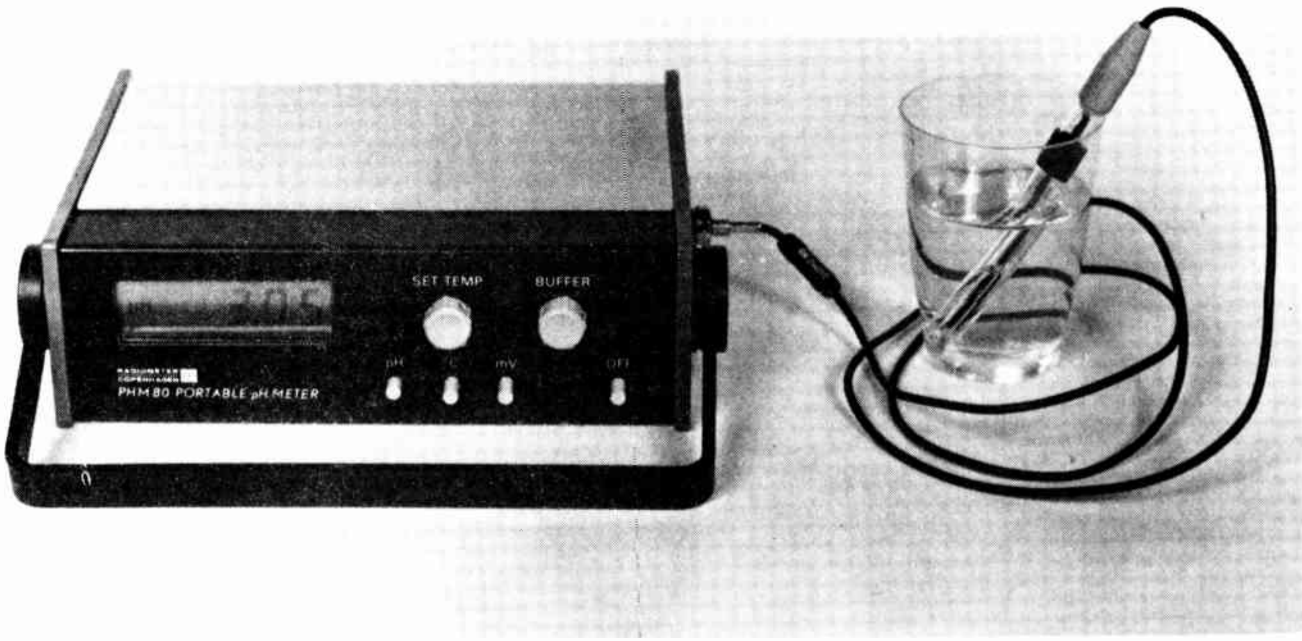
and sulphuric acid dissociates almost completely in water into hydrogen ions and sulphate residues thus:

$$H_2SO_4 \rightleftharpoons 2H^+ + SO_4^{-}$$

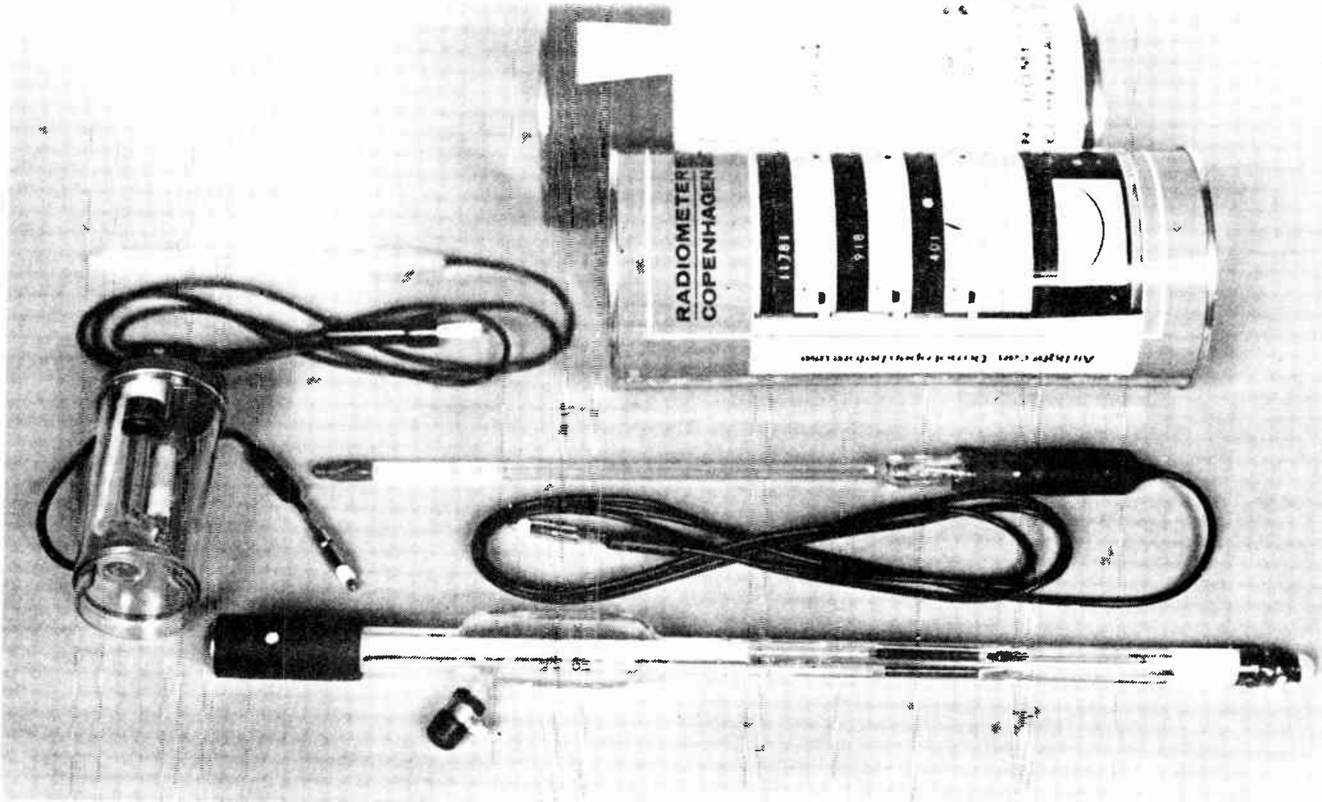
Alkalis are extreme examples of a class of substances known as bases. Bases are like converses of acids. When they are dissolved in water they tend to break up into a negatively charged hydroxyl ion ($OH^-$) and a positively charged residue. For example the strong alkali potassium hydroxide ($KOH$) breaks up thus:

$$KOH \rightleftharpoons K^+ + OH^-$$

and the weaker base calcium hydroxide (lime) partly breaks up into calcium and ▶



A high quality portable pH meter with a liquid crystal display that directly indicates the pH of the solution under test.




pH electrodes are made in a variety of shapes and sizes to suit different applications. at the rear of the picture are two cans of 'buffer solutions' — liquids whose pH does not change much when they are contaminated. Buffer solutions are used to calibrate pH electrodes.

hydroxyl ions, thus:

$$Ca(OH)_2 \rightleftharpoons Ca^{++} + 2OH^-$$

Bases and acids in the same solution tend to neutralise each other. The free hydrogen ions from the acid combine with the free hydroxyl ions from the base to form molecules of water, thus:

$$H^+ + OH^- \rightleftharpoons H_2O$$

## Neutrality and activity

The reaction between hydrogen and hydroxyl ions can also proceed in the other direction — that is, water molecules can break up again into free hydrogen and hydroxyl ions. There is only a slight tendency for this to happen, however. In pure water at room temperature only about one water molecule in 600 million dissociates into ions. In other words, the concentration of free hydrogen ions in pure water is one part in ten million. This concentration of hydrogen ions is known as a *neutral* solution.

If an acid is dissolved in water, the solution will no longer be neutral — there will be more hydrogen ions because of the dissociation of the acid. Dissolved bases will initially result in a solution that has more hydroxyl ions than neutral water, but these hydroxyl ions will tend to combine with any free hydrogen ions to form $H_2O$ molecules. The net result is that the number of free hydrogen ions in a basic solution is *lower* than in neutral water.

Clearly if we can measure the number of free hydrogen ions in a solution we can find out if it is acidic or basic, and to what extent. Actually what we will be interested in is not the absolute number of hydrogen ions, but their relative numbers, i.e. their concentration.

For reasons of mathematical convenience and logical purity, chemists prefer to work with a quantity known as the *activity* of hydrogen ions. Since the activity is generally proportional to the concentration, the exact distinction between the two terms need not concern us here.

The range of possible values for hydrogen ion activity is very wide, from 10 for the strongest acid solution to $10^{-14}$ for the strongest alkali. This leads to numbers that are awkward to write and even more awkward to speak (try saying $2.76 \times 10^{-11}$ quickly!).

The pH notation, which was introduced in 1909 by the Danish chemist S.P.L. Sorensen, makes things a bit easier. It defines pH as the negative logarithm of the hydrogen ion activity, i.e.

pH = − log A (where A is the hydrogen ion activity)

Low values of pH indicate acidity, high values alkalinity. Neutral water is pH7.

## pH measurement

The best way to measure the hydrogen ion activity of a solution is to use that solution as part of an electric cell. Before 1937 this was commonly done with a 'hydrogen cell'.

When a platinum electrode is dipped into a solution containing $H^+$ ions, the positively charged ions tend to attract negatively charges electrons out of the metal. The higher the activity of the ions, the stronger the attraction of the solution for the electrons.

One way to compare the $H^+$ activities of two different solutions is to put an electrode into each solution and join the electrodes with a wire. The solution with the higher activity will exert a greater pull on the electrons and a current will flow through the wire. If the wire is broken, a voltage will appear ▶

between the two break points. This voltage is a measure of the hydrogen ion activity and hence of the pH.

There are considerable practical and theoretical difficulties involved in the 'hydrogen cell' method of measurement described above. The invention of the 'glass electrode' pH meter in 1937 overcame these difficulties and was a boon to chemists.

A typical glass electrode consists of a porous glass bulb containing a saturated solution of silver chloride ($AgCl$) in which a silver electrode is immersed. This electrode is connected to one terminal of a voltmeter, whose other terminal is wired to another electrode that sits in a reference solution. Because the silver ions in the silver chloride solution tend to suck electrons from one electrode and the positive ions in the reference solution suck electrodes from the other electrode at fixed but different rates, the voltmeter normally reads some steady voltage.

The glass bulb containing the silver chloride is immersed in the solution whose pH is being measured. The hydrogen ions in the latter solution migrate across the glass membrane of the bulb and alter the activity of the silver chloride solution, thereby altering the attraction of the silver chloride solution for the electrons in the silver electrode dipped into it. Consequently, the reading on the voltmeter will alter.

Careful design can result in a glass electrode pH meter which generates a voltage that is linearly proportional to the pH of the solution being tested. (Sometimes this linearity is achieved by putting the test solution in contact with the reference solution as well, via a 'bridge' of some electrically conducting salt).

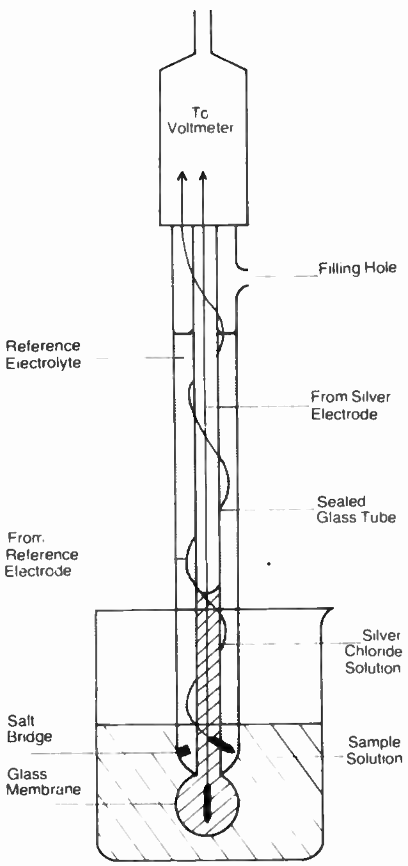
## pH in medicine

The complex chemical interactions that take place in the human body are very sensitive to changes in pH so the body is constantly trying to keep the pH of its blood within the narrow range from 7.38 to 7.42.

A complicated feedback system, controlled by the endocrine glands, operates to counteract any abnormal deviations in blood pH, which would otherwise be traumatic. For example, after a heavy intake of alcohol, which makes the blood over-acid, the lungs breathe deeper and faster so as to expel carbon dioxide (which makes carbonic acid when it is dissolved in the blood) and the kidneys extract more carbonic acid from the blood and pass it into the bladder where it can do no harm.

Acidosis and alkalosis, which are the medical terms for abnormally low and abnormally high blood pH, are generally indications of serious diseases like diabetes, kidney or lung failure.

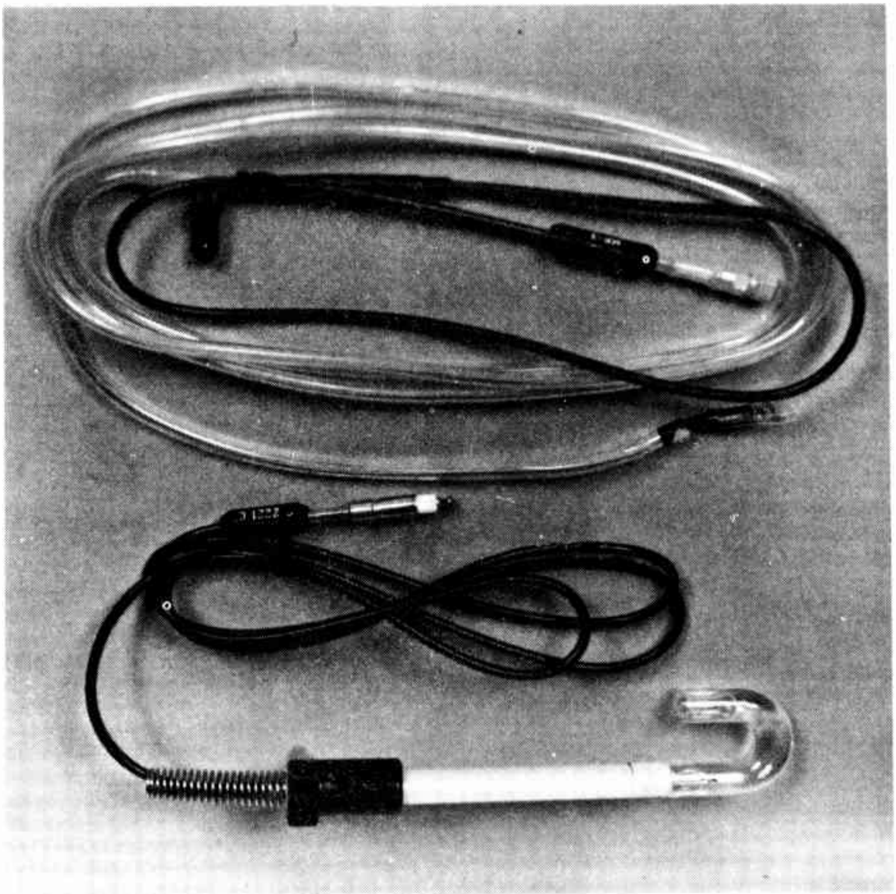
Polio victims and others in artificial respirators sometimes suffer from an excessive build-up of carbon dioxide in the blood (because their lungs cannot excrete it). Fortunately this can easily be detected in time for corrective action to be taken by routinely monitoring the blood pH. The amount of blood required for this purpose is quite small — a few




### A GLASS ELECTRODE

**Above is a cross-sectional diagram of a typical pH electrode or 'probe'. It consists of a glass membrane in the shape of a bulb, inside which is a solution of silver chloride and a silver metal electrode. Around the stem of the probe is a refillable reservoir which contains a reference solution and a reference metal electrode.**

**The two electrodes are connected to the terminals of a voltmeter, which normally reads a steady voltage. When the probe is immersed in the sample solution, some ions from the sample migrate across the glass membrane and alter the activity of the silver chloride, so that the voltmeter reading alters.**



Two special pH probes for medical applications. The upper one is a gastric pH probe, designed to pass through a patient's nose and the lower probe is used for blood analysis.

millilitres, which must be syringed directly to a gas analyser because exposure to the air would alter its pH.

The pH level in the stomach is quite different to that of the blood. The gastric juices are rich in hydrochloric acid and vary from pH 1.5 to 3.5. A hormonal feedback control system normally keeps the gastric pH within bounds, but this system can be upset by abnormal secretion of adrenaline in times of prolonged nervous tension. This is why people who live under a great deal of stress tend to have ulcers caused by gastric over-acidity.

There are also some people who have little or no free hydrochloric acid in their stomachs. This group run a very high risk of developing stomach cancers. Clearly the measurement of gastric pH levels is of considerable medical importance and over the years physicians have developed various methods of doing this. Perhaps the commonest technique nowadays is to pass an electrode through the nose and down the alimentary canal into the stomach, to give a fast and accurate indication.

## Soils

Soil acidity or alkalinity is one of the major factors that affect the growth of plants. The pH of a soil is an indication of the extent to which exchange reactions in the soil are preventing nutrients from reaching the roots of plants.

Roughly what happens is this — the fine particles in a soil aggregate into bodies known as colloids, which have an electrical charge distributed over their surface. The water that permeates the soil contains dissolved ions which plants need and which they normally suck up from the solution by capillary action through their roots. However, some of these ions in solution may change places with less valuable ions on the colloid surfaces. Plants can only absorb ions from the aqueous solution surrounding the colloids; they cannot attract them from the colloid surfaces, so the soil is effectively depleted nutritionally.

Plant nutrient ions are commonly attached to the colloids in exchange for hydrogen ions, which pass into solution. Measuring the soil pH obviously gives an indication of the extent to which this has happened.

Plants vary a great deal in the range of pH they will tolerate. Most will flourish somewhere between pH 6 and 8, but some well known plants grow best outside this range. Potatoes and tomatoes, for example, like an acid soil with a pH between 6 and 7, while camellias and azaleas do best with a pH around 5.

Acid soils can be neutralised by adding lime and over-alkaline ones will benefit from a dressing of sulphate of ammonia. If you want to measure the pH of your own soil, you should first make a ten per cent aqueous solution (i.e. 10 grams of soil in 100 millilitres of water) and measure the pH of that.

## Aquariums

Fish are sensitive creatures and won't flourish unless the pH of their environment is correct. Most freshwater fish do best between pH 6.5 and pH 7.5, but goldfish (whether they are cold or warm water types) like their water a little more alkaline, i.e: pH greater than 7.5.

Acidic water in a goldfish tank encourages the growth of fungus and also induces a malady known as 'acid burn', which makes the fish look as if they have had bites taken out of them. It is advisable to measure the pH of goldfish tanks about once a week, preferably when the water is refreshed.

If you don't have a pH meter you can get some idea of the acidity by inspecting the plants growing in the tank. If they are looking unhealthy, the water is too acid.

## Swimming pools

The recommended pH for swimming pool water is between 7.2 and 7.6. In the summer months when pools are in frequent use the pH should be tested every second day and chemicals added if necessary to keep it within bounds.

Over-acid pool water enourages the growth of algae, whose colour depends on the degree of acidity. First to form are green algae, in sheltered areas around steps or ladders. Brown algae that stain the tiles are the next stage, followed by black. ●

**Chlorinated pools should be maintained at a pH between 7.2 and 7.6. An automatic chlorinator is the best method.**

Project 572

# Digital pH meter is simple and accurate

A pH meter has many applications in widely varying fields of interest; in chemical analysis, in soil analysis (gardening!); swimming pool chlorination; care of tropical fish, etc. This project features a 3½-digit liquid crystal display, simple construction and straightforward operation.

**Peter Eliot**
**Phil Wait**

FROM TIME TO TIME readers write or 'phone us with a project suggestion that, at first sight is attractive and practical, but on further investigation runs into what seems insuperable difficulties — generally with the supply (or lack!) of a critical component.

We first looked at this project in response to a spate of reader enquires. They generally pointed out that a pH meter was something we have never done but there were plenty of commercially available models — generally at prices well beyond the hobbyist or student. The electronics for such a project could be designed in several ways and this seemed to present few problems. So, we went looking for a suitable pH electrode.

That's where it all started to come apart at the seams. Our early efforts turned up imported probes costing in the vicinity of $100 for the least expensive model. We figured the electronics for an analogue readout instrument (using a moving coil meter) would cost around $30 or so and for a digital readout instrument around $40 or so. With probes at three times or more the cost of the electronics, a project started to look decidedly unattractive. It almost fell by the wayside.


However, during a conversation one day with Peter Eliot of the Amalgamated Instrument Company, who make and market a range of digital panel meters and portable digital instruments for industrial applications, the editor enquired where he obtained the pH probes for his digital pH instruments, and what did they cost? Peter was using Australian made probes chiefly because they cost less than half the equivalent imported types, and what's more they were readily available. Quick as a flash, we were talking to the man from Starcross Scientific, who distribute the range of 'Ionode' probes made in Queensland. A suitable probe was priced at around $40 so we figured a project would be timely and popular. What's more, having already done much of the required development work, Peter Eliot volunteered to provide us with a circuit and some material to suit our requirements. With some pc board and packaging work from the project staff, this project is the result.

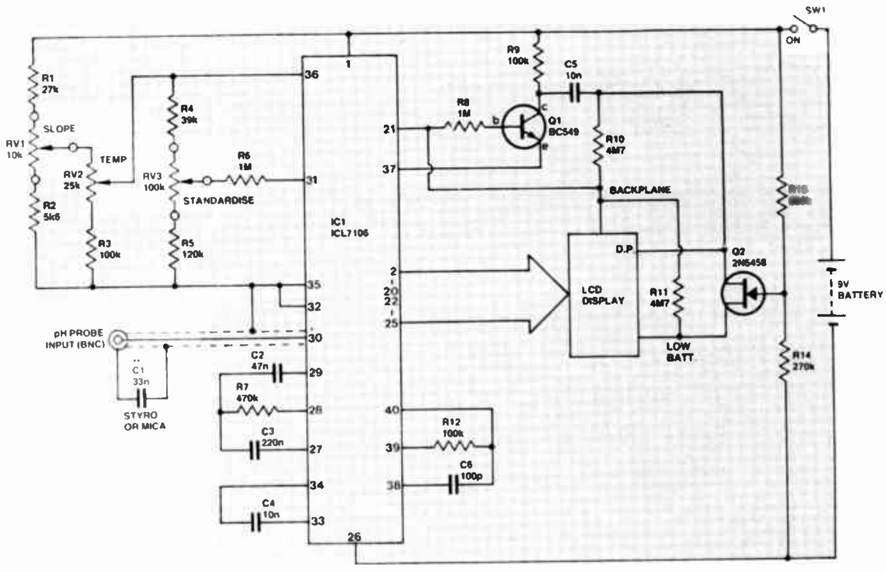
## Principles

The preceding article in this book explains the theory behind the pH index as well as detailing applications of pH ▶

measurement in various fields. This discussion is confined to the principles of operation behind this particular instrument.

The pH electrode or probe consists basically of an electric cell which, when immersed in a solution, will generate a voltage proportional to the hydrogen ion activity of that solution. The voltage generated is a measure of the pH of the solution. Measure the voltage generated by the electrode, display it, and you've got a pH meter. Simple enough, but there are a few difficulties.

First problem is the internal (or source) impedance of the pH probe. It is generally around $10^9$ to $10^{10}$ ohms! This means that whatever instrument you use to measure the voltage output of the pH probe needs to have an input impedance at least an order of magnitude (i.e: 10 times) higher.




* PIN 30 DIRECTLY CONNECTED TO SCREENED CABLE
** C1 CONNECTED DIRECTLY AT BNC CONNECTOR

The second problem that has to be tackled has to do with the "slope" variation with temperature of the pH electrode. The output of an electrode is typically 60 mV per pH unit, i.e: for a change in pH of a solution from, say, 7.5 to 8.5, the probe's output voltage will vary 60 mV. The electrode generates a *positive* voltage for pH values less than pH 7 and a *negative* voltage for pH values greater than pH 7. The electrode output is zero at pH 7.

If you plot a graph of probe output versus pH, where pH is represented on a log scale, you get a straight line as illustrated by the unbroken line in Figure 1. However, that line is only correct for one temperature. At another temperature, a line having a different "slope", indicating that the probe's nominal "mV per pH unit" output has varied, results as illustrated by the broken line in Figure 1. In general, a probe's sensitivity (mV per pH unit) increases with increasing temperature and vice versa.

The slope of a probe also varies with the age of the unit. Regular calibration checks remove any error that this may bring to the reading.

There are two general ways to correct for slope variations with temperature: by means of a manual control in the circuit, or automatically. For obvious reasons, the first method is the simplest and that's what we've elected to do.

Fortuitously, the input impedance of an ICL7106 analogue-to-digital conversion IC is around $10^{11}$ to $10^{12}$ ohms which is just what we need, apart from providing an appropriately scaled digital output to drive a display. Consequently, most of the circuitry for the pH meter is contained within two ICs; the ICL7106 and an LAD204 LCD display. The external circuitry is used to provide the appropriate scaling (so that the display reads directly in pH units) as well as slope and temperature compensation controls.

As this is a battery operated instrument, we thought it would be convenient to have some indication of when the battery was getting low. Surprise, surprise — the LCD display we chose incorporates a little "low batt." warning display in the top left hand corner. This is activated with a little extra circuitry once the battery voltage falls below 8.5 volts.

### HOW IT WORKS — ETI 572

The instrument employs a single-chip analogue-to-digital (A/D) converter IC, type ICL7106, driving a liquid crystal display. Virtually all of the instrument is contained within the A/D converter chip and display. Operation of the 7106 is explained in a separate box. The reference voltage for the A/D converter is varied by three controls to provide the appropriate 'scaling' of the input so that the instrument reads directly in pH units, corrected for "slope" and temperature variations.

Input to the 7106 is applied between the IN LO pin (30) and COMMON pin (32) as the input is negative-going and we require a display which reads positive. The IN HI pin (31) has a portion of the reference voltage applied to it via a resistive divider involving R4, RV3 and R5. This sets the display to read (positive) 7.00 when the input is zero i.e: when the probe is in a pH 7.00 solution.

The A/D converter reference is developed between pins 35 and 36, derived from a resistive divider pick-off between the positive supply rail and the COMMON pin (32).

Varying the reference voltage by a small amount is used to provide temperature and "slope" compensation. The SLOPE control is part of the reference voltage divider and provides a 'vernier' control over a reasonable range, so making the control easy to adjust. The TEMPERATURE control forms part of a resistive divider from the wiper of the SLOPE control, RV1. Again, this provides a vernier adjustment. The voltage appearing on the wiper of RV2 is applied to the REF HI input of the 7106. The whole arrangement minimises interaction between the controls.

The internal clock of the 7106 is run at 50 kHz for maximum mains hum rejection, as explained elsewhere. The LCD display is driven by a square wave signal between the backplane and the numeral segments. This is provided by the 7106 from pin 21. The decimal point requires a drive signal in anti-phase to this and Q1 is arranged as an inverter to provide the appropriate drive to the decimal point.

The LOW BATT. indicator is activated by Q2. The gate of this FET is biased by a voltage divider using R13 and R14. When the battery voltage falls below about 8.5 V, Q2 turns on and applies the anti-phase backplane signal (from the decimal point drive) to the LOW BATT. pin on the display.

Hum filtering at the input is provided by a 33n capacitor connected directly across the input socket.

## The pH probe

The pH probe we obtained for our instrument comes from Starcross Scien-

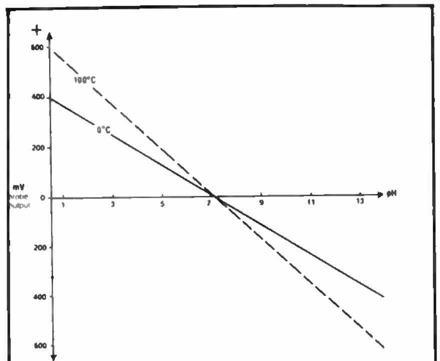



*Figure 1.* Illustrating how the "slope" of a pH electrode's sensitivity varies with temperature.

tific, P.O.Box 151, Frenchs Forest, NSW 2086. They are available by mail order. At the time this book was published the price was around $50.00. The probe, designated G101NFE, comes complete with a plastic protector cap, a wetting cap for storage and a comprehensive booklet plus two 200 ml containers of buffer solution, one of pH 6.88, the other pH 4.00. A BNC plug is fitted to the coaxial cable connection. The probe is a "non-flow" or sealed type and will have a long life without needing replenishment of the internal electrolyte.

In addition, Starcross have available accessories such as 100 ml plastic beakers and plastic wash bottles. They can also supply spear point electrodes suitable for soil analysis.

## Construction

The pH meter is housed in a plastic box measuring 150 x 80 x 50 mm, although a 'zippy' box of similar size having an ▶

### ABOUT THE 7106

The ICL7106 is manufactured by Intersil of the USA and contains all the circuitry for a digital panel meter employing the 'dual-slope integration' technique all housed in a 40-pin dual-in-line package. It is designed to drive any multiplexed 3½-digit liquid crystal display. A companion chip, the ICL 7107 is designed to drive any suitable 3½-digit LED display.

The internal circuitry of the 7106 can be divided into several areas: firstly there's the precision dual-slope integration type analogue-to-digital converter, then display decoder/driving circuitry and display multiplexing.

The precision dual-slope A/D converter is the most important, so let's take a close look at that.

In this method of A/D conversion the analogue input voltage is first converted to a time period which in turn is converted into a binary number by a timer/counting system. Referring to the block diagram here, and the associated timing diagram, the system commences the measurement when the switch connects the analogue signal input to the integrator which commences to 'ramp up'. At the same time the counter begins, from zero, to count the clock pulses. When a predetermined number of pulses, 1000 with the 7106, appear in the counter, the integrator is electronically switched over to the reference voltage. At this point, the integration capacitor, C, has then charged linearly from the input, rising as a ramp voltage to a level decided by the average input signal value over the counter time period (T). As the switch changes to the reference, the counter is reset to zero and commences counting again. The reference, which is of opposite polarity to the input signal, now causes the charged integration capacitor (C) to ramp downward with a fixed slope. When the output of the integrator reaches the zero threshold the counter is stopped and its contents displayed on the digital readout. The count displayed is the ratio of the counts during the 'downward' ramp (over time 't') to the counts during the upward ramp. Thus, for a limit of 1000 counts during the upward ramp, a direct reading of input voltage is obtained if the reference voltage is chosen appropriately.

The absolute value of the integration capacitor and the clock frequency are of little significance provided they are stable for the duration of the conversion period.

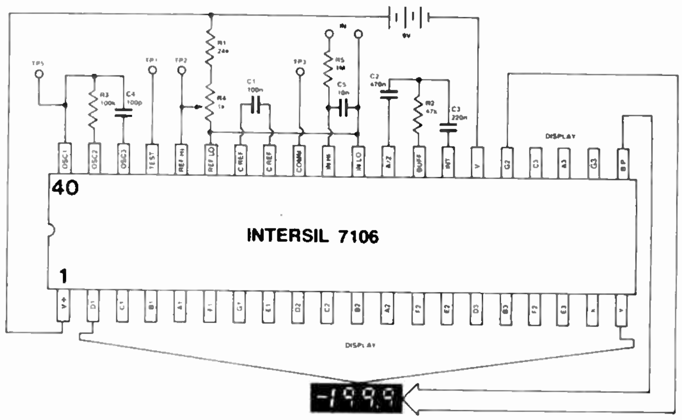
The relatively long analogue-to-digital conversion period has an inherent advantage in that it ignores noise. When noise is integrated over an extended period, its amplitude tends to zero. Thus, dual-slope integration results in excellent accuracy.

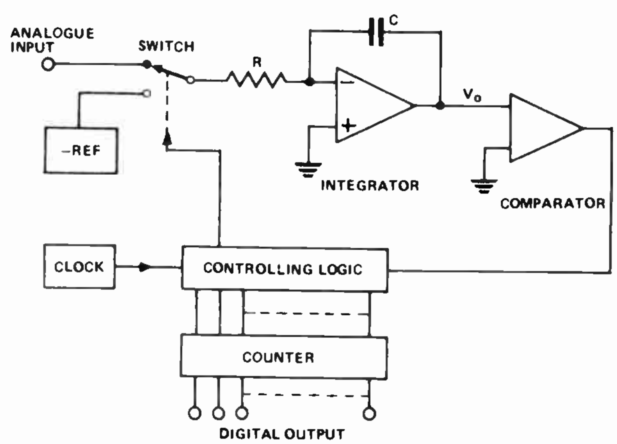
The 7106 has an on-board clock oscillator, the frequency of which is determined by external RC components — R3 and C4 in the circuit here, connected between pins 38 and 39. The clock frequency has been set to 50 kHz for the pH meter project. The oscillator frequency is divided by four internally to give a clock period of 80 us. As the integration period is 1000 clock periods long, the analogue input is integrated over a period of 80 ms. This results in pretty nearly optimum mains hum rejection as any 50 Hz ripple on the input will be integrated over four cycles and will thus have a dc value approaching zero.

Clock input is to pin 40 (TP5 in the circuit here) and the 7106 may be driven from an external clock if so desired. It requires a square wave drive of 5 V amplitude, positive with respect to the **common** pin. For external clock drive the clock RC network (R3-C4) is not required.

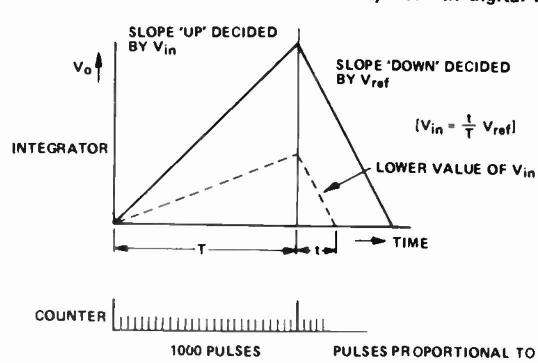
The A/D converter reference voltage is developed between pins 35 and 36 (REF LO and REF HI respectively). Pin 35 is set internally to be always 2.8 V lower than the positive supply rail applied to pin 1. The full-scale sensitivity of the 7106 can be 'programmed' by setting the value of the voltage between the REF LO and REF HI pins. For 200 mV full-scale sensitivity (reading of 1999 on the display) the voltage between pins 35 and 36 should be set to 100 mV, for 1 V sensitivity it should be 500 mV and so on.

Input current drawn by the 7106 is extremely low, typically one picoamp (1 pA or $10^{-12}$ amp as it has an input impedance measured in Giga-ohms ($10^9$ ohm)! For this reason, the unit can be used to measure voltage sources having a source impedance up to $10^{11}$ ohms — making it ideal for application in a pH meter. A useful spin-off from the 7106's high input impedance is that only quite small value capacitors are required in parallel with the input to provide good hum rejection. In addition, the input impedance is readily defined by using an appropriate value parallel resistor or simple attenuator on the input.




**Block diagram of the 'dual-slope integration' technique of analogue-to-digital conversion commonly used in digital meters.**




**Timing diagram for the dual-slope A/D conversion technique.**

## PARTS LIST — ETI 572

**Resistors all ½W, 5%**

| | |
|---|---|
| R1 | 27k |
| R2 | 5k6 |
| R3, 9, 12 | 100k |
| R4 | 39k |
| R5 | 120k |
| R6, 8 | 1M |
| R7 | 470k |
| R10, 11 | 4M7 |
| R13 | 680k |
| R14 | 270k |

**Capacitors**

| | |
|---|---|
| C1 | 33n styroseal or mica |
| C2 | 47n greencap or polycarbonate |
| C3 | 220n greencap or polycarbonate |
| C4, 5 | 10n greencap or polycarbonate |
| C6 | 100p ceramic or mica |

**Semiconductors**

| | |
|---|---|
| Q1 | BC549, BC109 or similar |
| Q2 | 2N5485, 2N5484 or similar |
| IC1 | ICL7106 see text |
| LCD Display | LAD204 see text |

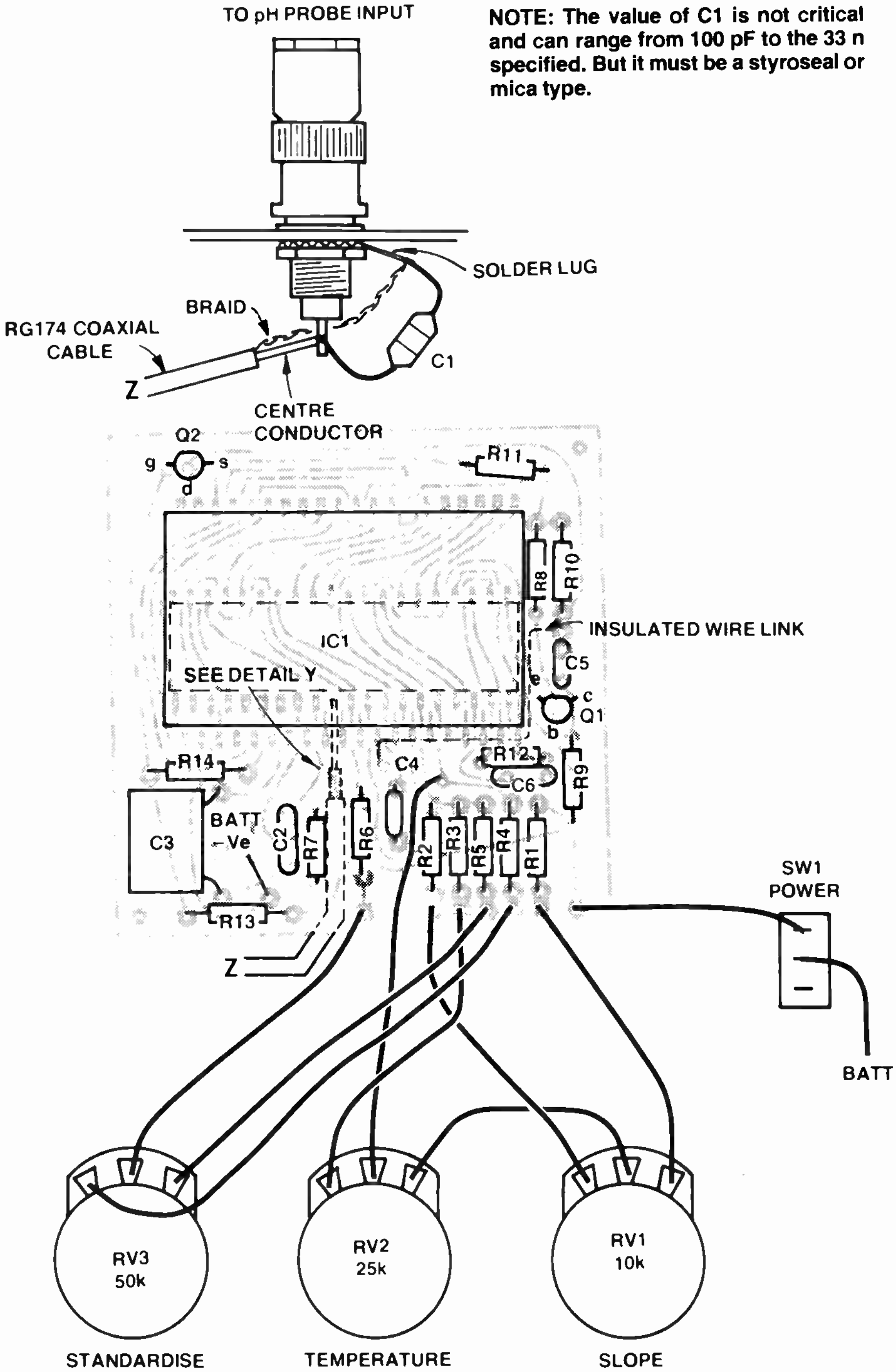
**Potentiometers**

| | |
|---|---|
| RV1 | 10k linear |
| RV2 | 25k linear |
| RV3 | 50k linear |

**Miscellaneous**

| | |
|---|---|
| SW1 | SPST miniature toggle switch |

ETI 572 pc board; plastic box 150 mm x 80 mm x 50 mm; battery clip and No. 216 nine volt battery; length of 4 mm diameter coaxial cable, RG174 or similar — not shielded audio cable; BNC socket (teflon insulated and not second hand); three collett knobs; 40 molex pins; nuts, bolts etc.

