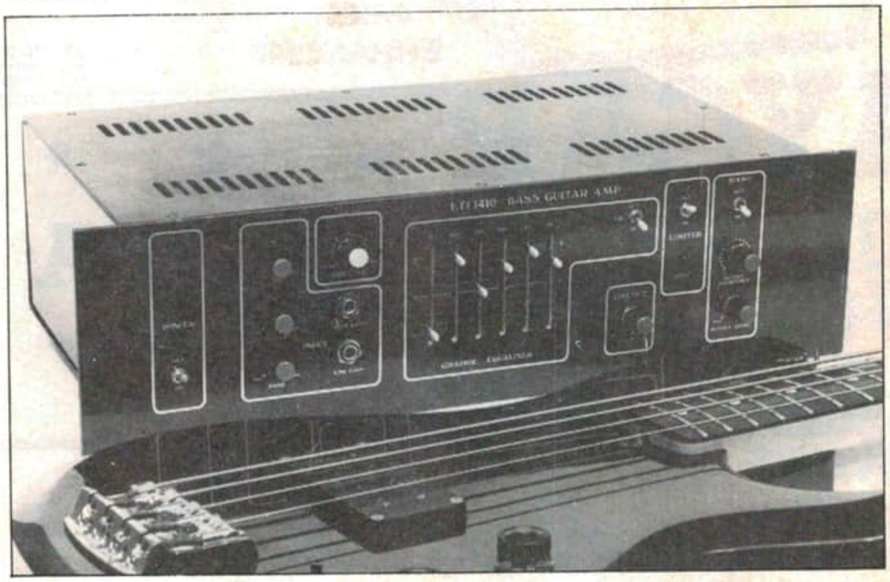
150W BASS GUITAR AMP

Robert Irwin



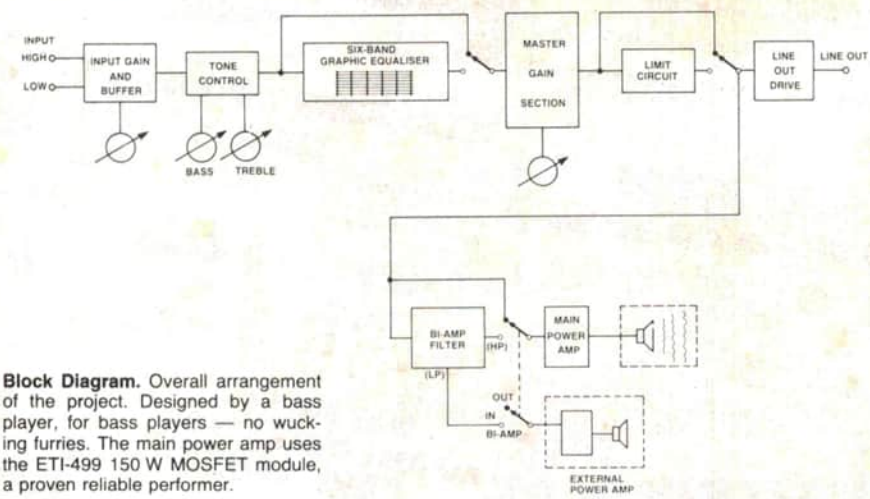
This guitar amp for impecunious bass players features many facilities found on expensive 'bought' ones. It delivers 150 watts into 4 ohms, has a 6-band graphic, limiter, line out and bi-amp facilities.

THERE HAVE BEEN many requests over the years from the growing numbers of build-it-yourself musicians for some good quality musical projects, particularly for stage amps of various descriptions. In the past, ETI has published some excellent power amp designs such as the old faithful '480 module, and in more recent times the '490 MOSFET module. Both of these amps are very suitable as the driver stage in a guitar or keyboard stage amp but, up until now, there have been no designs published for really suitable preamp stages to go with them. This has meant that these power modules have been primarily used in PA applications where they have been driven from a mixer or small mixing preamp.

