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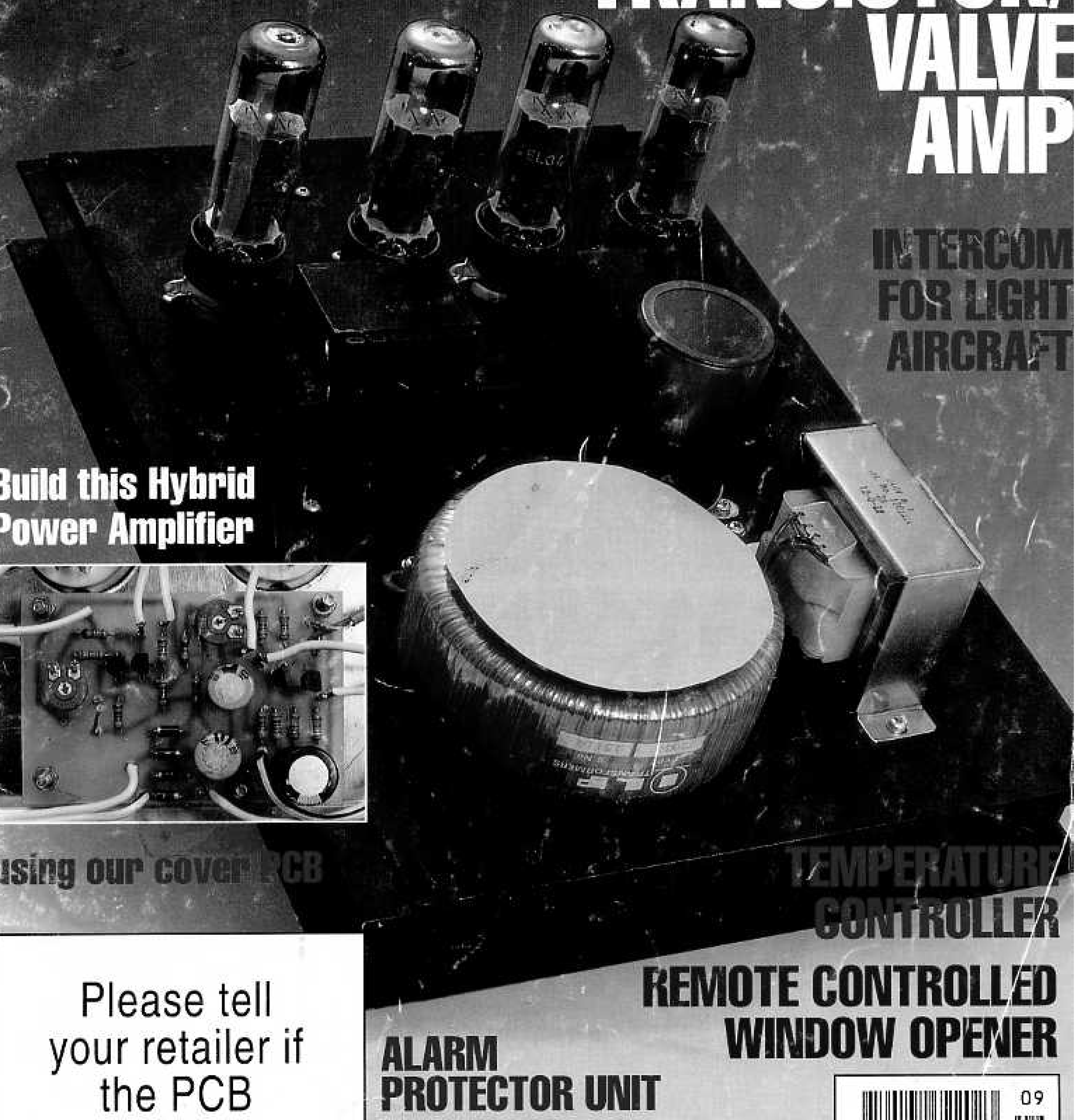
45W DIRECTLY COUPLED TRANSISTOR/ VALVE AMP