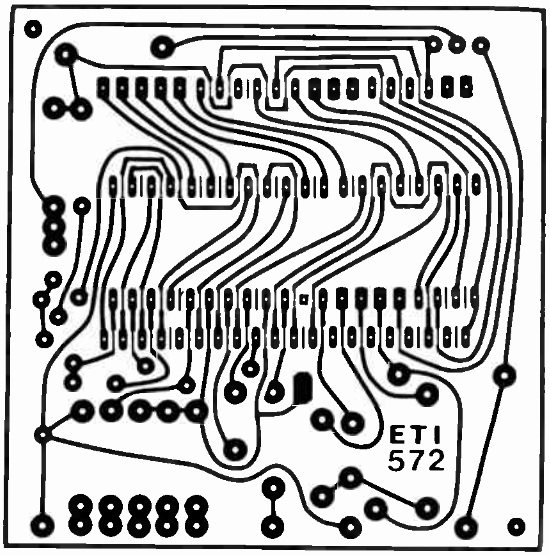


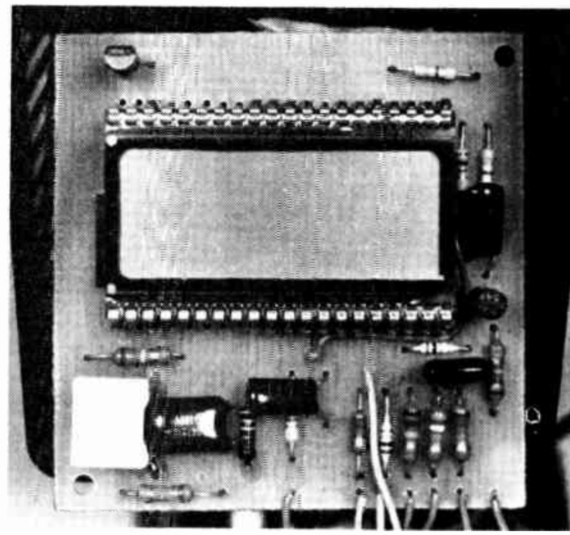

aluminium front panel would also suit. The pc board is mounted behind the front panel, positioned such that the display may be viewed through a cutout. The three control potentiometers are also mounted on the front panel. The input connector is a BNC coaxial socket which has PTFE insulation. This was chosen as it has very high insulation resistance. We mounted the socket on one end of the case and it is connected via coaxial cable. The battery was mounted on the bottom of the case, held in place with double-sided adhesive tape.

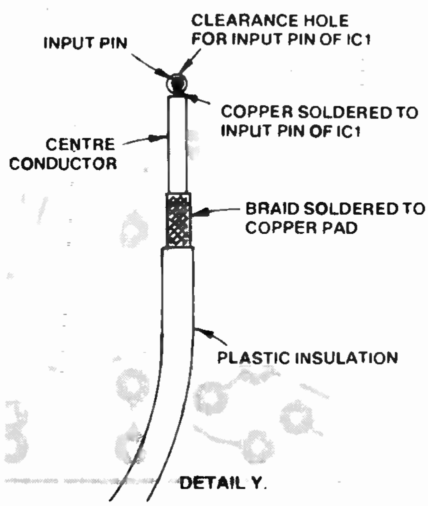
Since the input impedance of the 7106 is extremely high, as explained previously, the input pin (pin 31) must be connected directly to the coaxial cable, without touching the fibreglass board. To do this a 1.5 mm diameter hole was drilled through the pc board immediately beneath pin 31 of the 7106, allowing the pin to pass straight through the board where the cable to the input connector can be terminated directly to it. If you look at the pc board artwork, you will see this drill hole marked by a small square pad with a drill centre marked on it.

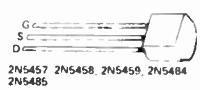
First step in the construction is to drill the lid of the case for the potentiometers, power switch and display cutout. This is best done by using the front panel artwork as a template. Scribe around the inside of the cutout, then mark a parallel line about 2 mm inside this. Drill a series of 3 mm diameter holes using this inside line as the drill centre line, and then pop out the centre of the cutout. Use a flat file to smooth off the edges to the first scribed line.

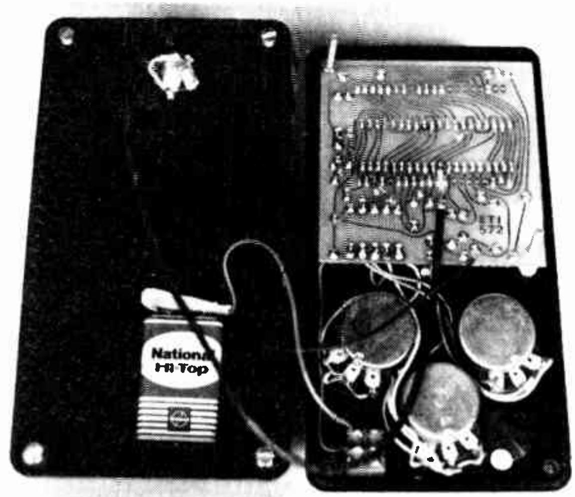
Mark the centres of the potentiometer holes and centre punch them. These holes are drilled to 10 mm diameter. The hole for the power switch should be





**Top right: view of the printed circuit board, showing the liquid crystal display.**

**Right: showing the rear of the pcb, with connections to the probe and potentiometers.**

marked in the same way and drilled to 6 mm diameter. Next, mark and drill the hole for the BNC input socket (also 10 mm diameter).

The front panel transfer should not be attached yet. The pc board is mounted behind the front panel using two countersunk-head bolts and nuts either side of the board to position it. Using the unloaded pc board as a template, mark and drill the holes for the bolts that are to hold it. Countersink the holes on the *upper side* of the panel.

The pc board may be tackled next. All the smaller components should be mounted first. The capacitors are bent down onto the board so that they will be lower than the display. Capacitors C2, C3, C4 and C5 can be greencap, polycarbonate or mylar capacitors. If you have bought an Intersil ICL7106EV digital panel meter evaluation kit, some of the components may be used in the project. The clock capacitor, C6, can be either an NPO ceramic type or silver mica. The evaluation kit uses a 100p silver mica type for this capacitor.

Next mount transistor Q1, and the FET Q2, pushing them hard down on the pc board so the tops of their cases will sit below the display (when it is mounted). The FET has an unusual pin-out configuration so be extra careful that you insert it the right way round.

Mount the 7106 IC as shown in the overlay diagram, being careful to orient it correctly. Forty pin ICs are very hard to get out again!

We mounted the display directly above the 7106 on two rows of Molex pins. This permits quite a compact pc board and elevates the display somewhat above the surrounding components on the board. It may also be unplugged, which might be necessary as we explain shortly.

Insert the two rows of Molex pins, but only solder those pins which are actually used. Those pins not having pc board tracks attached are not used. When the pins are in place, bend back the steel connecting strip between the pins with a pair of long-nose pliers until the strip breaks off. The unused pins will come away with it.

Some displays do not have pin 1 designated, but if you turn the display edge-on to the light you should be able to see the numerals faintly. Alternatively, you have a 50-50 chance of getting it right (or wrong — but we're optimists!) if you take a guess

Mount and wire the three potentiometers and the power switch next. Connections are indicated on the wiring diagram. The potentiometer terminals are positioned at odd angles so that they can be fitted in the available space. This necessitates the use of collet knobs so that the pointer can be positioned correctly in relation to the shaft. Some small grub-screw knobs will work, but you may have to shop around. Speaking of Shoparound, see page 150 of this book for details of where to buy suitable collet ▶

knobs. Wire the battery clip and power switch last.

At this stage you can check to see if you have the display inserted the correct way round. Temporarily plug in a battery and turn the unit on. If all is well, you will see numbers come up on the display. If not, no numbers will appear. Unplug the display and reverse it if this is the case.

With all the components mounted, the pc board can now be mounted to the front panel. Adjust the position of the board so that the display sits firmly behind the cutout in the panel, but don't strain the board.

Finally, solder the coaxial cable from the input socket to the pc board as indicated in the accompanying diagram. Make sure that you use good quality coaxial cable such as RG174 (4 mm dia.), not ordinary 'shielded cable' as its insulation resistance is not good enough for this application. Also ensure that the PTFE insulation on the BNC socket is clean and free from flux. If necessary, wash the socket in alcohol.

Terminate one end of the cable on the socket being careful not to leave any flux on the socket's insulation, or heat the coaxial cable insulation too much. Use a good hot iron with a clean tip and solder quickly. Use a large solder lug under the socket's nut for the braid connection or solder the braid to the edge of the nut. Capacitor C1 mounts directly across the input socket and it must be a styroseal or mica type.

Cut the cable to about 150 mm length and terminate the other end to the input pin of the 7106 as shown in the drawing on page 102. Don't let flux flow down onto the hole in the pc board or allow the solder bead at the joint to touch the board.

Now you can plug in the battery and your pH probe and give the unit a try. If all is well, the front panel artwork can be mounted. Scotchcal panels will be available from the usual suppliers.

## Using the instrument

Before making a measurement, the instrument should always be 'buffered'. Remove the wetting cap from the probe and attach the plastic protective cap — that little bulb on the end is *very* fragile. Set the TEMPERATURE control to room temperature (say, 25) — the scale on this control is marked in degrees centigrade (°C). Clean the electrode with distilled water if you have used it recently.

You will need two buffer solutions, one having a pH near 7 and the other a pH near 4. The two most commonly available have a pH of 6.88 and 4.00. Put the probe in the pH 7 solution and adjust the STANDARDISE control for the correct reading according to the marked pH of the buffer. Allow about two minutes or so for the reading to stabilise before finally adjusting the control. Remove the probe and wash it again in distilled water.

Now put the probe in the pH 4 buffer and allow the reading to stabilise. Then adjust the SLOPE control for the correct reading according to the marked pH of the buffer.

Go through the procedure again to ensure correct adjustment. Only then can you take a reading in the solution or solutions to be tested. Wash the probe before making a measurement and between successive measurements.

If the temperature of the solution, or solutions, to be measured differs substantially from the temperature of the buffers, set the TEMPERATURE control to approximately the temperature of the solution to be measured. This control only has a minor effect and its operation is very 'broad'.

There you have it, your own digital pH meter with an Australian-made probe to boot! ●

### THE CARE & FEEDING OF YOUR pH ELECTRODE

**To ensure the maximum life and best response from your pH electrode, the following procedures are recommended.**

**1) When not in use the pH electrode should be stored with its tip soaking in distilled water. It is important that the porous glass membrane and salt bridge are *not allowed to dry out.* If for some foolish reason this does occur the electrode will require soaking in distilled water for 24 hours before it can next be used.**

**Store the pH electrode with its tip soaking in distilled water, use the protective shield and rinse with distilled water between measurements.**

**NEVER clean a pH electrode on a rag, or on your sleeve, or under a running tap.**

**2) For long term storage, cover the glass bulb with a 'wetting cap' containing distilled water. (Note that plastic wetting caps are supplied with the Australian-made Ionode pH electrodes).**

**3) When in use, the electrode should be rinsed thoroughly with distilled water (preferably applied with a fine-nozzled wash bottle — see the accompanying illustration) between successive readings and between buffer calibrations.**

**4) If the electrode is used with non-clean or organic solutions the electrode may require extra cleaning from time to time. The most common method used is to soak the electrode for 24 hours in a '0.1 normal' hydrochloric acid solution. Alternatively, simply soaking the electrode in a mild solution of household detergent and distilled water will generally emulsify the contaminants and restore the electrode to normal.**

**5) *Always be careful not to touch, scratch or damage the porous glass membrane.* It is advisable to use a plastic protector cap as shown in the accompanying illustration. (These are supplied with the Ionode electrode).**

**6) Generally, a sluggish response from the electrode will indicate that it needs cleaning.**

**For troubleshooting other problems it is best to consult the instruction booklet supplied with the electrode or the supplier from whom you purchased the electrode.**

# Simple, sensitive Geiger counter

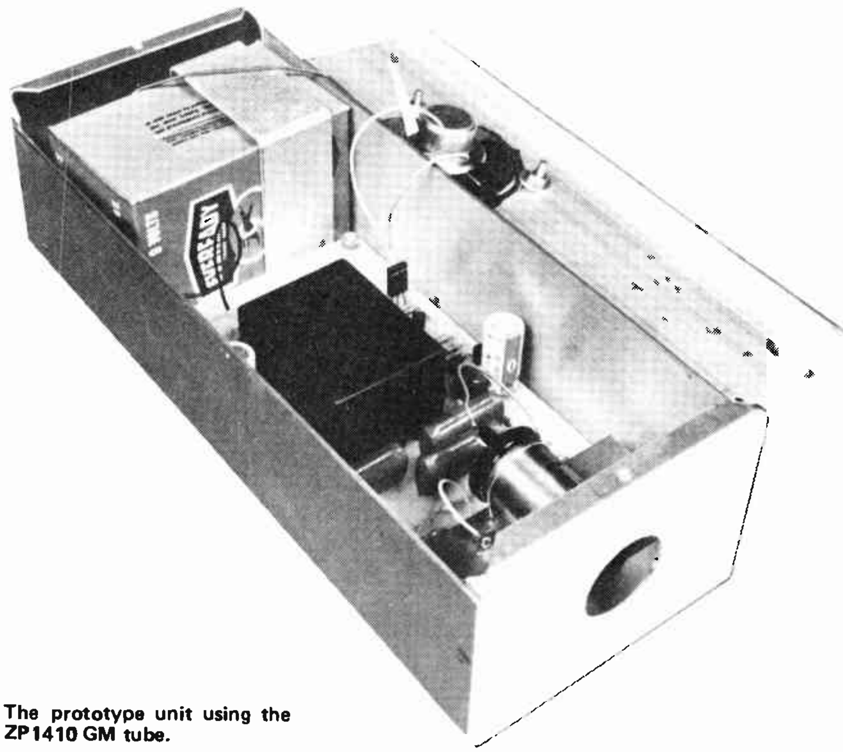
Radioactivity is a fascinating subject. The more you learn about it, the more questions there are to ask! This project is simple to construct and relatively inexpensive. It should prove of great interest to science teachers, students and anyone generally interested in radioactivity.

**David Tilbrook**

IN 1896, Henri Becquerel announced the discovery of radioactivity. He had been experimenting with the element uranium and found that it spontaneously emitted energy, without activation by another energy source. Immediately, researchers started the quest for other elements that might also exhibit this property of natural radioactivity. Pierre and Marie Curie isolated two new elements from a uranium ore called pitchblende. Naming these elements polonium and radium they discovered their new elements were enormously radioactive. Polonium for example, is approximately 10 billion times more active than an equivalent mass of uranium.

The radiation emitted by radioactive elements was at first likened to X-rays, discovered only four months earlier, but it was Ernest Rutherford who first found that there was more than one kind of radiation. The most obvious difference was the ability of the radiation to penetrate matter and he called the least penetrating radiation $\alpha$ (alpha) rays, and the other more penetrating radiation $\beta$ (beta) rays. Magnetic field deflection of the rays showed that $\beta$ rays were in fact free electrons. Further work carried out by Rutherford on the $\alpha$ ray showed that it consisted of particles also and had a positive charge equal to the charge of two protons. The particle of the $\alpha$ ray was later proved to be the nucleus of the element helium, consisting of two protons and two neutrons bonded together. The poor penetrating ability of the particle is thought to be due to its positive charge and the repulsive force it will experience if it approaches the nucleus of an atom.

In 1900 a third kind of radiation was discovered. Called 'gamma' ($\gamma$) radiation, it was found to have tremendous penetrating power because of its neutral charge. Gamma particles turned out to be electromagnetic radiation, the same as light, but with much higher energy.




The prototype unit using the ZP1410 GM tube.

## Measuring radioactivity

With the development of the understanding of radioactivity it was necessary to invent detectors which would enable the radiations to be recognised and measured. The most sophisticated of these is the *bubble chamber*. A development of earlier cloud chambers, these devices enable the tracks of nuclear particles to be studied, the particles themselves being recognised by the characteristic 'tracks' they make in the chambers.

Just as important are the simpler radiation detectors, the *scintillation counter* and the *geiger counter*. These enable the presence of radiation to be recognised and measured quickly and conveniently.

Scintillation counters use a crystal that fluoresces when a particle travels through it. This crystal is mounted on top of a sensitive photomultiplier, which will detect any generation of a light pulse in the crystal. Scintillation tubes however are expensive and require a complicated power supply and amplifier, making them unsuitable for home construction. The geiger counter, on the other hand, is simple to construct and inexpensive.

## Geiger counter

Since this project is designed as a general purpose geiger counter I have made it compatible with two GM tubes. These are manufactured by Philips and are designated ZP1310 and ZP1410. The ZP1410 is an end window $\alpha$, $\beta$ and $\gamma$ sensitive tube and is therefore more expensive than the ZP1310. It is also more fragile and the end window should not be touched. The ZP1310 having no end window will only detect particles with sufficient energy to penetrate the tube, such as higher ▶

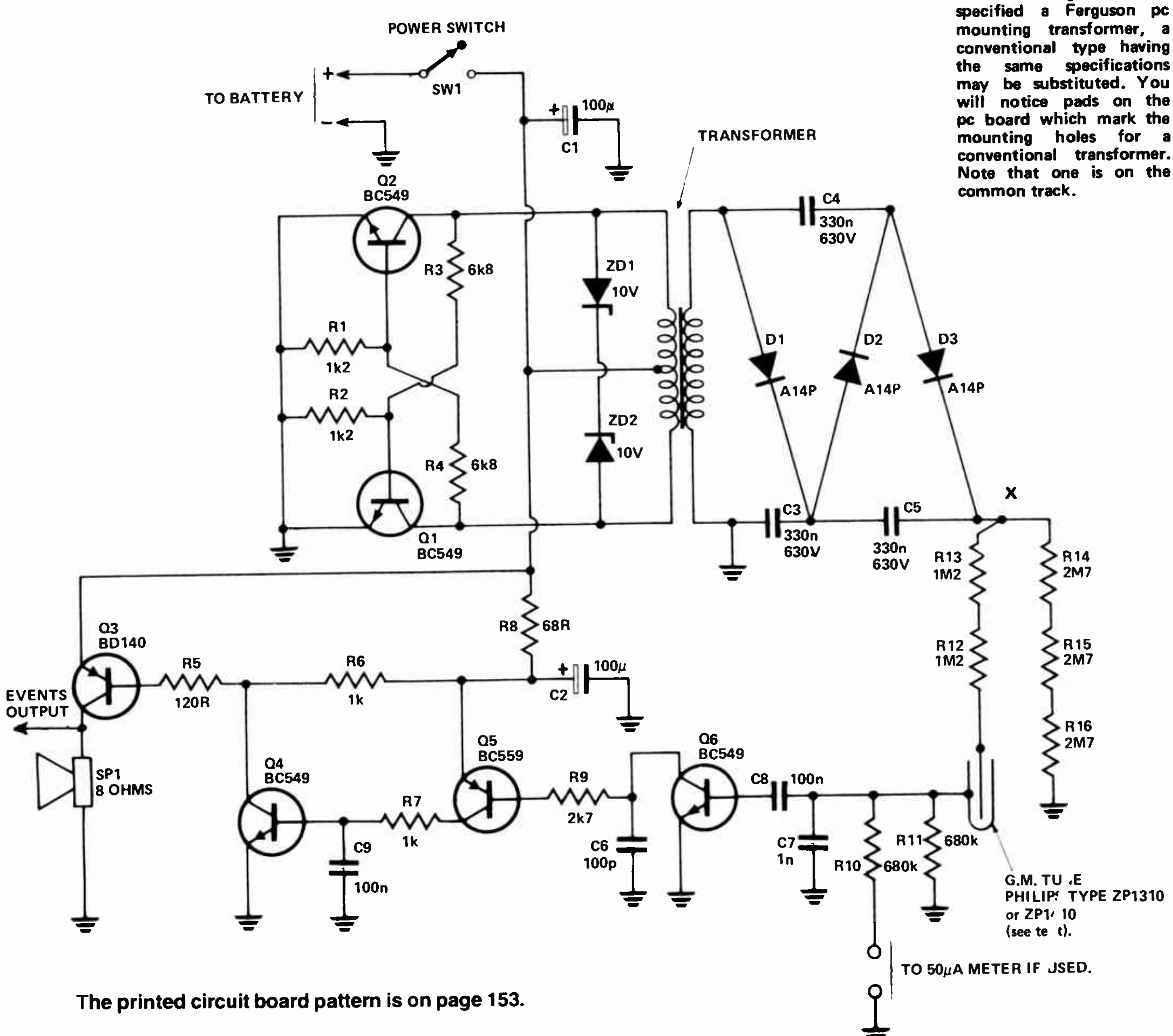
## HOW IT WORKS – ETI 562

The geiger tubes specified for this project have plateau regions around 600 V. To obtain this voltage from a six or nine volt battery the circuit uses an astable multivibrator, formed by Q1 and Q2, driving the 12 volt side of a Ferguson pc board mounting power transformer. This is normally the secondary side of the transformer but in this circuit it is used as the primary. Zener diodes ZD1 and ZD2 limit the voltage that can be applied to the primary of the transformer to around 10.5 volts, and this gives approximately 200 volts on the secondary. Diodes D1, D2 and D3, and capacitors C3, C4 and C5 form a voltage tripler that produces 600 V at the point marked X on the circuit diagram.

This voltage is applied to the anode of the GM tube via two 1M2 resistors R12 and R13. Most common ½W resistors have maximum voltage ratings around 270 volts, so it is necessary to use the series combination of R12 and R13 to provide the series anode resistance for the tube, rather than use a single 2M2 resistor. Resistors R14, R15 and R16 discharge the supply after turn-off and help to stabilise the anode voltage by providing a slight current drain on the tripler at all times.

When a particle enters the tube, ionisations take place and a current pulse flows through the tube via R11 to ground. This pulse causes a momentary voltage rise across R11. When this voltage gets to 0.6 volts the base emitter of Q6 is turned on, causing Q5 to conduct momentarily. This provides a pulse onto the base of Q4, driving Q3 to produce a pulse in the loudspeaker.

The capacitors C2, C6, C7 and C9 provide filtering, primarily to remove any injection from the multivibrator.




Note: although we have specified a Ferguson pc mounting transformer, a conventional type having the same specifications may be substituted. You will notice pads on the pc board which mark the mounting holes for a conventional transformer. Note that one is on the common track.

The printed circuit board pattern is on page 153.

energy $\beta$ particles and $\gamma$ particles. Fortunately most radioactive elements emit all three radiations so the ZP1310 is entirely adequate for most purposes.

## Construction

The construction is reasonably simple, since it is mostly confined to the printed circuit board. Start by mounting the resistors and capacitors on the pc board. Then mount the transistors, diodes and power transformer. Be sure the transistors, diodes and electrolytic capacitors are connected the correct way around. The pc board has provision to drive a 50 uA meter movement although I did not use this facility when building the prototype. The biggest problem is one of calibration. The meter is useless unless one has access to a calibrated reference instrument. For most purposes it is sufficient to use the click rate as an indication as to how radioactive a sample is.

If the ZP1310 tube is used it is mounted directly onto the pc board. Do not solder directly to the anode of the tube. The tube should be supplied with an anode connector. Solder this onto the pc board first and then plug the tube into it. If the tube is not supplied with an anode connector remove one of the socket pins from a 9-pin valve socket and use this instead. Once the anode is connected the cathode strap supplied with the tube can be soldered to the pc board. Do not solder directly to the GM tube to make the cathode connection. If you are using the ZP1410 tube, this must be mounted so that it is insulated from the case and connecting wires taken back to the pc board. I used a piece of pc board that is mounted on insulated 25 mm spacers. The tube is fixed to the board using two wire loops, around the tube and through holes drilled in the board. The cathode connection to the tube is made by soldering the cathode strap onto the small pc board. As with the ZP1310 do not solder directly to the anode of the tube. Use an anode connector if it is supplied or a socket pin from a 9-pin valve socket.

Once the board is completed it can be mounted in a suitable chassis. I used ▶

### PARTS LIST - ETI 562

**Resistors** ....... all ½W, 5%

| | |
|---|---|
| R1 | 1k2 |
| R2 | 1k2 |
| R3 | 6k8 |
| R4 | 6k8 |
| R5 | 120R |
| R6 | 1k |
| R7 | 1k |
| R8 | 68R |
| R9 | 2k7 |
| R10 | 680k |
| R11 | 680k |
| R12 | 1M2 |
| R13 | 1M2 |
| R14 | 2M7 |
| R15 | 2M7 |
| R16 | 2M7 |

**Capacitors**

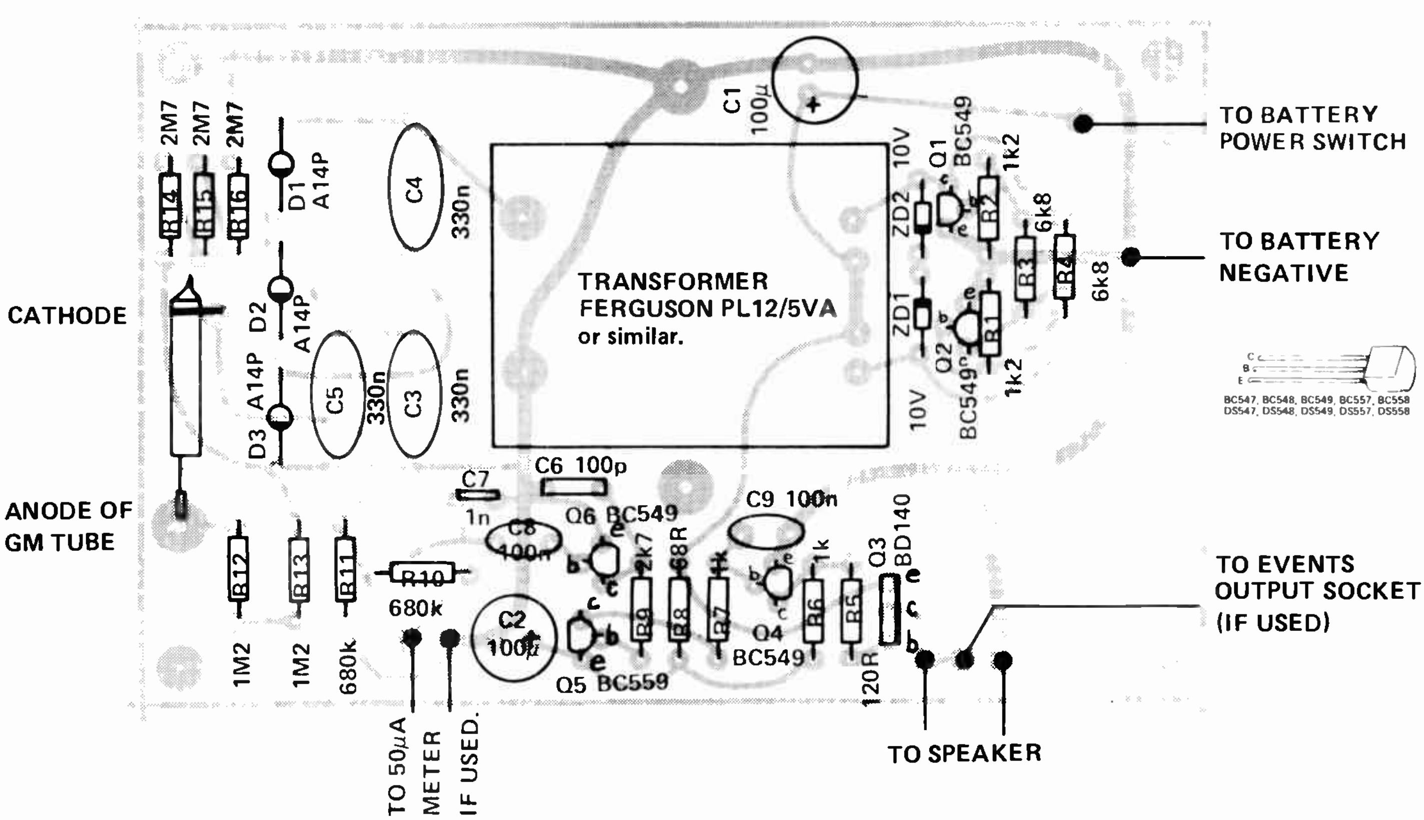
| | |
|---|---|
| C1 | 100u 25V electrolytic |
| C2 | 100u 25V electrolytic |
| C3 | 330n 630V greencap |
| C4 | 330n 630V greencap |
| C5 | 330n 630V greencap |
| C6 | 100p disc ceramic |
| C7 | 1n greencap |
| C8 | 100n greencap |
| C9 | 100n greencap |

**Semiconductors**

| | |
|---|---|
| Q1 | BC549 |
| Q2 | BC549 |
| Q3 | BD140 |
| Q4 | BC549 |
| Q5 | BC559 |
| Q6 | BC549 |
| D1, D2, D3 | A14P or similar 1000V piv diode |
| ZD1, ZD2 | 10V 400mW Zenner diode |

**Miscellaneous**

1 x pc board ETI562; 1 x Ferguson pc mounting power transformer; 1 x ZP1310 or ZP1410 geiger tube (see text); 1 x Horwood aluminium chassis, type 34/10/DS; 1 x battery - Eveready 276-P or equiv.; 1 x on/off switch, spst; 1 x chassis mounting RCA socket; assorted nuts, bolts, washers etc.



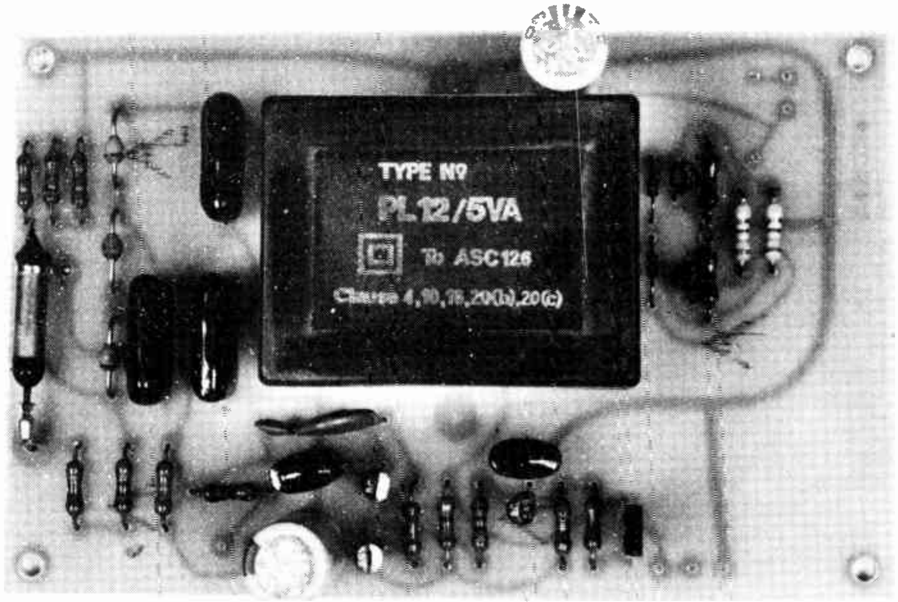
a Horwood type 34/10/DS, in which everything fits quite nicely. The circuit operates from six to nine volts and the battery used in the prototype was an Eveready type 276-P. This is a nine volt battery and is best mounted using a bracket of bent-up aluminium. The circuit pulls around 50 mA, so whatever battery you choose make sure it is capable of delivering this amount of current.

## Powering up

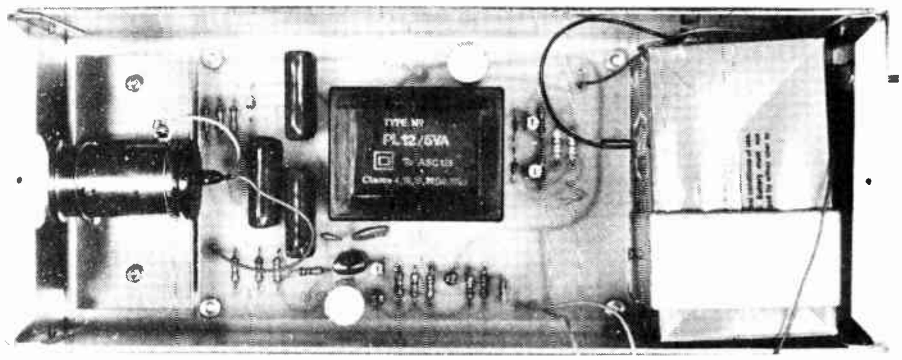
Before applying power to the circuit check the pc board layout. Make sure that all polarised components have been mounted on the pc board correctly. Make a special check of the two 10 V zener diodes. These regulate the voltage that is applied to the tube so it is important that they are inserted correctly. If all is well connect the battery and measure the voltage at point X on the pc board. This is the output of the voltage multiplier and the voltage at this point should be between 550 V and 650 V.

The moment the unit is turned on it will start to detect background radiation. The unit will 'click' once every couple of seconds. This background radiation is caused mainly by cosmic radiation.

Some older watches used small amounts of radioactive isotopes to activate the luminous dial. Even if the dial has long since lost its luminosity it will still be radioactive. If this watch dial is brought near the geiger counter the count rate will increase significantly. ●




Overall view of the pc board of one unit constructed using the lower cost beta/gamma GM tube, ZP1310. Be careful with the anode and cathode connections, as explained in the text.



The alpha/beta/gamma-sensitive GM tube is an end-window type and requires a different mounting method. I secured the ZP1410 to a small piece of pc board, as described in the text, mounted in the end of the case. The tube's window must be aligned with the hole in the case end.

### THE GEIGER MULLER TUBE

This consists of a metal tube or cylinder, hermetically sealed and filled with a gas at less than atmospheric pressure. If the tube is intended for the detection of alpha particles (as well as beta and gamma radiations), it will be constructed with an 'end window', as illustrated here. Since alpha particles have so little penetrating ability the window must be extremely thin. Thus, the windows are difficult to manufacture and are *fragile*.

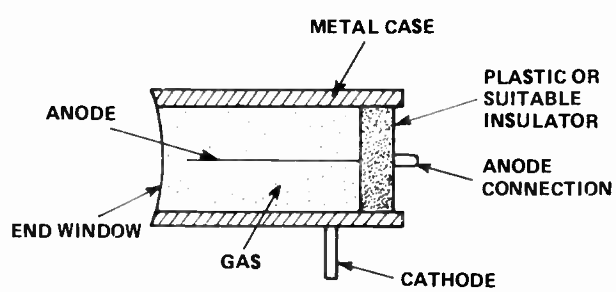
Geiger tubes constructed to detect only beta and gamma radiations do not have an end window, otherwise construction is similar.

In the centre of the tube is a wire ANODE. The metal cylinder itself serves as a CATHODE. In operation, a high voltage is connected between the anode and cathode, the cathode, anode being positive with respect to the cathode.

As the voltage between the electrodes is increased, the tube goes through three phases: if the voltage is lower than a particular value, the gas in the tube will not be ionised and no current will flow. Above this particular voltage (the 'striking' voltage), the gas ionises and a small current flows continuously through the tube. This is the phase in which the tube is operated — referred to as the "plateau region". If the voltage is increased even further still the tube will enter the third phase — that of arc discharge between the anode and cathode. If the tube is allowed to operate in these conditions it will almost certainly be damaged.

When a particle enters the tube operating in its plateau region, it ionises the gas further and the ions produced are accelerated towards the cathode, electrons towards the anode. These moving ions cause further ionisations and an avalanche of ions (and electrons) occurs.

When the tube is operated in its plateau region a single particle of radiation will cause an avalanche of millions of ions and electrons. Each avalanche is registered as a momentary increase in the current through the tube. This current pulse can be detected as a voltage pulse across a resistor connected in series with the tube. If the voltage pulse is coupled to a sensitive audio amplifier driving a loudspeaker, a sharp 'click' will be heard. Each 'click' from the geiger counter represents the incidence of a particle on the GM tube.




A TYPICAL END WINDOW G.M. TUBE

**Microwave ovens sure have lots of zip, but don't get zapped!**
**Build our —**

# Microwave oven leak detector

While microwave ovens are generally well-designed and safe to use, the human factor (even Murphy's Law) can thwart the manufacturer's efforts and possible unsafe levels of microwave energy may be radiated without warning. Simple and inexpensive to build, this project will indicate if your oven is safe . . . or not.