This project describes a complete 150 W bass guitar amp using the ETI-499 MOSFET power amp module. The amp is housed in a standard 19" rack-mount case which allows it to be dropped into a standard wooden road case or mounted in an amp rack. The preamp contains features ▶

FEATURES — ETI-1410 BASS GUITAR AMP

- 150 W RMS output into 4 ohms using the renowned ETI-499 MOSFET module
- High gain and low gain inputs
- 6-band graphic equaliser; 50, 100, 250, 500, 1k and 3k Hertz
- Line output facility
- Bi-amp facility
- Output limiter to avoid power amp overdrive
- Housed in a standard 19" rack-mount case.



Block Diagram. Overall arrangement of the project. Designed by a bass player, for bass players — no wucking furries. The main power amp uses the ETI-499 150 W MOSFET module, a proven reliable performer.

HOW IT WORKS — ETI 1410

This article describes the design and construction of the preamp, equaliser, and 12 V power supply sections of the Bass Guitar Amp, so only these three items are covered here. The other sections are covered in Part 2.

ETI-1410a PREAMP

This is the input board. It comprises three main sections. IC3 is a 5534 op-amp configured as an inverting amplifier stage. The gain is dependent on which input is chosen. If the LOW GAIN input is chosen, then the gain is given by −R5/R3, which two for the values shown. If the HIGH GAIN input is chosen, then the gain is given by −R5/R4, which is −10 (i.e. ×10 inverted, for the values shown.

The gain of this stage may be altered by changing resistors R3, R4 or R5 and can be tailored to suit different input levels. It should be noted however, that if the gain is increased by any great amount (say, to 20), then it would require only a few hundred millivolts to saturate the input amp and drive it into clipping. Therefore, it is recommended that, unless the expected input signal is only a few hundred millivolts, the input stage gain should be left at unity. Also, the input resistance is set by the parallel combination of R1 and R3 for the LOW GAIN input, and R2/R4 for the HIGH GAIN input. These should be kept above about