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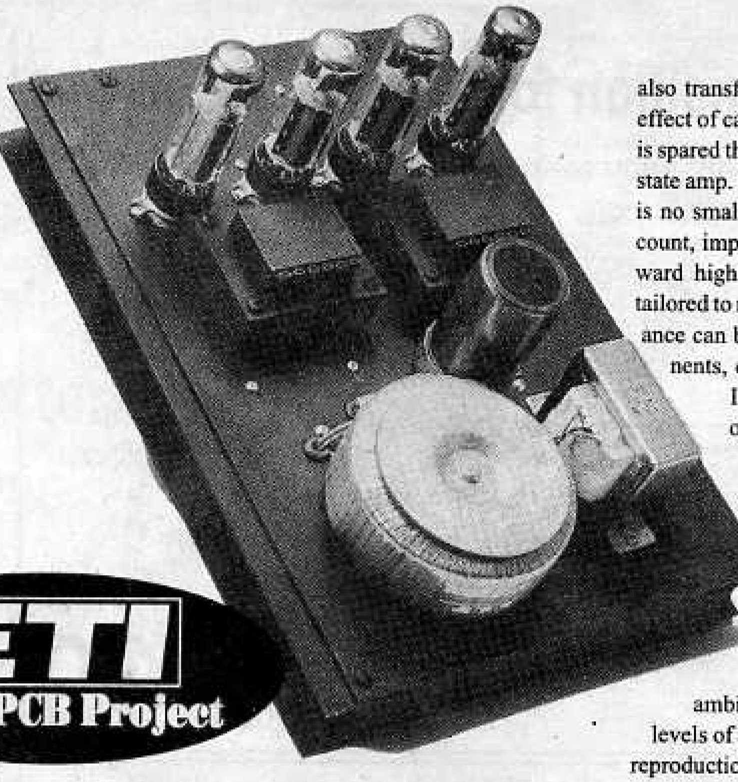


ETI Cover PCB Project

45w Hybrid Power A

Use our free PCB to help you construct this transistor/valve amp. Presented by Jeff Macaulay

Although transistor power amplifiers have ruled the roost since the late 60's there are many, myself included, who have yet to hear anything sounding better than a pair of EL34s working in push pull. The EL34 was first introduced by Philips in 1956. With an anode dissipation of 25W this valve produced something of a revolution in the design of audio amps. After all, in those days a 10W amp was considered high powered. A pair of EL34's, correctly biased, can produce 45W of power. Whats more the valve is vastly more linear than a transistor output stage and can be operated with considerably more bias, relatively speaking than a transistor output stage.

Traditionally valve amplifiers have been designed around cascaded small signal triode amplifiers. This well tried and tested method is simple to implement but requires extensive capacitive coupling. In an audio amplifier based on valves the ammount of feedback that can be applied depends on the phase shifts imposed by the various stages, coupling capacitors and the output transformer. However it is possible to build a power amp taking advantage of the standard push pull valve output stage that has very little phase shift and that can be directly coupled together.

The main gains to be had from a valve amplifier stage include class A operation without the need for huge mains transformers and heatsinks. The ability to cope with very awkward speaker loads without distress, plus the ability to shrug off short circuit at the output. Valve output stages are also transformer coupled which means that in the unlikely effect of catastrophic failure of the valves the speaker system is spared the damaging DC currents that would flow in a solid state amp. Considering the cost of a good speaker system this is no small advantage! Direct coupling reduces component count, improves transient response and allows a straightforward high performance design to be realised that can be tailored to modern requirements. Also high levels of performance can be realised without recourse to expensive components, especially coupling capacitors.

I listen extensively to CD's and to realise the optimum performance of this medium the specification of the amp must comply with stringent requirements. In particular I don't want hum or noise to detract from my enjoyment. Frequency response must extend to at least 15Hz at the low end and 50kHz at the top. THD must be firmly below 0.1% at all levels and frequencies below clipping level. The proper reproduction of low level detail and ambience effects require class A operation at least at levels of a few watts. In many ways S/N ratio and low level reproduction are closely related. Bearing in mind the relatively high impedances and supply voltages required in a valve amp some method must be devised to keep noise pickup below audibility. Here silicon transistors score heavily. Apart from not requiring heaters they are generally much quieter devices.

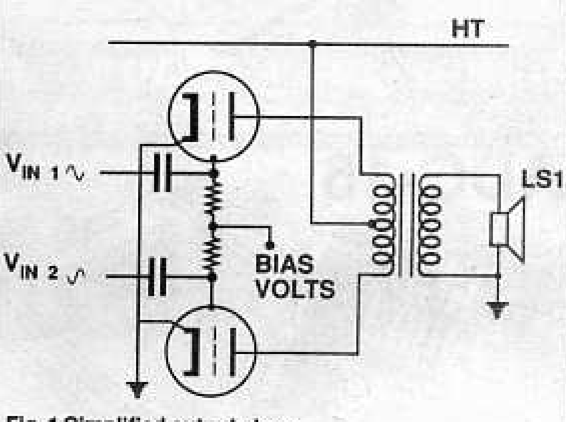


Fig. 1 Simplified output stage

To achieve quiet operation of the circuit a fully balanced design is used. As there is no such thing as a PNP valve, valve output stages tend to look wierd to our eyes. In fact the output stage is quite straightforward when broken down into it's component parts.