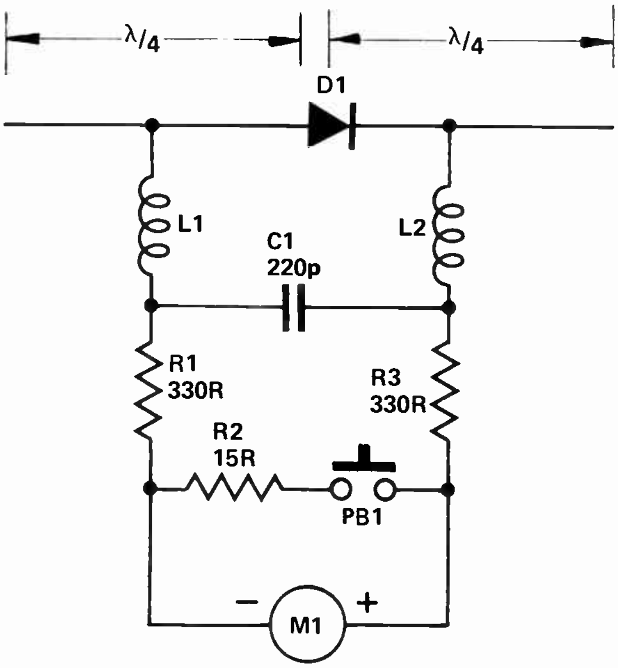
**Jonathan Scott**

THE MICROWAVE oven is one of the most recent examples of advanced technology finding application in the home. Many thousand such devices are sold for domestic use in Australia alone each year, while commercial units have long been found in restaurants and snack-bars.

The microwave cooking method, while unlikely to usurp conventional cooking methods, has distinct advantages. It is usually quicker; two to five times quicker in fact. Because it heats the foods directly, but does not heat the bowl or container, the food can be left enclosed. The process is often cleaner and less utensil-consuming as a result. Because the energy penetrates below the surface of a lump of food and does not rely so completely on conduction, it can be used for rapid defrosting of foods. (See "How a microwave oven works").

Unfortunately, the microwave energy is quite dangerous. It must be carefully contained within the cooking chamber. The window is usually sealed to the radiation by a fine metal grille similar to heavy duty fly-screen. The door fits flush and firm, and the instructions warn against allowing any distortion of


The device is housed in a 'zippy' box, everything being attached to the front panel, held in place by the four screws. Our prototypes were calibrated through the kind assistance of the Electrical Engineering Department of Sydney University.




The printed circuit board pattern is on page 152.

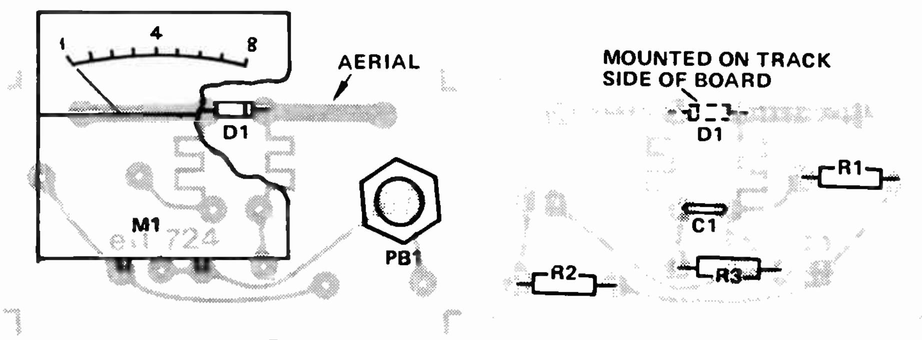
### HOW IT WORKS – ETI 724

Operation is very simple. The device is completely passive and requires no batteries. It uses the radiated energy from the oven to deflect a meter directly.

The pc board dipole, when exposed to microwave radiation of about 2.5 GHz, develops an ac voltage across D1. When the diode is positively biased the diode conducts, shorting the dipole. When reverse biased it isolates, thus leaving a net voltage on the diode. This DC component is filtered by L1, L2 and C1.

The amplitude of the dc component varies somewhat with the type of radiation from the oven – CW or pulsed, depending upon the supply rectification and filtering used with the magnetron. It will also vary with distance, of course. The Australian safety limit is 5 mW/cm$^2$ at a distance of 5 cm from the oven. R1, R2 and R3 define the sensitivity, the values chosen being suitable to produce FSD for 5 mW/cm$^2$ CW at the pc board plane with PB1 closed.

Some variation should be expected from unit to unit. This should not normally be of any concern, however, as a healthy oven will emit at least one order of magnitude less than the 5 mW level, and so the readout is unambiguous even when the unit is not the exact 5 cm from the oven surface.




TRACK SIDE

COMPONENT SIDE

Component overlays of both sides of the pc board. Note that the diode is mounted on the COPPER SIDE of the board. It is strongly recommended that the device is constructed using the pc board design shown so that results are consistent with the calibrated prototype.

### PARTS LIST - ETI 724

**Resistors**
R1 . . . . . . . . . 330R
R2 . . . . . . . . . 15R
R3 . . . . . . . . . 330R

**Capacitor**
C1. . . . . . . . . . 220p ceramic

**Semiconductor**
D1 . . . . . . . . . HP 5082–2800 Shottky Hot Carrier Diode

**Miscellaneous**
PB1 . . . . . . . . . momentary push button
M1 . . . . . . . . . 250μa FSD Signal Strength meter
L1, L2 . . . . . . . Etched on pcb

ETI 724 pcb (includes L1, L2 and antenna).

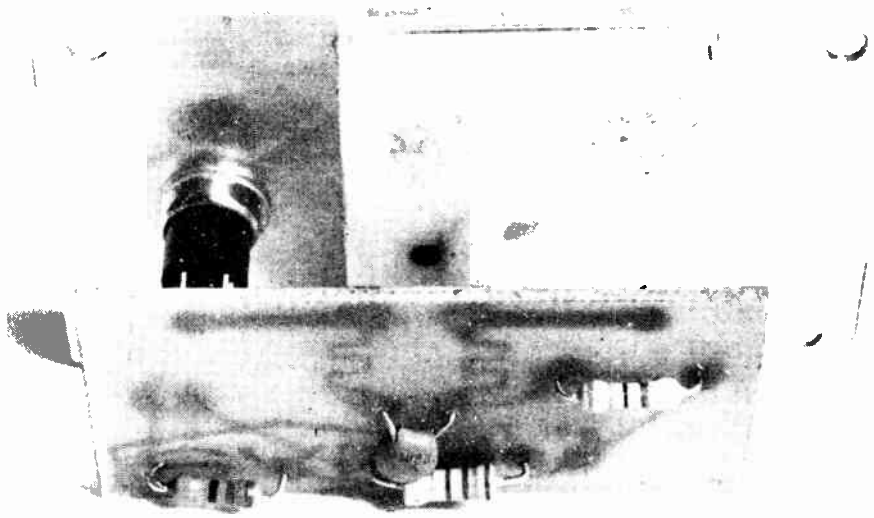
Plastic jiffy box (25 mm x 50 mm x 90 mm).

the door. All ovens have safety circuits preventing the power being applied with the door open. Some ovens have as many as five interlocks against accidental activation without correct door closure. They do not, unfortunately, incorporate an alarm which warns if a leak occurs. This can happen if the door is slightly bent by being closed on a lump of stray food or if damaged during a domestic fracas.

In view of these things it seems wise to have some additional method of checking for leakage.

## Leak detectors

There are some commercial leak detectors available. The most common one is made by the CSIRO. This consists of some circuitry, including a LED, encapsulated in a clear plastic tube. Entirely passive in operation, it illuminates the LED if the integral 62 mm long dipole is exposed to radiation of approximately the safe recommended limit. The CSIRO device is the cheapest available and sells for around $15. In operation it is satisfactory, but has two drawbacks. Firstly, were the hot carrier diode to be destroyed, as could happen for any number of reasons, including being exposed to cook strength signal, a 'safe'



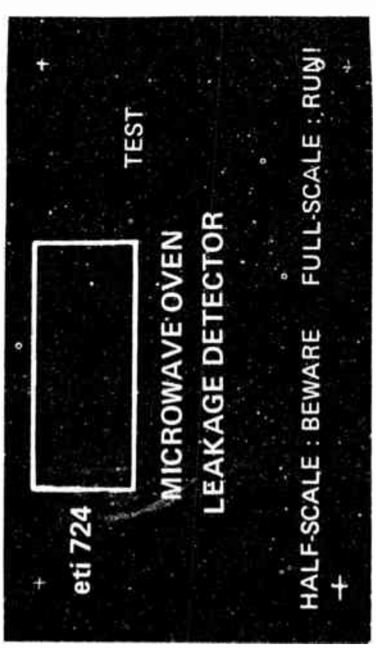
Internal view of the microwave oven leak detector shows the simplicity of construction.

report would always be given. In other words, the device cannot easily be checked. Secondly, the output is go/no-go. No indication of gradual increase in leakage is available.

So, if leakage from your oven has been gradually getting worse, you won't know until it reaches the level that trips the sensor (admittedly this may still be well below the harmful level).

Our design does not suffer from these drawbacks. The output is an analogue meter. This is set to read full-scale deflection (FSD) for a signal of approximately 5 mw/cm$^2$ in the 'test' mode. Hence, as little as 10% of the danger level can be read.

When the test button is released, the sensitivity increases by about an order of magnitude. In this condition the unit acts like a signal strength meter, and should show some deflection with the normal residual leakage of an oven. This confirms that it is working. We estimate that it should cost \$10-\$12, pc board included, as a kit. If you have upwards of \$300 worth of oven, ten dollars is not a bad investment to insure the family jewels . . .




## Construction

Unless you are very experienced with high frequency work already it is important to use the pc board. The antenna is printed onto the board and so, is inherently tuned sufficiently closely when the correct board is used. It is also convenient as the meter and button are soldered directly on the copper side and the whole assembly is self-contained.

No box at all is actually necessary, but if you choose to use one, ensure that it is not metallic except for the front panel. There are no flying leads, etc, so if need be, one could leave the whole circuit just as is, with no box.

We used a 25mm x 50 mm x 90 mm jiffy box which was just big enough inside.

Ensure that the diode and meter are soldered in the right way round. Also try to solder the diode neatly, as shown in the overlay. It should be soldered onto the copper side directly, flat against the pc board in the centre of the dipole. Use of the board and close adherence to our design will ensure that your unit is close to prototype sensitivity and will thus read true.

## Using it

The meter is moved around the door rim with the oven operating, meter facing away, button depressed, the back parallel to the door and spaced approximately 40 mm from the surface.

When testing, it should be moved over the oven in each polarisation, just to be sure. To check if it is working, simply repeat the procedure without depressing the test button. Some erratic flicker of the needle should be evident, indicating correct operation. It can be left on top of the oven when not specifically being used, so that some drastic leak will cause deflection should that occur.

## How a microwave oven works

There are several separate sections to a microwave oven. Firstly, there is a Magnetron, which is the heart of the system. This is a thermionic device incorporating a resonant cavity. It is an oscillator and will deliver power at super high frequencies (microwave ovens operate on 2.45 GHz). The oven has a power supply incorporating a number of safety interlocks preventing activation in unsafe circumstances.

There is a cooling system for the electronics, usually a fan. The cooking chamber has metal walls and some system of ventilation to remove steam, etc. The one fan is often used to cool the electronics as well as ventilate the cooking chamber. A duct (waveguide) transfers the microwave energy to the chamber from the magnetron. Some form of disperser spreads the energy and prevents standing waves within the chamber. This is either a rotating platform moving the food or a set of vanes in the chamber ceiling reflecting the beam about. (This is often driven by the fan motor or even the stream of cooling-ventilating air).

Finally, a control panel allows varying degrees of automatic control of the RF power. This always includes a timer and a door interlock.

Water is the primary microwave absorbing agent in food. Dry food and glass or plastic containers are substantially unheated by the radiation. The energy can penetrate to a depth of about 20 mm effectively, though this varies markedly with the food.

Domestic ovens consume about 1200 watts altogether, of which about half appears as microwave power in the food chamber. This, considering the mode of absorption, is considerably more efficient than an ordinary oven which is why the cooking speed is so rapid. ●

# GSR MONITOR

Learn to reduce tension levels with ETI's galvanic skin response meter. Design by Barry Wilkinson – editorial by Jan Vernon.

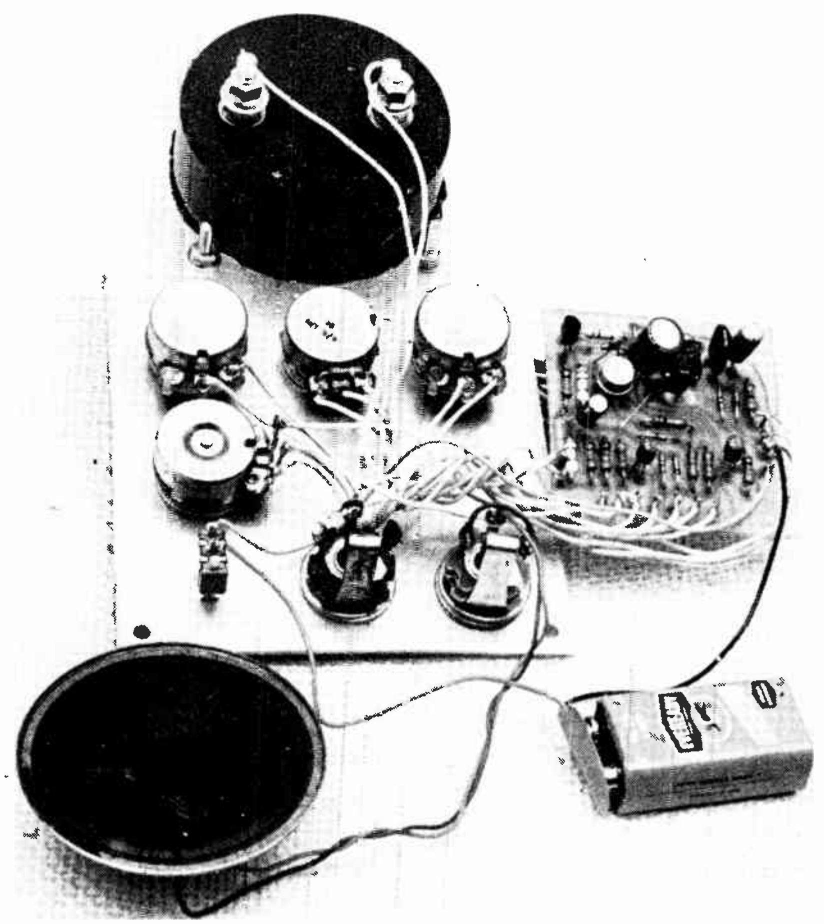
THE BEST WAY TO START EXPERimenting with biofeedback is to use a galvanic skin response monitor, a device which measures changes in skin resistance. In September 1976, we published an article which covered the background and theory of biofeedback and we discussed the various types of biofeedback instruments which are available. The GSR monitor is the most simple to use, the electrodes can be simply attached to the fingers with Velco straps and the technique of using the machine can be quickly learned.

Skin resistance changes with changes of emotional state. When tension increases, the skin resistance falls – when tension decreases there is an increase in skin resistance. (Some biofeedback instruction manuals speak in terms of conductivity rather than resistance and state measurements in mhos, and the meter we use gives a positive deflection for decreasing resistance.)

The connection between skin resistance and tension is not fully understood. Tension affects sweat glands and with the changes in the sweat glands there is a change in the membrane permeability of the skin and this change in permeability is the major cause of changes in electrical activity.

Almost a century ago, a scientist named M. Ch. Fere discovered the resistance of the skin to a small electric current changed in response to aroused emotions. This information has since been used in various ways; one obvious example is the polygraph, or lie detector, which responds to the tension generated when a person is lying.

It was not until 1961 that Dr. J. Kamiya, whilst conducting a series of



experiments with brain waves, found that with feedback his subjects developed the ability to produce 'Alpha waves' at will.

Dr. Kamiya's experiments created considerable interest and started investigations into whether other bodily functions could be brought under conscious control. Since that time it has been demonstrated that with feedback it is possible for people to control heart beat, blood pressure and temperature — all previously considered to be automatic bodily functions mostly beyond conscious control.

Of course it should be stated that various mystics and yogis have previously demonstrated this type of ability but the fascination of biofeedback is the speed and ease with which this type of control can be learned.

Biofeedback has exciting medical possibilities. GSR machines are being used by therapists for the treatment of many disorders related to tension. The average person will find a GSR machine mainly useful for relaxation training. With the GSR machine it is possible to recognise tension and learn how to decrease tension levels. This type of training is so effective that the machine quickly becomes unnecessary.

However not everyone suffers from tension. The biofeedback machine can be a fascinating toy to play with. Discovering that you can bring an internal bodily function under conscious control with the same ease that you can twitch your nose is most interesting. And of course you can then perfect this ability just as you perfect your ability at a game like tennis. For many people this is reason enough to build this machine.

### What you do with it once you have built it

The ETI GSR monitor has an on/off switch, a sensitivity control and fine and coarse level controls. The machine also has a connection for headphones.

To start relaxation training, you'll need a comfortable chair, low lighting and no distractions. Taking any type of drug can interfere with your ability to relax. This applies to alcohol and cigarettes. Attach the electrodes to the fleshy part of the first two fingers on one hand — firm but not too tight (the non-dominant hand is recommended). Set the sensitivity control to minimum and the 'fine' level control to mid-range. Turn the volume control to minimum. Now you have to set the level with the 'coarse' level control (when the sensitivity is set low the 'fine' level control need not be used). Start with the 'coarse' control at full anticlockwise and turn it up until the meter needle starts to move. Carefully set the needle to mid-range. Now the instrument is set-up in its minimum sensitivity position.

Having mastered setting up with minimum sensitivity try to set the GSR monitor with the sensitivity set halfway. It will require delicate adjustment of the 'coarse' level control. Now the effect of the 'fine' level control can be seen. This control enables you to set the level on a high sensitivity setting.

Although the GSR machine measures minute changes in skin resistance, the level of skin resistance varies considerably from person to person so a wide range of settings is provided.

Now turn up the volume and observe that the meter reading is accompanied by a medium pitched tone. (A convention has developed to link high-pitched tone with tension increase and low pitched tone with a decrease in tension.) Now you relax and bring the tone down and the needle back to zero.

How? Basically you are supposed to find this out for yourself. After watching the needle for some time you will notice it move up or down. Something has happened to cause a change in your skin resistance. You would be barely aware of what had caused the change but aware enough to try to reproduce the effect. Eventually your awareness grows and so does your ability to control your tension. Many people find that relaxation of the stomach muscles makes the difference. It varies from person to person.

There are several relaxation techniques which work very well. One method is to tense all the muscles of the body as hard as possible, hold them tense for several seconds then very deliberately relax all muscles. There are several books and cassettes available which describe relaxation techniques. The techniques work. The biofeedback machine makes it possible to monitor progress.

As you relax, the needle on the meter and the audible tone will decrease. When the needle reaches zero, reset it again towards the fsd end of the scale and repeat the procedure.

Twenty minutes is the recommended time for a training session. After about one or two weeks of daily relaxation training, it should be possible to produce the same level of relaxation without using the machine and the machine can simply be used occasionally as a reference.

# GSR MONITOR

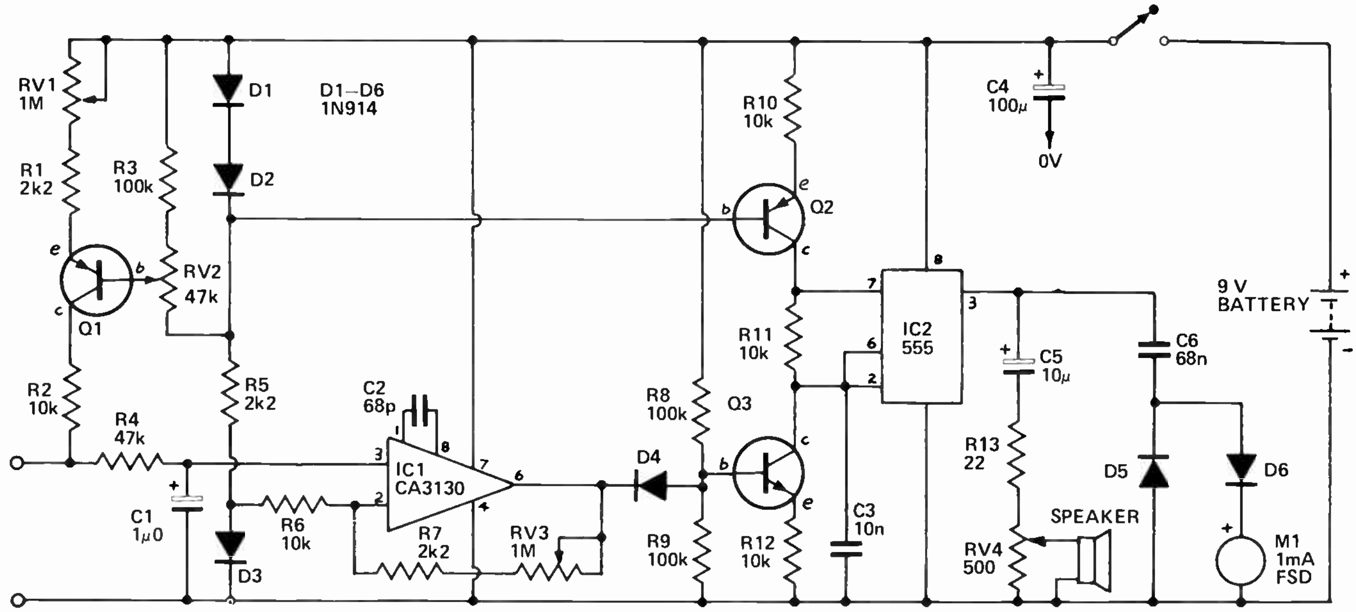
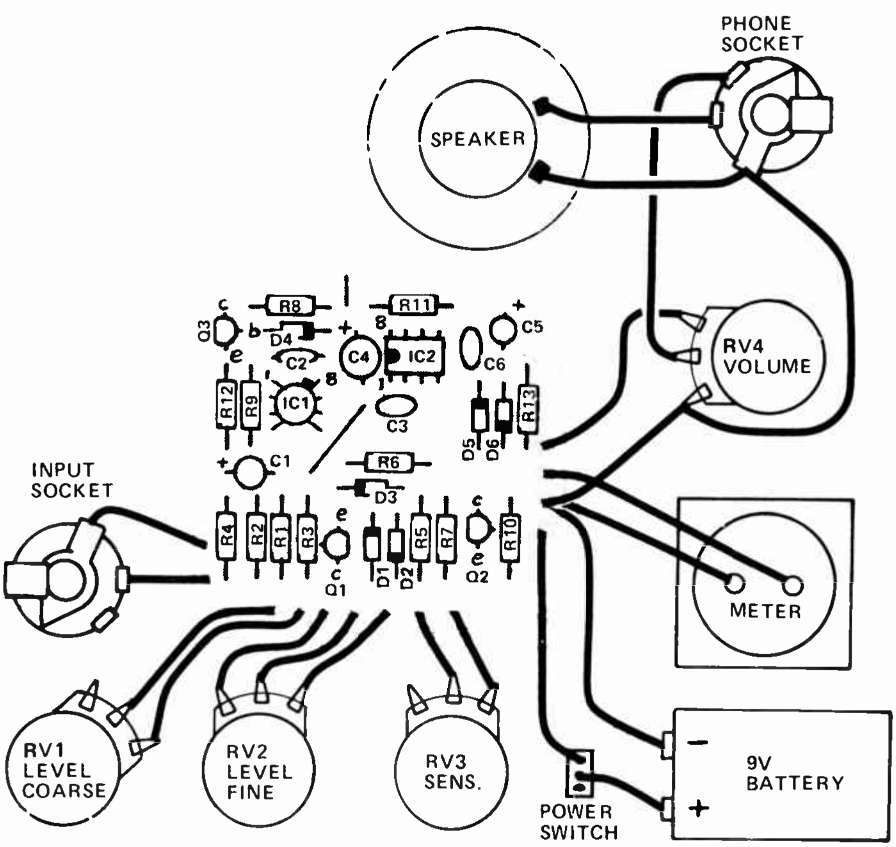



*Fig. 1. Circuit diagram of the GSR monitor.*

*Fig. 2. Component overlay and interconnection diagram.*




## PARTS LIST ETI 546

**Resistors all ½ W 5%**

| | |
|---|---|
| R1 | 2k2 |
| R2 | 10 k |
| R3 | 100 k |
| R4 | 47 k |
| R5 | 2k2 |
| R6 | 10 k |
| R7 | 2k2 |
| R8,9 | 100 k |
| R10–R12 | 10 k |
| R13 | 22 ohms |

**Potentiometers**

| | |
|---|---|
| RV1 | 1 M log |
| RV2 | 47 k lin |
| RV3 | 1 M log |
| RV4 | 500 ohm lin |

**Capacitors**

| | |
|---|---|
| C1 | 1 µ 16 V electro |
| C2 | 68 p ceramic |
| C3 | 10 n polyester |
| C4 | 100 µ 16 V electro |
| C5 | 10 µ 16 V electro |
| C6 | 68 n polyester |

**Semiconductors**

| | |
|---|---|
| D1–D6 | Diodes 1N914 |
| Q1,2 | Transistors BC559 |
| Q3 | Transistors BC549 |
| IC1 | Integrated Circuit CA3130 |
| IC2 | Integrated Circuit NE555 |

**Miscellaneous**

PC board ETI 546
Meter 1 mA FSD
Zippy Box 196 x 113 x 60
Two phone jacks
Four knobs
Small speaker
Six AA battery holder
Pickup probes

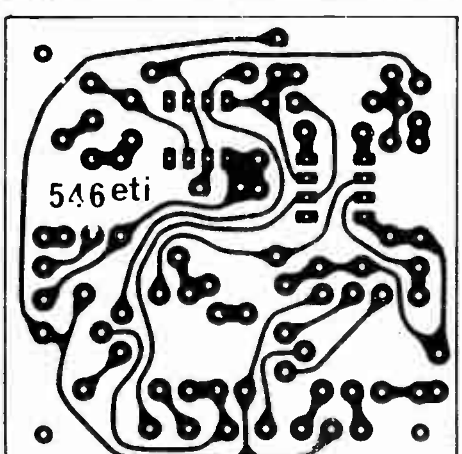
## How It Works — ETI 546

This project measures the skin resistance and displays it on a meter. An audio tone gives an aural indication of the meter reading. The meter operates in reverse sense to a usual resistance meter: low resistance gives full scale (or high tone) and high resistance gives zero (or low tone). Skin resistance can vary over a large range but the variations studied in biofeedback experiments are small — so an offset is needed.

Transistor Q1 acts as a constant current source — the actual value can be varied over a large range by RV1 and over a limited range by RV2. These act as the coarse and fine level controls. This current is passed via R2 to the probes. The voltage developed across the probes is proportional to the skin resistance and is fed to the input of IC1. This amplifies the signal with reference to 0.6 V (drop across D3) and the gain is variable by RV3.

The second IC is an NE555 oscillator where Q2 provides a constant current (about 60 $\mu$A) to the capacitor C3. When the voltage on C3 reaches 6 V the IC detects this and shorts pin 7 to ground, discharging C3 via R11. This continues until the voltage reaches 3 V at which point the short on pin 7 is released allowing C3 to recharge. The output of the oscillator is connected to a speaker via the volume potentiometer RV4 and the meter via C6 and the diodes D5 — 6.

We vary the frequency of the oscillator and the meter reading by robbing some of the current supplied by Q2 into Q3. In this way the frequency can be lowered and actually stopped. Transistor Q2 is controlled by IC1 completing the connection between the probes and the output.



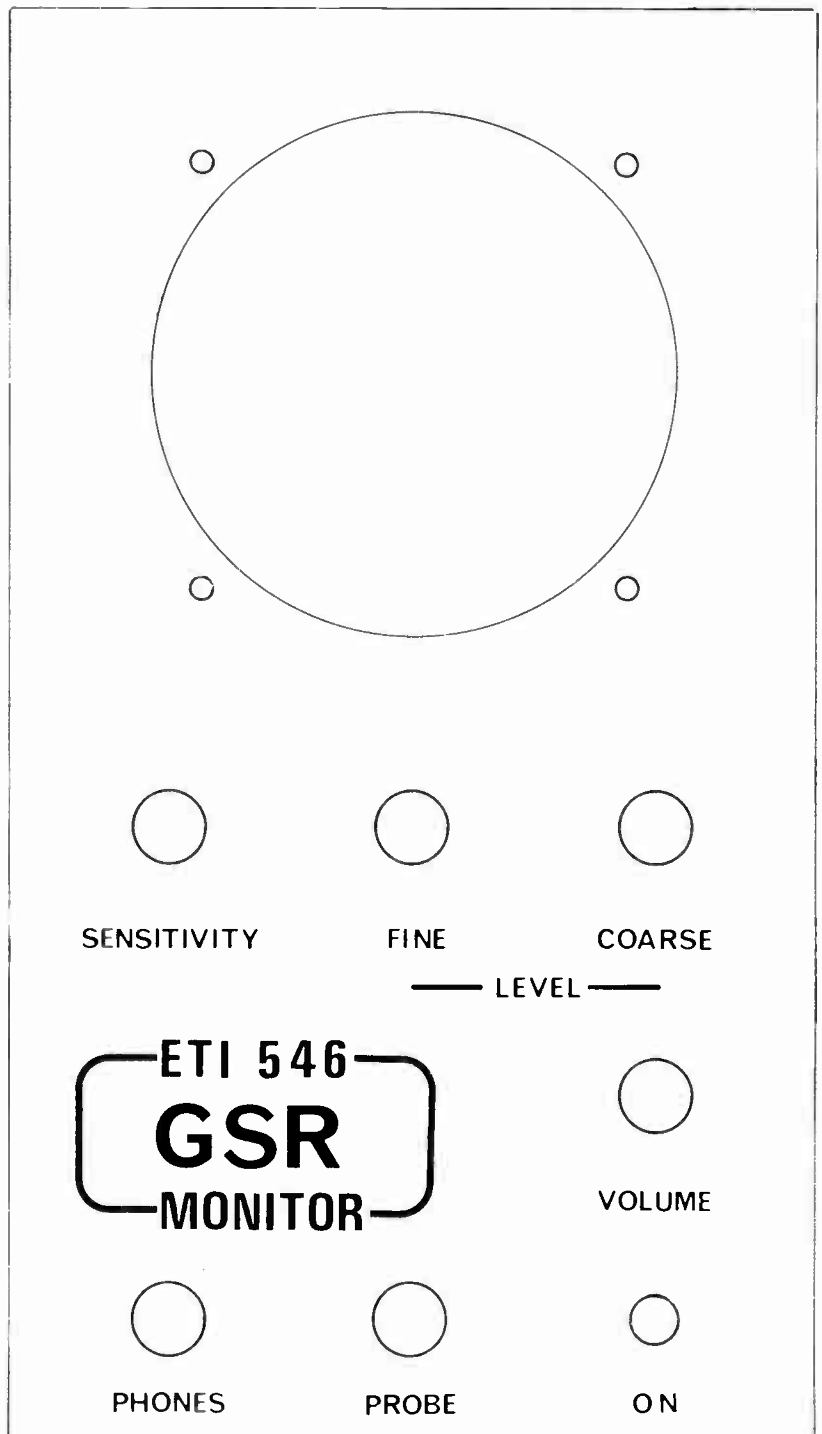

## Construction

Construction is not critical although we recommend you use the pc board as it makes things easier. Before soldering the components made sure they are orientated correctly. External wiring can be done with the aid of the overlay-wiring diagram.

## Probes

Probe construction and electrical contact is not nearly as critical as with most other biofeedback machines.

Commercial GSR machines use a pad of soft steel wool which is held firmly onto the finger by a short length of Velcro strap (Band-Aids work fine!). However, any method ensuring a firm contact between probe leads and the fleshy part of the finger will do. One method which works very well is to bind tinned copper wire around a guitar finger pick (or solder to a steel pick). Two probe connections are of course required — one for each of the first two fingers.



# House alarm is simple to construct, features high reliability

Collyn Rivers

This project is adequate for the average household or small business and will provide years of reliable operation.

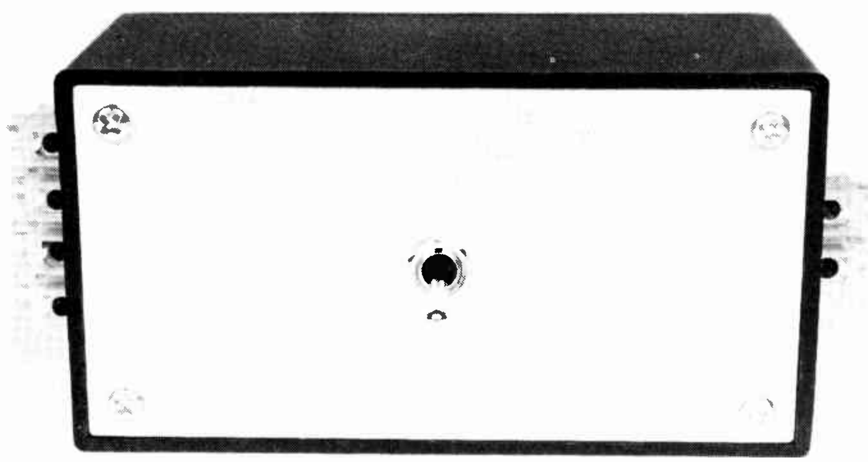
WHEN YOU HEAR a burglar alarm the chances are less than three in a hundred that the alarm has been set off by an intruder. The other 97 times it's been falsely triggered. And if it's raining at the time — especially if there's a thunderstorm — the chances of the alarm being genuine are very much smaller still.

This is a thoroughly unsatisfactory situation and one that has caused police and security organisations many headaches over the years.

False alarms are generally caused by poor installation techniques and/or the wrong choice of alarm control unit for the specific application. In the case of non-professional designs and installations the cause is usually lack of appreciation of the problems inherent in what at first seems to be a simple problem in electronic circuit design.

The alarm unit and installation techniques described in this article have been devised to combine total reliability with immunity to false triggering. Both were progressively developed over a number of years and the unit itself was produced commercially (by the author) in large quantities for the security industry some years ago. It is still one of the simplest and most reliable units around.

The system is adequate for the average household or small business. If built and installed as described it will provide years of reliable operation.



## Defining the risk

Really determined and skilled burglars will find ways to break into almost anywhere — no matter how well it is protected. But experts like these will be far too occupied sizing up the local bank to bother about most houses or small businesses. Who you're mainly up against are 15-25 year olds with generally limited intelligence.

Figure 1 shows how and where most forced entries will be attempted. A surprising 29.2% of illegal entries are made through unlocked doors or windows. Most other entries are made by forcing with a jemmy. Only rarely is entry made by breaking glass.

So your first step should be to 'harden up' the house. Fit really strong concealed catches, especially to those windows which are not overlooked from the street or by neighbours' houses. You'll have to search around for decent fittings — the sliding bolt catches sold by most hardware stores are jokes. One good kick will tear them in half — if the toy screws supplied don't pull out first! So consider carefully how the various devices will withstand a jemmy used in earnest — and whether the woodwork to which they are attached will need strengthening.

Once this is done it's time to think about alarm protection.

## The basic system

The simplest adequate alarm system detects the opening of doors or windows and when an 'opening' signal is received causes the alarm to sound continuously even after the door is subsequently closed.

The alarm should also sound and continue to sound if any associated wiring is detected and cut. The alarm should be battery operated so that it will continue to operate if mains power fails or is disconnected.

This all seems simple enough to do but there are a number of unsuspected traps along the way.

## Detecting entry

Doors and windows may be protected by switches which are closed when the openings to be protected are closed. All such switches are connected in a series loop so that if one or more are opened, or interconnecting wiring is cut, the alarm is actuated.

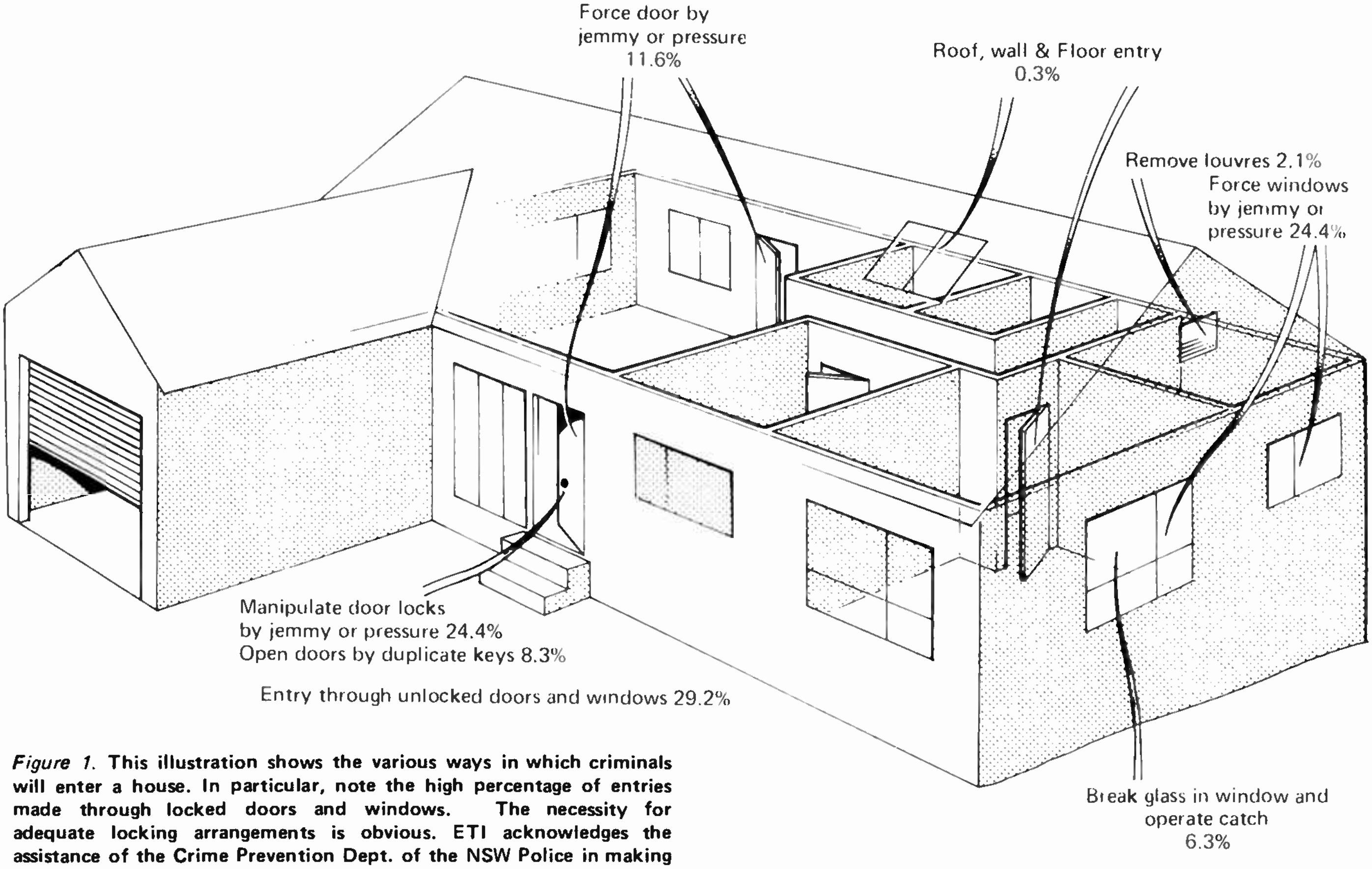



***Figure 1.*** **This illustration shows the various ways in which criminals will enter a house. In particular, note the high percentage of entries made through locked doors and windows. The necessity for adequate locking arrangements is obvious. ETI acknowledges the assistance of the Crime Prevention Dept. of the NSW Police in making these statistics available.**

Many of the windows to be protected may remain closed for months — sometimes years — so the switches chosen must be absolutely reliable and resistant to corrosion. Most switches are designed so that the contacts are automatically cleaned every time the switch is operated — but this doesn't help much if the switch is actuated only once in ten years!