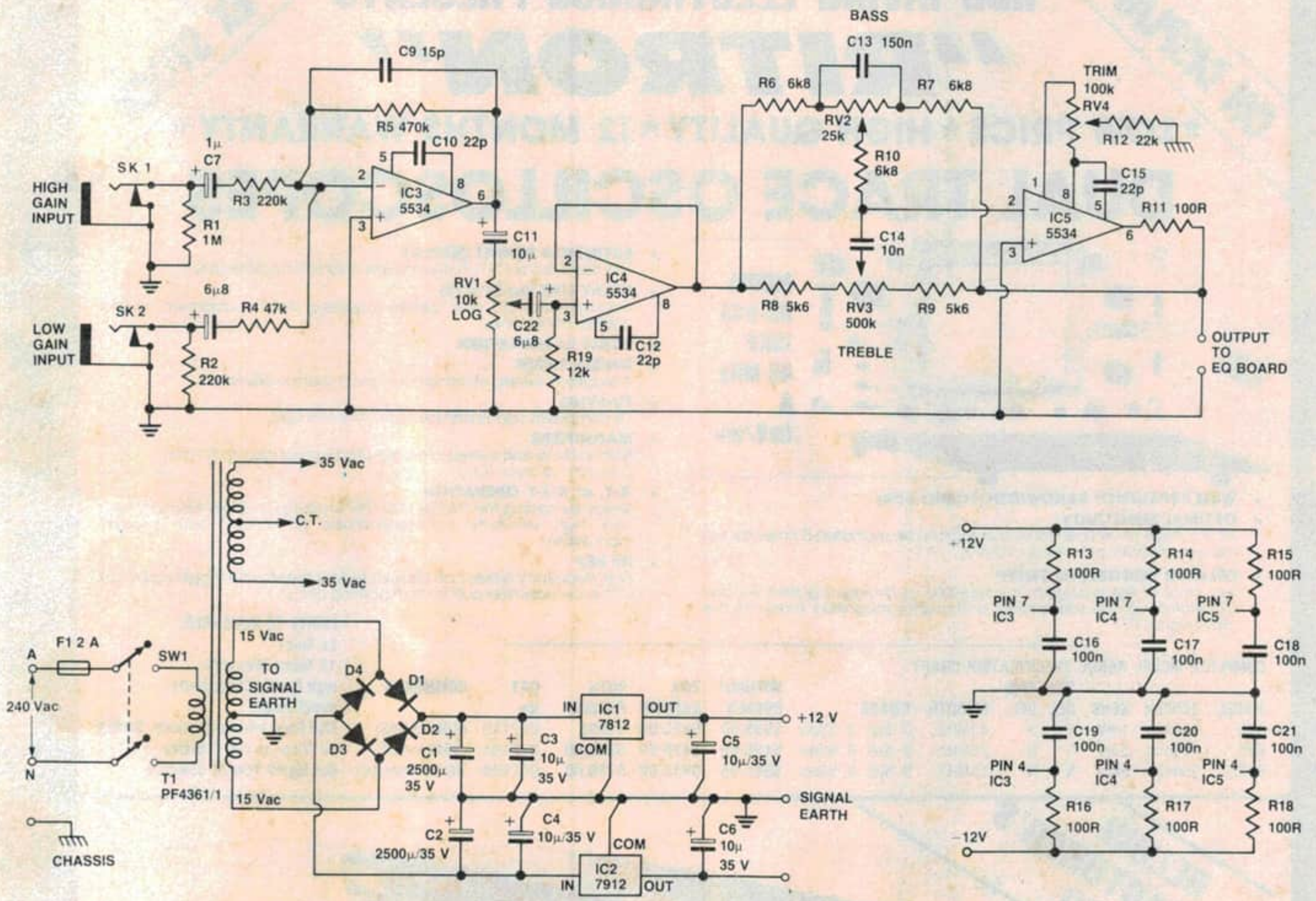


Figure 1. Tone control at low frequencies.

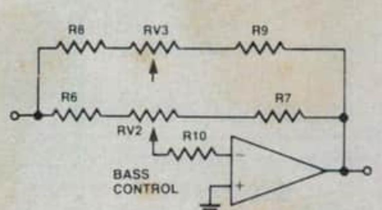


Figure 2. Tone control at high frequencies.

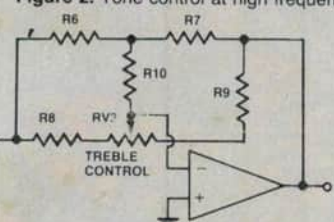
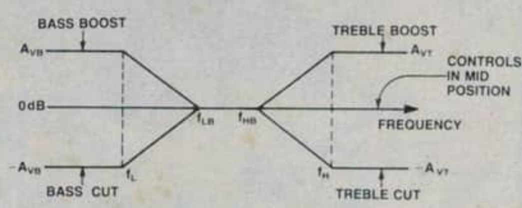


Figure 3. Bode plot of tone control circuit behaviour.



30k or so to give minimum loading to the bass pickups.

The input is ac-coupled via C7 or C8. Resistors R1 and R2 ensure that no charge can build up on the input line due to stray capacitances.

Capacitor C10 compensates IC3 at unity gain. Actually, the value used overcompensates the 5534, but since a very wide bandwidth is not essential in bass applications, it was decided to overcompensate for the greater stability it provides.

The output of IC3 is fed to IC4 via RV1 which provides signal level control. IC4 is a 5534 op-amp configured as a unity gain buffer. This isolates the input section from the tone control network and provides a low impedance drive for that network. Capacitor C12 provides the necessary compensation for IC4.

The tone control network itself is an active 'Baxandall' negative feedback type. Bass control is provided by RV2 and treble control by RV3. To see how it works, let us examine simplified circuits for the high and low frequency operation.

Figure 1 shows the simplified low frequency model. The capacitors become virtual open circuits at low frequency and the gain is dependent on the setting of RV2 only.

Figure 2 shows the equivalent high frequency circuit. This time, the capacitors become virtual short circuits and the gain is dependent on the setting of RV3 only.

The values for the tone control network were found using the equations for this type of circuit derived in the *National Audio Handbook*.

