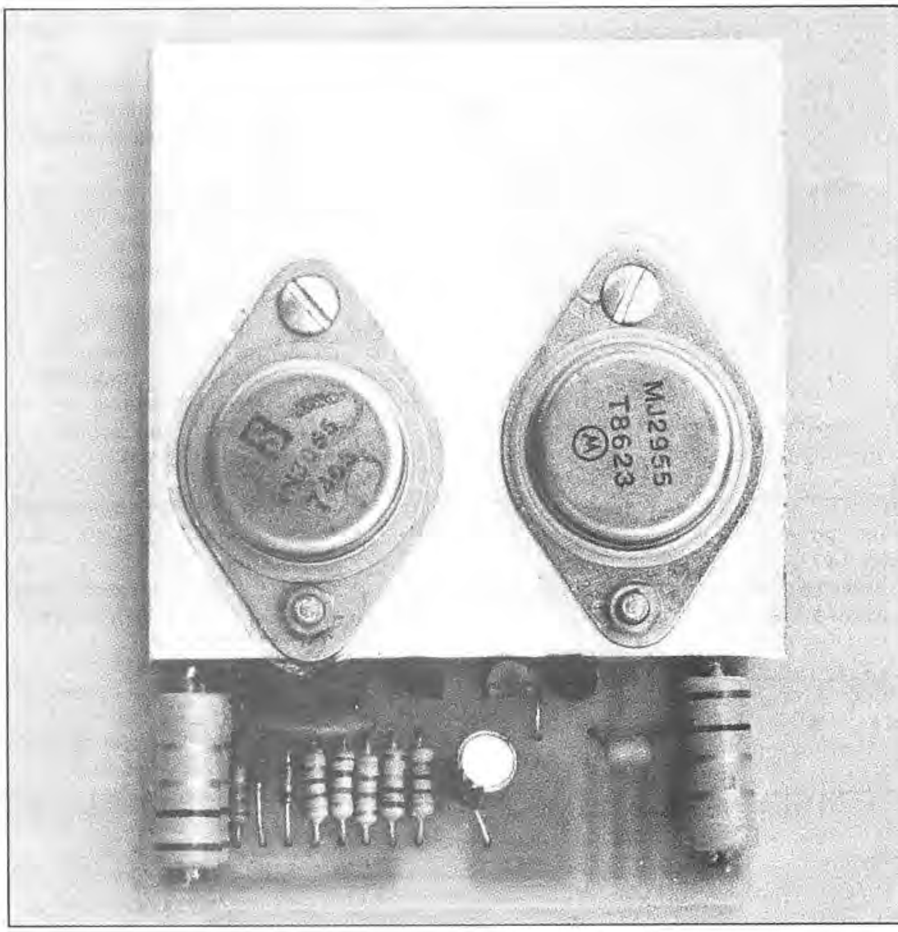
DIGI-125 AUDIO POWER AMP MODULE

A 75/125 watt audio power amp module for around $30? Unbelievable! But here it is, by Graham Dicker.

ELECTRONICS
ETI - 1430



The ETI-1430 75/125 watt audio power amp module prototype; up to 125 watts output for $30 or less! And it fits in the palm of your hand.

With the advent of modern digital audio devices such as the compact disc, digital audio tape (DAT), pulse-code modulation (PCM) and FM stereo sound on hi-fi VCRs, the quality of the audio source of music has improved dramatically. With this improvement in signal sources came the use of vented enclosures with typical efficiencies around 0.2%. This has placed a strain on the average domestic stereo amplifier to be able to provide enough headroom with adequate sound pressure levels. There are two solutions to the problem – spend megabucks on a commercial amplifier, or build your own.

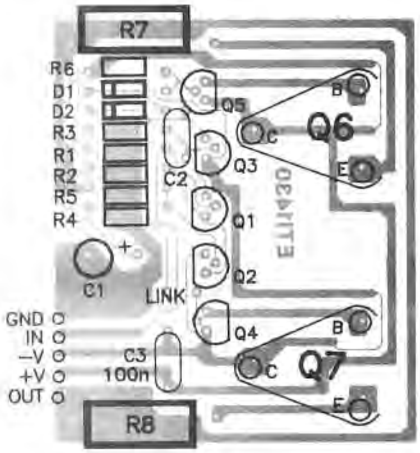
Over the years there have been many power amplifier designs published for home construction; some have been complex, others difficult to build and set up and designs using MOSFETs, against all the theory and promises, have, in general, not been as reliable as some earlier bipolar designs. Some designs have been very good but there are virtues to a bipolar design, if nothing else the ready availability and low cost of output devices.