A simplified valve push pull output stage is shown in Figure 1. First the output transformer. Output valves are capable of producing plenty of power but unlike transistors they are high voltage high output impedance devices. The output impedance of an EL34 varies with bias but is of the

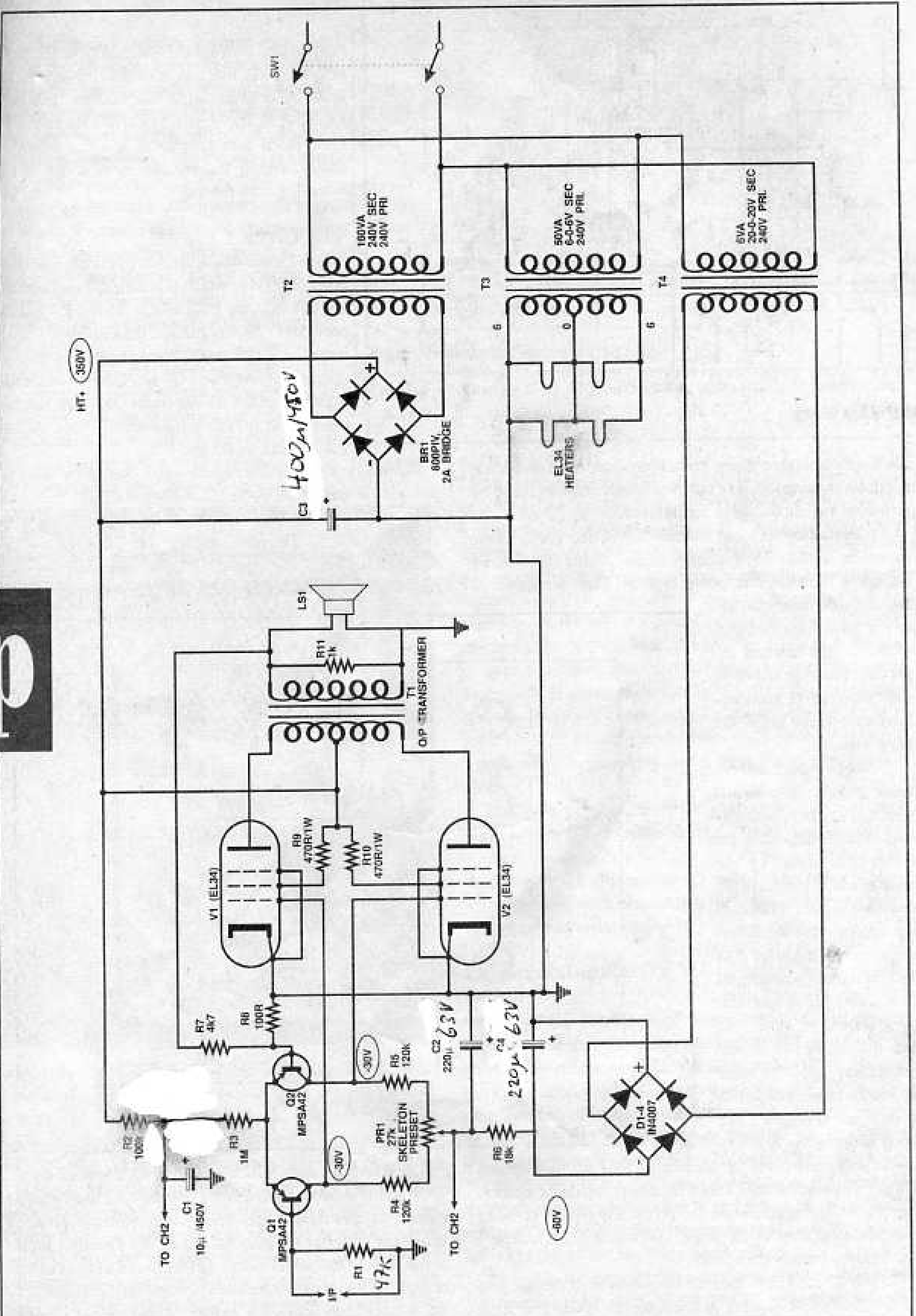


Fig. 2 Circuit diagram of Hybrid Power amp

order of several kilo-ohm. To produce a drive suitable for feeding into a speaker a stepdown transformer is required.