Figure 3 shows a Bode frequency plot for this circuit.

The circuit was designed for $A_{VB} = A_{VT} =$ 14 dB, and $f_L = 40$ Hz, $f_{LB} = 200$ Hz, $f_{HB} =$ 600 Hz and $f_h = 3$ kHz.

The op-amp used is, once again, a 5534. Capacitor C15 provides the compensation for unity gain operation. An offset null adjustment is provided via RV4 and R12. This allows cancellation of any dc offset at the output which could affect the bass control operation and generate noise.

ETI-1410b 12 V POWER SUPPLY

Referring to the circuit diagram, T1 has 15-0-15 Vac which is rectified by diodes D1 to D4. The two diode pairs provide positive and negative outputs which are filtered by capacitors C1 and C2, respectively. This yields two supplies of around +18 V and −18 V or so.

A three-terminal regulator, IC1, produces a regulated +12 V from the +18 V supply. Similarly, another three-terminal regulator, IC2, produces a −12 V output. Capacitors C3 to C6 are necessary for stable operations of the regulators.

The circuit diagram also shows the mains wiring, including the mains input fuse and neon bezel. These components are not mounted on the pc board and are covered in the general constructional details in Part 2.

NOTE: Board artwork is reproduced on page 158.

such as 6-band graphics, limiter, line out and bi-amp facilities, which are usually found on only the more expensive commercial units.

This article details the overall concept and goes into the construction of the input board, the 12 V power supply and the power amp section. Part 2 will complete the project, giving details of the graphic equaliser and limiter/output boards and final assembly. Some options on setting up and using the amp will also be discussed.

It should be noted that, although far cheaper than a comparable commercial unit, this project would cost up to a few hundred dollars to build. Therefore, to avoid seeing some hard earned cash going up in smoke, only you folks with some experience in building electronic projects should attempt this one. If you still want to attempt it but don't have much electronic experience, then perhaps you can find a friend who does and is willing to give a helping hand to a starving muso.

The basic design approach

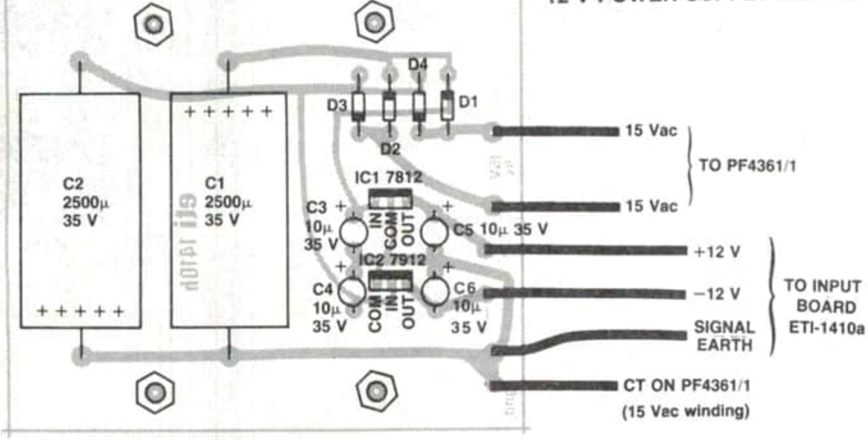
Several factors must be taken into account in the design of an amp for an electric bass guitar. Firstly, the frequency response. The low E string on a bass is usually tuned to 41 Hz. This means that the highest notes played on the bass will be only around three or four hundred hertz. As well as this, the average bass speaker box (a TL box for instance) will usually have an upper −3 dB cutoff frequency of around 1 kHz. With this in mind, it is important to design the bass and treble and equaliser sections to work in a suitable range. It's no good putting equalisation at 15 kHz since all you'll be equalising will be noise. Taking into account the need to be able to amplify harmonics as well as the fundamental of the notes it was decided to design the amp to work in the range 20 Hz to 5 kHz.