Without doubt, the most popular power amplifier module ever described and built worldwide is the original ETI-480, using 2N3055/MJ2955 output transistors, with an estimated 100,000 being constructed in one form or another. The 480 had only a few problems for constructors, and with the new DIGI-125 power amplifier these problems have been addressed and overcome.

The new design

The new DIGI-125, so named from the common use of digital sources and its 125 watts RMS capability, uses new techniques and old, well proven technology, some a little unusual.

When Sir Clive Sinclair designed his series of amplifier modules in the 1960s, he worked on the premise that small is good and his modules were very popular the world over. This project is smaller than Sir Clive's earlier efforts as I have used CAD (computer-aided



Component overlay, showing placement of the components on the printed circuit board and the supply, input and output connections.

draughting) for the pc board design; this makes the best use of board area while allowing simple construction. The whole module uses only 22 components and, unlike any other amplifier, this one has been specially designed for the easiest home construction and setup ever. The circuit in Figure 1 shows just how simple it is.

All the resistors and capacitors are assembled in a row so that there is no need to go looking to ensure the right component is in the right hole.

The board has been designed to mount to an aluminium bracket, secured by bolts holding the output devices, the base and emitter pins of which solder directly into the board. The bracket then mounts to a suitable heatsink.

All the low power transistors are placed in a single line and the pc board has been designed so that only one link is necessary. The board measures just 55 x 60 mm and has only 49 holes. The average time taken to assemble a complete amplifier is around 10 minutes and for a production run of 40 modules completed shortly before writing this article, it took an average of 3.5 minutes per module.

The design uses no supply rail fuses, and has no presets for quiescent current as in other designs, and as such is ready to go as soon as it is assembled. The project can be assembled in two versions, one with a pair of MJ802/MJ4502 transistors which will deliver 125 watts RMS into a 4 Ohm load from a +/- 35 volt regulated supply, or using the popular 2N3055/2N2955 pair the project will deliver 50 watts RMS into 8 Ohms or 75 watts RMS into 4 Ohms from a +/- 35 volt unregulated supply. The first system can be bridged for up to 250 watts RMS output into 8 Ohms. The module should be used with a heatsink with a thermal resistance of better than 10°C/watt, if it is required to run at full power continuously.

Assembly

First, check the printed circuit board for any shorts or open tracks, using a small magnifying glass if necessary. Of necessity, this board has some fine tracks and closely-spaced pads. When assembling it, you will need to use a fine-tipped iron, preferably featuring temperature regulation of the tip. In addition, use a narrow gauge (say, 20 gauge) resin-cored solder for best results.

The bracket is prepared from a 60 mm length of 50 x 50 mm by 3 mm thick right angle aluminium extrusion. You can use the pc board as a template to mark out three of the four hole positions for each transistor, then use the insulating washer to mark the position of the remaining holes. Centre-punch or otherwise mark the hole centre before drilling. Hole sizes are determined from the insulating washer and plastic bushes supplied with the transistor insulating kits. Don't forget to mark out and drill suitable holes for attaching the bracket to your heatsink.

> *'Fewer than 25 components on a 55 x 60 mm pc board and no setting up required'*

Start assembling the board by soldering the low power resistors, the two diodes, the wire link and the three capacitors in place. Note the polarity of C1 and the two diodes. The wire link goes between the two holes adjacent to Q2 and Q4. All components must be seated right against the pc board. Next insert the plastic low power driver transistors, ensuring that the right device is in the right hole. Note that Q5 and Q4 face the opposite way to the other three transistors. WARNING: some manufacturers' devices have differing pinouts, so it's wise to check the emitter-base-collector pinout of each of these transistors before placing them in the board.

It is easiest to solder the R7 and R8 resistors in last. Unless 2 W or 5 W 0.33 Ohm resistors are used here, you should first solder one 0.68 Ohm 1 W resistor in each place, positioning it about 2 mm above the board to allow some air flow. Then place the other 0.68 Ohm resistor on top, trimming the leads to a suitable length and soldering them to the leads of the first resistors.

The last stage is to assemble the output transistors and the bracket, as shown in the assembly diagram given here. Note that Q6 and Q7 are first mounted to the bracket and secured by one bolt and nut each, then the board is placed in position and the second bolts and nuts are secured. Then solder their base and emitter pins.

Power supply

The power supply circuit shown here is a universal design to provide +/- ("split") rails. The same supply is suitable for a 100 or 50 watt version of the project. If two 100 watt power amps are required it is suggested that two transformers be used, each with separate rectifiers and filters. This will improve the crosstalk and peak music power capability of the modules.