Another essential requirement is that the door or window must be able to open at least 20 mm before the switch is actuated. This will allow for movement caused by swelling in wet weather and rattling during storms.

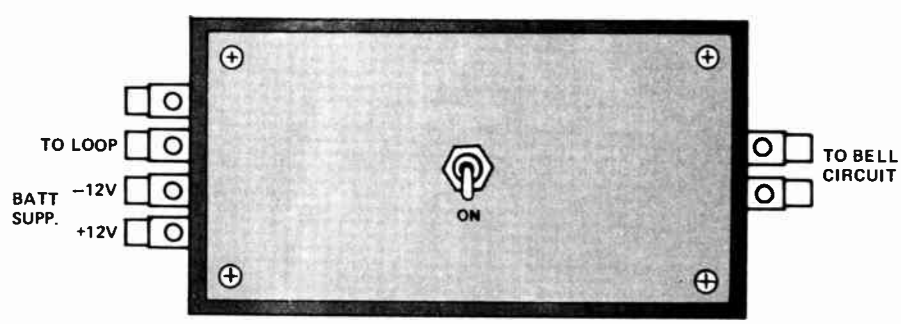
The ideal device for this purpose is the magnetic reed switch. This consists of a pair of ferro-magnetic reeds and contacts, hermetically sealed in a small glass tube, and held closed by a magnet a few millimetres away. The contacts open when the magnet is moved away from them.

Commercial installers use these switches extensively but they generally keep them packaged in rectangular plastic mouldings. A neater, but more time-consuming method, is to recess them into the architrave surrounding the opening. Whichever type is used the magnet should always be attached to the moving part of the door or window.

The reed switches *must* be designed specifically for security and similar applications — standard reed switches may not necessarily be suitable as some tend to remain closed when the magnet is removed if they've been held closed for any length of time. To be on the safe side, buy your switches from a security equipment supplier — you'll find addresses in the Yellow Pages.

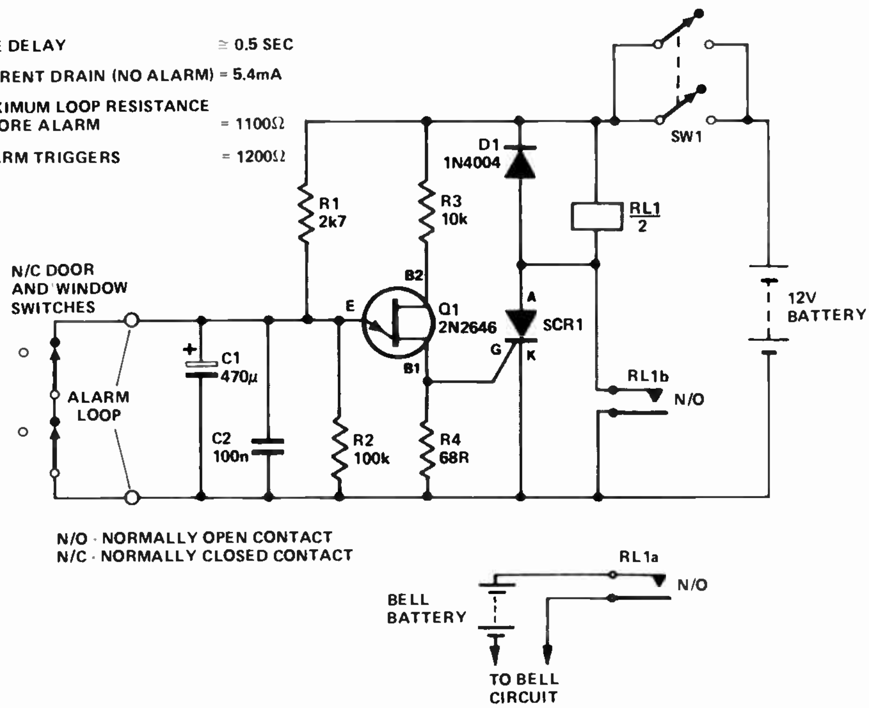
The best magnets are ferritic-ceramic bar types — they're made by many companies and should not be hard to locate. They're usually round or square and sections 25 mm or so long will be fine. These will pull in the switch at a distance of 10-12 mm and will hold it closed at 15-20 mm.

Choose suitable locations and install switches and magnets as shown in the accompanying picture. Before making the final choice of position make sure that the door can open 20-30 mm with- ▶




**External connections to the unit are made via the two plastic screw-terminal blocks.**

TIME DELAY ≃ 0.5 SEC
CURRENT DRAIN (NO ALARM) = 5.4mA
MAXIMUM LOOP RESISTANCE BEFORE ALARM = 1100Ω
ALARM TRIGGERS = 1200Ω




out triggering the switch. One trick that's not immediately obvious is to mount the switch and magnet closer to the hinged side rather than the moving side of the door. Keep the wires leading to and from the switches as far apart as possible. Leave a small amount of slack in the wiring so that building movements will not stress the wiring or connections.

It is worthwhile protecting one or two internal doors — particularly if you have one leading from a garage or carport into the house — but don't overdo the number of protected entry points. Every additional switch increases the probability of false alarms.

The switches should be connected in series using multi-strand wire (14/0076 is about right). Don't use single strand wire — it's more prone to failure if moved. Solder the wires to the switches using *non-corrosive* solder and clean off any residual flux with detergent and clean water. When all switches are installed and connected, check the overall resistance around the loop with a multimeter. The total should not exceed 20 ohms — preferably less.

If all is OK, paint over the solder points and any bare wire with bituminous paint — or smear well with Vaseline. This may seem technical overkill but it's surprising what pollution can do to wire left bare for several years.

## The unit itself

The alarm unit should ideally be battery powered and draw little current. It should be capable of accommodating *some* resistance in the external signal loop but must *not* accept more than two hundred ohms before triggering. And that's where so many amateur and magazine-designed alarms go wrong, for in the quest for low current consumption designers plump for a high impedance input. Figure 2 shows what can happen if the woodwork around the

### HOW IT WORKS — ETI 250

Resistors R1, R2 and R3, capacitor C1 and the unijunction transistor Q1 form a basic pulse generator. With the external alarm loop 'open', C1 charges via R1 until the voltage across it reaches about half the applied battery voltage. When this level is reached the unijunction 'fires' — C1's charge being dissipated via R2. This action causes a positive-going pulse to appear across R2, the pulse in turn causing the SCR to conduct.

An SCR once conducting will remain so even though the triggering signal is removed, provided the anode-cathode voltage remains steady. The SCR is thus 'latched on' and energises the double-pole relay RL. The instant the relay is energised contacts RLb connect the relay directly across the battery supply, 'latching' the relay on. The relay will now stay latched even if the entire circuitry — both internal and external — subsequently fails.

Diode D1 protects the SCR against voltage transients generated by the relay coil.

In use, the external alarm loop shorts out C1, and whilst voltage spikes may well appear across C1, they will not charge the capacitor sufficiently to raise the voltage level to the firing potential of the UJT's emitter — B1 junction.

The time taken for the circuit to respond following an alarm signal is determined by the combination of R1 and C1. Do not *reduce* the value of C1 nor substantially *increase* the value of R1. Capacitor C1 may be increased by a desired amount if a longer time delay is required.

### PARTS LIST — ETI 250

**Resistors** all ¼W, 5%

| | |
|---|---|
| R1 | 2k7 |
| R2 | 100k |
| R3 | 10k |
| R4 | 68R |

**Capacitors**

| | |
|---|---|
| C1 | 470u16 V electro |
| C2 | 100n greencap |

**Semiconductors**

| | |
|---|---|
| Q1 | 2N2646 UJT |
| SCR1 | C106D SCR |
| D1 | 1N4004 or similar |

**Miscellaneous**

RL1 — cradle relay, 12 V coil with two change-over contacts (Pye, type 265/12/G2V); SW1 — DPST toggle switch; 12 V battery; pc board ETI-250; small box to suit; barrier strip terminals (six-way), plated type; suitable reed switches; magnets etc as per the article.

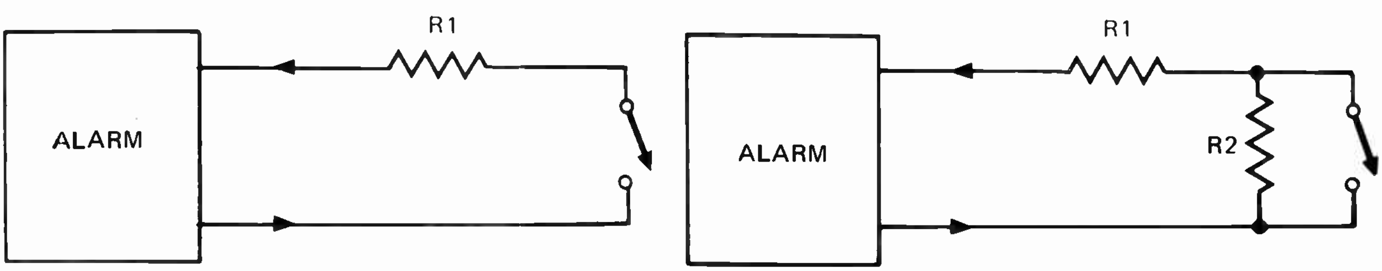
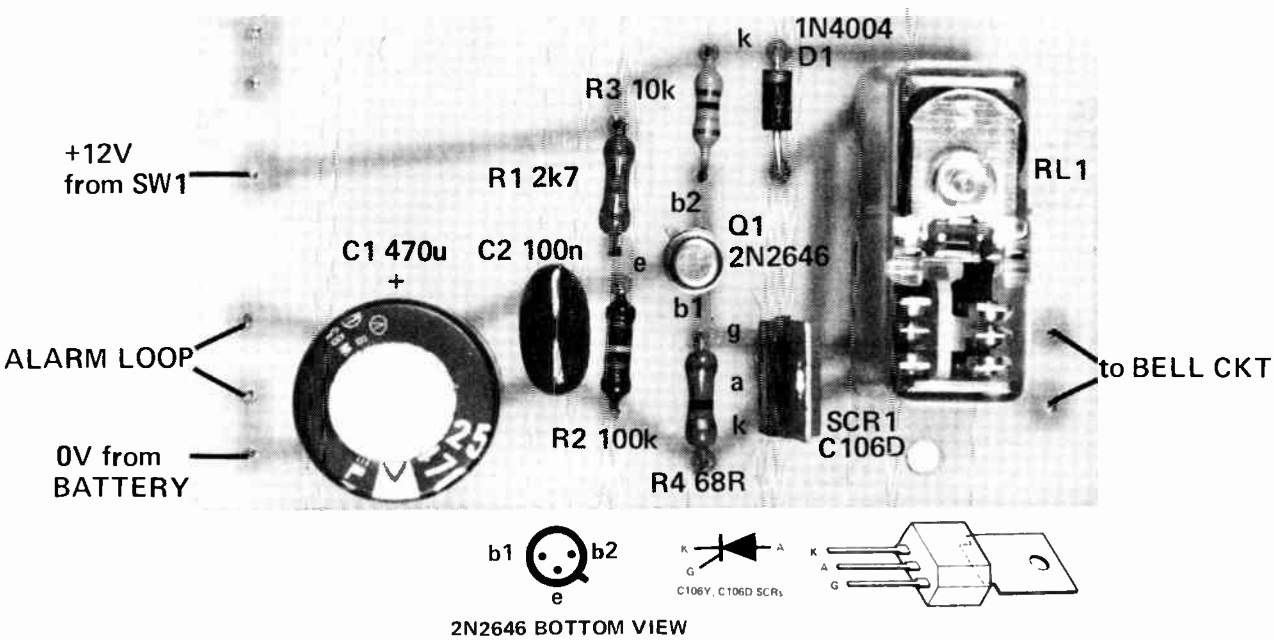



*Figure 2.* Resistance R1 represents series resistance of the loop (see text). Resistance R2 represents leakage paths across alarm contacts.




switches gets moist — a leakage path may develop in parallel with the switch (that's why you keep those leads apart) and if this happens when the control unit can tolerate more than a few hundred ohms, that switch can be opened *without triggering the alarm* !

The alarm unit must be insensitive to voltage spikes picked up by the external loop — remember that's quite an antenna you'll have there. Such voltages can be surprisingly high and are caused by lightning strikes, arc welders, faulty fluorescent lighting starters, capacitor start motors (often found in 'fridges and freezers), contactors, etc. Existing alarms can be protected to some extent by connecting two capacitors (in parallel) across the input terminals. One should be about 10 uF, the other about 10n. Figure 3 shows how — and why you need the two.

A good test for voltage spike immunity is to wind fifty to a hundred metres of wire around a power drill. Connect the two ends to the input of the alarm unit and switch the drill on and off about fifty times. If the alarm isn't triggered by this it's a fair bet it will be satisfactory when installed. Very few alarm control units will withstand this test and those that don't will sooner or later cause problems.

Don't for a moment consider any alarm unit in which the external loop is connected directly to the gate of an SCR. It is *impossible* to protect such a circuit if the external loop is more than a few centimetres long. Yet, incredibly, such circuits are shown time and again in electronics magazines — presumably because at first sight an SCR is (almost) a single component control unit.

Likewise, don't connect a bell or siren directly to the anode of an SCR. Voltage spikes induced in the wiring to and from the bell can and will trigger the SCR into conduction. If you have such a device at present, modify it by interposing a relay between the SCR and the bell circuit — and connect a diode across the relay coil to protect the SCR against the relay's collapsing magnetic field.

The circuit of the ETI-250 alarm con-▶

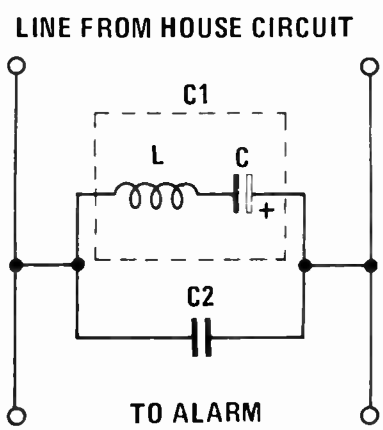
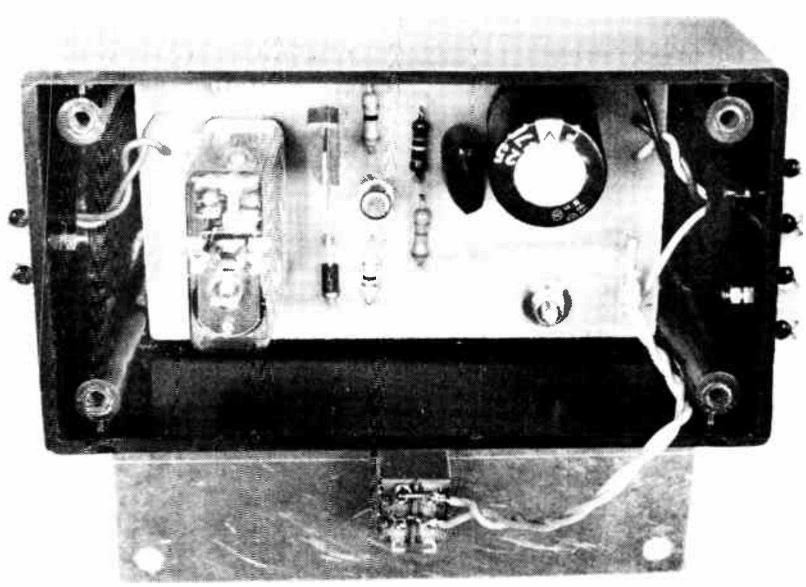
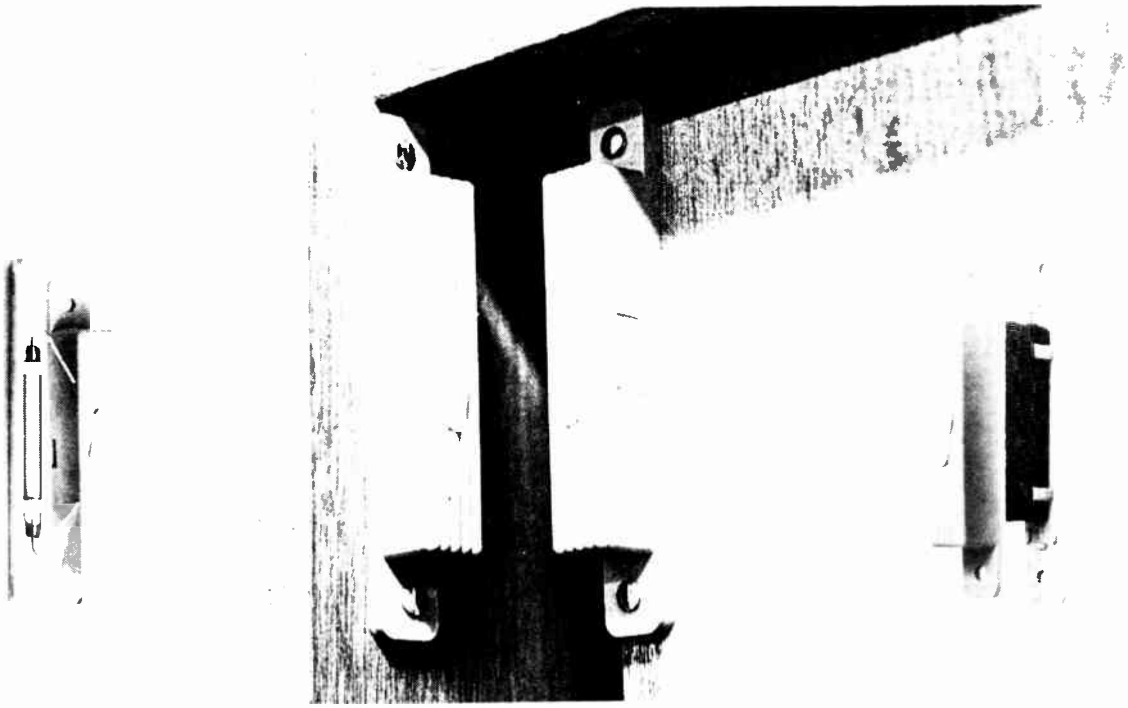



*Figure 3.* **The large value capacitor, C1, will effectively bypass low frequency interference but its high series inductance, L, will prevent the bypassing of high frequency interference. A smaller value capacitor, C2, usually a ceramic type with a low series inductance, will bypass the high frequencies effectively.**



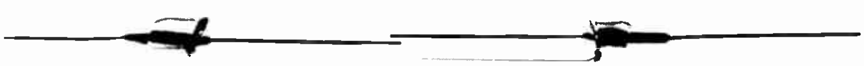


**Reed switches and magnets for burglar alarm systems are designed for easy installation.**

trol unit is shown in the accompanying diagram. It's essentially a simple circuit but one in which several components perform more than one function. The basic idea is that a unijunction pulse generator is normally prevented from operating by the closed external alarm loop. When the loop opens, the unijunction 'fires', causing an SCR to conduct and latch on, which in turn actuates the alarm relay.

The best way to construct the control unit is to use the printed circuit board shown (full size) on page 121. Make sure that C1 is inserted the right way round and that all joints are very carefully soldered. Clean off any residual flux after soldering.

Resistor R1 controls the length of time between a switch being opened and the alarm being triggered. The value shown will trigger the circuit after approximately ¾ sec. Altering values to reduce the triggering delay will increase battery drain. The delay enables doors to rattle in a gale without triggering the alarm accidentally (it is impossible to open a door, pass through and close it again in less than one second).



**A magnetic reed switch.**

Don't be tempted into replacing R1 by a potentiometer — it will rarely be moved once the alarm is installed, so that corrosion will eventually build up between the wiper and the track.

Keep the leads from the alarm unit to the battery as short as possible — 300 mm at most. Preferably build the battery in with the unit as we've shown. Use a *second* battery to power the alarm bell.

Do not delete the relay and run the bell straight off the SCR. *It will work*, but with reduced reliability and increased susceptibility to false alarms.

The alarm unit draws very little current, so batteries will normally last for nine to twelve months. It is advisable however to replace them routinely every six months. It's not worth building a mains power supply. You'll need an automatic mains/battery changeover unit to cater for mains failures — so you'll have to have a battery anyway. The best power sources for this application are six volt 'lantern' batteries. Use proper soldered terminal lugs on the ends of the battery leads.

It is worth considering powering the *bell* from a small Nicad battery with an automatic charger. This is also an elegant way of ensuring that the bell cuts out after an hour or two when the Nicad has exhausted itself.

Arrange for a key operated switch to short out the alarm switch on a chosen 'silent entry' door. Suitable switches may be obtained from security equipment companies. The associated wiring should be concealed.

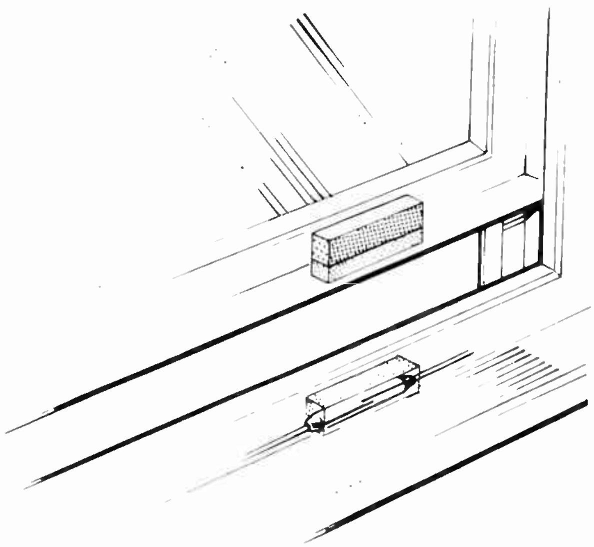
The main on/off switch on the unit itself should be double-pole single-throw with the contacts wired in parallel (to enhance reliability). Do not attempt to economise by fitting a cheap switch.

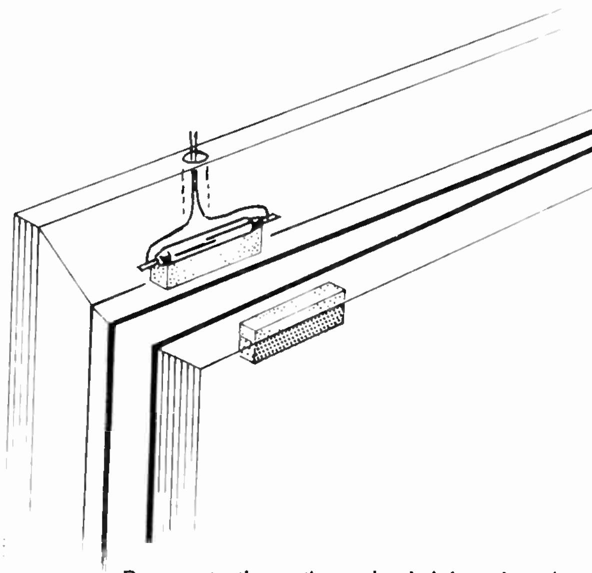
If you wish to further increase reliability you could duplicate the entire system, but as long as the unit and external wiring is put together carefully the chance of failure is almost negligible anyway.

## Scaring them off

Good quality electro-mechanical bells are still the best form of audible alarm for household protection. Being mechanically resonant they make a very large amount of noise and consume little power whilst doing so. The average 12 inch bell (it's an old-fashioned industry and they still think in inches) draws less than half an amp and can be heard at least a hundred metres away.

For window protection, the reed switch is recessed into the frame of the casement window. The magnet is set into the moving part.





Door protection -- the reed switch is set into the architrave.

A siren has a potentially larger range but is more directional. Good ones draw a lot of power — five to ten amps or more. Small cheap sirens should not be considered. The alarm bell should be mounted unobtrusively, and high up in an inaccessible position. Leads to the bell should be totally concealed. Use 40/0076 wire to reduce voltage drop.

It is worth locating one or two spotlights in strategic positions and arranging for these to be switched on as the alarm is actuated.

Finally, don't be put off by stories about people ignoring alarm bells — burglars don't!

## Should you tell

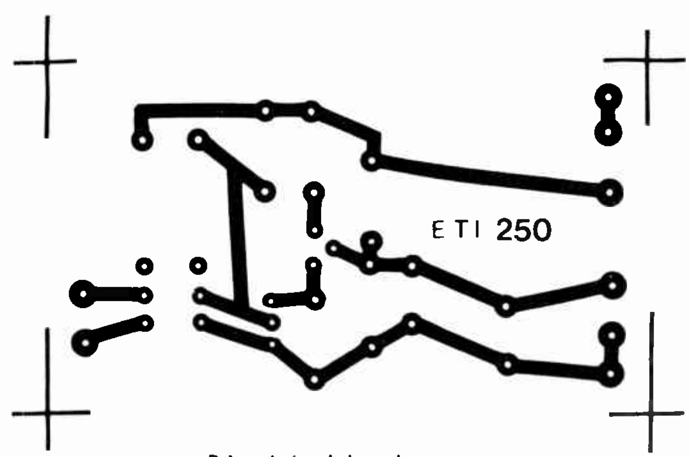
Providing you have a good installation and a concealed bell there's a lot to be said for making it clear to intending intruders that the premises *are* protected.

One way of doing so is simply to place warning notices in strategically chosen windows. This is done by most professional security companies — to such effect that there's quite a strong argument for using just notices alone!

We've included a suitable warning notice (extra copies printed on heavier paper can be obtained for 50 cents each plus a large, stamped, addressed envelope — address to write to is Electronics Today International, 15 Boundary Street, Rushcutters Bay, 2011).

A further very worthwhile tactic is to install a circuit which flashes red LEDs set into the frames of all visible windows and doors. The old 555 will do nicely, or those new-fangled self-flashing LEDs. Combine these with the printed notices plus the alarm circuit, just in case anyone thinks you're bluffing, and your chances of being robbed are negligible.

One final note: no matter how good the installation, it's *useless* unless you switch it on. ●

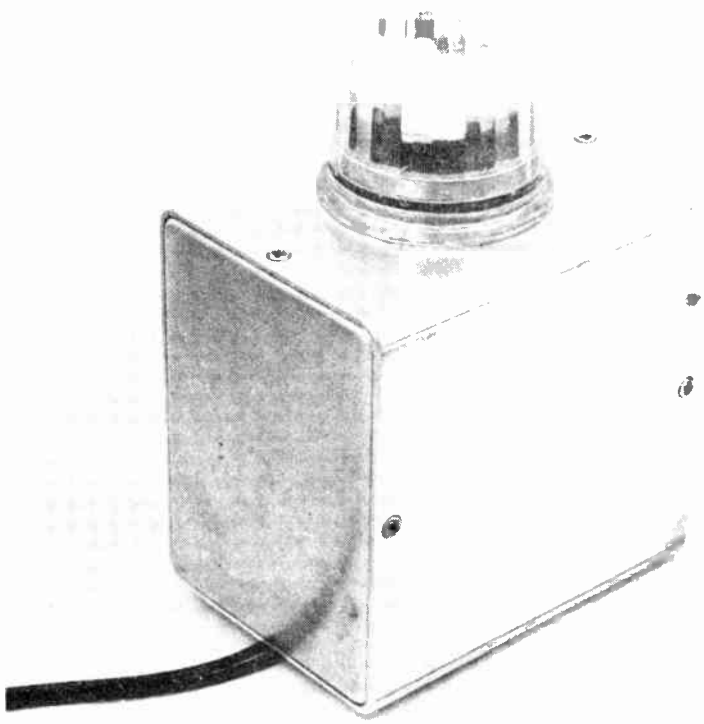



Printed circuit board pattern.

**THESE PREMISES**
**PROTECTED BY**
**E.T.I. SECURITY ALARM**
**SYDNEY, AUSTRALIA. eti 250**

# Masthead Strobe

Improve your visibility with this project.



TO A YACHTSMAN, one of the greatest fears of either a long ocean passage or negotiating busy coastal waters is being hit by another, and probably much bigger ship at night. A large fast ship on computer steerage could pass over the top of a small craft without knowing it.

Conventional masthead lights are barely adequate, being typically 5 to 25 watts, and almost useless in a storm or fog. As the wattage of the light is increased the current drawn from the ship's limited battery capacity becomes prohibitive. The answer is to use a xenon flash tube giving an intense white flash about every two seconds. Equivalent to many thousands of watts, the flash can be seen for large distances, even in bad conditions. The average power of this beacon is only about 1.5 watts, similar to a torch bulb. The unit can be permanently mounted on the mast or kept portable for emergency use.

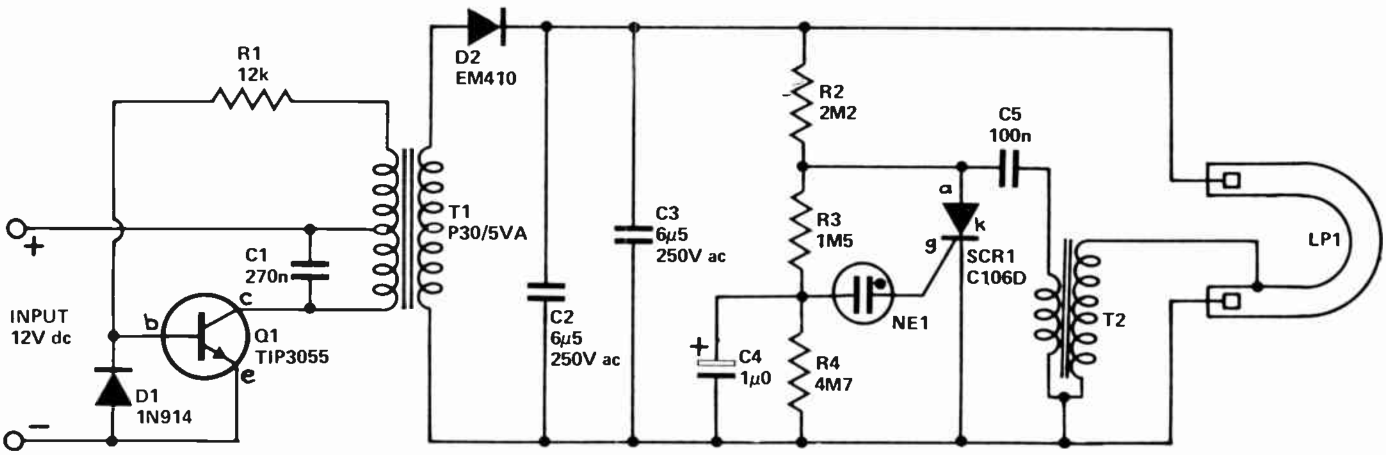
## Construction

The assembled pcb together with the two storage capacitors are mounted in a Horwood Instrument case type 34/4/D. Styrofoam is used to hold the pcb in position to avoid having to drill extra holes in the case. The transformer used is a commonly available Ferguson type PL30/5VA, which mounts directly onto the pcb.

The storage capacitors used are designed for operation in fluorescent lights and are rated at 240 Vac. These capacitors which can withstand a high

**SPECIFICATION PROTOTYPE - ETI 558**

| | |
|---|---|
| Voltage | 11 - 15 volts |
| Light output | 1 watt per sec |
| Flash rate | Approx. 1 every 2 sec |
| Supply Current | 80 mA average |



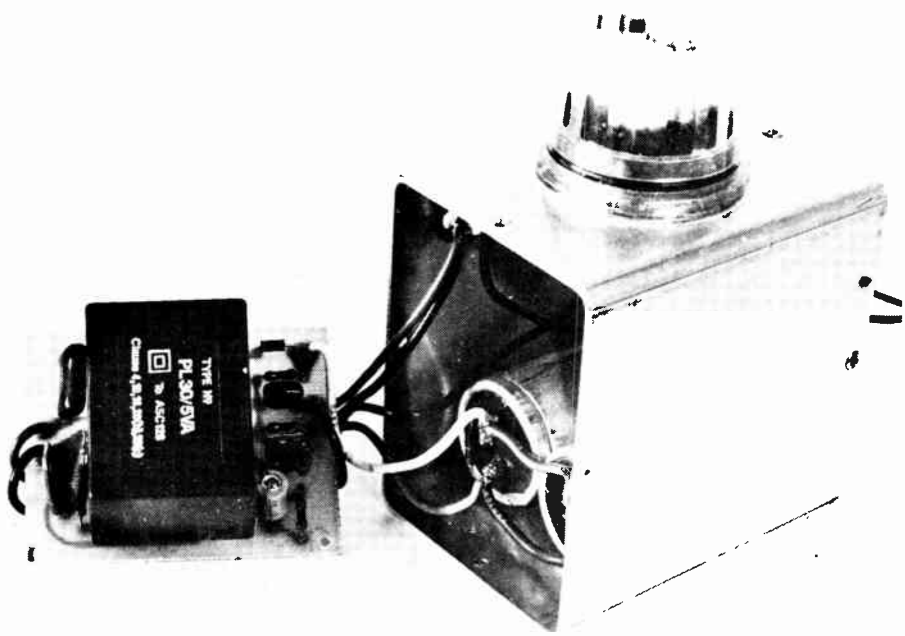

dc voltage, are suitable for use in fast discharge applications and are available in a variety of values from any electrical supplier or from Dick Smith Electronics.

Special attention must be paid to the light housing if the unit is to be left out in the open in all weathers. We purchased an easily available Hilite Marine masthead light from a local marine shop.

The tungsten light and its socket were removed and the strobe tube together with its trigger transformer were fixed into the base of the fitting with Silastic rubber. This light fitting has a lens which focusses the light, and a rubber 'O' ring which should be covered with silicon grease to prevent moisture penetration. If the beacon will not be left out in all weathers a cheaper automotive light fitting could be used.

To ensure long life from the strobe tube we used a 10 watt per sec. tube run at only a fraction of its full output. The tube we used was a CZT127 available together with a trigger transformer from *Circuit Components, 383 Forest Rd, Bexley, NSW.*

Finally the ends of the box and the light fitting were fixed into position with copious amounts of Silastic rubber to prevent moisture penetration. The battery lead should be taken out through a hole in the bottom of the box which also allows drainage if any water manages to get in.



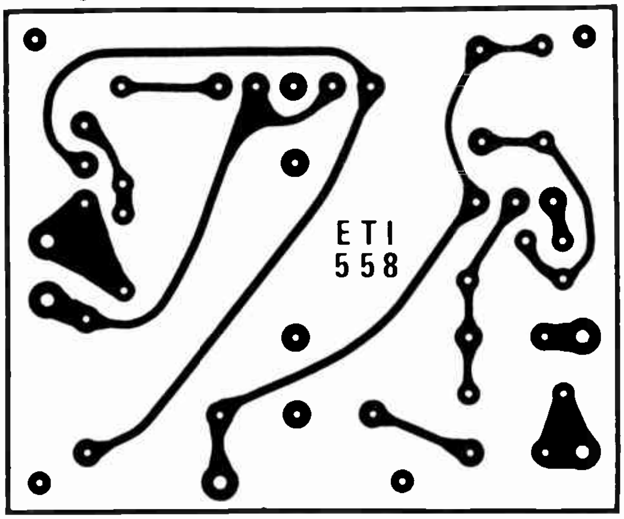

## HOW IT WORKS – ETI 558

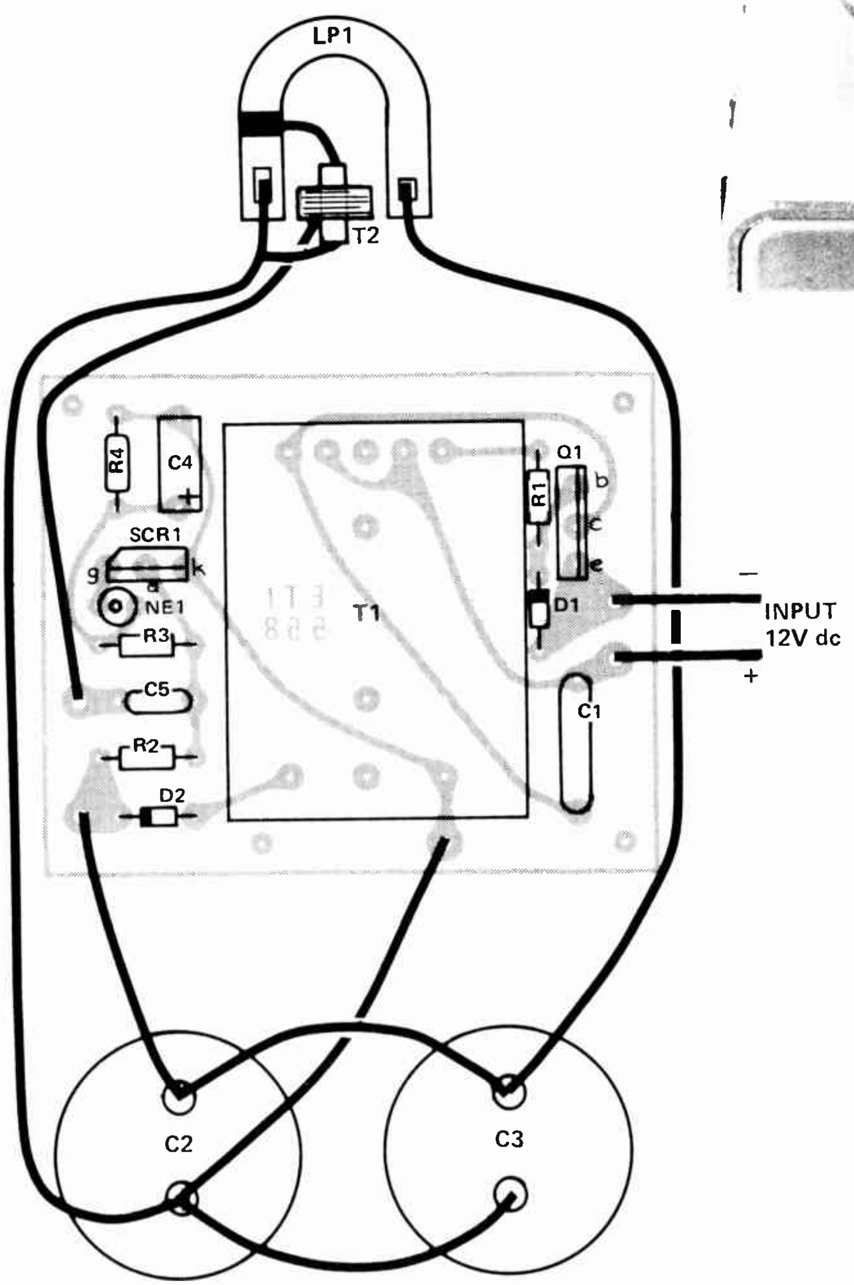
The power transistor Q1, together with the transformer, T1, form a oscillator with a frequency of about 1kHz. Feedback is provided by one half of a centre tapped 30 volt winding. The output is taken from the normal 240 volt primary winding of the transformer. The amount of feedback and hence the output voltage is set by R1.