Unlike a normal guitar, a bass is usually amplified 'clean' (i.e: no clipping) and therefore it is important to ensure that there is plenty of "headroom" in the preamp stage. Most modern bass pickups are capable of putting out signal levels of a couple of volts peak (or more if pickups such as EMGs are used). Therefore the gain structure of the preamp should allow this level of input without causing clipping at the input stages. To facilitate the use of a bass with older pickups which may not have as high an output level, low gain and high gain inputs have been provided.

The power amp

The power amp used as the driver section for this amp is the ETI-499 150 W MOSFET power amp module described in the March 1982 issue of ETI. This module was chosen as it is very reliable, reasonably easy to construct and offers excellent performance and stability. The module will delivery 100 W into an 8 ohm load and 150 W into a 4 ohm load. All the components, including the power supply components, are mounted on the one pc board and the pc board mounts directly onto a heatsink.

The circuit of this amp module will not be reprinted in this article and, for the purposes of description, the power amp module will be treated as a 'black box'. For full details of the specifications and circuit of this module see the article in the March 1982 issue of ETI. (Photostats are available from ETI Reader Services for $3).



12 V POWER SUPPLY BOARD

12 V power supply

The transformer specified for the ETI-499 power amp module (which is also the transformer used in this project) has an auxillary 15-0-15 V winding which is used, in this project, to provide the positive and negative supply rails for the op-amps in the preamp boards.

The power supply board consists of a full-wave diode bridge rectifier which is filtered with two 2500 µF capacitors to form split rails of around 20 V. This is used to power 7812 and 7912 three-terminal regulators to provide the plus and minus 12 V rails used to run the op-amps.

Input board

The input board contains the initial gain control stage and the tone controls. Two inputs are provided which are designed to give maximum gains of 20 dB and 3 dB respectively. The tone controls are of the Baxandall type. These provide bass and treble control works in the region 20 Hz to 200 Hz and the treble control covers 400 Hz and up.

Equaliser board

The equaliser section is designed to provide unity gain with all controls set flat and 14 dB of boost and cut for each equaliser section. The equaliser consists of a series of filters incorporated into the feedback loop of an op-amp. This is based on the Series 5000 1/3-octave graphic equaliser published in the November 1982 issue of ETI. The equaliser has been configured to give centre frequencies of 50, 100, 250, 500, 1 kHz and 3 kHz, a total of six bands.

The output of the equaliser section is fed into a gain section which acts as master volume control with a maximum gain of 34 dB. This will give an overall maximum gain from the preamp of 34 dB or 40 dB depending on the input used. If the bass you are using has high output pickups, such as EMG types, then you may want to decrease this gain so as to get full use from your volume controls.

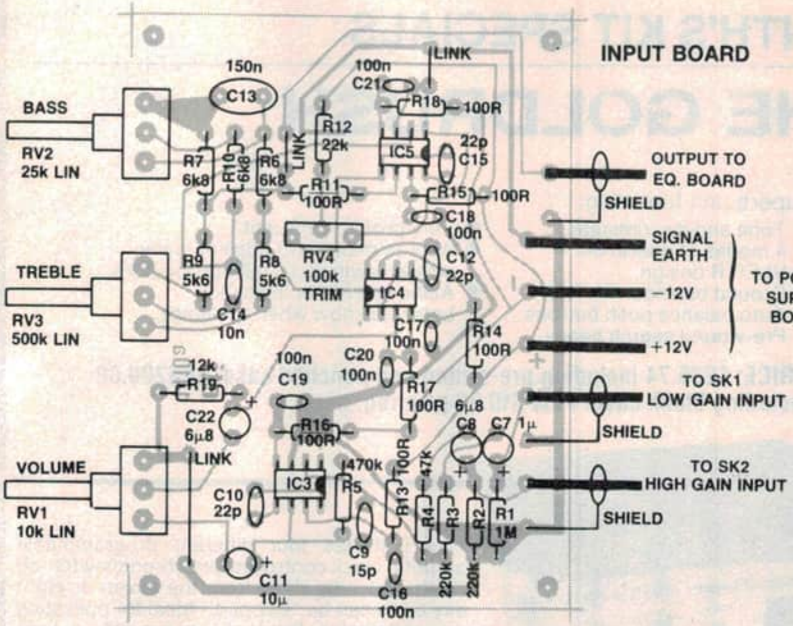
Slider pots are used to control the amount of boost or cut at the equaliser frequencies. These were mounted on a separate pc board which will mount on the front panel of the amp. The only problem you may encounter in this is cutting the slots in the front panel to accommodate the six sliders. This problem will be discussed in 'Constructional details' section in Part