The design uses a conventional full wave bridge with centre tapped transformer to charge suitable reservoir capacitors on

ABBREVIATED DATA SHEET
2N3055/MJ2955, MJ802/MJ4502

The output devices employed in the ETI-1430 have been chosen for their availability, low cost and ruggedness, as much as for the specifications required for the job. Complementary pairs of silicon NPN/PNP devices are selected: the 2N3055/MJ2955 pair for the lower power version; the higer-rated MJ802/MJ4502 pair for the higher power version.

The devices are all housed in the common TO3 package, the pinout for which is given here.

DEVICE TYPE

NPN : C	PNP :	Ic max.	Vceo	hFE at Ic	Pd at 25 deg.
2N3055	MJ2955	15A	60V	20-70 at 4.0 A	115 W
MJ802	MJ4502	40A	100V	25-100 at 7.5 A	200W

Notes: Ic max. is the maximum continuous collector current permissible; Vceo is the minimum breakdown voltage between collector and emitter (base open-circuit); hFE is the dc current gain at a given collector current – maximums and minimuns are given; Pd is the maximum permissible power dissipation of the device.

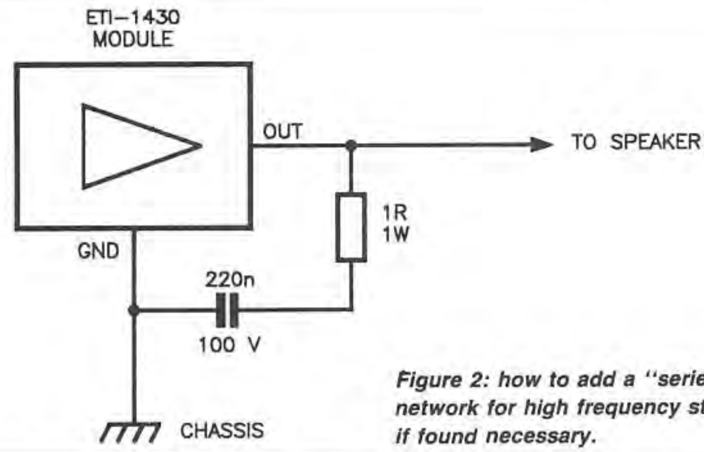


Figure 2: how to add a "series step" network for high frequency stability, if found necessary.

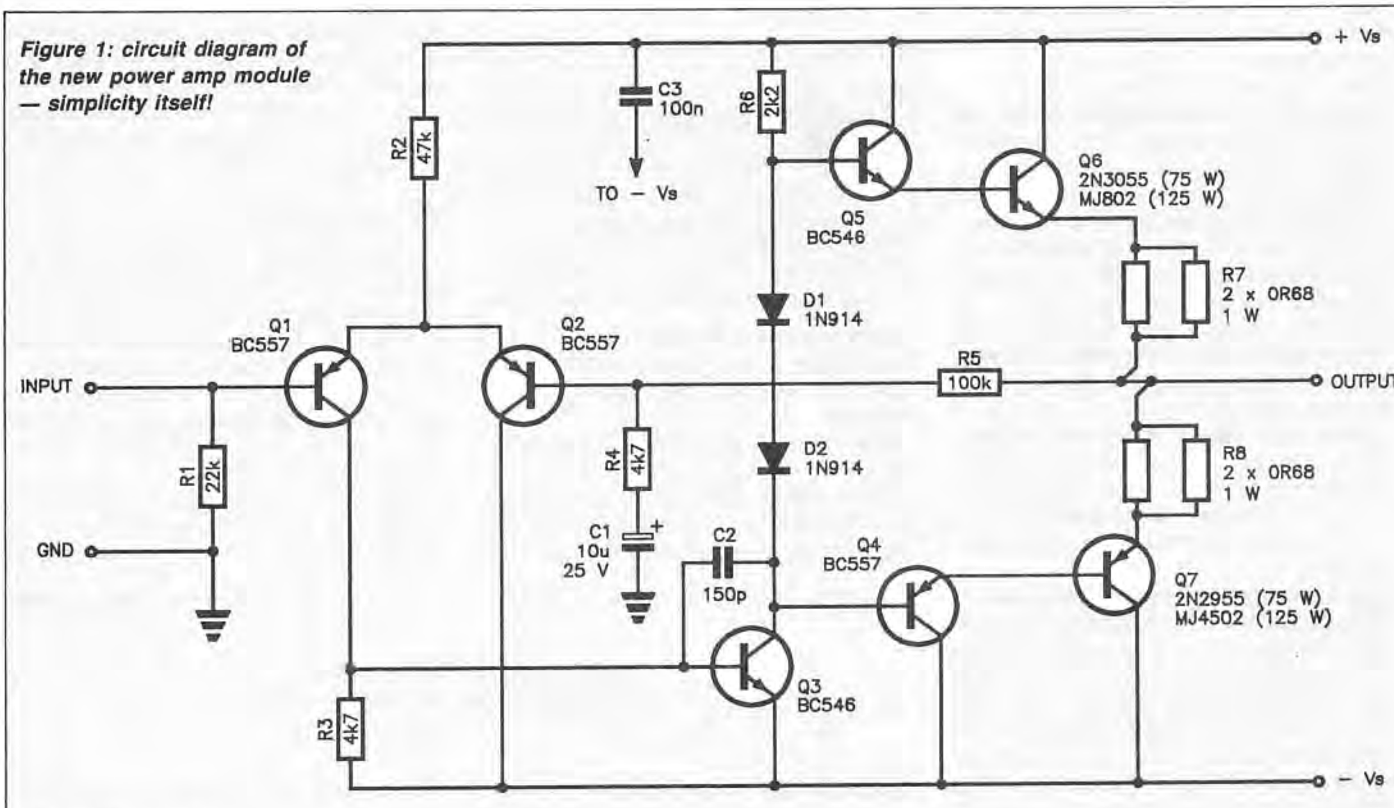
alternate cycles from each half of the transformer winding. Alternatively, two transformers may be used with their secondaries connected in series. The peak voltage appearing across the capacitors is given by:

VRMS x 1.42

which gives +/- 38 volts when using a 28-O-28 V secondary transformer, such as the DSEO144 from Dick Smith Electronics and legions of similar trannies, or +/- 32 volts from a 24-O-24 V transformer. These voltages are within the specified working voltage of the electrolytics. Under load, these voltages will reduce as a result of the dynamic regulation of the design (owing to the internal resistance of the transformer and diodes).

The wiring diagram here shows how to wire

Figure 1: circuit diagram of the new power amp module — simplicity itself!



How it works

The circuit is shown in Figure 1. The input stage consists of two BC557 PNP transistors, Q1 and Q2, connected as a differential pair with Q1's base being ground referenced. This results in a slight output offset voltage of about 300 mV, but does not adversely affect performance or reliability; it does however allow for dc coupling to the audio source. It should be noted tha many of the new CD players have frequency responses that extend down to a few Hertz (almost dc!), and it has been argued in the past about the benefits and disadvantages of a response this low. Needless to say, if it's there it can be reproduced.

The output of Q1's collector goes to the base of Q3, which is the main gain stage for the amplifier. This stage has a voltage gain of approximately 200 and unilateralisation and compensation is provided by C2. The two diodes D1 and D2 provide forward bias for the output stage to enable a quiescent current in the order of 40 mA to flow, to reduce crossover distortion. Resistor R6 provides current from the positive supply rail when Q3 is not conducting. Bootstrapping was initially tested in the prototype but the added components did not warrant the extra power available.

The output stage consists of a super-gain pair of output transistors in the familiar complementary symmetry configuration. The 50 watt version uses 2N3055/MJ2955 output devices which have a Hfe of 20 at 1.5 amps collector current, whereas the MJ802/MJ4502 pair have a Hfe of 25 at 4.5 amps collector current. The salient characteristics of the devices are detailed in the accompanying data sheets.

It is here that economy of design can be made over the original EIT-480 design. Instead of using two pairs of devices for 100 watts and increasing the drive requirements, we actually decrease the drive requirements over the 50 watt design by using devices with higher gain at the normal operating conditions. Secondly, as the output stage of up the power supply and module. While can-type (chassis-mounting) electrolytics are shown, pigtail types (either RB or axial) may be used and wired directly to the tagstrip. However, they should be mechanically secured to prevent fracture of the leads sometime in the future. The leads between the diodes and the electrolytics should be heavy duty hookup wire (at least 32 x 0.2 ? mm), and also the supply and ground leads to the module and speaker. Keep the supply and ground leads as short as possible, preferably shorter than 150 mm.

To improve the regulation, larger electrolytics and a transformer with a lower winding resistance (higher current rating) may be used. As a rule, the value of the electrolytic capacitor in such circuits is approximately 4000 ?F per amp, and here a 1.5 amp +/- 38 V supply was required, hence the 5600 ?F capacitors. With audio it is wise to go by the adage "bigger is better", so you may wish to use some of the many secondhand computer grade capacitors about.