Output from the transformer is rectified by D2 and then charges the storage capacitors C2 and C3. The value of R1 should be selected to give a peak voltage across the storage capacitors of about 350 - 400 volts.

As the voltage across the storage capacitors builds up the trigger capacitor, C5, charges through R2 and the primary of the trigger transformer, T2. The timing capacitor, C4, is also charged through R2 and R3 until the voltage across the neon, NE1, reaches about 120 volts, when the neon fires, dumping the charge from C4 into the gate of SCR1. This fires SCR1 which then discharges C5 through the primary of the trigger transformer, producing a high voltage pulse to initiate the discharge of C2, 3 through the strobe tube.

The storage capacitors are then recharged and the process repeated for the next flash.




## PARTS LIST – ETI 558

**Resistors** all ¼W, 5%
R1 . . . . . 12k
R2 . . . . . 2M2
R3 . . . . . 1M5
R4 . . . . . 4M7

**Capacitors**
C1. . . . . . 270n greencap
C2, 3 . . . . 6µ5 250 Vac (see text)
C4. . . . . . 1µ0 350 V electrolytic
C5. . . . . . 100n 400V polyester

**Semiconductors**
Q1 . . . . . MJ3055
SCR1 . . . . C106D
D1 . . . . . 1N914
D2 . . . . . EM410

**Miscellaneous**
T1. . . . . . Ferguson P30/5VA transformer
T2. . . . . . trigger transformer to suit strobe tube
NE1. . . . . NE2 neon
Strobe tube see text
Horwood box type 34/4/D, light fitting (see text), pcb ETI 558, Silastic adhesive/sealant.

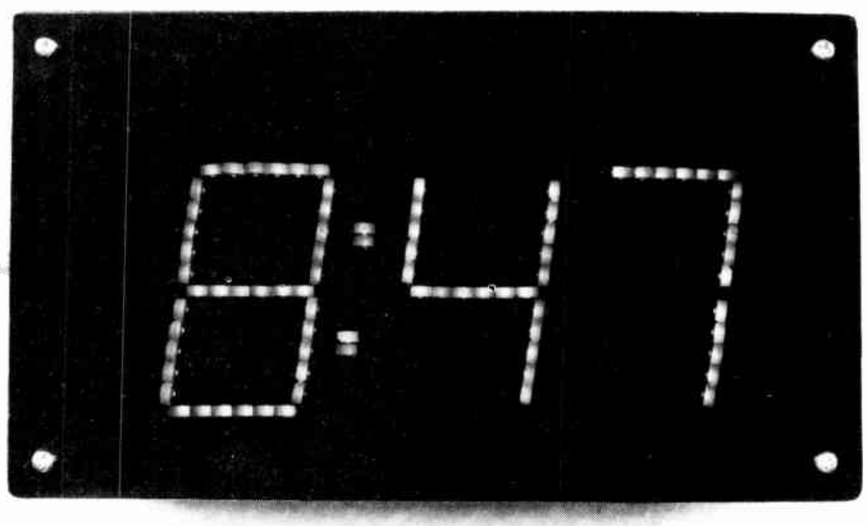
# Digital clock features huge display

Here's just the thing for the kitchen, workshop, garage or shack — anywhere in fact, you need a digital clock that just can't be missed!

**Barry Wilkinson**

ISN'T IT just what you've always wanted — a digital clock with a decent sized display? Seeing the time at a glance is convenient in many situations and that's just what this clock has been designed for. The display features three seven-segment digits for the 'minutes units', 'minutes tens' and 'hours units' plus a single column '1' for the 'hours tens' displays. Each segment in the individual displays is made up of a string of LEDs connected in series. Each vertical segment contains five individual LEDs, while each horizontal segment contains six. Overall height of the display is around 60 mm.

We used rectangular LEDs as they provided by far the best looking display compared to the more familiar round LEDs. Suitable rectangular LEDs are made by a number of manufacturers and are readily available through a variety of suppliers. A 'flashing colon' between the hours and minutes digits is provided to reassure you that the clock is going! However, as a binary divider clocking from the mains is used to drive the clock, a one-second output is unfortunately not available and so the next best output was chosen. This proved to be a division of 32 and thus, from 50 Hz, a pulse every 1.56 seconds is obtained and this is used to flash the colon.



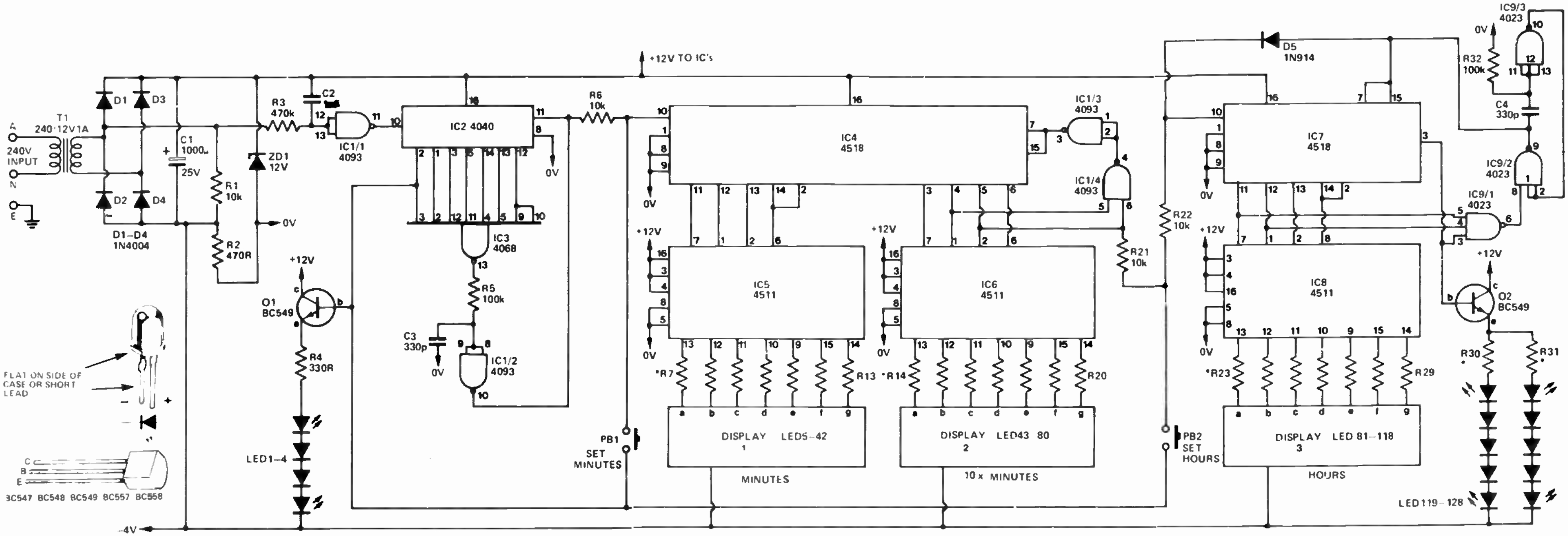
## Design

There are a number of interesting aspects to the design of this digital clock. For a start, conventional CMOS binary dividers have been used in preference to one of the special clock divider chips. The latter are very handy, no doubt about that, but they are incapable of driving a large sized display like the one used here. Firstly, the voltage drop across each segment of the multi-LED display varies depending on the type and colour of LED used. Whilst we have used red LEDs, which have a voltage drop of around 1.6 V each, red or yellow LEDs may be used and these have around a 2.1 V drop each. The Philips rectangular LEDs type CQX10-2 are red but have a voltage drop of 2.1 V too while some of the new 'high efficiency' LEDs also exhibit a 2.1 V drop. This means that, for a horizontal segment in our display the maximum voltage drop may be as high as 12.6 V (six LEDs times 2.1 V). The clock chips available cannot readily cope with this but CMOS decoders can be arranged to do what we want.

You will notice from the circuit that the LED segments are driven by 4511 CMOS decoders which provide up to 25 mA per segment, with the actual current being determined by current limiting resistors. The current per segment in our circuit is limited to around 20 mA. However, the maximum voltage across CMOS is limited to 15 volts and a supply of around 18 volts was necessary to allow for the drop across the display segment plus the drop across the limiting resistor and the 1.5 V lost in the 4511 output circuit. To overcome this difficulty, we stabilised the negative supply rail for the CMOS to 12 volts and the negative side of all the display segments is taken to the *unregulated* negative supply. The zener action of the LEDs (i.e: there is no current flow below about 1.4 volts per LED) the outputs of the 4511s are never 'pulled' below their negative supply rail.

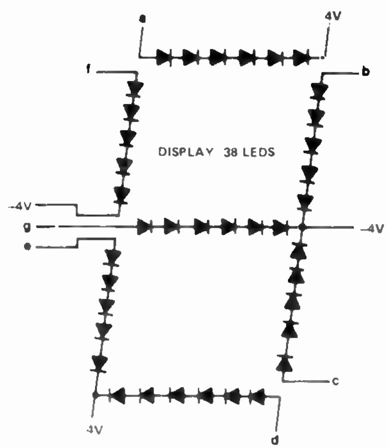
To obtain a 'clean' 50 Hz square wave for accurate clocking, the ac input (taken from the power transformer) is 'squared-up' by a 4093 two-input NAND gate. This device is similar to the 4011 except that it has Schmitt trigger inputs and this helps to prevent false triggering. ▶

# Project 564 — digital clock




*FOR VALUES OF R7 – R20, R23 – R31, SEE TABLE

NOTE: rectangular LEDs have one lead longer than the other. The longest lead is the anode.




A total of 38 LEDs are used in each seven-segment display. Each of the vertical segments uses five LEDs, while the horizontal segments use six.

## HOW IT WORKS ETI-564

The power supply is simply a 12 V output transformer, full-wave rectified and filtered by C1. The IC supply is stabilised by ZD1 to 12 volts. For timing, the ac voltage is coupled to the input of IC1/1 via R3, with C2 providing some filtering to prevent false counting. The value of R3 protects IC1/1 against input damage as the ac voltage exceeds the supply rails of the ICs. IC1 is a 4093, which is a two-input NAND gate, similar to the 4011, except that it has Schmitt trigger inputs, and this helps to prevent false triggering with the output of IC1/1 being a clean 50 Hz square wave.

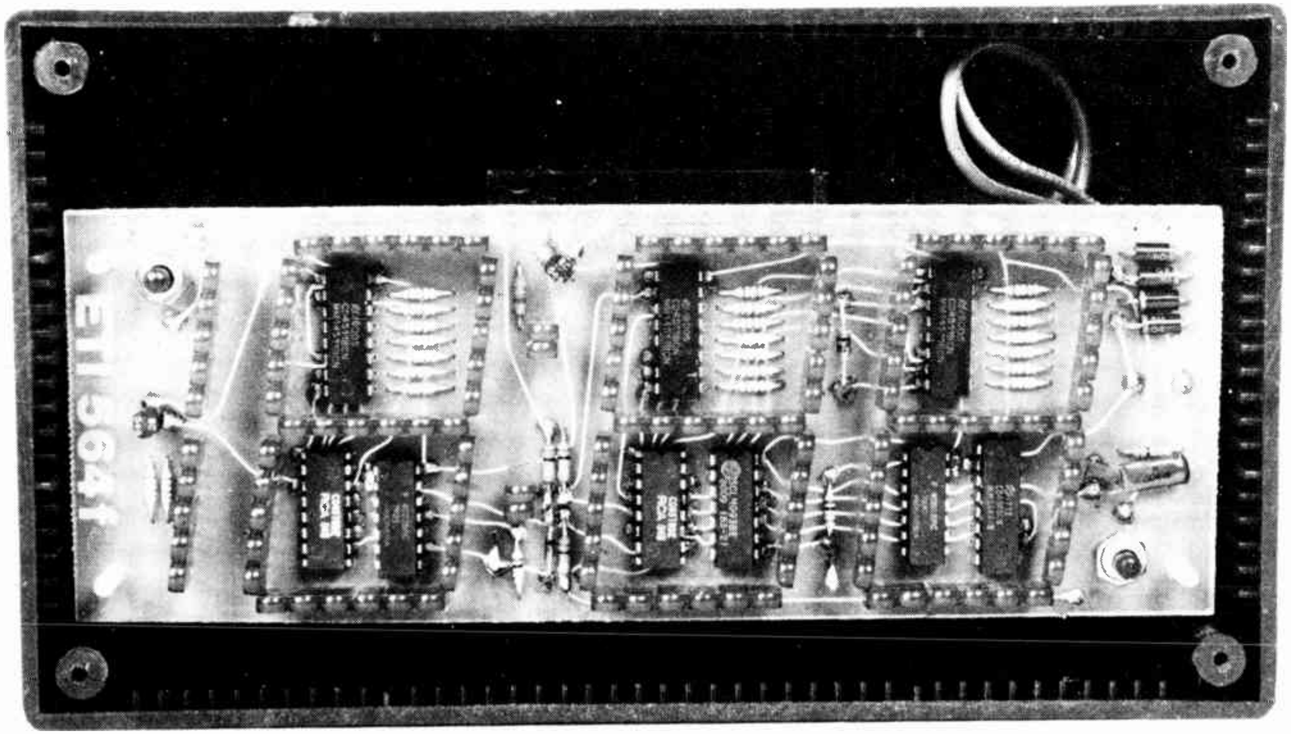
As the first digit is the minutes display, a division of 3000 is needed. For this IC2, 3 and IC1/2 are used. IC2 is a 4040 which is a 12-stage binary divider. The outputs of the 4th, 5th, 6th, 8th, 9th, 10th and 12th stages are decoded (when all are high ) and the counter reset at that time to provide a division ratio of 3000 (binary 101110111000). This is detected by IC3 whose output goes low on that number. After a short delay (about 30 us) due to R5/C3 the output of IC1/2 will go high, resetting IC2. This immediately causes the output of IC3 to go low but, again due to R5/C3, the output of IC1/2 will remain high for about 20 us, ensuring correct resetting and the clocking of the minutes counter.

An output of IC2 (pin 2) is used to drive the colon and to provide the clock for the fast set modes. Unfortunately, exactly one second is not available using a binary divider so we chose the 1.56 second (50/32) output.

The output of IC1/2 (a 20 us pulse once per minute) clocks IC4 which is a dual decade (10) counter. The first half is used as a ÷10 and its output is decoded by IC5 to give the minutes display. The second half is clocked by the output of the first (10 minutes) and is decoded by IC6 to display the tens of minutes. As time has yet to be decimalised (!), we have to reduce the second half from ÷10 to ÷6. This is done by IC1/4 which detects when the 2nd and 3rd outputs are high (binary 0110) and resets it to zero.

The third output is used to clock the hours counter, IC7. This, like IC4, is a dual decade counter with the first half being decoded by IC8 and the second being clocked by the output of the first. As only a simple "1" is needed for the tens of hours (12 hour clock) no decoder is necessary, only a buffering transistor. IC9 is used to decode when IC7 reaches decimal 13 (0001 0011 binary) and this triggers a monostable formed by IC8/2,3. This is used to reset IC7 to zero hours, but, as there is no zero hour in the 12 hour system we need a reset to "1". This is done by the diode D5, which pulls pin 10 high for the duration of the reset pulse and allows it to fall back again — a few microseconds (delayed by stray capacitance) after the reset pulse, clocking it on to 1.

Fast setting is done simply by injecting, by the use of push buttons, the 1.5 second pulse directly into the minutes or hours counters.



## PARTS LIST — ETI-564

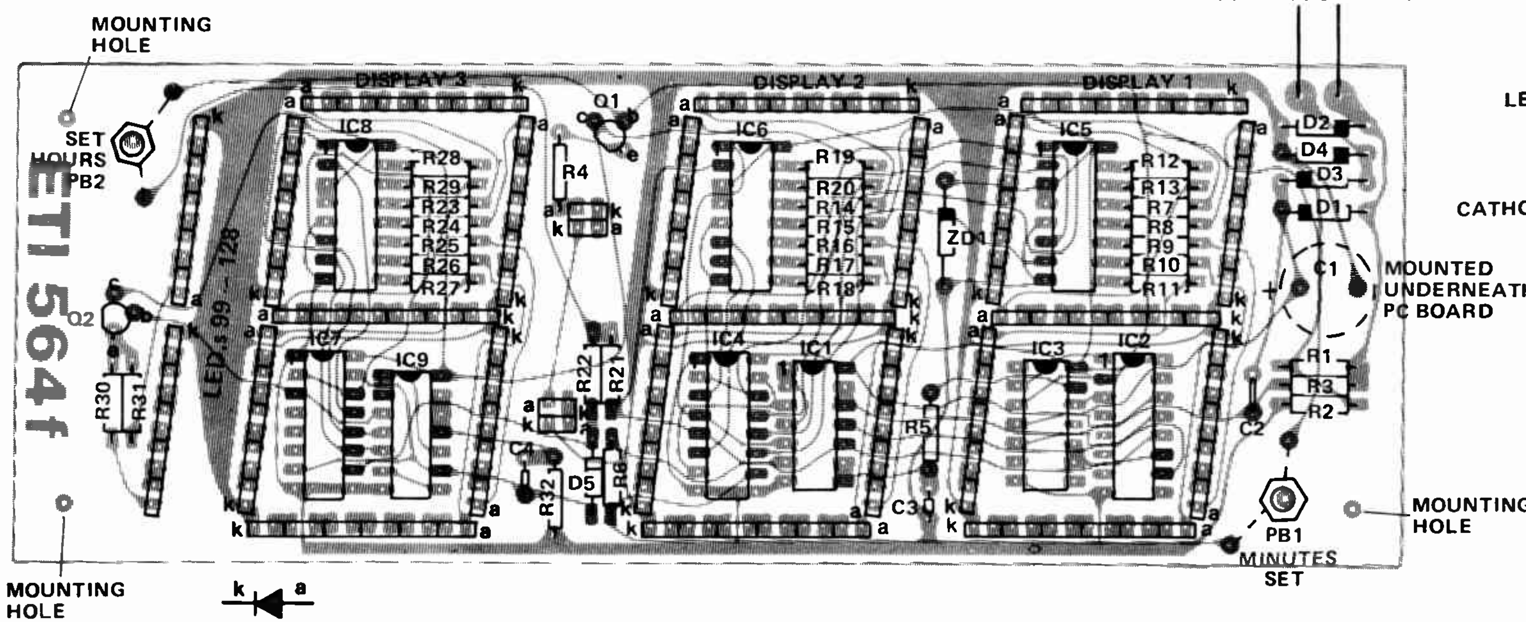
**Resistors** all ¼W, 5%
R1,R6,R21,R22 .... 10k
R2 .............. 470R
R3 .............. 470k
R4 .............. 330R
R5, R32 .......... 100k
R7 - R20 ......... see Table 1
R23 - R31 ........ see Table 1

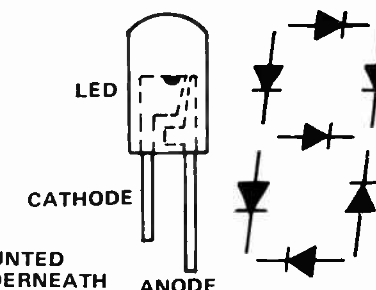
**Capacitors**
C1 .............. 1000u, 25 V pc electro
C2 .............. 4n7 polyester
C3 C4 ........... 330p ceramic

**Semiconductors**
IC1 .............. 4093
IC2 .............. 4040
IC3 .............. 4068
IC5, 6, 8 .......... 4511
IC9 .............. 4023
Q1, Q2 ........... BC549
D1-D4 ........... 1N4004
D5 .............. 1N914
ZD1 .................................. 12 V, 400 mW zener
LED1-128 .............................. LEDs (see text)

**Miscellaneous**
Two push-button switches; transformer 240 V to 12 V at 1 A; sheet of polarised plastic; pc board ETI-564, case to suit; nuts, bolts etc.

The printed circuit board patterns are on page 152.




**Overlay diagram, looking from the components side. Note that this is a double-sided pc board.**

To derive a 'minutes' output, the 50 Hz mains frequency is divided by 3000. To perform this division a 4040 12-stage binary counter is used. As this provides a total division ratio of 1:4096 ($2^{12}$ = 4096) the counter has to be reset once it reaches the 3000th count. To do this we detect when the outputs of stages 4, 5, 6, 8, 9, 10 and 12 are all high and provide a reset pulse.

To derive the 'hours' output, a dual decade counter is used. This is IC4. One half is used just to divide by 10 while the other half is arranged to be reset before completing its count to provide a further division of six, resulting in a total division of 60. A decoder on the ÷10 stage provides the 'minutes units' display while a decoder on the ÷6 stage provides the 'minutes tens' display.

The output from the tens-of-minutes divider (second half of IC4) is divided by six in the same way as just described to provide the 'hours units' output and this is followed by decade counter to provide the 'hours tens' output. These divisions are provided by IC7 which is reset to '1' when it reaches a count of '13'.

The hours units display is derived by a decoder from the first half of IC7 as for the other digits, but the 'hours tens' is only ever a '1', provided by a row of 12 LEDs. A buffer transistor drives this display.

## Construction

We found it necessary to use a double-sided printed circuit board for this project to avoid a large, cumbersome board which we feel sure you'd agree would be rather unattractive. To avoid ulcers, premature greying of the hair, muscle tremors and other assorted maladies that may develop from attempting to completely handwire this project, we suggest you obtain a printed circuit board as specified.

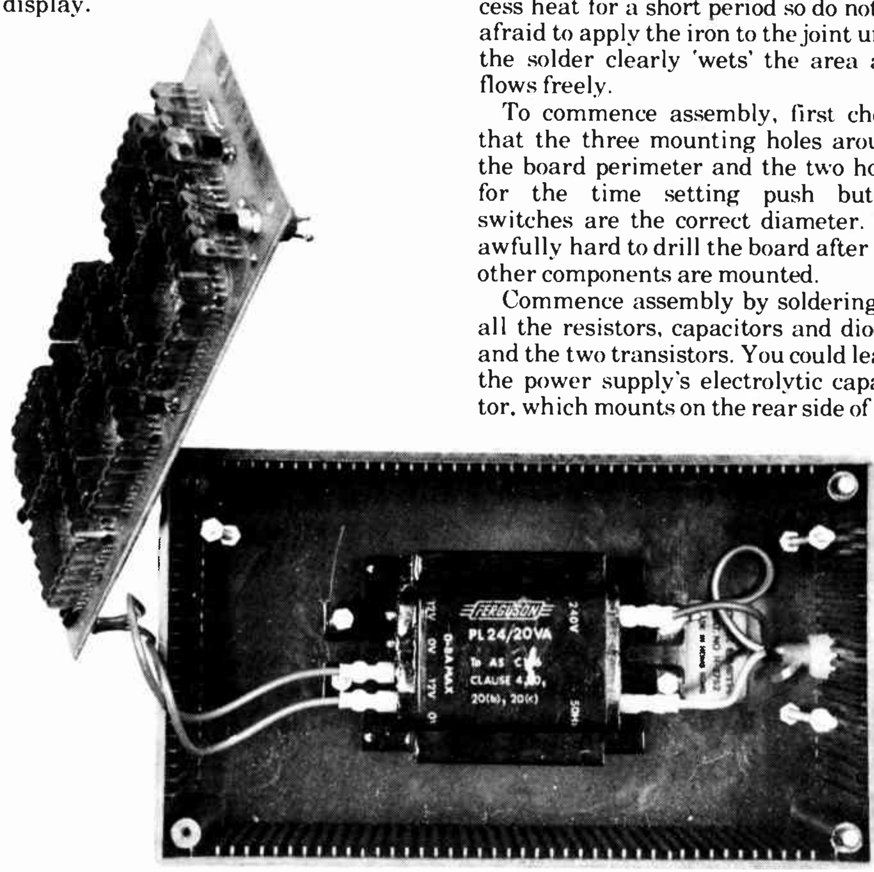
The board used in our prototype did not use plated-through holes as it is not really necessary. However, there are many fine tracks on the board and we recommend you use a soldering iron with quite a small tip. When soldering tracks on the top side of the board where a component lead connects to a corresponding track on the underside of the board, always ensure that you heat the joint sufficiently to get a good flow of solder and avoid a dry joint. From previous experience we find that many constructors tend to be afraid of overheating an IC or other components and do not provide enough heat for a good joint with the result that dry joints occur. These may work initially but often give problems some time after the project is completed and in use. Modern components will readily withstand excess heat for a short period so do not be afraid to apply the iron to the joint until the solder clearly 'wets' the area and flows freely.

To commence assembly, first check that the three mounting holes around the board perimeter and the two holes for the time setting push button switches are the correct diameter. It's awfully hard to drill the board after the other components are mounted.

Commence assembly by soldering in all the resistors, capacitors and diodes and the two transistors. You could leave the power supply's electrolytic capacitor, which mounts on the rear side of the board, until all the other components are assembled if you wish. Take care with the orientation of the diodes, paying particular attention to the component overlay. Note that different value ballast resistors are required, according to the type (and thus the voltage drop) of LEDs chosen. Refer to Table 1 for the appropriate values.

As CMOS ICs are used, take care when inserting them that you handle the devices with due care. Carefully remove them from their packaging, taking care not to handle the pins — pick them up with your thumb and forefinger grasping the ends of the package, not the pins. Make sure you have them correctly oriented before inserting them in the board. Also ensure that you put each IC in its correct place and on the correct side of the board too! Sockets cannot be used for the ICs as many of the pins are soldered on both sides of the board.

With the LEDs used in our prototype (Siemens LD80-2 and Philips CQX10-2) we first taped the groups for each segment together. To do this, lay a group of five or six LEDs down, anodes or cathodes all facing the same way, butt their heads against a straight edge and run a strip of tape first over one side, then the other. This makes assembly much easier. Having done this, insert the LEDs into the board. The LEDs we used have a shoulder or 'step' in their leads a few millimetres from the base. We pushed the LEDs down onto the pc board until this shoulder stopped them going any further. The outside lead of each segment array was soldered and then each group checked for align-



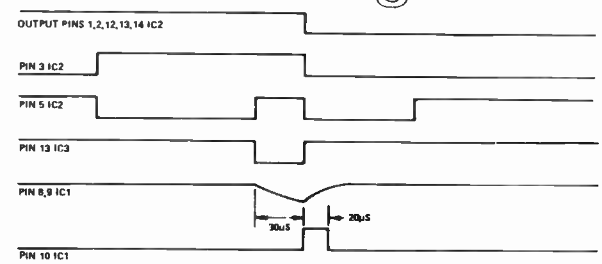

**Inside the clock, showing how we mounted the transformer. Take care with the mains wiring.**

### Setting the time

1. Switch on.
2. Press the minute button (the right hand one) until the minutes display is correct. To prevent multiple pulsing due to contact bounce, the button should be pressed and released when the colon is **OFF.**
3. Set the hours in a similar manner to the minutes (left hand button). If the minutes display is less than 40, again operate the button when the colon is **OFF.** If the minutes display is 40 or more, operate the button when the colon is **ON.**
4. An easy way to set the clock to the *exact* time is to first set it some 20 - 30 seconds fast by the push buttons, then compare it to a known time standard (you might use Telecom or a radio time signal for this). Turn off the power for the exact time *difference* and the clock will cease counting. The large filter capacitor will hold its charge long enough to store the last time, for up to a few minutes, until the power is turned back on. When the time signal equals the clock display, turn the clock on.

**TABLE 1: Value of ballast resistor for the LEDs**

| RESISTOR | 1.6V LEDs | 2.1V LEDs |
|---|---|---|
| R7, 10, 13, 14, 17 | 180R | 150R |
| R20, 23, 26, 29 | 180R | 150R |
| R8, 9, 11, 12, 15, 16 | 270R | 180R |
| R18, 19, 24, 25, 27, 28 | 270R | 180R |
| R30, 31 | 270R | 180R |




Waveforms around IC2 and IC3.

ment before soldering the other leads.

The rectangular LEDs specified measure 2.5 mm wide by 5 mm long. If you elect to use conventional round LEDs, the miniature 3 - 4 mm diameter types should be used. Many of the larger sized round LEDs will not fit this pc board as they have a shoulder around the base of the unit that measures 6 mm diameter, preventing the close packing possible with the other types.

Once you have the LEDs mounted and soldered in place, the two push button switches may be mounted. Short lengths of tinned copper wire are run from the switch lugs to the adjacent pads on the pc board.

At this stage, if you are satisfied everything has been mounted correctly, the board may be tested — *but give it another thorough check first!* In particular, look for solder 'bridges' between IC pins or across closely-spaced tracks as well as possible dry joints.

Simply apply 12 Vac to the two pins marked on the board overlay and see that the clock operates as it should. Try the 'hours set' and 'minutes set' buttons to see that they have the required effect. If all is not well, switch off and re-check the component placement and orientation, check for dry joints, etc.

We mounted our clock in a convenient plastic 'jiffy' box measuring 196 x 113 x 60 mm. The PL12/20VA 'low height' transformer is screwed to the rear of the box. The mains lead enters one side through a cable clamp. The pc board is mounted on three 58 mm long bolts with nuts positioned at a distance from the rear of the case determined by the height of the transformer.

To drill the case, first mark the position of the holes for the pc board mounting bolts. Use the pc board as a template, laying it face down on the outside rear of the case. It's probably best to do this before loading the board. Failing that, measure the position of the holes and accurately mark them on the case. Use the photographs here as a general guide.

The board is not located centrally between the two long sides of the case. The upper edge of the board is located about 30 mm from the top side of the box. Ensure that the board does not foul the inside mounting flutes or pillars. If all is well, drill the holes and check that the board mounts properly.

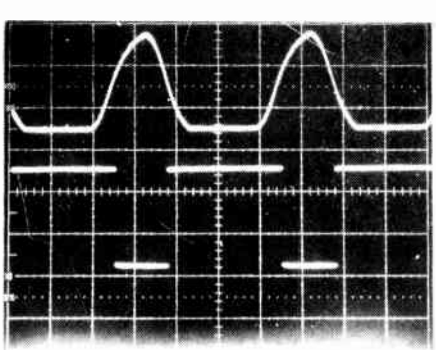
Next, mark the position of the mounting bolts for the transformer, which is located under the board. Drill these and check that the transformer will mount without fouling anything. It should, there's plenty of space. The hole for the mains cable clamp should be located and drilled next.

The front panel may now be tackled. A large rectangular cutout is made in the front panel, just larger than the display. A piece of circularly polarized plastic is cut to the *outer dimensions* of the case, using the case as a template. As we chose red LEDs, we bought a piece of red plastic. For other colour LEDs, use grey. This plastic is available through Polaroid Australia. Lay the case face down on the piece of plastic and scribe around the edge. Remove the case and carefully cut around the scribe mark. Next, place the panel over the piece of plastic and mark where the four panel mounting holes are located, then drill them. Two further holes have to be drilled in the plastic panel to permit access to the time setting push buttons. You're going to have to use a little judgement in locating these, but they don't have to be located all that accurately, just such that a match can be inserted to depress the buttons.

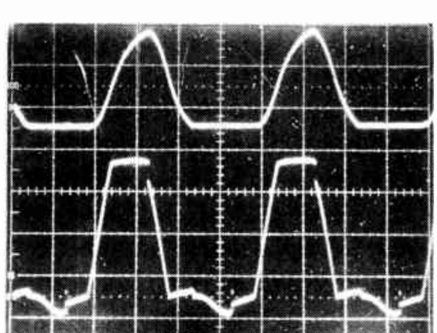
The plastic may now be glued carefully to the panel, or stuck on with double-sided sticky tape. As the clock dissipates some ten watts, ventilation is necessary. The easiest way to provide this is to stack some washers behind the front panel, on the mounting screws, such that the panel stands out from the case about 2 mm.

Now the clock may be finally assembled. Mount the mains transformer and secure the three pc board mounting bolts. Attach the mains cable and clamp then wire up the transformer primary and secondary. An earth lug should be mounted under one of the transformer mounting bolts and the mains cable earth soldered to it. A piece of cardboard, about 80 mm by 50 mm, should be stuck to the top of the transformer with a piece of double-sided tape. This is to insulate the rear of the pc board from the transformer case.

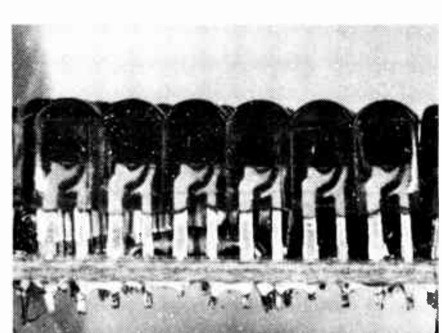
The nuts to locate the rear of the pc board should now be put on the mounting bolts and the pc board carefully secured in position. Make sure the board is held securely without it bending. Mount the front panel, plug in and you're ready to set the time! ●



Waveforms around IC1. At top is the waveform on the input, bottom shows the output.



Top waveform shows the input to IC1/1, lower trace shows the ac input to R3.



How the LEDs were mounted. The 'shoulders' on the leads are butted against the pc board.

# An introduction to lasers

**David Tilbrook**

A fascinating rundown on these devices, the physics of their operation and the various types. This article prefaces a practical construction project which follows immediately.

THE FIRST LASER was built in 1960 by Theodore Maiman, a research scientist working for the Hughes Aircraft Corporation. His research paved the way for the development of a fantastic array of fascinating devices and very useful tools. Today, lasers are used in surveying, geophysical measurements, medical applications, electronic component manufacture, atomic fusion research, precise distance measurement and a host of other applications.

The word laser stands for *light amplification through stimulated emission of radiation*. Whilst this implies that lasers are amplifiers, they are generally configured as oscillators. The light radiation they produce is very 'pure' — occurring at a specific frequency (or frequencies) — and the beam is well collimated, that is, it diverges only a tiny amount rather than spreading as does the beam from a torch or spotlight.

The unique properties of laser light make the laser a prime candidate for wide application in technology and physical measurement. Many different types of laser have been developed but all employ the same basic principle of operation. All lasers have two fundamental components — a 'laser medium' and an energy source. The latter is used to excite the laser medium by a process called *pumping* — but I'll explain that further when I get into the physics behind the laser. First, let's look at the various 'breeds'.

## Solid-state lasers

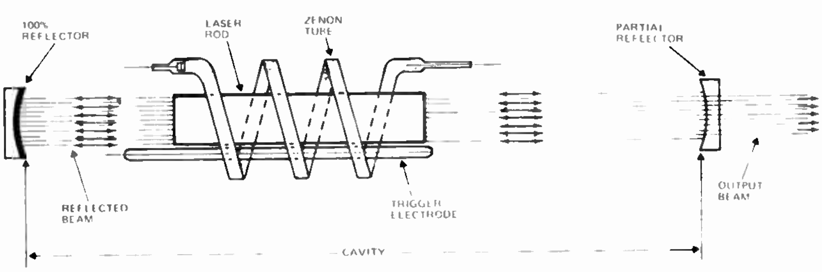
In laser physics, solid-state does not refer to semiconductor lasers but to a breed having a laser medium that is formed by doping a crystalline or glass material with an impurity material which produces the laser action when pumped. The most common of these is the **ruby laser**.

This type of laser consists of a central, cylindrical synthetic ruby crystal made from aluminium oxide as a base material and doped with chromium as the impurity. The crystal is mounted with mirrors at each end and is surrounded by a xenon-filled flash tube (or tubes). These xenon tubes provide optical pumping — a requirement of all solid-state lasers. One of the mirrors is 100% reflective while the other is very slightly transmissive so that a small portion of the laser light produced within the crystal is tapped off.

When the xenon flash tube is fired, laser action occurs within the ruby and laser light travels back and forth down the crystal, exciting further laser action and generating an intense pulse of light that passes through the slightly transmissive mirror.

One of the early problems with solid-state lasers was to achieve a continuous output. In 1962 a solid-state laser was built at Bell Telephone Laboratories. It consisted of the base material calcium tungstate, impregnated with neodymium. More recently, solid-state lasers have been built with continuous outputs of over 1000 watts.