Limiter/output board

This board contains several sections of the circuitry. Firstly, a limiter circuit. This uses an NE570 IC compander. Its function is to limit the output of the preamp to a maximum of 1 V RMS which means that large transients, such as occur when a bass string is struck hard, will not over-drive the power amp and cause unwanted clipping.

The output section of the board provides the drive stages for a line level output which can be used to feed a mixer or for recording. A state-variable filter is used to provide high-pass and low-pass outputs with the cut-offs variable from about 50 Hz to a few hundred Hertz. These outputs are used in the bi-amping facility which allows the use of an external power amp to drive a speaker covering the low frequency end of the spectrum. The internal power amp is then fed from the high-pass filter and amplifies the higher frequencies only.

Level controls are provided for the line and bi-amp outputs to enable matching of the signal levels to the equipment they're driving.



The output facilities provided on this board make the amp very versatile and easily expandable into a large, higher-powered system if 150 watts doesn't hurt your ears enough.

Construction of the pc boards

All of the boards are relatively easy to construct. First, however, check the boards to see that all holes are correctly drilled and that there are no broken tracks or 'bridges' between closely-spaced tracks. Start with the 12 V power supply board (ETI-1410a). Solder in the big electrolytic capacitors (C1 and C2) followed by four tantalum caps. Make sure that you get the correct orientation of these capacitors as they are all polarised and tend to fail rather spectacularly if inserted the wrong way round.

Next, solder the diodes in place followed by the two voltage regulators, IC1 and IC2. These too are polarised and must be placed the correct way round. It is advisable to use solder pegs on the lead connections to this board since several leads may need to be soldered to the same point.

Tackle the input board next. Start by locating and soldering the small link wires in place. Solder in all the resistors and capacitors next. Note that RV1, RV2 and RV3 are specified as the miniature pc mount type with the standard size shaft. These will sit directly on the pc board and are soldered in place. Standard pots can be used but these will have to be attached to the board with hookup wire and, since the prototype board was held on the front panel by the miniature pots, an alternative board mounting scheme would have to be used. The only thing that remains to be done on this board is the mounting of the ICs, one transistor and diode.

The use of IC sockets is not recommended when mounting audio ICs since the stray resistances and capacitances associated may affect the performance of the circuit. For this reason it is very important to put them in the right way round first time. It can be a real pain in the thumb to go round de-soldering ICs if a mistake is made. This then completes the construction of the input board.

The board left to construct at this stage is the main power amp board. As previously mentioned, this is the ETI-499 MOSFET power module which was described in the March 1982 issue. This should be constructed as shown in the original article (with the omission of the large heatsink since a different one is used in this project). If you are one of the very few people who do not have every copy of ETI ever published, then you can obtain a photocopy of the article by writing to our general enquiries service as detailed on page 3 of this issue.

Once all the boards have been completed a thorough check should be made to ensure that there are no small solder bridges between tracks on any of the boards and that all ICs and any other polarised components are mounted the correct way round. This then, completes the first part of the construction of the bass amp.