Should you be using two separate transformers in series instead of a single centre-tapped transformer, ensure that the windings are in phase (adding).

Testing

Check with an Ohm meter that the output transistors are insulated from the heatsink. If all is well, apply the supply voltage without an input and without a load. Measure the output voltage; if it is close to zero volts, then all is well. You may now connect a load (loudspeaker or "dummy" 8 Ohm resistor load) and apply a sine wave input.

Check the output at a wide range of levels; if you can beg, borrow or steal an oscilloscope, view the output waveform. You should see a clean, well formed sine wave with no traces of high frequency oscillation at any output level. Try turning up the output until the waveform is "clipped"; the waveform should neatly square off top and bottom. If you are happy now, hook up a source of music and blow the cobwebs out of your speakers!

Load stability

The project has proved stable driving a wide variety of loads, including a 100 volt PA line output transformer. However, you may encounter some situations where the load causes high frequency instability, in which case either a HF damping network or a Zobel network (or both) connected to the module's output terminals will be called for.

Figure 2 shows how to connect a "series step" resistor-capacitor network to provide a high frequency load on the output. The resistor should be rated at 1 W and the capacitor should be a low inductance metallised polyester (MKT) or polypropylene

the new design has a voltage gain of 1 by using emitter followers (super alpha pairs) the output stage simply becomes a large current amplifier, whereas the ETI-480 design used common emitter configuration drivers and provided a voltage gain of the order of times 4. This is all very well but it results in two problems:
(1) nonlinearity in base drive impedances and currents in the pre-drivers which can result in increased distortion (try removing the ac feedback and observe the unequal voltage gains on positive and negative peaks), and
(2) the driver stage is inefficient due to the load sharing and local negative feedback resistances in the circuit. This can result in a problem of obtaining sufficient drive for the output devices.

After years of experience in designing equipment for broadcast applications, one thing I have learnt is that symmetry is the best way of solving problems before they occur. If the device is full of worms to begin with, negative feedback will only hide the symptoms not cure the problem.

It is interesting to note that, in the development stages, all ac negative feedback was removed from the prototype amplifier and the distortion rose to only 0.12% and the resulting output was stable and symmetrical. In this case, the feedback applied is to stabilise the closed loop gain of the amplifier to 20 times, to compensate for parametric spreads in Q3, not to reduce distortion or other ills.

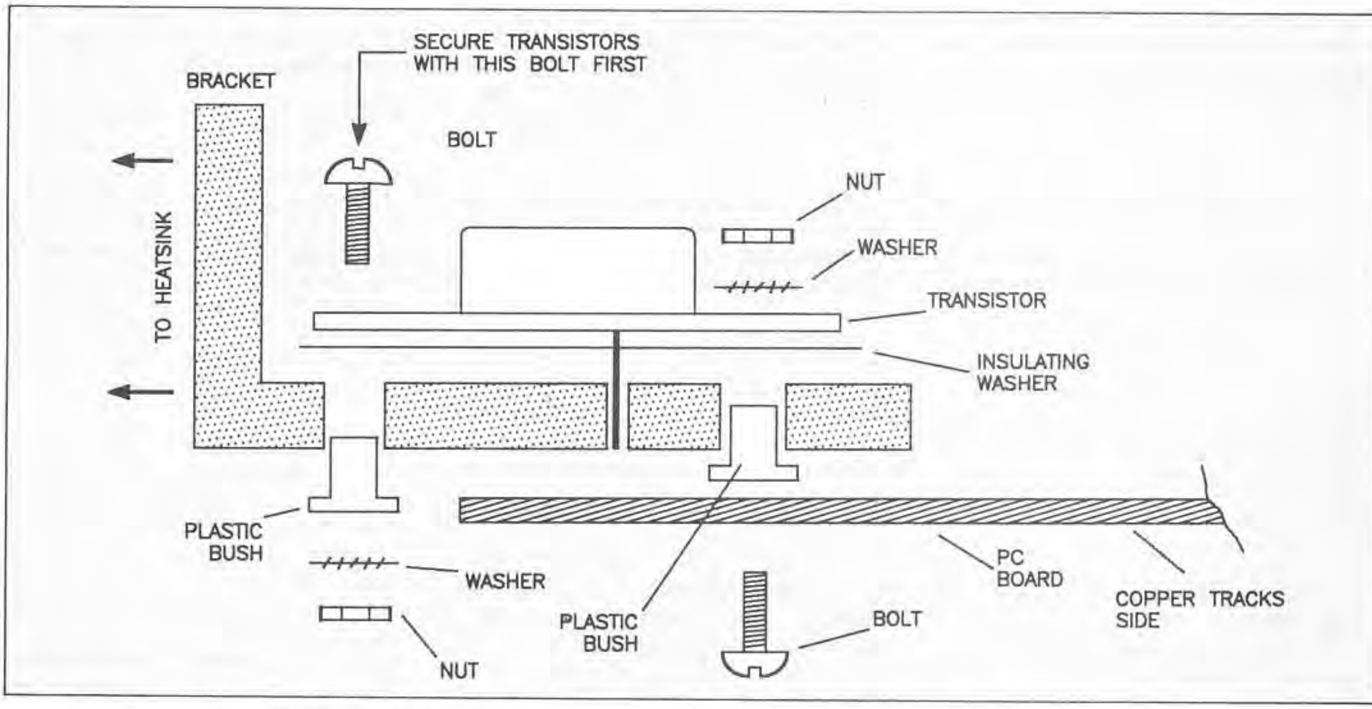
It is interesting to look at common current designs of amplifiers and note that very few designs use complete symmetry in all audio stages. Logically, if one does not use all fully symmetrical stages then local or overall negative feedback must be used within a design to overcome the problems caused by parametric spreads in components. It is my design philosophy that all stages, regardless of the signal levels involved, should be of symmetrical design. This, in turn, will assist in the reduction of transient intermodulation distortion (TIM).