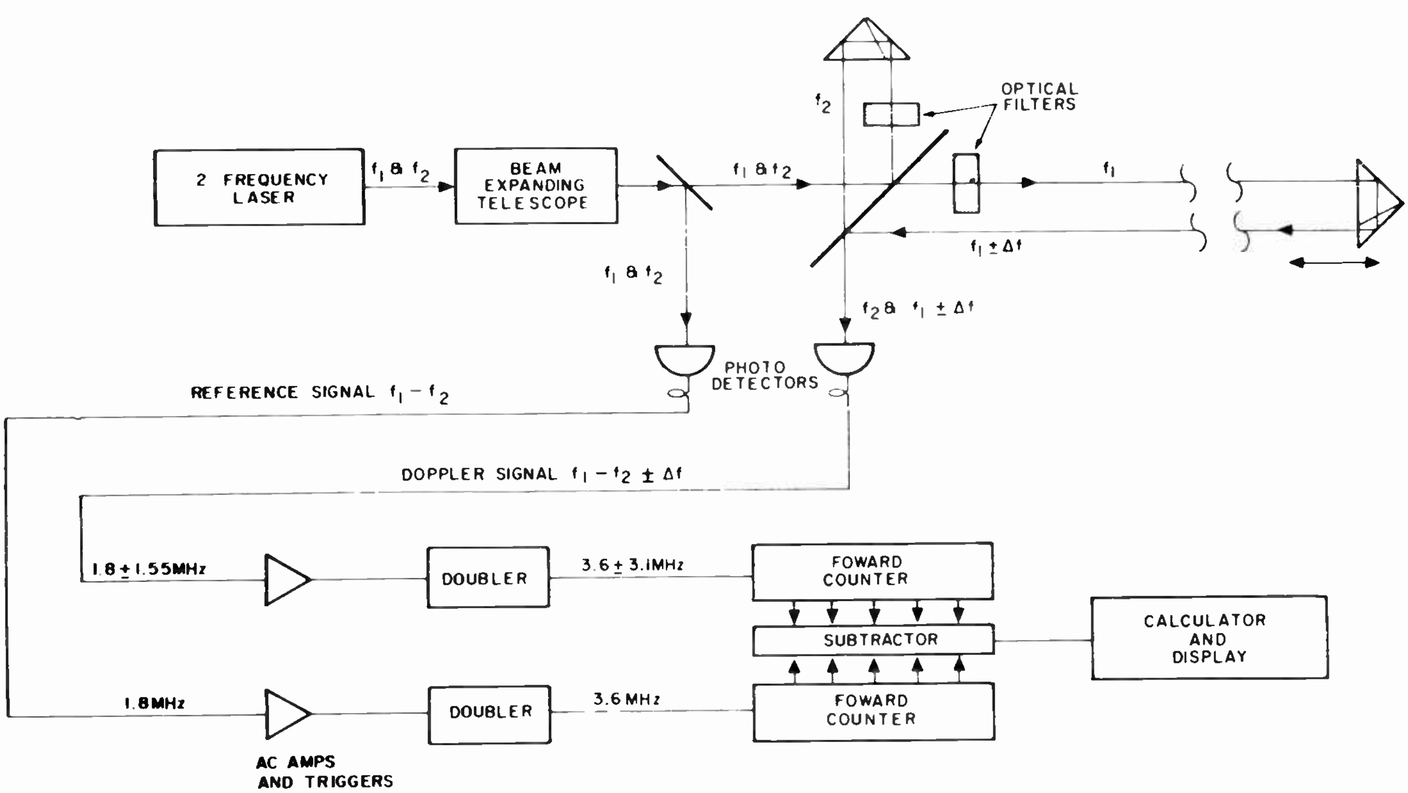
Much experimenting has been done to optimise the method of pumping solid-state lasers. One means developed by RCA in 1962 used a 300 mm hemispherical mirror to focus sunlight onto a laser crystal of calcium fluoride immersed in liquid helium. This laser produced a continuous output of 50 W, and was the first laser to use sunlight to power the device directly.



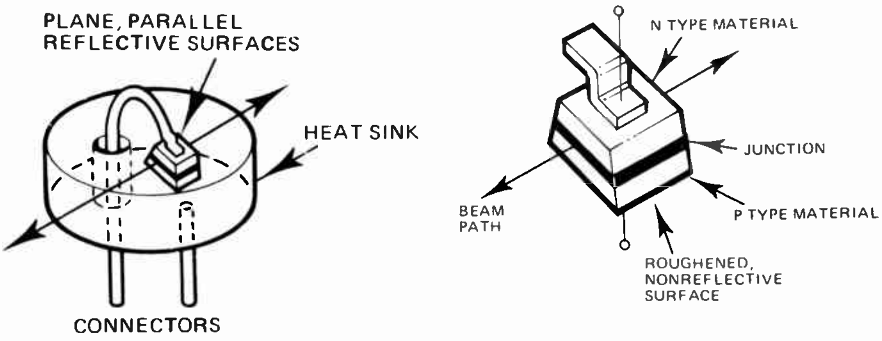

In the ruby laser, as first developed by Theodore Maiman, "pump" light from a xenon flash tube raises the energy level of chromium atoms in a ruby rod until a pulse of coherent red light emerges from the partial reflector (at right).

## Semiconductor lasers

Semiconductor lasers are relatives of the common light emitting diode, or LED. The most common of these is the **gallium arsenide laser**, and consists of a semiconductor diode junction formed by gallium arsenide doped with two different impurities to form the p and n materials. When forward bias is applied, a large number of electrons and holes move towards the junction where they recombine and generate laser light. ▶




An important application of helium-neon lasers is in distance and velocity measurements using interferometric techniques. This block diagram shows a system devised by Hewlett-Packard for an instrument which has the ability to measure length to an accuracy of 1 part in $10^6$ over a distance of 60 metres (that's 1 mm in 1 km !).




**The semiconductor laser comprises a gallium arsenide junction doped with two different impurities. Construction of the junction is illustrated on the right, this is mounted on a heatsink header in the practical device, as shown at left.**

Typical power outputs of gallium arsenide lasers are low, around one watt maximum, but efficiency is very high. Furthermore, they are easily modulated and for this reason should be of great importance in optical communications in the future.

## Liquid lasers

Most liquid lasers use an organic dye as the laser medium and are optically pumped. Their big advantage over other types lies in the fact that the frequency of light generated can be varied. For this reason they are called **tunable lasers** and are being used experimentally to 'steer' chemical reactions.

Often the optical pumping of liquid dye lasers is done by other lasers, such as the nitrogen gas laser which has an output in the ultraviolet spectrum.

## Gas lasers

Gas lasers are probably the most important single category. The **carbon dioxide** laser for example provides the highest continuous power outputs of any breed. Furthermore, its output is in the infra-red spectrum which makes it useful commercially for cutting applications.

The most common gas laser is the **helium-neon** type. It provides a continuous output of red laser light that has been used commercially in distance measuring equipment as well as a general purpose "straight line". It is also used extensively in laboratories for diffraction, for general optical experiments and in interferometers. It has evolved into an inexpensive and reliable device and it was for this reason that we chose a HeNe laser tube for the project following this feature.

The HeNe laser consists of a mixture of the gases helium and neon, placed in a sealed tube at low pressure. Originally, HeNe lasers were excited by high frequency ac current (around 28 MHz) but these days high voltage dc is used. As in most other lasers, mirrors are used at each end of the tube, so that most of the light produced is trapped within the laser itself, maintaining a special condition needed for laser action called *population inversion.*

In order to understand the laser phenomenon in any greater depth it is necessary to look at some of the physics of atomic structure.

## Quantum physics

When studying the universe we apparently find two fundamentally different types of quantities, those quantities with a continuum of values and those with only a discrete or 'quantised' number of values. For instance, the speed of an object can range from zero up to the speed of light and seems to consist of an infinite number of possibilities. Similarly, the set of all numbers is infinite. These are examples of continuous quantities, but not all quantities are continuous. A dice can only show 1, 2, 3, 4, 5 or 6 on its upper face and this is a quantised quantity.

Similarly, standing waves on a violin string, resonances of a quartz crystal, or harmonics of a square wave are all quantised — they occur only at fixed frequencies.

Quantum physics is based on the discovery that a large number of quantities involved with molecular, atomic and sub-atomic physics are quantised. Many of these quantities were assumed to be continuous in "classical physics" and it has only been through the recognition of their quantised nature that modern physics has been able to achieve a reasonably workable model of atomic structure.

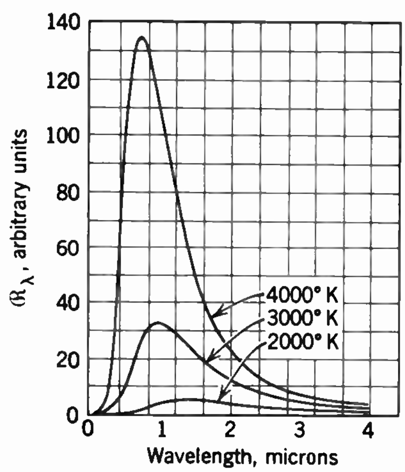
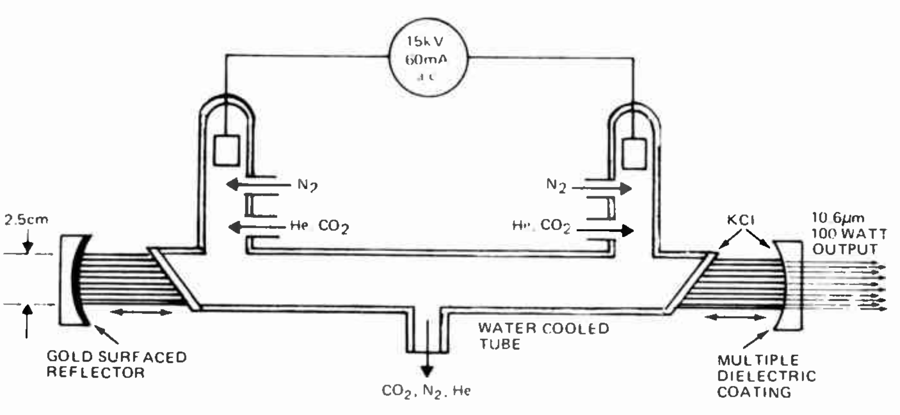



*Figure 1.* **The spectral radiancy for cavity radiation at three different temperatures. (After Halliday and Resnick, "Physics for Students of Science and Engineering".)**




**Some gas lasers can generate enormous output powers. This diagram illustrates the general construction of a carbon dioxide laser.**

Most light sources today consist of either a solid (like a tungsten filament) or a gas (as in the fluorescent tube) through which an electric current is passed. This current heats the filament or gas to incandescence and light is emitted. Using a spectrometer, it is possible to measure the relative intensities of the different light wavelengths emitted. If the temperature of the heated objects is varied the relative intensities change. All of these results can be plotted to make a family of curves on a graph like Figure 1. Each curve represents a different temperature and the shape of these curves is related to the particular material that is being heated.

The number of variables in the case of a heated solid makes any mathematical analysis unnecessarily complicated so scientists sought an idealised heated solid. They called this a *cavity radiator*, and the light emitted proved to be largely independent of the material used to make the cavity radiator. Furthermore, the light emitted was found to vary in a fairly simple way as the temperature was varied.

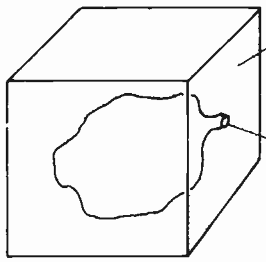



*Figure 2.* **Representation of a cavity radiator. At a particular temperature, light emitted from the hole is brighter than that radiated by the body of the material.**

Practical cavity radiators simply consist of a hollow container with a small hole drilled in one side (see Figure 2). If the cavity radiator is heated, more light is emitted from the hole than from the outside walls. The light emitted from the hole is called *cavity radiation* (sometimes called *black body radiation*) and was of intense interest in the later part of the nineteenth century.

The explanation of the related intensities of the various wavelengths emitted in cavity radiation was one of the outstanding problems for classical physics. Several attempts had been made but all of these had only fitted the experimental data partially.

In 1900, a German physicist, Max Planck, derived a formula that fitted cavity radiation perfectly. He was forced to the conclusion that the atoms inside the cavity radiator were acting like tiny electro-magnetic oscillators. They could emit light into the cavity and absorb light energy from it, but only at certain characteristic frequencies.

Planck was forced to make the radical assumption that an oscillator cannot have a continuum of different energies These energies were quantised so that the only possible values were given by the equation.

$E = nh\upsilon$

where 'E' is the energy
'n' is an integral number, i.e: 1, 2, 3, 4, 5, etc.
'h' is a constant (now called Planck's constant)
and '$\upsilon$' is the frequency of the oscillator.

The oscillators could not radiate light continuously but only in jumps, or 'quanta', and only when the atom jumped from a high energy state to a lower one. If the atom jumped just one energy state then 'n' in the above equation becomes equal to one, and the equation becomes:

$E = h\upsilon$

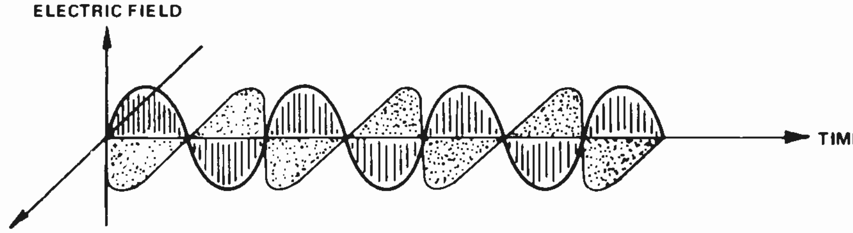
This is known as *Planck's equation* and is one of the more important equations in modern physics.

This was the start of quantum physics. A physical event could only be explained by assuming that atoms radiate integral amounts of energy.

Planck's ideas were reinforced several years later by Albert Einstein who applied the concepts of quantisation to another area of physics that was to revolutionise our understanding of the nature of light. Up to this time, light was thought of as an electromagnetic wave. Even though Planck had quantised the energies of atomic oscillators in the cavity walls, he still regarded the radiation within the cavity as a wave. This wave picture of light had been enormously successful in explaining light phenomena up to that time, but Einstein was to point out its inadequacy in some circumstances.

## The Photo-electric Effect

This effect was another experiment which had not been satisfactorily explained in terms of classical physics. Figure 3 shows a circuit diagram for the apparatus used in the photo-electric experiment. If light is shone onto a clean metal surface some electrons are liberated from the metal. If the metal is placed in an evacuated glass cylinder,




**According to the electromagnetic wave theory, light is seen as a continuous wave of oscillating electric and magnetic fields.**

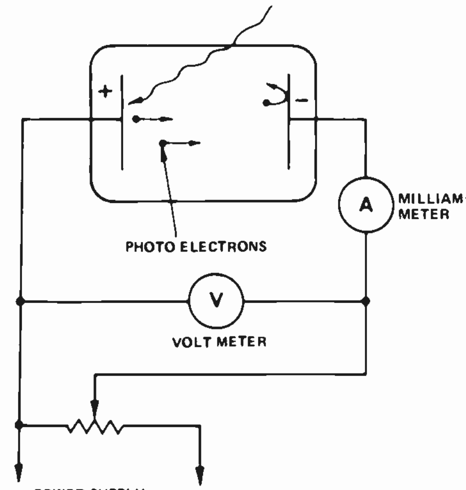



*Figure 3.* **Circuit diagram of the apparatus used in the photo-electric experiment.**

the liberated electrons (called *photo-electrons*) can be made to constitute a current flow, which will register on the meter. If the other electrode is now made negative with respect to the first, by connecting the two to a power supply, the negative electrode will tend to repel the photo-electrons and decrease current flow. When the voltage is great enough, the photo-electrons can be brought to a stop. If the voltage is increased even further the photo-electrons are turned back toward the anode. The voltage applied to the plates is called the retarding potential and can be used to measure the energy of the photo-electrons.

When the experiment is carried out it is found that photo-electrons are emitted almost instantaneously when the light is turned on. If the wavelength of the incident light and the retarding potential are kept constant, then the current flowing is found to be proportional to the intensity of the light beam. Furthermore, for any particular metal the energy of the photo-electrons is found to be independent of light intensity, but varies with the frequency of the light.

These results were difficult, if not impossible, to explain on the basis of the wave theory of light. Since light was thought of as a continuous wave, the energy absorbed on the photo-electric surface should have been proportional to the light intensity. If the intensity was decreased enough it should have taken a certain amount of time for sufficient energy to be absorbed by the electrons before any emission could start. So the wave theory of light could not explain why photo-electric emission starts instantaneously, even if the intensity of light is decreased.

Similarly, the fact that the energy of the photo-electrons varies with the ▶

frequency of the light and is in no way affected by the intensity of the light, cannot be explained by the classical theory.

## A quantum approach

In 1905, Albert Einstein applied quantum theory to the problem of photo-electric emission and obtained a theory that explained all the observed characteristics. He postulated that light was not a continuous wave but consisted of small quanta of light called *photons*. Each photon has an energy, 'E', that is related to the wavelength of the light by Planck's equation.

Any single photon can interact with a single electron so the energy imparted to this electron will depend only on the energy of the photon. i.e: its frequency. Increasing the intensity of the light beam increases the number of photons and will only increase the number of photo-electrons emitted. Emission will start instantaneously, as all the energy needed for a photo-electron to escape the surface of the metal is contained in any single photon.

The photo-electric effect occurs because the energy imparted to the photo-electron by the photon has exceeded that needed by the electron to break bonds that normally bind it to the metal surface; but it is not the only example of electron-photon interactions. In the photo-electronic effect the electron struck is a bound electron, inside an atom. The photon disappears and the electron is dislodged. However if the electron is a free electron it will recoil and cause the generation of a second photon of lower energy. This is called *the Compton effect.*

Another set of electron-photon interactions are called *pair production* and *pair annihilation*. If a photon is given enough energy it can convert into an electron and a *positron* when passing another heavy particle. A positron is an antimatter electron. It has all the properties of a normal electron except that it has a positive instead of a negative charge. This process is called pair production. Pair annihilation occurs when a positron and an electron interact. Both are annihilated and two photons are generated.

All these electron-photon interactions are manifestations of a single process, the exchange of photons, called *virtual photons*, between charged particles. Indeed, it is this effect that gives rise to the attractive and repulsive forces between charged objects. The study of photo-electron interactions is called quantum electrodynamics and is one of the major fields of research in modern physics.

## Spontaneous and stimulated emission

When a photon interacts with a bound electron it may not have sufficient energy to overcome the binding forces. In this case the photon is absorbed by the electron, as would happen in the photo-electric effect, but the electron is not liberated from the atom. Instead, it jumps up to a higher energy level or orbit. Quantum physics has determined that electrons cannot have a continuum of different energy levels, only energy levels that are integral multiples of a fixed amount. When the electrons of an atom are in their minimum energy states the atom is said to be in its ground state. If an atom is in its ground state, say with energy $E_1$, it can be forced to a higher energy level, say $E_2$, by absorption of a photon. If the photons absorbed have energy $E = h\upsilon$ then the increase in electron energy will be exactly $h\upsilon$, i.e: $E_2 - E_1 = h\upsilon$.

After a certain amount of time, approximately $10^{-8}$ seconds, the electron will drop back down to its lower energy level, automatically emitting a photon, again with energy $h\upsilon$.

The excited atom was initially at rest and has no preferred direction in space. As a result the photon can be radiated in any direction while the atom recoils in the opposite direction. This process is called *spontaneous emission*. If a group of atoms are excited in this way they will generate photons in all directions randomly, as excited atoms return to their ground states; see Figure 4.

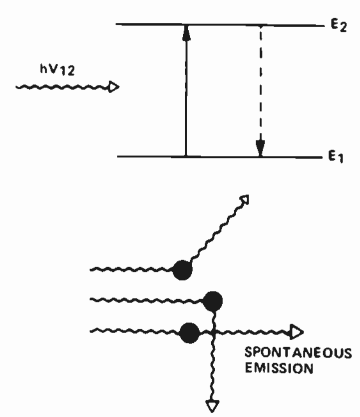



*Figure 4.* **Energy level diagram for the process of spontaneous emission.**

If an electron at energy level $E_2$ interacts with another photon of energy $h\upsilon$, the electron is forced to return to its ground state with the emission of a second photon. This process is called *stimulated emission* and is the basis of laser action.

The most important point about stimulated emission is that both photons leave the atom with the same phase and direction as the incoming photon, see Figure 5. The two photons are said to be coherent. It is essential that the two photons be coherent. If they were even slightly out of phase cancellation would occur between them, violating the law of conservation of energy. If a group of atoms is excited in this way the initial beam of photons will be augmented by additional photons, so the beam is amplified.

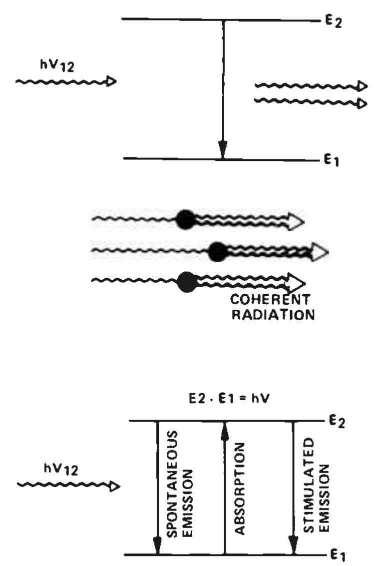



*Figure 5.* **Energy level diagram for the process of stimulated emission.**

## Population inversion

If a material is in thermal equilibrium at a temperature T, the distribution of atoms in a lower energy state to those in a higher energy state is normally accented heavily toward the lower energy state. If $N_1$ is the density of atoms in the lower state and $N_2$ the density of atoms in the more excited state, then the ratio of $N_2$ to $N_1$ is given by the equation

$$\frac{N_2}{N_1} = \exp(-h\upsilon/kT)$$

where 'T' is the temperature of the material in Kelvin
and 'k' is Boltzmann's constant.
If the material is at $10^3$K, then:

$$\frac{N_2}{N_1} = 10^{-5} \quad !$$

So, only one atom in $10^5$ is in the excited state.

The condition in which the number of excited atoms exceeds the number of atoms at the ground state is a non-equilibrium condition called *population inversion*, but it is precisely this condition that is needed to maintain laser action. If the vast majority of atoms are in the non-excited state, only spontaneous absorption followed by spontaneous emission, can occur. If, on the other hand, a population inversion can be

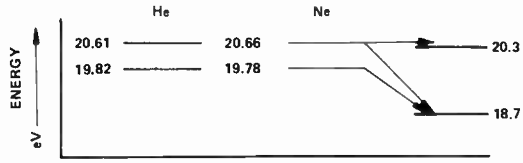



*Figure 6.* **Energy level diagram for the helium-neon laser.**

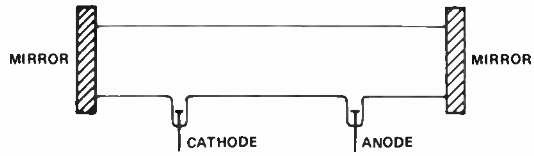



*Figure 7.* **Basic construction of a gas laser. A glass cylinder, containing a gas at a low pressure, has two mirrors placed at either end — one is totally reflective, the other slightly transmissive. When current is passed through the gas, population inversions of the atoms occur and laser action results.**

maintained then stimulated emission will occur leading to photon multiplication. *Pumping* is simply the process used to maintain the population inversion.

## A closer look at the HeNe laser

In the helium-neon laser, population inversion is maintained by generating a glow discharge in a low pressure mixture of helium and neon gases. Figure 6 is a simplified energy diagram for a HeNe laser.

The helium energy levels at 20.61 and 19.82 electron volts (eV) are called *metastable levels.* Once at a metastable energy level an atom cannot move to a lower state by the emission of a photon. It can only be de-excited by some other process. A transition from a metastable level to a lower level is called a *forbidden transition* and the fact that these transitions are not permitted is predicted by quantum theory. So, once an atom has been excited to one of these energy levels it will stay at that energy level for a relatively long period of time, approximately $10^{-3}$ seconds, hence large metastable populations can exist.

Two of the energy levels of neon closely coincide with those of the metastable levels of helium, these are at 20.66 and 19.78 eV. An energy transfer will occur between helium metastable atoms and neon ground state atoms, exciting neon atoms to the 20.66 and 19.78 eV energy levels. As a result, very large populations of excited neon atoms are produced. The population of neon atoms in these energy levels vastly exceeds that achievable from direct excitation by the electric discharge. Below these two highly populated energy levels there are two lower neon levels that are only populated by direct excitation and consequently have much smaller populations, and this is a population inversion.

Whenever an excited neon atom jumps to one of these lower energy levels a photon is emitted, and the frequency of the photon will depend on the difference in energy between the two levels. The three possible transitions are shown in Figure 6 and are:

20.66 eV to 20.3 eV
(3391 nm in the far infrared)

19.78 eV to 18.7 eV
(1152 nm in the infrared)

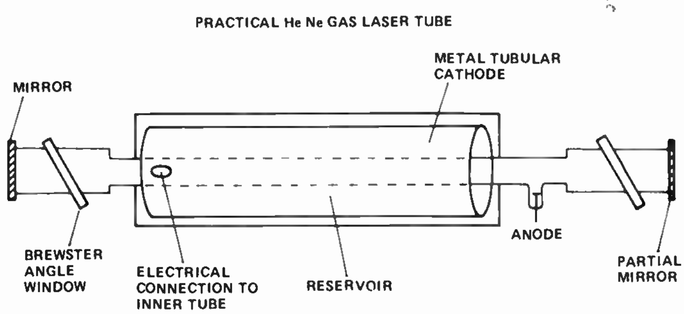
20.66 eV to 18.7 eV
(633 nm in the visible spectrum)

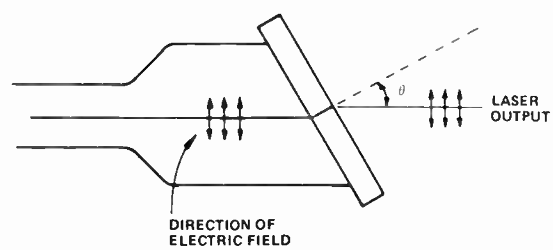
Figure 7 shows the basic elements of a helium neon laser. The tube contains roughly 90% helium and 10% neon gas at a pressure of one to three Torr.

When a current is passed through the tube a variety of collision processes take place. Among these are the collisions that lead to population inversion. As neon and helium atoms jump between higher and lower energy levels, photons are emitted randomly in all directions. However, since there are large populations of neon atoms at the 20.66 and 19.78 eV energy levels, any photon with one of the above three wavelengths has a high probability of causing stimulated emission of a second, identical, photon. Those photons travelling parallel to the axis of tube are reflected back and forth between the two end mirrors, and each pass through the tube gives rise to further identical photons by the process of stimulated emission. A limit is finally reached when the rate of production of neon atoms at the higher energy levels equals the rate of stimulated emission.

If one of the mirrors is made a few percent transparent, (i.e: slightly transmissive) a portion of the coherent radiation can escape from the tube and this is the laser output. The word laser stands for *light amplification through stimulated emission of radiation*, but the helium neon laser is not really an amplifier, it's more of an oscillator generating coherent electromagnetic radiation at three distinct frequencies. ●

## A practical HeNe laser tube

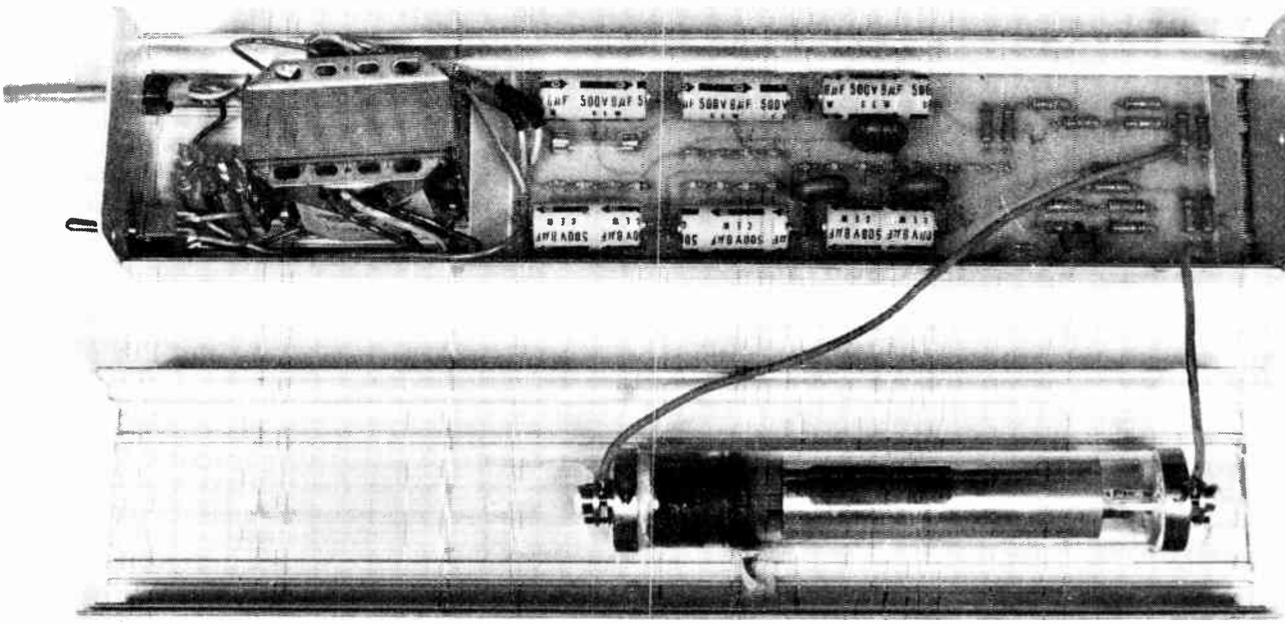



TRANSMISSION OF LIGHT THROUGH A BREWSTER ANGLE WINDOW.

A practical HeNe laser tube is shown in the diagram. It features a number of improvements over the basic system. The cathode consists of a large metal cylinder instead of a single wire electrode. This decreases the current density around the cathode and increases the rate of excitation of helium atoms to metastable states. Plane mirrors are very difficult to align accurately and a common system used to overcome this difficulty is the use of slightly concave mirrors, separated by their radius of curvature.

Another configuration employed, and the one used in the tube for the project, is referred to as a "hemispherical" configuration. This uses a totally reflective, flat-backed mirror and a concave front mirror with a radius of curvature of around 1.4 times the tube length. The mirrors used are designed specifically for laser use and constitute a significant portion of the cost of the device. The mirrors are used as bandpass filters to optimise the particular output required. The tube specified for the project uses a system like this to enhance tube operation at the 633 nm emission wavelength and to suppress operation at the other two dominant wavelengths. The front mirror is approximately 0.9% transmissive at 633 nm but considerably less transmissive at the two longer wavelengths. The rear mirror is almost totally reflective at 633 nm, but more transmissive at longer wavelengths. HeNe tubes often employ a "Brewster angle polarizing filter". This is a glass disc placed in the light beam at an angle determined by its refractive index. Light of the correct polarization is transmitted through the filter. All other polarizations suffer high reflections and are attenuated. This does not cause any loss in the light output of the laser since any one polarization will be amplified by stimulated emission to produce a full output intensity coherent laser beam with a single polarization.



# Build a helium-neon laser

## David Tilbrook

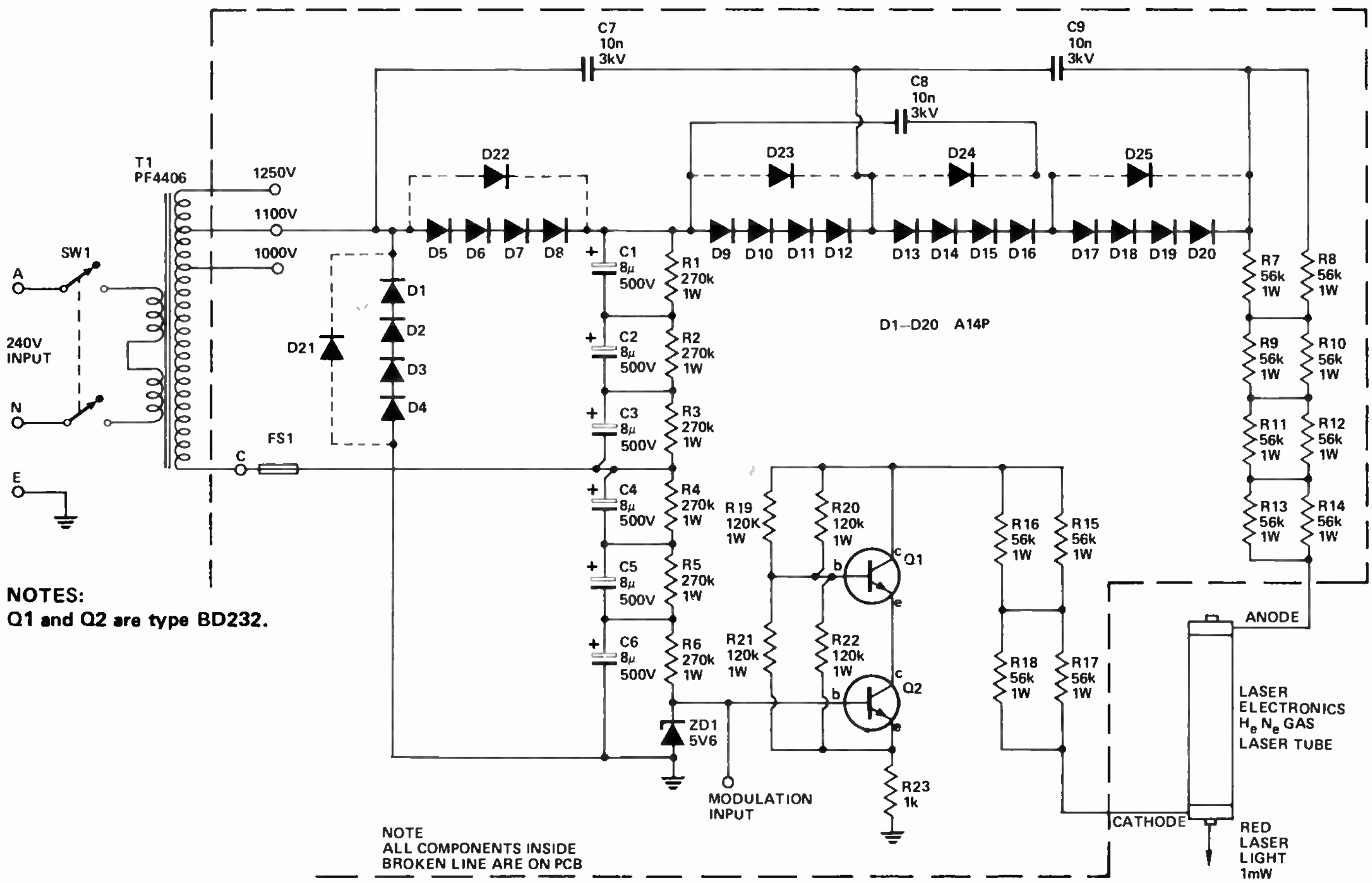
This project has been designed around an Australian designed and manufactured laser tube having a 1 mW output at a wavelength of 633 nm in the red section of the visible spectrum.

WHEN WE first considered doing a laser as a construction project we approached a Queensland company, Laser Electronics, for details about laser tubes presently available in Australia. Fortunately, at that time they had just embarked on the design of a helium-neon laser tube which they planned to manufacture here. They have subsequently achieved their aim and we decided to use their laser tube in our project. Laser Electronics has been of great assistance in supplying design ideas and information on lasers in general. The particular tube used in our unit (as pictured) is a prototype only and some slight physical variations could be expected in the final production model. The laser tube used on the front cover is an imported model supplied by Laser Electronics for our experimentation.

To assist constructors, Laser Electronics have made arrangements to supply complete kits for this project, including metalwork. Their address appears at the end of this article.

There are a number of design challenges involved in getting a helium-neon laser to operate correctly.

The circuitry is really all power supply ! — but it is called on to perform a number of tasks. Firstly, helium-neon laser tubes require a high voltage pulse of around 8 - 10 kV to start ionisation. Thus, the power supply must provide a 'kick start' for the tube. Secondly, the tube requires a certain voltage supply to maintain operation once 'fired' and the current through it must be maintained at a constant value, both depending on the characteristics of the particular tube design. However, all gas-discharge tubes (and the helium-neon laser falls into this category) exhibit a *negative resistance characteristic* during operation. That is, an *increase* in the voltage applied between the anode and cathode will result in a *decrease* in current through the tube. Under certain circumstances, this property will cause the tube and surrounding circuitry to become an oscillator — an undesirable mode of operation, to say the least! To avoid this, the negative resistance of the tube is "swamped" with a large value series resistance. The value of this ▶




swamping resistance is determined from the particular tube's characteristics and, for this reason, laser tubes are supplied with details of the required minimum series anode resistance and our circuit adheres to the requirements of the tube supplied by Laser Electronics.

We have designed the power supply for this tube to deliver a constant current of 5 mA, which marginally decreases the output intensity of the laser beam, but ensures maximum tube life. At this current, the tube will maintain a voltage of around 1550 volts between anode and cathode. *A word of warning* — don't attempt to measure the voltage directly across the tube as the inherent capacitance of most high voltage probes will cause the laser action to stop, the power supply circuit will immediately ramp the tube voltage up in an attempt to re-start the tube and you'll have a 'relaxation oscillator' instead of a laser!

Physical construction of high voltage power supplies presents some unique problems. An obvious one is providing sufficient clearance between individual components having a high potential difference and between components at high voltages and conducting bodies nearby — the chassis, or whatever. Components have to be chosen with care. Adequate voltage ratings have to be specified for diodes and capacitors, as well as allowing an adequate safety margin.