This not only steps down the voltage but also steps up the current available. By suitable choice of primary and secondary windings the correct ratio is obtained. Notice that the centre tap of the transformer primary is connected to the HT voltage. This has several ramifications. Firstly the anode current flows through both halfs of the transformer. When the stage is correctly biased these currents are equal. The transformer coil therefore doesn't magnetise or saturate as it

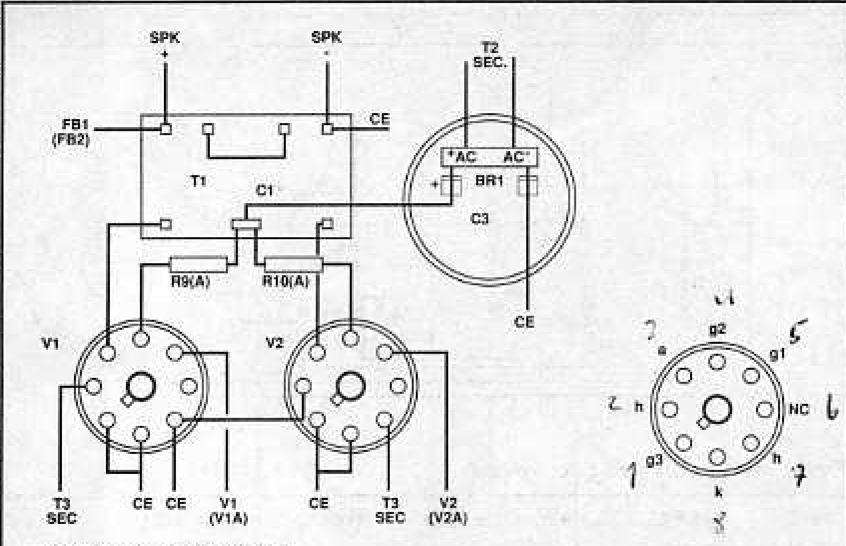


Fig.3 Output stage wiring

could with a single ended output. Increasing drive levels will not cause magnetisation of the transformer either because the signals at the anode are in antiphase.

Unfortunately any old transformer of the correct ratio cannot be used as a high quality output device. To enable a good low frequency response high primary inductance is required. Similarly, to obtain a good high end performance the internal capacitance must be kept low. This is one of the main reasons that valve amps are expensive.

To work in push pull the valve grids have to be fed with 180+ out of phase signals. This is usually done with a circuit called a phase splitter which produces the requisite signals. The modern equivalent is the differential pair of transistors. In fact this circuit was derived from valve phase splitters.

It should be clear that, because the circuit is balanced, any ripple or noise appearing on one anode will also appear on the other.However because they are in phase there will be no output from the transformer. Unless steps have been taken to ensure adequate balance using a voltage regulator on the HT, it will merely disguise incorrect operation of the stage. Unbalance is immediately apparent by hum in the speaker!