For those purists that still have a valve power/preamplifier combination, you should note that most valve amplifiers were of symmetrical designs and few had local feedback around stages to compensate for spreads in components. In most cases there was only 6-12 dB of feedback used overall in power output stages, mainly to improve the distortion figures and frequency response of the output transformers. This is negligible to an average stereo amplifier of today, with 60 dB of feedback in the magnetic cartridge preamp, 30-45 dB feedback in the preamp & bass/treble circuits, 40-60 dB feedback in the power amplifiers, and if opamps are used with open loop gains of around 110 dB for each opamp, then the overall feedback from three stages is staggeringly high. On listening tests, it is interesting to compare the sound quality of the DIGI-125 and other top-of-the-line commercial amplifiers.

Because of the reasons explained above, the BC546/BC556 drivers have a greater reserve of drive current in the 100 watt version than the BD139/BD140 devices used in the ETI-480.

Note that the output stage bias diodes are not mechanically coupled to the heatsink bracket. I found this mechanically cumbersome and, in practice, unnecessary – in defiance of conventional wisdom. With dozens of these modules installed and operating in differing applications, no thermal problems have been experienced; the bias does climb with increasing temperature, but it does stabilise and in any case, more bias improves performance, albeit slightly!

No supply rail fuses were incorporated as, from my experience, the balance of expediency tips in favour of not having them. Often, I found transistors failed and protected the fuses!



Assembly diagram showing how the transistors, heatsink bracket and pc board go together.

SPECIFICATIONS

Output devices	Supply voltage	Load	Output Power
2N3055/2N2955	+/- 35 V	8 ohms	50 W RMS
2N3055/2N2955	+/- 35 V	4 ohms	78 W RMS
MJ802/MJ4502	+/- 37.5 V	8 ohms	62 W RMS
MJ802/MJ4502	+/- 37.5 V	4 ohms	112 W RMS
MJ802/MJ4502	+/-35 V Reg.	4 ohms	131 W RMS

Total harmonic distortion at full rated output	0.35%
Total harmonic distortion at 10 watts RMS	0.0015%
Signal-to-noise ratio wrt full output	-115 dBm
Power bandwidth (-3 dB)	100 kHz
Frequency response (1 watt RMS)	2 Hz-110 kHz, +/- 1 dB
	1 Hz-120 kHz, +/- dB
Damping factor (8 ohm load)	90

PARTS LIST ETI-1430

AMPLIFIER

Resistors

All 1/4 W, 5% unless noted

R1 .... 22K
R2 .... 47k
R3, R4 .... 47k
R5 .... 100k
R6 .... 2k2
R7, R8 .... 0R33, 2 W (2x 0R68 paralleled)

SEMICONDUCTORS

D1, D2 .... 1N914, 1N4148
Q1,Q2 .... BC557
Q3, Q5 .... BC546
Q4 .... BC556
Q6,Q7 .... MJ802/MJ4502 or 2N3055/2N2955

CAPACITORS

C1 .... 10 μF/25 V RB electro
C2 .... 150 pF/100 V ceramic
C3 .... 100 nF/100 V ceramic