Resistors used in voltage divider strings etc need to be of a size and type such that their maximum working voltage is adequate for the job. Resistor construction needs to be considered

## HOW IT WORKS — ETI 565

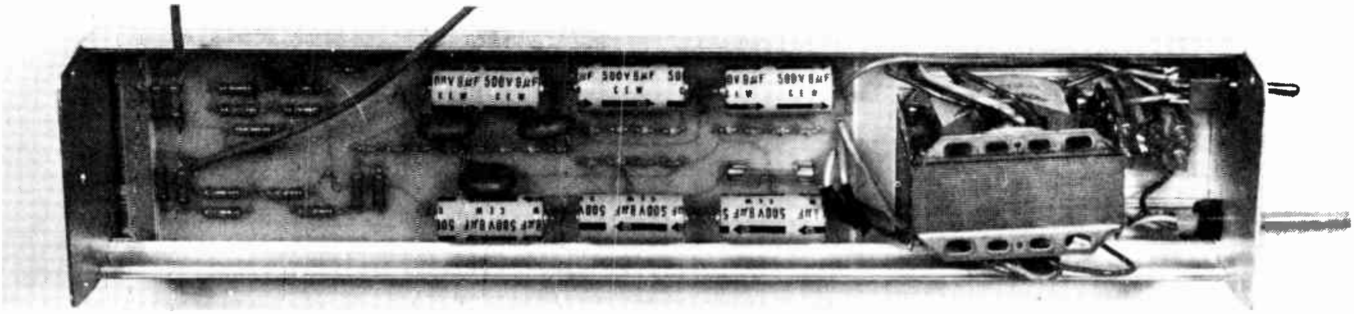
**The circuit can be divided into five compartments: power transformer, voltage doubler rectifier, 'kick start' voltage multiplier, laser tube plus series resistance and constant current sink.**

**The power transformer has a secondary voltage of 1250 V, with taps at 1100 and 1000 volts. The 1100 volt tapping is used in this instance, the other two are provided to allow the power supply to operate different laser tubes (although we don't plan to do so).**

**The 1100 V transformer output drives a voltage doubler rectifier, involving diodes D1 to D8 and capacitors C1 to C6. The resistors across the latter capacitors serve as 'bleeders' to discharge the capacitors when the supply is turned off. They also serve to equalise the voltages across each capacitor. The output of the voltage doubler is around 2800 volts (cathode of D8). As two single diodes for this rectifier would be required to have a peak inverse voltage rating of at least 3 kV, we have used four diodes in series, each rated at 1 kV PIV. If suitable high voltage diodes can be found, you can substitute these as shown dotted on the circuit diagram.**

**The output of the voltage doubler drives the input of a three stage voltage multiplier involving diodes D9 to D20 and three 10n capacitors, C7, C8 and C9. This provides the kick start for the tube, delivering somewhat in excess of 8 kV, but at a very low current (the impedance of the 10n capacitors at 50 Hz is rather high). Very quickly after turn on, the voltage at the cathode of D20 will rise to around 8 kV and the laser tube will 'fire'. When it does, the current drawn will be too great for the impedence of the voltage multiplier starting circuit to supply and the tube will be driven directly by the voltage doubler via the D9 — D20 diode string. The tube swamping resistance is provided by the series-parallel string of 1 W resistors, R7 to R18. The voltage at the anode of the laser tube is about 2240 volts during normal operation.**

**The constant current sink is formed by Q1 and Q2, plus associated components. It serves to regulate the current through the laser to the required 5 mA. The base of Q2 is clamped at 5.6 volts by the zener diode. This results in a voltage at the emitter of Q2 of 5 V, setting the current through the 1k resistor, R23, at 5 mA. Although the voltage across the two transistors will vary, the collector currents, and thus the current through the laser tube, will remain fixed at 5 mA. The worst-case power dissipation in these transistors is approximately 1.5 watts.**



Interior view of the electronics for the laser, mounted in the case bottom. This case will be supplied by Laser Electronics with their kit for this unit.

here, too. Carbon composition resistors typically have a maximum working voltage rating of 700 V for half-watt types, 1000 V for 1 W types. Carbon film resistors, on the other hand, are only rated at 350 V for half-watt and 500 V for 1 W types. The project's power supply has been designed such that the individual resistors in the voltage divider strings have no more than 200 V across them. Although carbon composition types have been specified — as they will be the most reliable in these circumstances — carbon film types may be safely substituted.

## Construction

You will notice construction is not difficult but care must be taken to ensure that adequate insulation exists between the tube, all high voltage points and the chassis. Make certain the chassis is correctly earthed to both the printed circuit board and the ground wire of the three-core mains cable, as shown in the wiring diagram.

Construction should commence with assembly of the components on the printed circuit board. Note that all the diodes point in the same direction, with their *anodes* towards the *output* end of the pc board. Make sure the six electrolytic capacitors are inserted correctly.

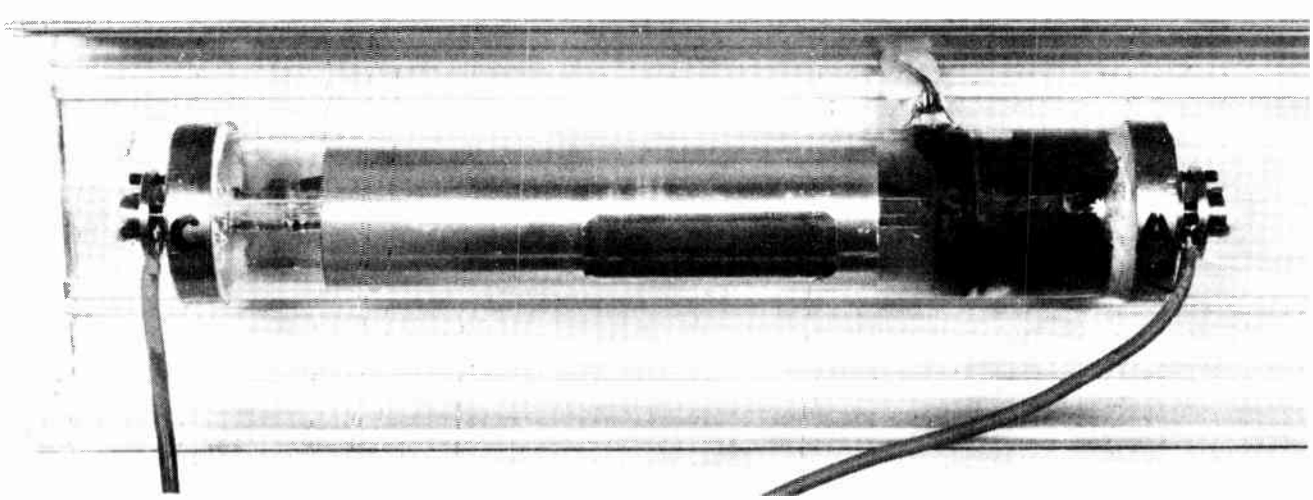
Drill the bottom piece of the chassis to take a mains cable terminal block. Solder the wires from the power transformer onto the pc board. Solder two lengths of well insulated wire to the output of the pc board. These will go to the laser tube and should be kept as short as possible. The remaining pad on the board is the modulation input. This is not used in this project but will be used in subsequent articles. At this stage it is recommended that a pc board pin be soldered to this pad so that the board will not have to be removed from the chassis at a later date. The prototype laser has been constructed in a length of aluminium extrusion that we obtained from Laser Electronics. If you are not using this chassis, ensure that the chassis used is metal and well earthed. If you have purchased the kit from Laser Electronics, slide the pc board into the extrusion and mount the transformer and terminal block. Mount the power switch and finish the 240 V wiring. Ensure that the connection between the chassis and the ground wire is secure, use a solder lug and lock washer, loop the ground wire through the lug and then solder.

Note that you can replace the strings of A14P diodes with single high-PIV rating types, as indicated by the diodes dotted in on the circuit diagram. They should have a PIV rating of at least 3 kV and have a low junction capacitance (under 150 pF). In general, diodes rated at 5 kV PIV and less than 1 A forward current will be OK. If you elect to replace the diode strings with single diodes, they should be connected from the anode pad of the first diode to the cathode pad of the fourth diode in each string.

If you have difficulty obtaining the BD232 transistors, you can substitute some other type providing they have a collector-emitter voltage rating of 300 V or more and can dissipate up to 1.5 W.

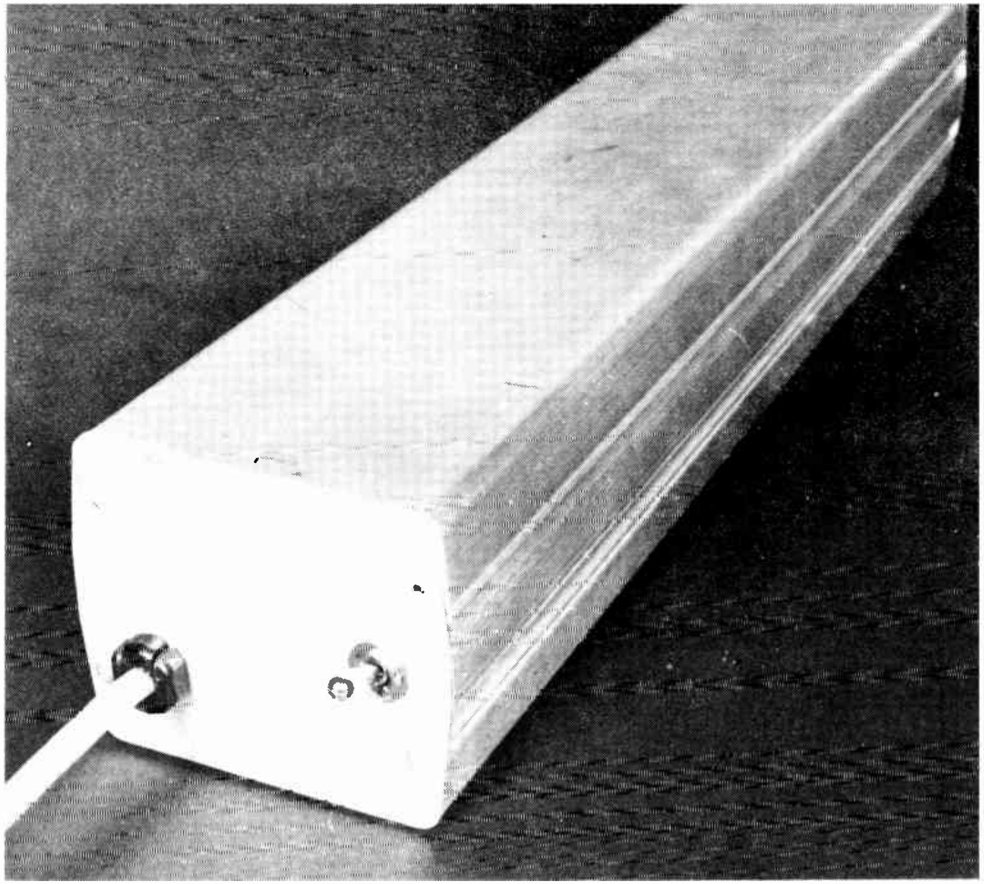
The laser tube has metal ends used as the anode and cathode connections to the tube, so it must be totally insulated from the case. In the prototype unit. ▶

A close-up of the laser tube mounted in the case top (see text).



# Project 565

The assembled unit, viewed from the rear.



perspex was slid into the extrusion and glued into place with Silastic. The laser tube was then glued to the perspex, again with Silastic. This provides a cheap and highly effective mounting method. Drill a small hole in the end plate through which the laser beam will pass. Connect the wires from the pc board to the laser tube, making absolutely certain they are the correct way around. Finally, push the two halves of the extrusion together and screw in the end plates.

## Powering up

*Do not apply power to the laser without the cabinet assembled.* If the laser doesn't operate correctly when turned on, turn it *OFF* before opening the chassis and allow sufficient time for any high voltage that may be present on the anode, to discharge before reopening the chassis. This will take several minutes.

**The output from this laser is rated at 1 mW and while this is not regarded as a dangerous level caution should** *ALWAYS* be taken when operating any laser. *DO NOT* look directly down the beam. Be careful also of reflections that may be able to enter the eye indirectly. ●

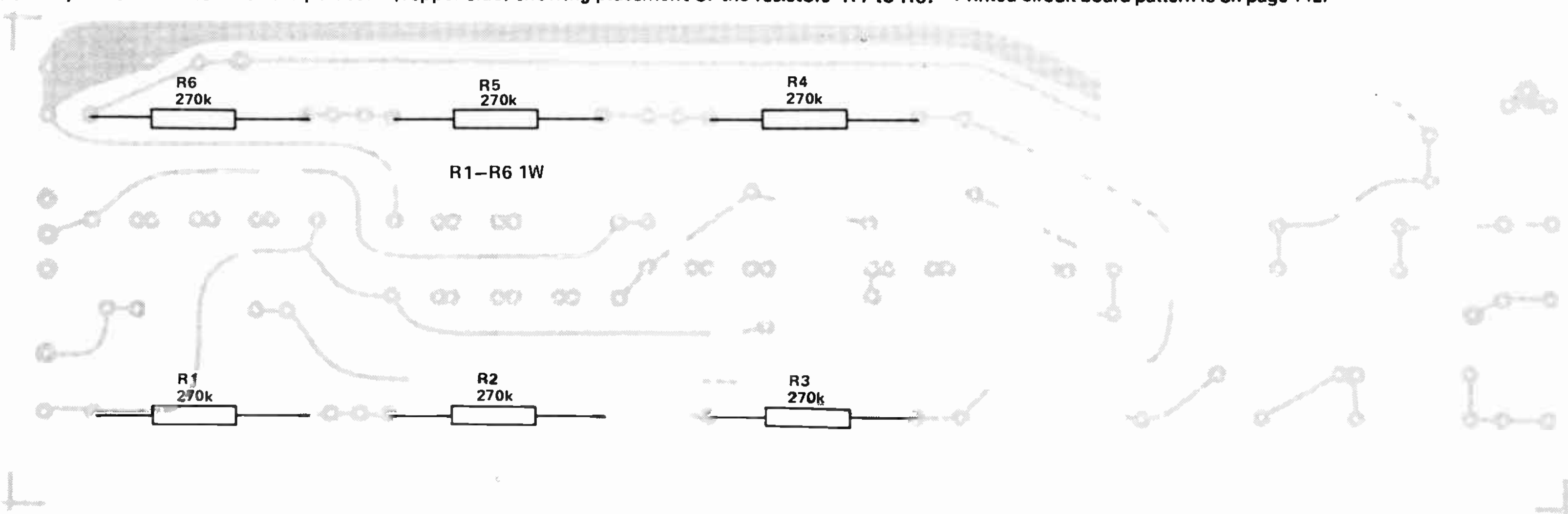
A complete kit of parts will be available from:

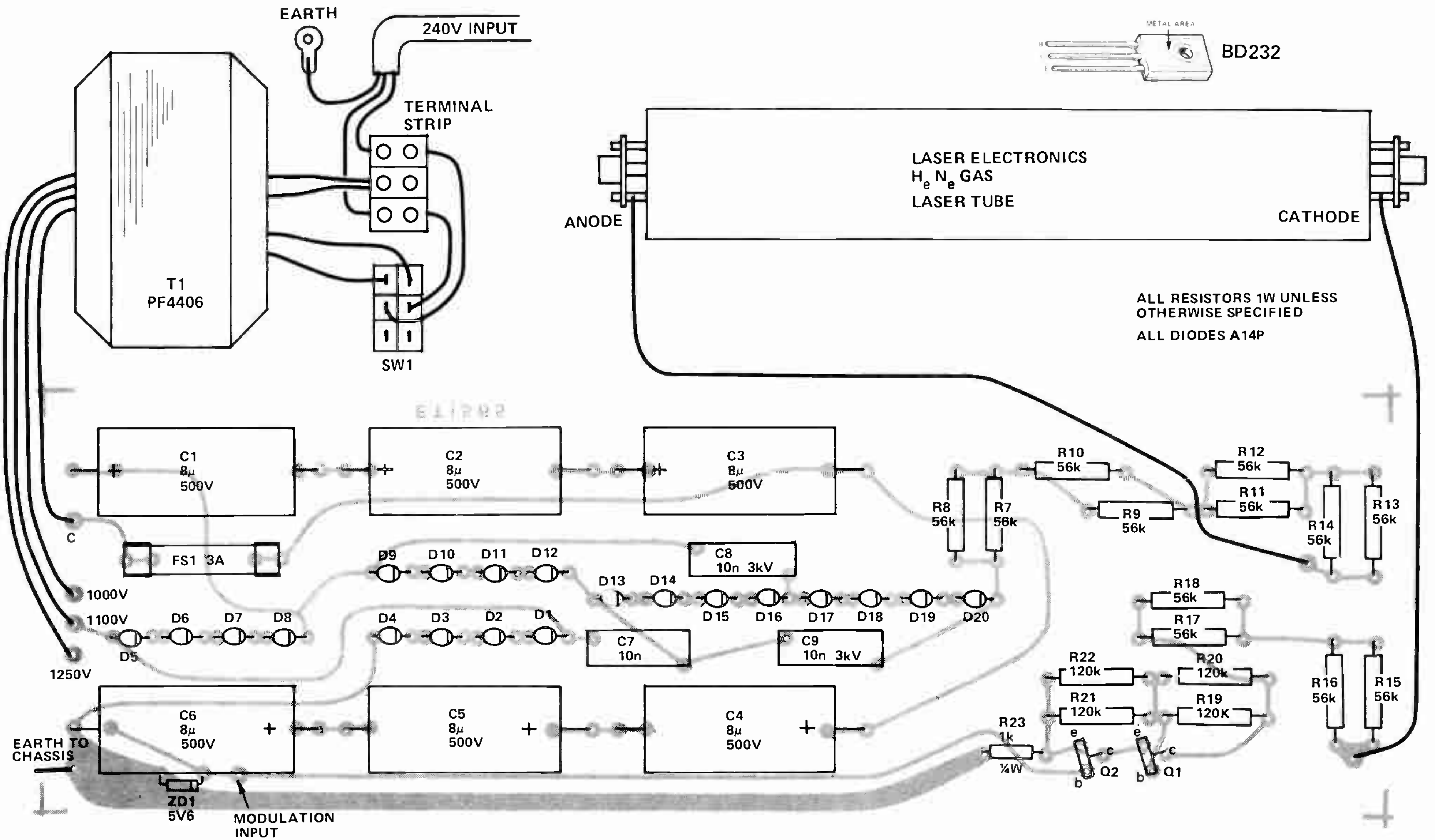
**Laser Electronics Pty Ltd**
**PO Box 359**
**Southport QLD**
**(075) 32-1699**

**DON'T attempt to do any measurement on the power supply without a proper high voltage probe. The voltages present will break through the insulation on most standard multimeter cables.**

***The power supply is quite capable of delivering 2000 V at 20 mA and this could be LETHAL if touched.***

Component overlay for the underside of the pc board (copper side) showing placement of the resistors R1 to R6. Printed circuit board pattern is on page 142.






## PARTS LIST — ETI 565

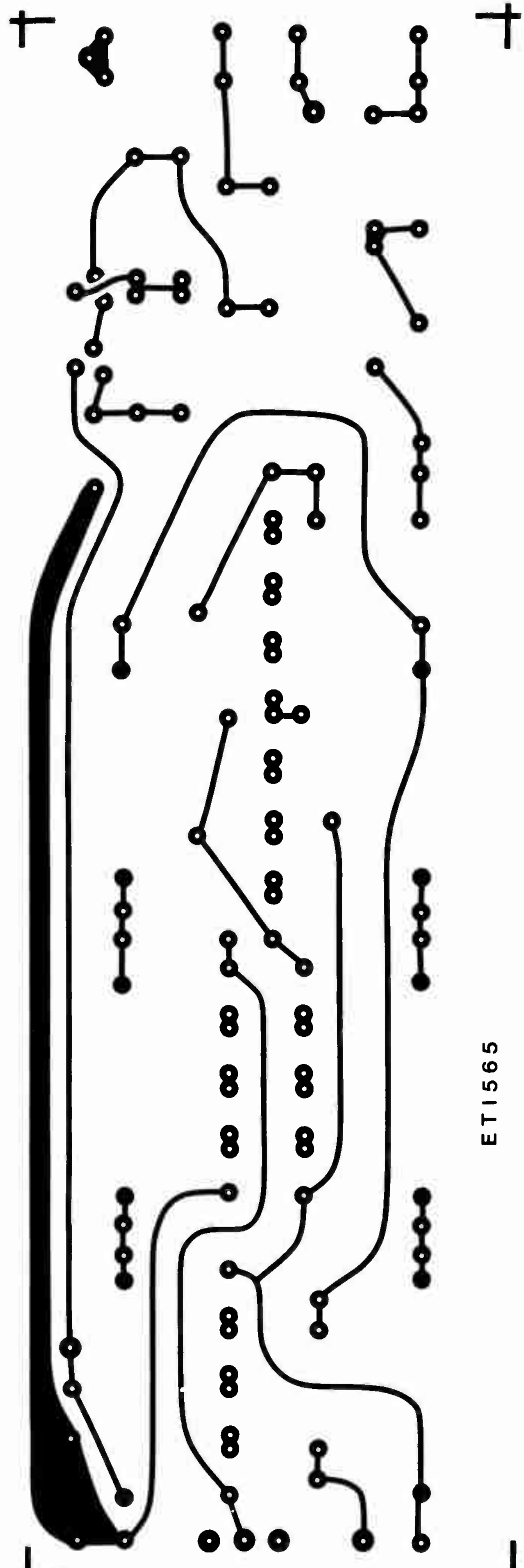
**Resistors**
- R1-R6 ............ 270k, 1W carbon
- R7-18 ............ 56k, 1W carbon
- R19-R22 ......... 120k, 1W carbon
- R23 .............. 1k, ½W carbon

**Capacitors**
- C1-C6 ............ 8u, 500 V electro
- C7-C9 ............ 10n, 5 kV ceramic

**Semiconductors**
- D1-D20 .......... A14P 1000 V PIV diodes
- ZD1 .............. 5V6 400 mW zener
- Q1,Q2 ........... BD232 or equiv.

**Miscellaneous**

HeNe Laser tube — Laser Electronics; pc board — ETI 565; Power Transformer — Ferguson PF4406 (240 Vac pri.) 0-1000/1100/1250 V sec.) 240 Vac DPST switch, cable, cable clamp, 3-pin plug; chassis; assorted hardware, etc.


ETI 565

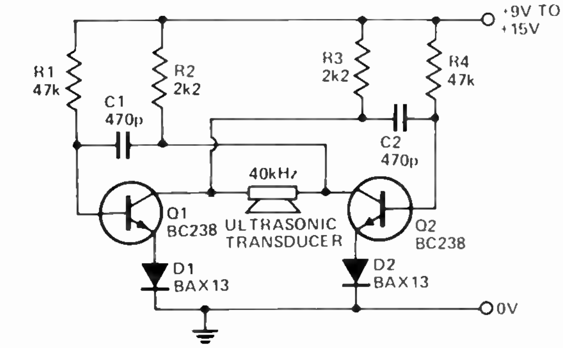



*Figure 3.* **An ultrasonic transmitter using discrete components. Synchronisation with the 40 kHz transducer is automatic. For 25 kHz operation, C1 and C2 should be increased to about 750 pF (560 pF and 180 pF in parallel). Most silicon NPN transistors can be used for Q1 and Q2; e.g: BC108, BC548 etc.**

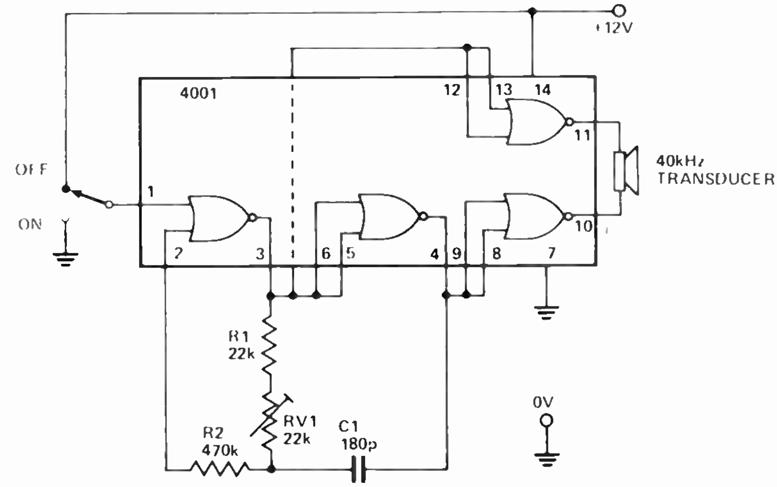



*Figure 5.* **A CMOS 4001 push-pull transmitter circuit. For 25 kHz operation, C1 should be increased to about 270 pF. A CMOS 4011 NAND gate can be used instead of the 4001 device but the ON and OFF connections to the switch are then reversed.**

their 36 kHz transducers, is shown in Figure 3. The diodes in the emitter circuits of the transistors suppress the reverse voltage peaks occurring between the base and the emitter; these peaks are likely to exceed the maximum permissible reverse value of 5 V for the transistor types shown and at the same time can give rise to frequency fluctuations. The diodes are not needed at low supply voltages, but the ultrasonic output is then lower.

The natural frequency of oscillation of the circuit in Figure 3 is determined by the time constants R1-C1 and R4-C2, but this natural frequency is made lower than the required frequency. When the ceramic piezo-electric element of the transducer is connected across the two collectors, the oscillations of the circuit make the transducer ring. The ringing transducer generates a voltage which causes premature triggering of a cut-off transistor so that the oscillator is synchronised to the transducer frequency. Thus, no trimming of the oscillator frequency is necessary in this particular circuit. Current consumption is about 5 mA with a 9 Vdc supply.

Circuits can usually be simplified by the use of integrated circuits instead of discrete components. Figure 4 shows how a 555 device can be used to drive an ultrasonic transducer at about 40 kHz. The preset resistor, VR1, should be adjusted for maximum current consumption which occurs when the 555 oscillator frequency matches the transducer frequency and maximum power is radiated. The 555 produces square waves with a mark-to-space ratio of about 1:1. If 25 kHz transducers are to be used, C1 should be increased to 1n5, alternatively R1 can be increased to about 18k.

Another simple ultrasonic transducer circuit is shown in Figure 5; it uses the 4001 quad two-input CMOS NOR gate. Two gates act as a square wave oscillator which drives the other two NOR gates in push-pull. The latter act as buffers and drive the transducer in push-pull, preventing any voltages from the transducer from affecting the oscillator itself. The oscillator frequency can be adjusted by means of the preset component VR1 so that maximum current is taken from the supply line. Capacitor C1 should be increased to 270p for 25 kHz operation.

The performance of each of the oscillators shown in Figures 3 to 5 inclusive is very similar.

More complex transmitter units can be made which radiate a modulated waveform or a pulse-coded waveform. For example, a 556 device (dual 555) can be employed to generate a 300 Hz signal to modulate the second 40 kHz oscillator of the 556; the advantage of using modulated ultrasonic waves is that the receiver can be made selective to the 300 Hz modulating frequency and reject noise.

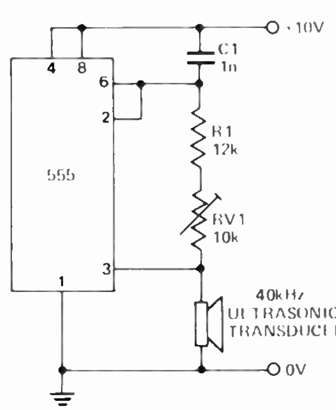



*Figure 4.* **A transmitter circuit employing a 555 timer/oscillator IC. For 25 kHz operation, C1 should be increased to about 1n5.**

## Receiver units

In the same way that the ceramic piezo-electric bimorph element bends when a voltage is applied across it (Figure 1), when ultrasonic waves fall on it, the bending of the element generates a small voltage across the transducer terminals. This voltage is a 40 kHz waveform, but unfortunately the amplitude is quite small. When the transmitting and receiving transducers are placed face-to-face and touching one another the voltage across the receiver transducer terminals is typically less than one volt, but at a distance of about 30 meteres the voltage across the receiving transducer falls to some tens of microvolts and any further increase in the distance between the transmitter and receiver will be likely to result in the signal being lost amongst the noise.

Thus, it is clear that an amplifier of considerable gain must follow the receiving transducer in the receiver unit. This amplifier may consist of discrete transistors, but the circuit can be considerably simplified by the use of one or more integrated circuits. In particular, it is interesting to note that the ICs developed for the amplification of 10.7 MHz IF signals in FM receivers, or for amplification of the inter-carrier sound signal in television receivers, are very suitable for the amplification of ultrasonic signals from a receiving transducer.

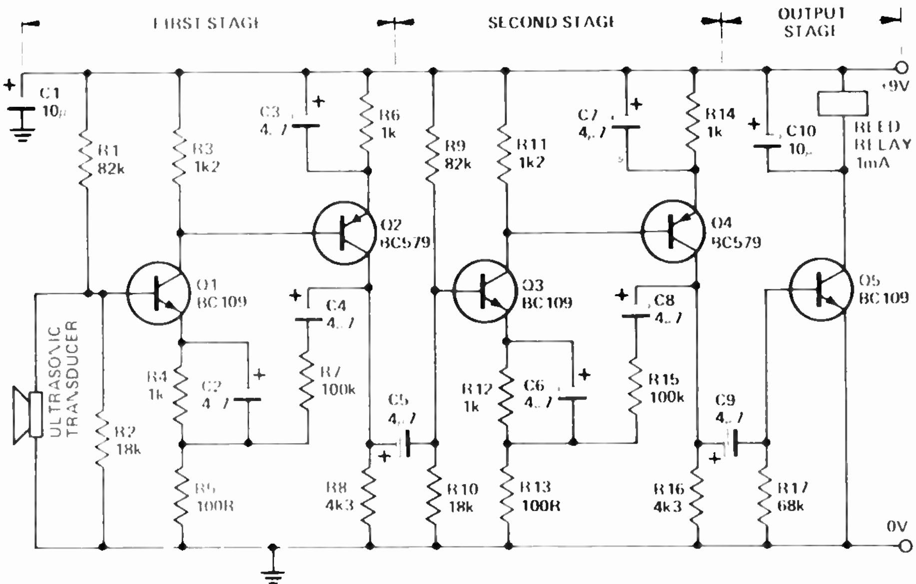



*Figure 6.* **An ultrasonic receiver circuit using discrete components. The reed relay closes when ultrasonic waves fall onto the input transducer.**

## Discrete components

A five-transistor discrete component receiver is shown in Figure 6. Each of the transistors employed is a high-gain, low-noise, small-signal type of the appropriate polarity. Q1 and Q2 provide the first stage amplification and this is followed by an identical second stage, Q3 and Q4, while Q5 controls a sensitive reed relay. When ultrasonic waves of the correct frequency (25 kHz or 40 kHz) fall on the transducer, the relay will operate.

The transducer can be connected directly to the base of Q1, since it has a very high dc impedance and will not affect the bias applied to Q1. The gain of the first stage is determined mainly by R7 and R5 and that of the second stage by R15 and R13. Either R7 or R15, or both, should be reduced if the circuit becomes unstable due to a poor layout or if a high sensitivity is not required. When the distance between the transmitting and receiving transducers is quite small, it is possible to use only a single stage of amplification before the output stage.

When the 40 kHz voltage peaks across R17 exceed about 0.65 V, Q5 commences to conduct and only a little increase in the ultrasonic wave intensity will then cause the reed relay to close. Capacitor C10 smooths out the 40 kHz half-cycles of current passing through the reed relay.

It is important to note that a very sensitive reed relay must be employed in this circuit which closes with a current of no more than about 5 mA with a coil voltage of about 6 V. During the setting up of the circuit and when experimenting with it, it is instructive to insert a 10 mA meter in series with the reed relay coil. Although the reed relay can switch only a small current (perhaps 100 mA), this current can be used to perform any desired operation, including the control of a much larger relay.

## TAB231 Receiver

Another receiver circuit for the control of a relay is shown in Figure 7. A TAB231 (SGS-ATES) or the equivalent, uA739 (Fairchild) or a similar device, is employed as a 40 kHz two-stage amplifier. Resistors R1 and R3 provide a bias for the non-inverting (+) input of the left-hand amplifier to which signals from the transducer are also fed. Capacitor C1 effectively ties the junction of R1, R2 and R3 to common (0V) as far as alternating voltages are concerned, so the resistor R2 appears as a load across the transducer terminals and broadens the frequency response of the transducer (see Figure 2).

The gain of the first 40 kHz amplifier stage is set by the ratio of R5/R4, but the other components in the feedback network reduce the gain at low frequencies. The output from pin 1 is fed directly into the non-inverting input of the second amplifier stage and also provides a suitable bias for this input. The second stage is of a very similar design to the first stage except that some component values are modified to reduce unwanted noise and low-frequency gain which can cause problems.

The output from pin 13 is fed through C7 to a diode pump circuit. The latter converts the 40 kHz waveform into a steady voltage which appears across the diode pump output capacitor C8 which has its upper end positive when the ultrasonic waves are present on the receiving transducer. Each 40 kHz input wave passing through C7 causes a small amount of charge to flow through D2 to the capacitor C8 which thus becomes charged. ▶

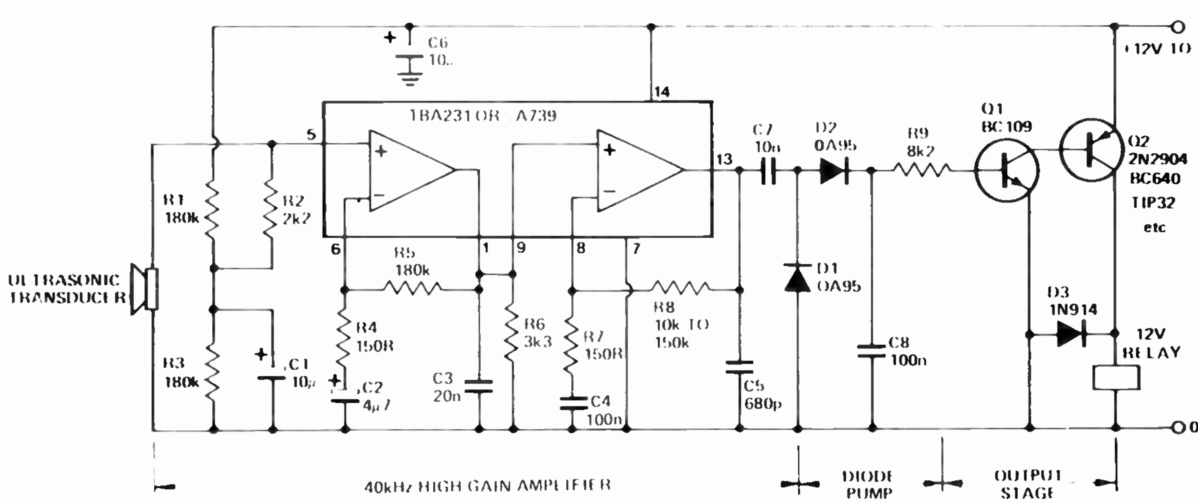



*Figure 7.* **Receiver circuit using the TBA231 or uA739 as a high gain amplifier.**

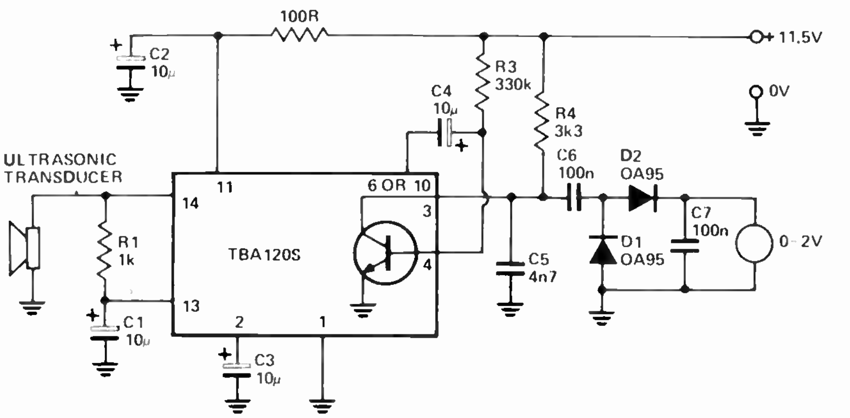



*Figure 8.* **A receiver employing the TBA120S as an amplifier and featuring a meter display.**

Charge from C8 passes through R9 and through the base-emitter junction of the high-gain transistor Q1; a collector current therefore flows in this transistor. The current flowing from the emitter to the base of the PNP output closes whenever ultrasonic waves fall onto the receiving transducer. The 2N2904 output transistor can switch a moderately large current, so a relay which requires a current of 150 mA or more can be employed. Such a relay can switch a substantial current through its contacts — perhaps 10 A in a 250 Vac circuit, so power levels of well over 1 kW can be controlled by this circuit directly.

The resistor R8 in Figure 7 may be adjusted to obtain the required gain. If the sensitivity is too high, spurious signals may cause the relay to close. In particular, the ringing of a telephone bell, even at a distance of some eight metres can cause the closing of the relay. The sensitivity can be reduced by reducing the value of R8. For some applications it is instructive to insert a meter (perhaps 100 mA FSD) in the 2N2904 emitter or collector circuit.

Transducers resonating at any frequency between about 20 kHz and 60 kHz may be employed in the circuits of Figures 6 and 7 with the component values shown. It is only in the transmitter circuits that component values must be slightly changed if transducer frequencies are altered so that the required frequency of oscillation is obtained.

## TBA120S circuit

The circuit of Figure 8 shows how a Philips TBA120S device may be used as a 40 kHz amplifier. The TBA120S is intended for use as an IF amplifier and an output may be taken from pin 6 or pin 10 through a 10n coupling capacitor, as shown, to the base of an internal transistor which is used to provide more gain. In the circuit, R4 forms the collector load and the capacitor C5 was found to be needed to prevent spurious oscillation.

The output or the diode pump in Figure 8 is shown connected to a 2V FSD meter, but it could also drive a two-transistor output stage such as that shown in Figure 7. Indeed, the parts of the circuits shown in this article can be regarded as building blocks which the experimenter can connect together in many different ways, although care may be needed to prevent oscillation.

## ULN-2212 circuit

A very simple receiver circuit for relay control can be made using one of the devices intended for use as a combined intermediate frequency and power amplifier (leaving any volume control circuit unused). The writer has used the LM1808, while the circuit of Figure 9 shows the use of a Sprague ULN-2212 device.

The section of the ULN-2212 intended for use as an intermediate frequency amplifier is used to amplify the 40 kHz signal from the ultrasonic transducer, the bias to the input pin 10 being applied through R1 from pin 11.

The output from pin 2 is coupled to the diode pump, D2 and D3, and the resulting positive potential is fed into the input of the power amplifier at pin 3. This power amplifier can pass enough current to control the relay connected in its output circuit (pin 7). As with the circuit in Figure 7, a diode is connected across the relay to shunt the reverse transient voltage produced when the relay coil current ceases to flow, since this voltage could damage the output device.

Although the circuit of Figure 9 is very simple, it is not so flexible or so sensitive as that of Figure 7.

The diodes shown in the diode pump circuits are germanium point-contact types (OA95), since these are switched to conduction by a potential of about 150 mV. Silicon diodes, such as the 1N914, can also be used in the diode pump circuits but they may not respond to weak signals as do the pump circuits using OA95s since they require about 0.65 V for forward conduction.

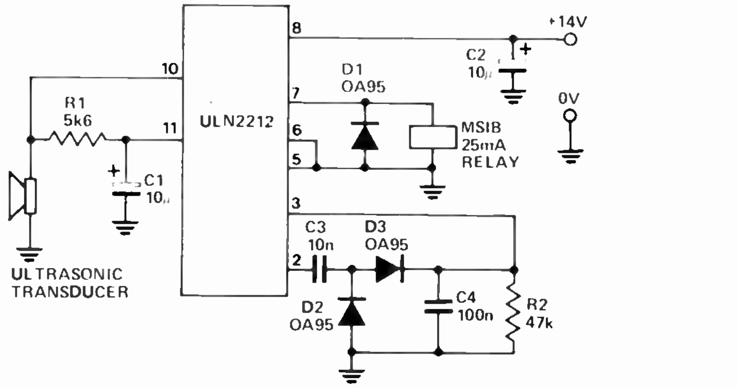



*Figure 9.* **This is one of the simplest possible circuits that will operate a relay from an ultrasonic transducer. The relay should be a sensitive type and may have whatever contact set is appropriate to your application.**

## Applications

The receiver circuits of Figures 6 to 9 inclusive can be employed in simple remote control applications in which one wishes to be able to press a button on a small hand-held transmitter unit in order to cause a relay to close in some equipment up to about 20 metres away. Unlike light beams, ultrasonic communications links are almost unaffected by the presence of rain, fog, snow, smoke or dust. Such a link could, for example, be used to call a person working in a garden shed into the house.