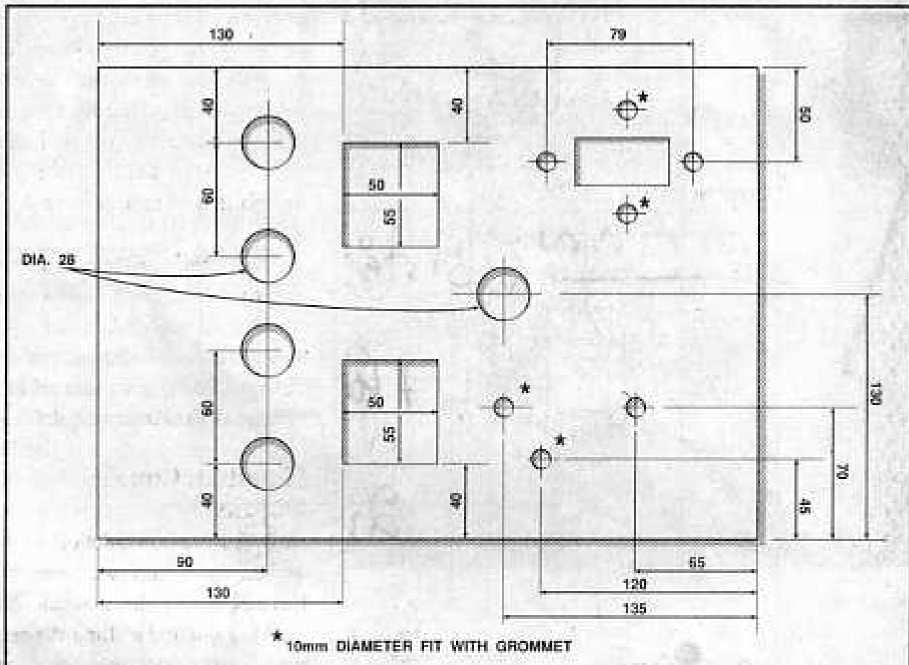


Fig.4 Case Details

In this design I have used the inherently high voltage gain of small signal transistors to eliminate the usual first stage valve. The phase splitter can be substituted with a high gain differential pair of transistors and these can be directly connected to the grids of the output valves providing both drive and bias.

Valves require a negative bias voltage on their grids to operate correctly. Normally this is achieved by connecting a small resistor between the cathode and ground. This works because the valve's current produces a voltage drop across the resistor thus providing the bias. A better method is to use fixed bias. As it's name implies this is done by connecting the cathode to earth and applying an appropiate negative voltage to the grid. Fixed bias requires a separate negative voltage supply but enables more output to be extracted from the valve.

The Circuit

Figure 2 shows the schematic of the amplifier the other channel of which is identical. Input signals are fed into the base of Q1 across R1 which provides Q1's bias and sets the amplifier's input impedance. Q1 and Q2 form a long tailed pair or differential amplifier. Q1 and Q2 are connected together by their emmitters and share the operating current provided from the HT line by the voltage divider R2 and R3.

Normally a separate transistor stage would be used to provide tbe current but as the HT voltage is so high the value of R3 is sufficiently high at 1 Megohm to provide constant current operation. This considerably simplifies the circuit. R2 and C1 form a decoupling network which removes any ripple present across R3. Both Q1 and Q2 are operated in the common emitter mode which providing high voltage gain.

In addition these transistors are operated at a low collector current to minimise noise. The output voltages obtained across the collector resistors R4 and R5 are directly coupled to the grids of the output valves. In this circuit a negative bias is required for correct valve operation and this is produced by the voltage drop across R4 and R5. As no overall negative feedback is applied at DC it is necessary to incorporate some method of balancing tbe drive signal to the output stage. This is the function of PR1.

It is hopeless using high tolerance resistors for R4 and R5 and expecting the circuit to automatically balance. This is due to both gain variations between ostensibly identical transistors and the difference in biasing components between the two halfs of the circuit. Also, although much closer matched than transistors in regard to parameters. The voltage gain of the stage can be made identical by varying the load resistors.This works because although the transistors will have different operating currents the voltage gain of the transistor stage is dependent only upon the voltage across these resistors.

It is common practicwe to place a small series resistor in the grid circuit.These components, called grid stoppers form a filter at RF with the valve's input capacitance. However as the amplifier is unconditionally stable without these devices their inclusion confirs no benefit and are thus ommitted.

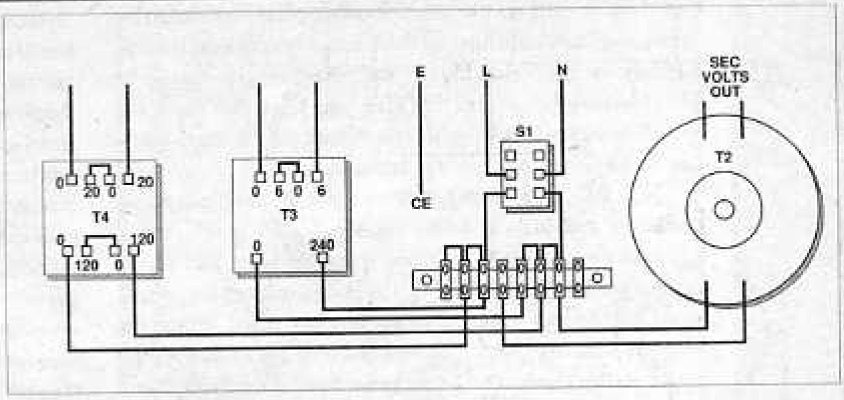
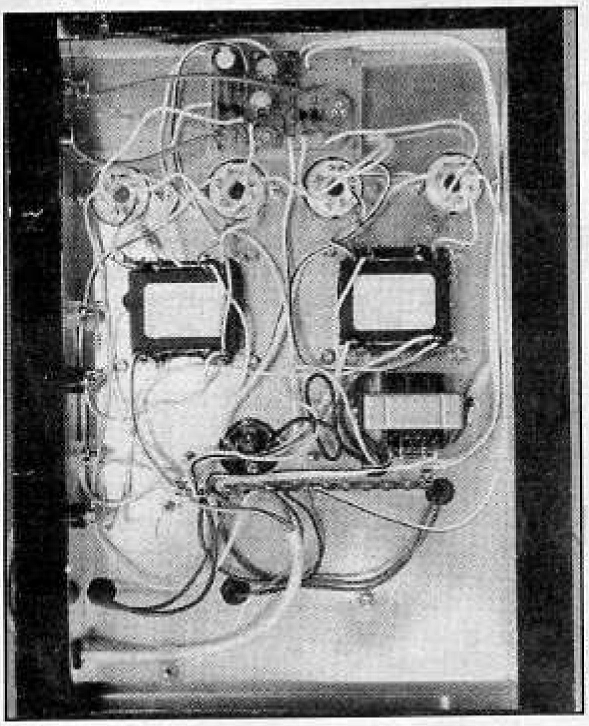