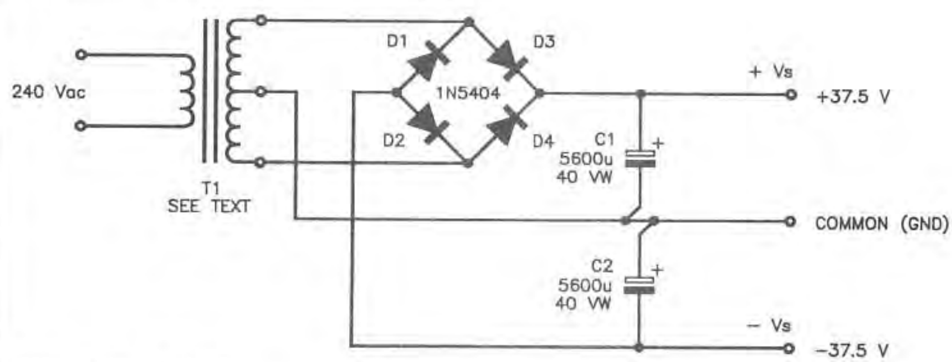
MISCELLANEOUS

ETI 1430 pc board; two TO3 transistor insulating kits; heatsink (each module) – eg. Rod Irving Electronics H10549 (100 W), H10535 (50 W). Dick Smith Electronics H-3426 (100 W).

Approx cost: $20-27

POWER SUPPLY

D1-D4 – 1N5624, 1N5404; two 5600 uF/40 VW electrolytics; T1 (mono 100 W, or stereo 50 W) – Rod Irving Electronics M21092 or Dick Smith DSE0144, two of these per channel for 100 W stereo setup.



Power supply circuit.

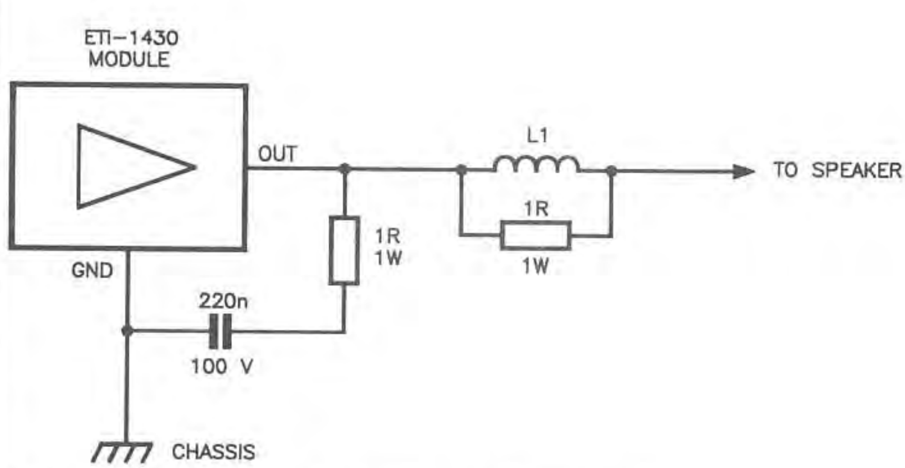
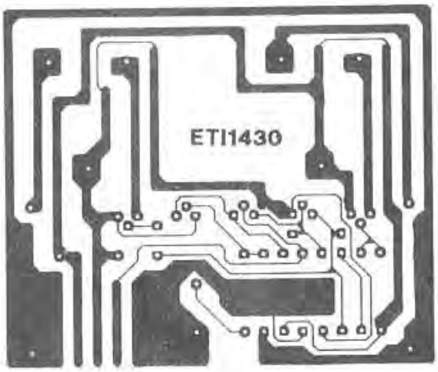


Figure 3: the addition of a Zobel (LR) network, in conjunction with a series step RC network, can solve stability problems with particularly "difficult" loudspeaker loads.