If an ultrasonic transmitter unit is mounted on the front bumper of a car, when the driver reaches his home he can transmit a short pulse of ultrasonic waves to a receiving unit near his garage door which causes his garage ▶

door to be opened automatically by a motor, without the necessity for the driver to leave his vehicle. Similarly, he can close the garage door as he leaves home.

Ultrasonic links have been widely used for the remote control of television receivers, but they have now been largely displaced by infra-red links. The latter tend to be more complex than ultrasonic links, but they do offer the wider bandwidth desirable for the many channels of communication required to control a colour television receiver (which may possibly include a Teletext decoder).

If an ultrasonic transducer is placed in a sealed enclosure, such as the interior of a car or a refrigerator, a receiver unit fitted with a meter in its output stage can be moved around the outside of the enclosure to locate any small leaks in the sealing rubber. The ultrasonic waves can only escape from the interior through any such small leaks and this method of leak detection is generally much more convenient than, for example, waiting until it rains to see where the water enters one's vehicle!

The circuit of Figure 8, or the circuits of Figure 6 or 7 (if fitted with a meter output) are very suitable for this application.

Leaks in pressure or vacuum pipes generate ultrasonic waves which can be used to deflect a meter in a suitable receiver. Thus the leak can be located. Similarly, some types of electrostatic corona discharge produce ultrasonic waves which can be detected in much the same way. Generally however, it is better to convert the ultrasonic frequency into an audible frequency by a heterodyne technique, as discussed later.

A simple transmitter and receiver of the types discussed, operating at a fairly low gain, can be used as an intruder detector. If an intruder passes through the beam, the interruption of the beam operates a relay and this gives the required alarm. Ultrasonic systems have the advantage that the intruder cannot hear the signal. However, the Doppler system to be discussed is normally much more satisfactory than a simple transmitter and receiver, since the Doppler detector is triggered by movement anywhere in a protected room and it is not necessary for the intruder to actually pass through any given point in the beam. Nevertheless, a simple transmitter-receiver is adequate for the protection of a corridor or other narrow area through which an intruder must pass.

Another application for an ultrasonic transmitter-receiver circuit is the remote control of slide projectors. If one wishes to have remote control without connecting wires merely so that one can cause the next slide to be projected, a simple system like those described will suffice. If, however, one wishes to be able to return to an earlier slide and to be able to alter the focusing in either direction, then a four-channel link is needed. Multi-channel systems are most easily constructed using some of the special devices developed for television receiver control.

At one time, the police in certain countries used ultrasonic transmitters to switch on motorway warning lights for fog or ice by merely directing the beam at a receiver near the warning light without stopping their vehicle.

Another application is in vehicle safety belt security systems in which the safety belt emits an ultrasonic tone from a transducer fixed to it; the vehicle cannot be started unless the signal is being received by a transducer mounted near the windscreen. Slightly different frequencies cover the driver and front passenger seats.

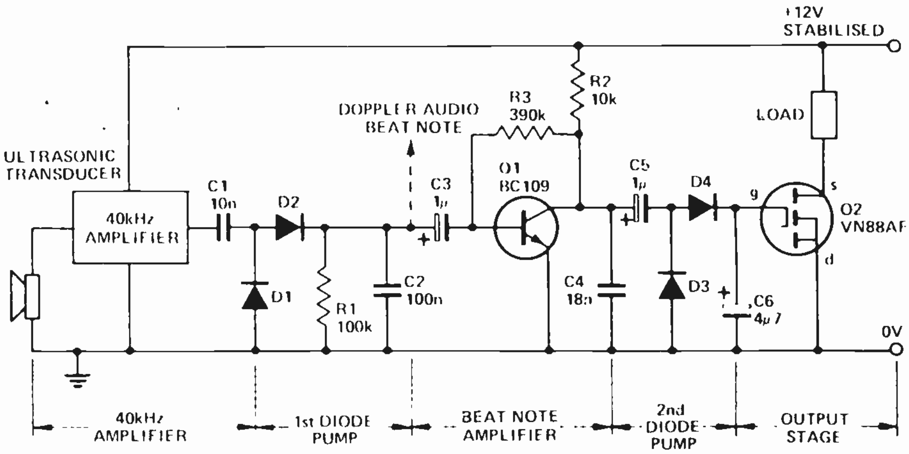



*Figure 10.* **Circuit of a receiver for a Doppler-type intruder detector.**

## Doppler intruder detector

A Doppler intruder alarm receiver circuit is shown in Figure 10. When used with one of the transmitter circuits discussed previously (which should be operated from the same stabilised power supply), the circuit can detect the slightest movement anywhere within a room of the size found in a normal house. The 40 kHz amplifier shown in block form may consist of the discrete circuit shown in Figure 6, up to and including Q4 (so that C9 of Figure 6 corresponds with C1 of Figure 10). Alternatively, the 40 kHz amplifier may consist of that shown in Figure 7, in which C7 corresponds to C1 of Figure 10.

The ultrasonic transmitter is placed in the same room as the Doppler receiver unit of Figure 10, but the two transducers should not be placed so that they directly face one another. The transmitted frequency is reflected around the room from wall to wall and some of the signal will be picked up by the receiver unit. If anything moves in the room, a Doppler-shifted ultrasonic tone will be reflected from the moving object to the receiver so that the two separate frequencies will be amplified by the 40 kHz input amplifier.

The output from this amplifier is fed to the first diode pump circuit so that the difference frequency or beat note is developed across C2. Objects which are moving fairly rapidly in the room develop a beat note in the audio frequency band which can be heard if the signals across C2 (Figure 10) are fed to an audio amplifier. More slowly moving objects develop sub-audio frequencies but the use of large coupling capacitors in the remainder of the circuit ensures that a response to either audio or sub-audio frequencies is obtained. Ultrasonic frequencies are shunted to common through C2.

The beat frequency is coupled by C3 to a single transistor difference frequency amplifier, Q1. Any residual 40 kHz frequency components are filtered out by C4 and the low difference frequency is passed to the second diode pump circuit. This circuit will develop an appreciable voltage across C6 only when a Doppler shifted signal is present at the input in addition to the transmitted signal. The presence of the Doppler-generated signal across C6 can be used to switch on the VN88AF power MOSFET output stage which allows a current to flow through the load and thus sound the alarm.

The power MOSFET output stage of

Figure 10 has been included as an alternative to the two-transistor circuit of Figure 7. The output stage of Figure 7 can be used as the output of the Figure 10 Doppler receiver, and vice-versa.

The writer has also used a circuit of type shown in Figure 10 with a power Darlington output stage controlling a relay. The relay did not close if a person some four metres from the equipment remained absolutely still, but if he breathed in or out (even relatively slowly), the movement of his chest wall was enough to cause the relay to close without fail!

One of the problems with such extreme sensitivity is that of false alarms, since even the occasional false alarm in the middle of the night can cause a great deal of trouble! One should also remember that this circuit is sensitive to any stray ultrasonic frequencies such as the ringing of a telephone bell or even the rubbing of two surfaces together if they are near the transducers. If the transducer of the Doppler receiver of Figure 10 (or the transducer of any sensitive ultrasonic receiver) is tapped with the finger, a considerable response will always be obtained in either an output relay or output meter. It should be noted that a regulated power supply should be used for the Figure 10 circuit, otherwise stray changes in the power line voltage may give rise to false alarms.

The 40 kHz amplifier can be the same type as that used in Figure 6 or Figure 7, its output being fed to the diode pump of the Figure 11 circuit. In addition, signals from an oscillator operating at a frequency close to the frequency of the incoming signals are fed through C2 to the same diode pump circuit. The oscillator circuit can be that of Figure 4, but the output from pin 3 is connected to C2 of Figure 11 instead of to the ultrasonic transducer shown in Figure 4.

The difference frequency between the incoming signal and the oscillator is developed in the non-linear diode pump circuit of Figure 11. The components C3 and C4 filter out the ultrasonic frequency signals and the difference frequency is passed to an audio amplifier through the volume control VR1. Any audio amplifier with a gain of the order of 50 is suitable (such as many of the integrated circuit audio amplifiers on the market). Either a small loudspeaker or an earpiece may be used to produce the audible noise.

Experimenting with a 'bat detector' circuit is of great educational value and makes one appreciate what a vast world of ultrasonic tones we are missing! If one rubs the palms of one's hands together or rubs any two suitable surfaces in front of the face of the receiving transducer, one can hear the rubbing noise, since such rubbing

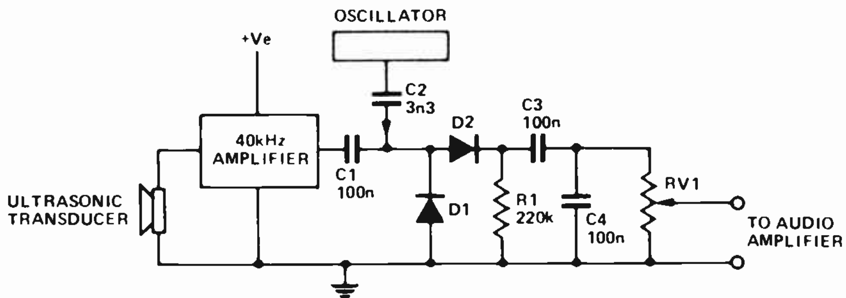



*Figure 11.* **Ultrasonic sounds can be rendered audible by 'heterodyning' the input to an ultrasonic transducer down to the audible frequency range. The frequency range covered depends on the particular transducer employed; i.e: a 25 kHz or a 40 kHz type.**

## Bat detector

A 'bat detector' converts incoming ultrasonic waves into audio signals which can be heard. In order to construct a bat detector which will respond to a wide range of ultrasonic frequencies, an expensive ultrasonic microphone is usually needed. However, reasonable results can be obtained using a cheap ultrasonic transducer in the type of circuit shown in Figure 11. No transmitter unit is needed.

generates ultrasonic waves. Snapping a finger and thumb together or blowing air through one's teeth are other simple ways of generating ultrasonic waves.

The performance of the Figure 11 circuit does not vary very much as one changes from 40 kHz to 25 kHz transducers, although one is listening to different frequency bands in the two cases. In addition, it does not make much difference whether one has the oscillator operating above or below the ultrasonic frequency to which one is listening. Indeed, no oscillator is required when receiving the ultrasonic waves from rubbing two objects together since the range of frequencies generated by such objects beat with one another.

The oscillator is required when receiving a note from an oscillator connected to an ultrasonic transmitting transducer (such as the circuits of Figures 3 to 5). The use of a transmitter with the bat detector circuit of Figure 11 results in a clear note being produced which it is easy to pick out amongst the noise. The writer found that the note could be detected when the distances between the transmitter and detector were as much as 35 metres in the open air. The maximum distances indoors are greater, since there is less stray ultrasonic noise to interfere with the wanted signal. In particular, ranges in a corridor can be considerably increased by reflections of the ultrasonic waves from the walls towards the receiving transducer. A further increase in the range can probably be obtained by placing the transmitting transducer or the receiving transducer, or preferably both, at the focus of parabolic reflectors.

It is interesting to note that bats emit ultrasonic vibrations between about 25 kHz to almost 160 kHz, whilst small rodents can emit vibrations from about 90 kHz down into the audible range. Insects such as grasshoppers and some moths emit frequencies up to about 80 kHz — 100 kHz. Some of these vibrations can be detected by the Figure 11 circuit, but for optimum results a purpose-built bat detector costing about $1000 is needed. The writer has used the Figure 11 type of circuit to detect the ultrasonic emissions from young mice a few days old by which they communicate with their mother.

## Conclusions

This article has been written to show the experimenter how he can use economical equipment for ultrasonic work. No attempt has been made to cover some of the more difficult aspects of the subject, such as voice modulation of ultrasonic waves for intercom systems or the measurement of distances by ultrasonic pulse techniques or the measurement of wind velocity. The aim has been rather to show what can be done easily by the use of simple circuits.

One can even use one of the circuits of Figures 3 to 5 inclusive to call a dog which has been trained to return to its master on hearing the ultrasonic tone, but it is advisable to use a relatively low frequency for this purpose (20 kHz to 25 kHz) to minimise air absorption and to use a frequency to which the dog is most sensitive. ●

# Shoparound

THIS PAGE is to assist readers in the search for components, kits and printed circuit boards for the projects in this book. If you are looking for a particular component or project — check with our advertisers if it is not mentioned here.

## ETI-561 metal detector

The only specialised component in this project is the crystal. However, it is stocked by Radio Despatch Service, Dick Smith Electronics, Ellistronics, Rod Irving, All Electronic Components and Altronics. All these suppliers carry ETI-561 pc boards and the other components.

The project is available in kit form from All Electronic Components and Rod Irving.

## ETI-1500 metal detector

The case, handle and head in this project are made by the UK firm Altek Instruments who are represented in Australia by All Electronic Components. Complete kits are available from them as well as Electronic Agencies. Spare search heads are stocked by Electronic Agencies, but, as they're hand made they're not cheap. The pc board and electronic components are stocked by Radio Despatch Service.

University Graham Instruments can supply a 50-0-50 uA meter with a special scale to suit this project. It is colour-coded: red to left of centre (bad), green to right (good). The pointer is painted fluorescent orange so that it is more readily visible from the normal carrying position of the instrument.

## ETI-325 auto-probe

A kit for this project is stocked by All Electronic Components. Printed circuit boards and the components are stocked by Dick Smith Electronics, Radio Despatch Service, Ellistronics and Rod Irving.

## ETI-324 LED tacho

Complete kits for this project are stocked by Electronic Agencies, All Electronic Components, Dick Smith Electronics and Rod Irving.

Printed circuit boards and components are stocked by Altronics and Radio Despatch Service.

## ETI-326 expanded scale LED voltmeter

Designed around the LM3914, which is widely stocked by suppliers, this project should not be difficult to get together. The pcb and components are stocked by Ellistronics and Radio Despatch Service. kits by Dick Smith and All Electronic Components.

## ETI-320 battery condition indicator

All bog-standard bits here. Kits from Dick Smith and All Electronic Components. The pc board and components can be obtained at Radio Despatch Service.

## ETI-456 140 W valve amp

The transformers, valves and components for this one can be obtained via All Electronic Components, Electronic Agencies and Radio Despatch Service.

## ETI-496 Series 4000/1

Complete kits are available from Electronic Agencies and Pre-Pak Electronics. The drivers are distributed by Sycom. Crossovers, either assembled or in kit form, are made by Selectronic Components and distributed by Rod Irving Electronics.

## ETI-476 Series 3000 stereo

Complete kits for this project are available from All Electronic Componets, Rod Irving, Tasman Electronics and Radio Despatch Service. The case, pc board and components can be obtained from Ellistronics, David Reid Electronics, Dick Smith, Magraths and Radio Parts.

## ETI-475 AM tuner

Kits for this one are stocked by Radio Despatch Service and All Electronic Components.

## ETI-457 scratch and rumble filter

A kit for this project is stocked by All Electronic Components. Bits and boards are available from Ellistronics and Radio Despatch Service.

## ETI-131 power supply

Kits are sold by Nebula Electronics and All Electronic Components. Parts and pcbs available from Radio Despatch Service.

## ETI-142 power supply

Kits from All Electronic Components (as usual) and boards etc from Radio Despatch Service.

## ETI-255 electronic thermometer

Complete kit is stocked by All Electronic Components. Parts and pcbs from Tasman Electronics, Altronics, Ellistronics, Magraths and Radio Despatch Service.

## ETI-572 pH meter

Complete kits, including the probe and solutions, can be obtained from Electronic Agencies and All Electronic Components. Boards and bits from Radio Despatch Service. Suitable pH probes and acessories are available from Starcross Scientific and Linbrook International. Collet knobs are distributed by C & K Electronics and Associated Controls.

The ICL7106 IC and 3½-digit LCD display are obtainable from R & D Electronics in a 'kit' called the RIK6017.

## ETI-562 geiger counter

The printed circuit board and components for this project are available through All Electronic Components and Radio Despatch Service. They may also be able to supply the Geiger tubes. The latter are distributed by Sycom.

## ETI-724 microwave oven leak detector

Complete kits are available from All Electronic Components, Dick Smith and Electronic Agencies. Boards and bits from Altronics, Tasman Electronics, Radio Despatch Service and Ellistronics.

## ETI-546 GSR monitor

The full kit is stocked by All Electronic Components. Boards and bits by Radio Despatch Service.

## ETI-250 simple house alarm

Kits (electronics only) are available from All Electronic Components and Rod Irving. Parts and pcbs can be obtained from Radio Despatch Service and Ellistronics. Dick Smith stocks suitable reed switches, alarms and other items.

## ETI-558 masthead strobe

Complete kit for this one is stocked by All Electronic Components. Boards and bits by Ellistronics and Radio Despatch Service. The CZT127 xenon flash tube and a suitable trigger transformer are sold by Circuit Components.

## ETI-564 digital clock

Kits are obtainable from Rod Irving and All Electronic Components. Parts and pcbs from Ellistronics and Radio Despatch Service. The polarised plastic is sold by Polaroid Australia; offices in each state capital.

## ETI-565 laser

A complete kit for this is sold by Laser Electronics, P.O. Box 359, Southport QLD (075)32-1699. They also sell just the tube and transformer. The pcb and other components are available from Radio Despatch Service and All Electronic Components. The 10n/5 kV capacitors may be hard to get; try David Reid Electronics, Martin de Launay and Radio Parts.

## Ultrasonic transducers

Suitable ultrasonic transducers, both housed and unhoused, may be obtained from: Magraths, All Electronic Components, Dick Smith and Altronics.

## PCB suppliers

All pc boards for the projects in this book are stocked by RCS Radio, Radio Despatch Service, All Electronic Components, Willis Electronics, and Trilogy.

Scotchcal front panels and labels may be obtained from All Electronic Components, Radio Despatch Service and Rod Irving Electronics.

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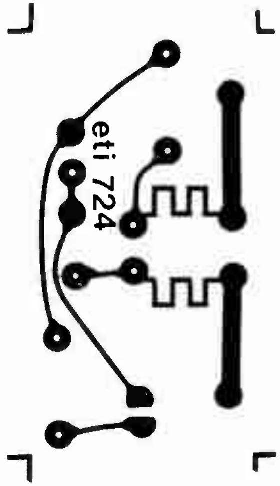
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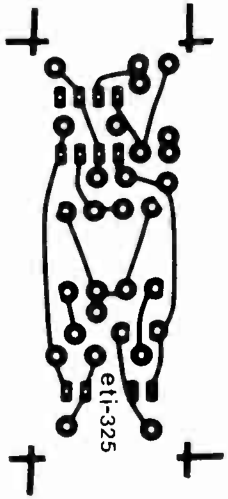
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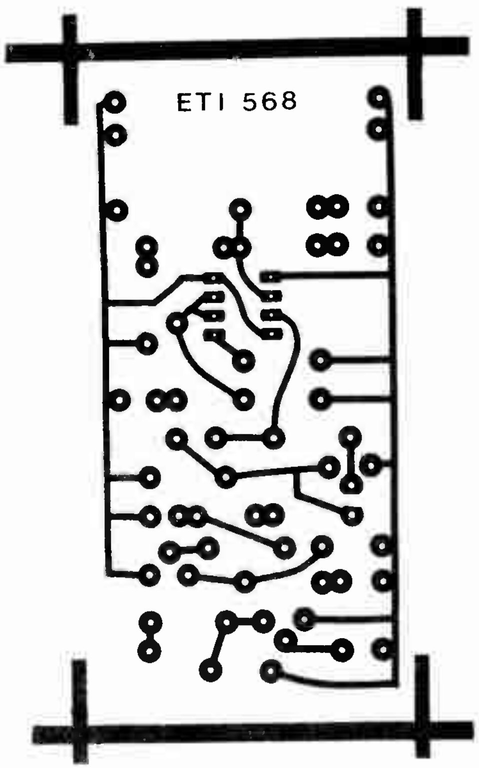
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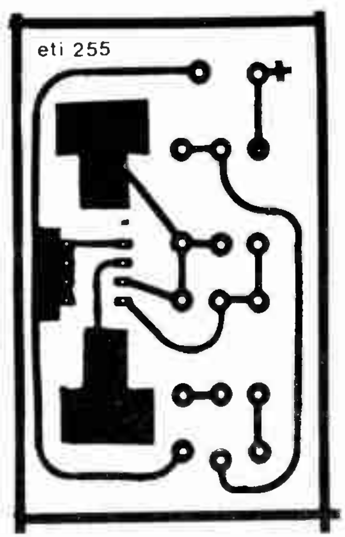
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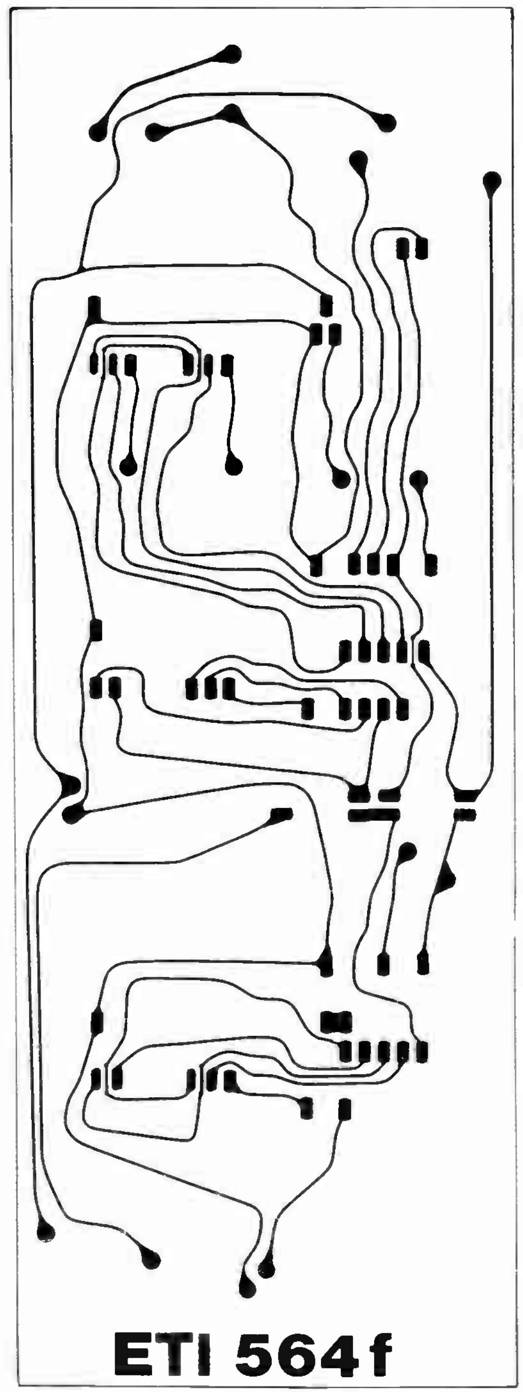
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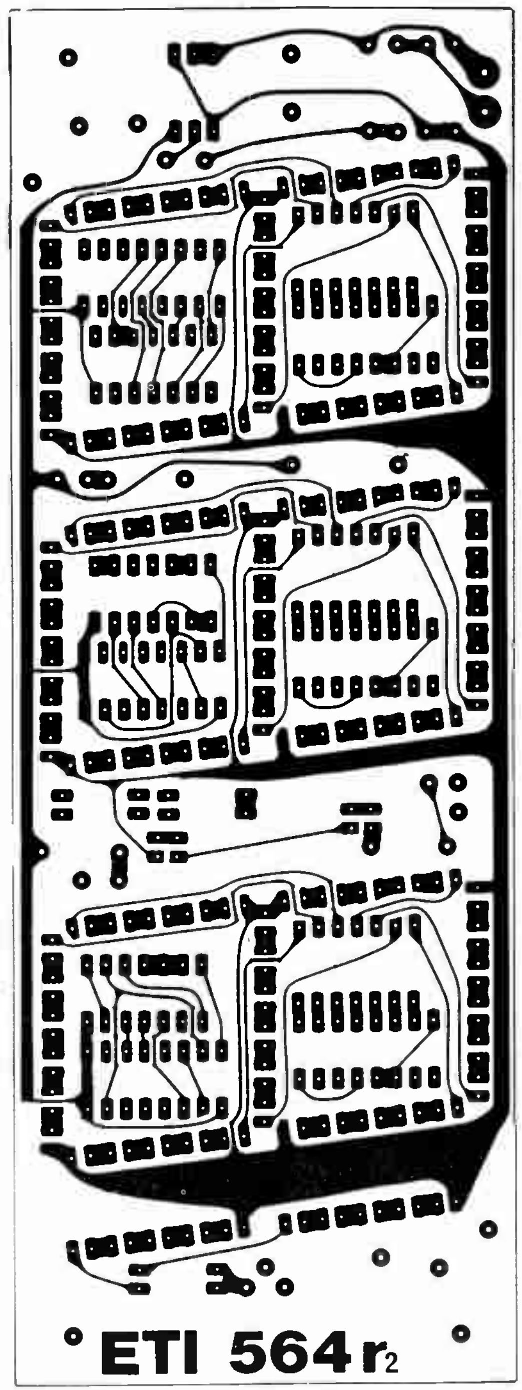
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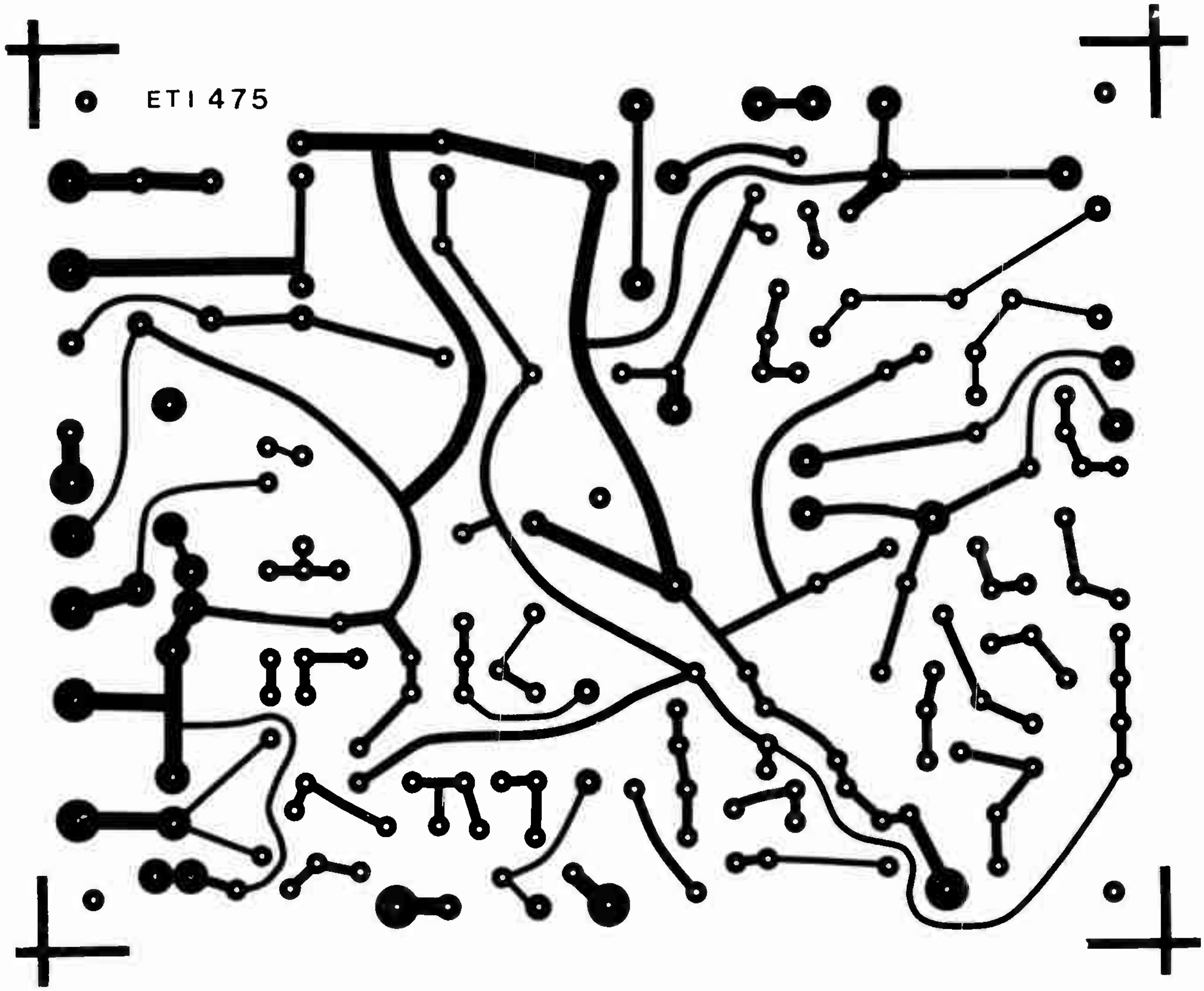
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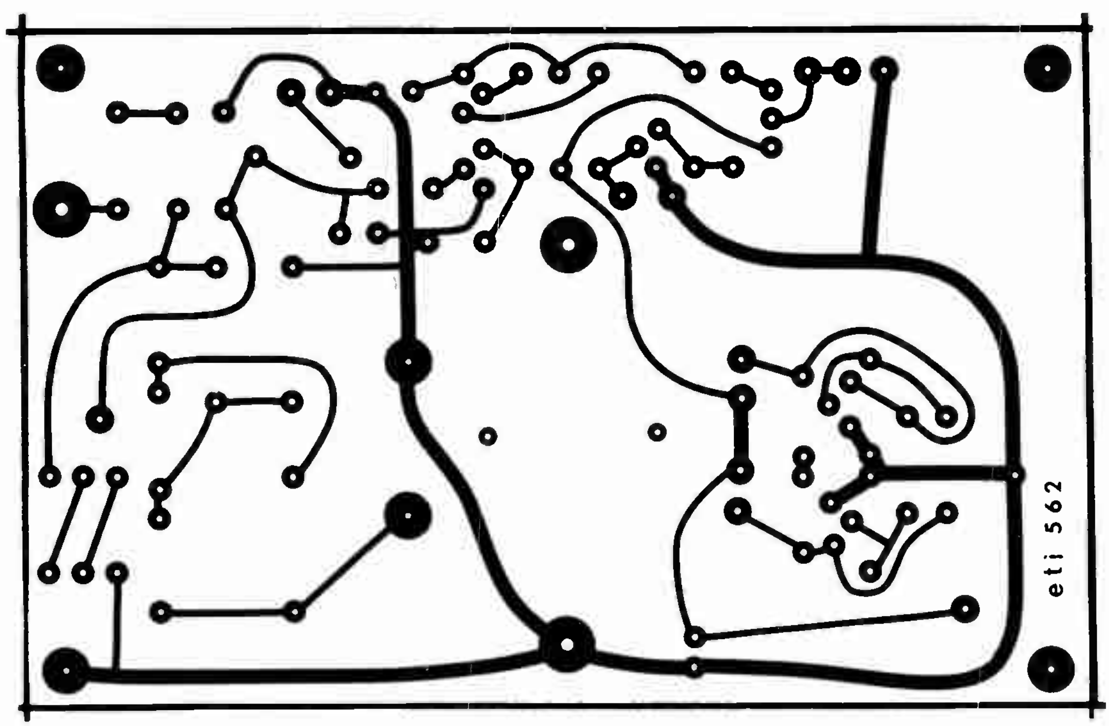
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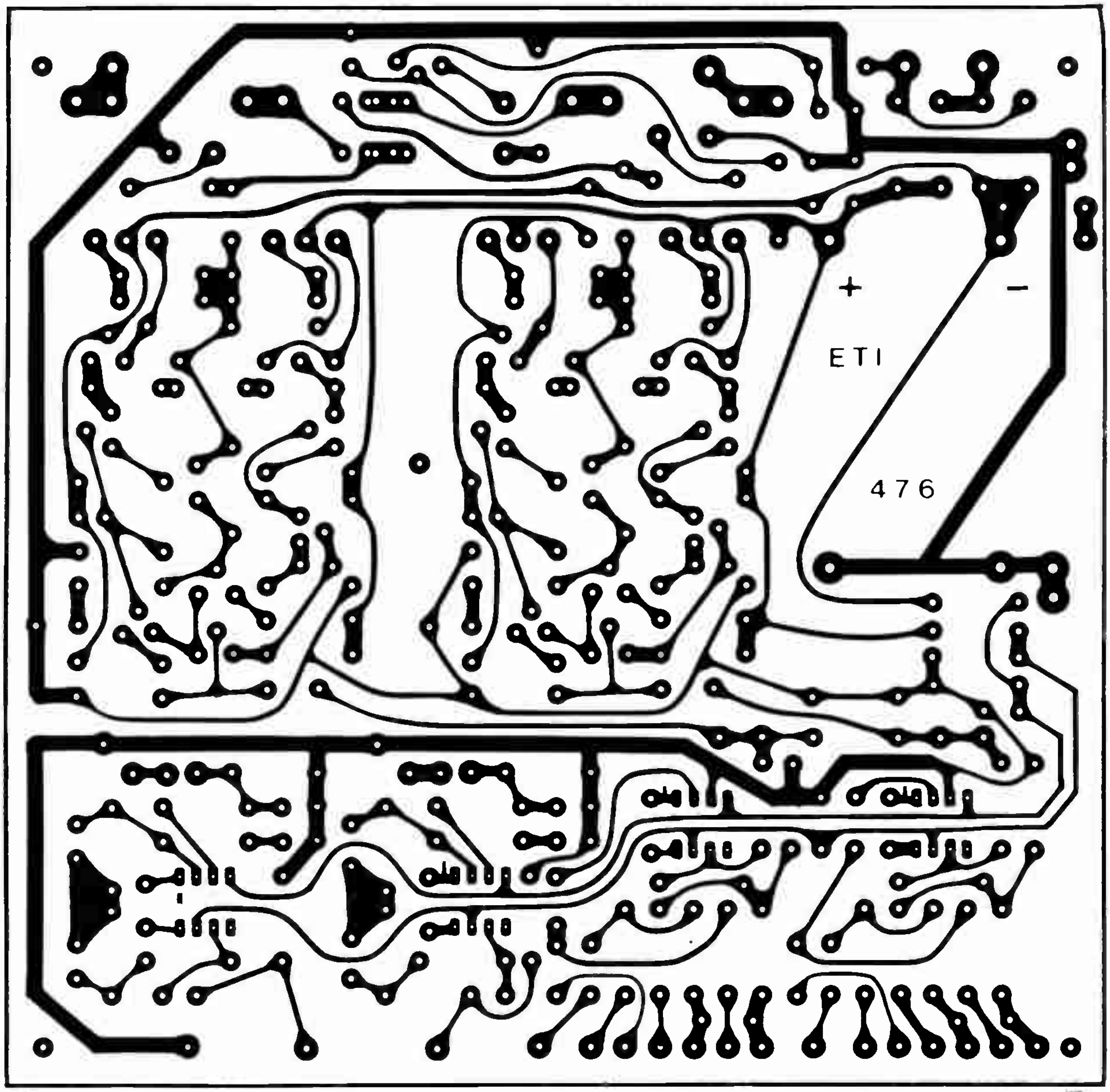
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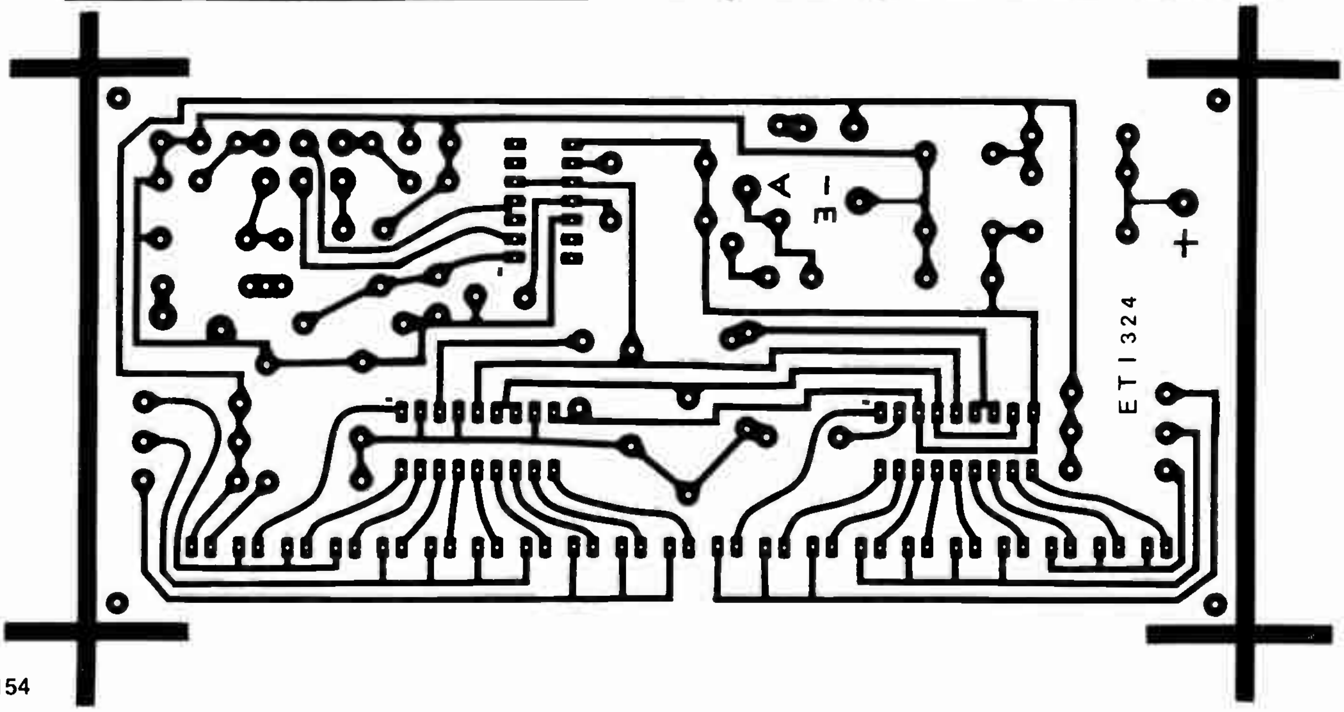
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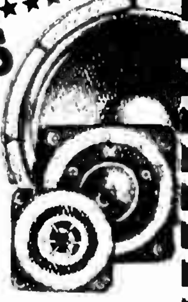

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