Fig.5 Power supply wiring via tag strip

Fixed bias is used for the valves. That is to say the cathodes are directly connected to ground. This method of biasing requires the negative grid bias voltage but allows more output to be obtained before clipping sets in.

The output devices are the venerable EL34s. This valve, an output pentode first made it's appearance in 1956. When



yours truly was in short pants. Despite the intervening years, or maybe because of them no worthwhile alternative has been forthcoming. To operate as a pentode the screen grid [g2] has to be fed with current from the HT supply. This is the function of R9 and R10. An alternative method of operating the valves is to tie the anode and g2 together to form a power triode. However, although believed to be audibly superior to pentodes by some, the output power produced is very much lower than with the standard pentode connection. As previously mentioned the output transformer is connected across the valve anodes with the centre tap being connected to HT. The voltage gain of the output stage just about compensates for the step down ratio of the transformer. Most of the open loop gain of the amplifier is contributed by Q1 and Q2. The output proper is obtained by connecting the speaker across the output transformer's secondary. Overall negative feedback is taken from the hot side of the secondary and applied to the base of Q2 biasing it's base to ground at the same time.

The overall voltage gain of the circuit is set by the ratio of R7 to R8 at 22, 13dB and sets the sensitivity to 650mV for full output.

Power Supply

Three voltages are required by the amplifier. The HT voltage of 350V is obtained by rectifying the secondary voltage of T1 by BRI and subsequent smoothing by C3. The valve heaters require 6.3V AC and this is obtained from a separate 6-0-6V AC secondary transformer whose primary is connected in parallel with T1's. One side of the heater supply must be connected to the negative power supply line. Otherwise the circuit will be prone to hum pickup. The 6V secondaries are connected in series and the valve heaters are connected in series parallel across the resulting 12V AC. The connection between heaters is connected to common ground. EL34's need 1.5A of heater current each so a reasonably rated transformer is required for this task. A 50VA type proved ideal.

Lastly the transistor circuitry requires it's own separate negative supply rail. In this design, a small transformer, T4 is used. the secondary voltage is full wave rectified and smoothed by C4. One side of the supply the positive side, is connected to system ground and the requisite negative bias voltage is thus made available.

Constructional Details

As usual the construction of a project such as this can be broken down into two parts, mechanical and electronic. In this case the mechanical side should be tackled first. Start by marking out and drilling the case as shown in Figure 4. The case consists of six separate pieces. The top and bottom panels are of 2mm thick aluminium. The side panels are 3mm thick aluminium channel sections 25mm by 37mm. The usual flimsy 18SWG of the shelf cases cannot be used because of the amount of weight that has to be carried. Once the main apetures have been drilled or punched up attention can be turned to the partial assembly of the case.

First drill out the 3mm dia holes around the periphery as shown in the figure. Bring the drilled top panel together with the side panels and, using the top panel as a template mark out the mounting holes on the sides. Screw the top panel and sides together using the self tapping screws provided. At this stage drill the peripheral screw mounting holes into the bottom panel. Turning your assembly top panel down mark out and drill pilot holes to take the self tapping screws. At this stage don't screw the bottom panel into position. Now attention can be turned to the output valve holder apetures.The best way to cut these in the panel is to use a Qmax cutter. Alternatively a saw hole cutter can be used fitted into an electric drill chuck. Whichever method is chosen the hole diameter should be 1.125",29mm in diameter. Once you have cut these out position the holders in the holes and mark out the fixing screw positions. Drill these with a 3mm, drill.