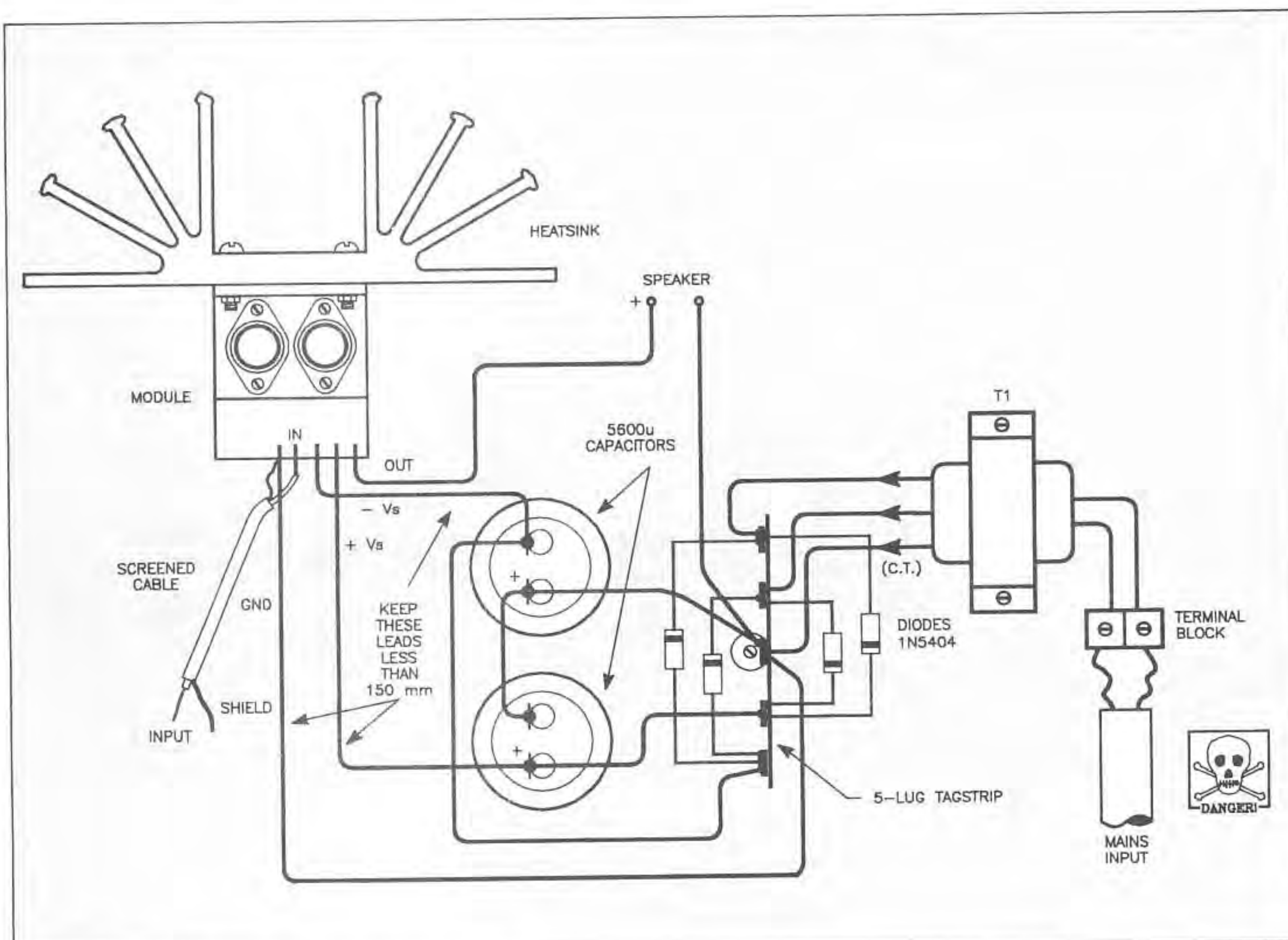


Full size artwork for the ETI-1430 pc board.

The author has retained copyright on the pc board so that constructors wishing to make boards for their own use may use this artwork for that purpose. Ready-made boards may be obtained from Graham Dicker at PC Computers, 36 Regent St, Kensington S.A. 5068, (08) 332 6513. Boards may be purchased singly or in small quantities, wholesale prices being available for larger quantities.

(MKP) type. Keep the leads as short as possible and solder the components directly to the tracks on the copper side of the pc board, the junction between the resistor and capacitor sitting in mid-air. The resistor may be any convenient value between 1 Ohm and 4.7 Ohms, while the capacitor may be any convenient value between 100nF (0.2 F) and 220n (0.22 F). It should be rated at 100 V minimum.

A Zobel network may also be added (useful with "difficult" speakers), comprising a coil with a parallel-connected capacitor, as shown in Figure 3. The coil can be wound with 1.0 mm diameter enamelled copper wire, using two 10-turn layers on a P24 potcore bobbin or a short length of 12 mm diameter wooden dowel. The network should be mounted close to the module to keep the lead between the module and the network short. eti



Wiring diagram for a single module and power supply.