Now take the PCB and position it on the panel as detailed, mark out and drill the fitting screw holes.

Lastly cut the 0.375",10mm Diameter holes and fit the grommets into place. Next fit the main components, output transformers and input/output sockets into place. Mount the holders with 6BA or M3 screws and nuts. Be sure to mount them so that the locating slots point toward the PCB. Don't forget to fit T4 into position. This component is sufficiently small to fit 'dead insect' fashion inside the chassis so avoiding the chore of having to insulate terminals etc.

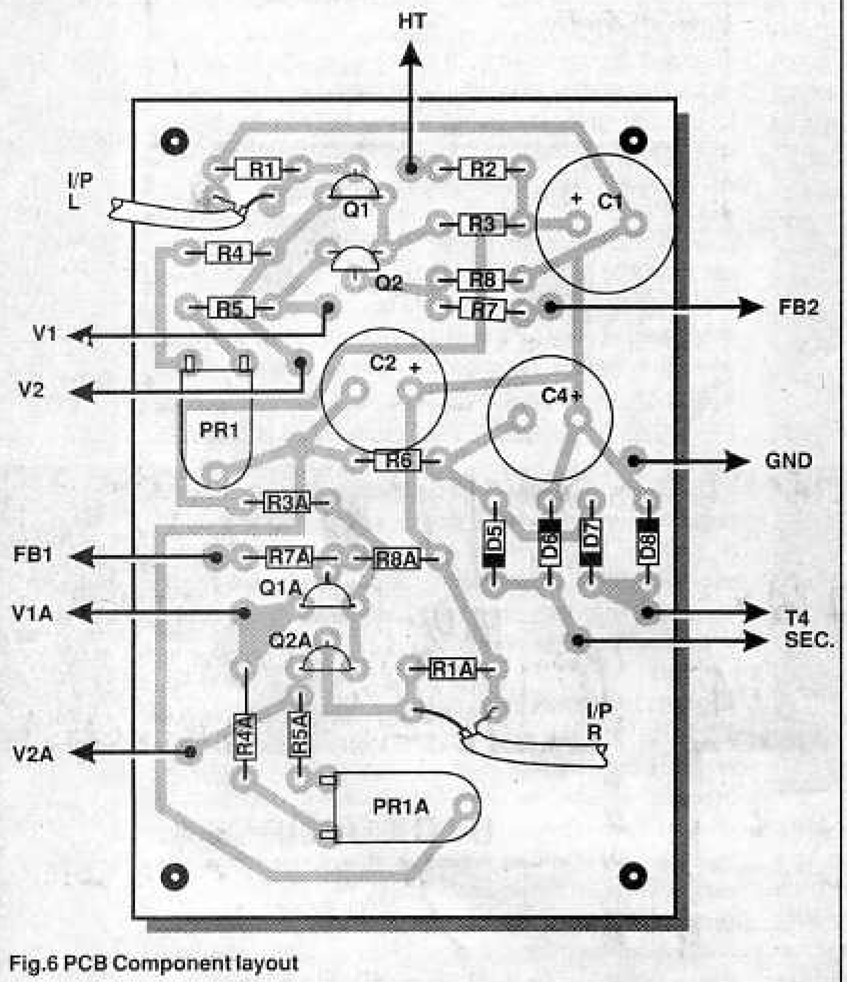


Fig.6 PCB Component layout

Having got this far the PCB can be wired up prior to fitting into position. No real comment is required about this just ensure that all the polarised components are correctly orientated before soldering them into position (See Figure 6). This done solder Veropins to the input and output pads. The board can then be mounted underneath the top panel spaced away by 4 x 6mm insulated spacers.

Before commencing the panel wiring now is the time to finish the panels in the manner of your choice. The prototype was sprayed matt black and legends were applied with white rub down lettering. The latter being fixed into place with a clear varnish spray. Both the paint and spray were obtained from my local modelling supply shop.

Panel wiring is done with 5A twin speaker wire obtainable from Halfords. A £1.35 reel being sufficient to wire the whole circuit. With reference to the wiring diagram start by wiring the power supply up via the tagstrip, as shown in Figure 5. Having done this the output stage can be wired up to the power supply and output transformers. The figure shows one channel the other being identical. The wires marked 'CE' are connected to a common point on the chassis.

Although it's location is unimportant a suitable place is on a solder tag on one of C3's mounting screws. Don't be tempted to join all the nearby CE wires on the schematic together. To maintain stability they must be separatly run to the earthing point. Similarly note the heater wiring. The valve heaters are connected in series across the 12V AC secondary of T3. The centre tap of the winding is unused and should be cut back. Pull it through the grommet and wrap a copious layer of insulating tape around it, to keep it out of harms way. The last bit of wiring is to connect the various flying leads to the board pins. Notice that R9 and R10 are not mounted on the board but are directly connected from valve to transformer T1 (Figure 3). Leave the bottom panel off to facilitate testing.

Setting Up

Once the circuit has been completed it only requires setting up to be fully functional. This is a quite simple proceedure that may be done with the aid of a multimeter, a screwdriver and a pair of ears!

Before applying power run a though check of all your wiring. Look especially that the electrolytics are correctly orientated, especially C3 which if reversed could have disasterous consequences. Once satisfied that all is well the next stage is to power up the circuit. Make sure that the valves are fitted and temporarily disconect the earth lead from the mains plug. The valves will have to be eased in gently. Octal holders are notoriously tight fitting especially when first used. Line up the valve with the socket and applying gentle pressure rock the valves into position. Prop the circuit up securely on its side. Firmly lodge the negative lead of your multimeter in the case so that it makes a good connection with the metalwork.

With your multimeter switched to a range that will give a good indication of 350V you are ready to start. Remember that high voltages are present on the chassis. The golden rule is not to let yourself come in contact with the circuit whilst it is switched on. A habit that is well worth cultivating is to keep one hand behind your back while testing.

With SW1 switched on apply power to the circuit. Watch for the heaters to start glowing after a few seconds. You can ignore the odd crackling sound as the glass envelopes heat up! If they don't you have a problem. In this eventuality switch the circuit off and monitor the voltage across C3. Before touching the circuit you will have to allow sufficient time for the voltage across this component to fall to a safe level. At least half an hour! Assuming all is well measure the voltages at Q1 and Q2 collectors, across R4 and R5. They should read approximately -30V. Don't worry if the the two voltages are different they probably will be. Setting up consists of matching them both up. With your testmeter set to a suitable low voltage range adjust PR1 until you get the two voltages approximately in balance. Switch off the power. Check that the voltage across C2 falls rapidly.

Temporarily disconnect the feedback wire from the board. Short out the input - attach a speaker and power up the circuit. After a few seconds the valves should begin to glow. After a few seconds more a slight hum accompanied by a low level hiss should emanate from your speaker. A few seconds more should see the hum subside to a much lower level. This initial hum is quite normal and coincides with the valves turning on. As this happens the anode currents are unbalanced hence the hum. Now getting your ear as close as possible to the speaker adjust PR1 slowly a quarter of a turn first in one direction then the other. What you are searching for is a null where the remaining hum disappears indicating perfect output balance. Once you've found it repeat the adjustment for the other channel then leave well alone! Remeasuring the collector voltages of Q1 and Q2 you should find that they are now closely balanced within 0.5V of each other and about -30V.

Now comes the bit where you need nerves of steel. Switch off and reconect the feedback wire. Switch on again. If after the few seconds the circuit wails like a Banshee switch off quickly, not that you'd need much persuasion! What has happened is that the feedback is positive instead of negative. To cure the problem simply swap over the wires to the grids at Q1 and Q2 collector end. Now when you switch on or if you were lucky the first time all you should get from your speaker is silence! Having got to this stage the construction is complete. All that remains is to connect a signal source to your brand new amplifier and enjoy! Not forgetting of course to screw the bottom panel into position.

PARTS LIST

RESISTORS
R1 47k
R2 100k
R3 1M
R4,5 120k
R6 18k
R7 4k7
R8 100R
R9,10 470R/1W
R11 1k
PR1 27k preset

CAPACITORS
C1 10µ/450V
C2,3 220µ/63V
C4 400µ/450V

ACTIVE DEVICES
V1,2 EL34
Q1,2 MPSA42
D1-4 1N4007
BR1 800PIV, 2A Bridge

TRANSFORMERS
T1 Output transformer
T2 160VA 240V sec, 240V pri
T3 50VA 6-0-6V sec, 240V pri
T4 6VA, 20-0-20V sec, 240V pri

MISCELLANEOUS
Tagstrip
4 Octal valve holders
Case
PCB
Dual phono socket
4 x 4mm output sockets
Wire

BUYLINES

EL34's are available from Cricklewood Electronics.
The output transformer is available from the author at **HOBTEK**
A full designer approved kit for this project is available for £169.99 inclusive from:
HOBTEK, The Cottage, 8 Bartholomews,
Brighton, E.Sussex, BN1 1HG