Next Part

In Part 2 of this article, the details of the final board (the limiter/output circuits) will be given as well as full constructional details, wiring diagrams and front panel artwork. For those experimenters out there, a few optional circuit ideas will be discussed which could be incorporated into the amp if you're after some super-deluxe features. ●

PARTS LIST — ETI-1410a PREAMP

Resistors ....all ¼W, 5% unless noted
R1 ....1M
R2, 3 ....220k
R4 ....47k
R5 ....470k
R6, 7, 10 ....6k8
R8, R9 ....5k6
R12 ....22k
R11, 13, 14, 15, 16, 17, 18 ....100R
R19 ....12k
RV1 ....10k/C rotary pot (Soanar V16L)
RV2 ....25k/A rotary pot (Soanar V16L)
RV3 ....500k/A rotary pot (Soanar V16L)
RV4 ....100k min trimpot

Capacitors
C7 ....1μ/10 V tant
C8, C22 ....6μ8/10 V tant
C9 ....15p ceramic
C10, 12, 15 ....22p ceramic
C11 ....10μ tant
C13 ....150n greencap
C14 ....10n ceramic
C16, 17, 18, 19, 20, 21 ....100n ceramic bypass

Semiconductors
IC3, 4, 5 ....NE5534N, LM5534N

Miscellaneous
SK1, SK2 ....6.5 mm insulated, earthing-type, panel-mount mono jack sockets.
ETI-1410a pc board; hookup wire.

Price estimate: $17-$20

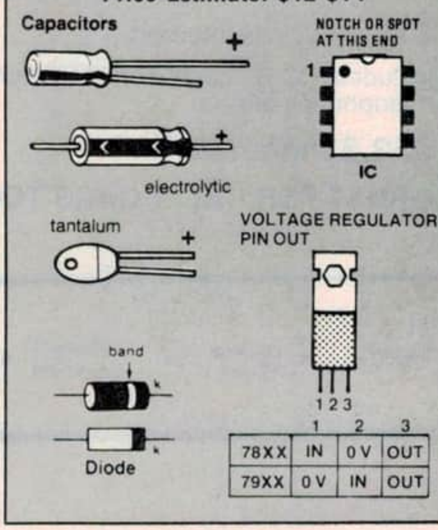
PARTS LIST — ETI 1410b ±12 V SUPPLY

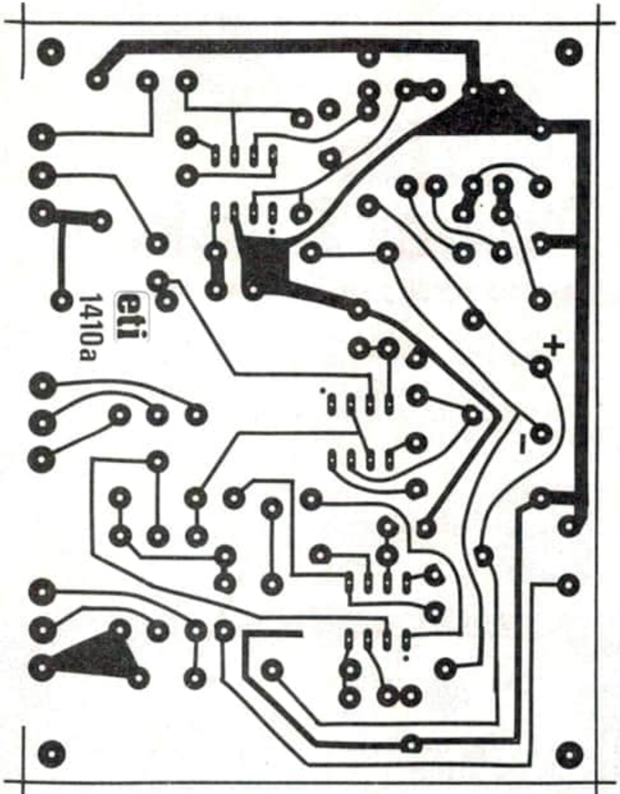
Capacitors
C1, C2 ....2500μ/35 V axial electros
C3, 4, 5, 6 ....10μ/35 V tant

Semiconductors
D1-D4 ....1N4001, 1N4002, etc
IC1 ....μA7812, LM340/T12
IC2 ....μA7912, LM7912

Miscellaneous
ETI-1410b pc board; pc pins; hookup wire (T1 is the main transformer, the HT secondary of which supplies the power amp section of the project — see Part 2).

Price Estimate: $12-$14

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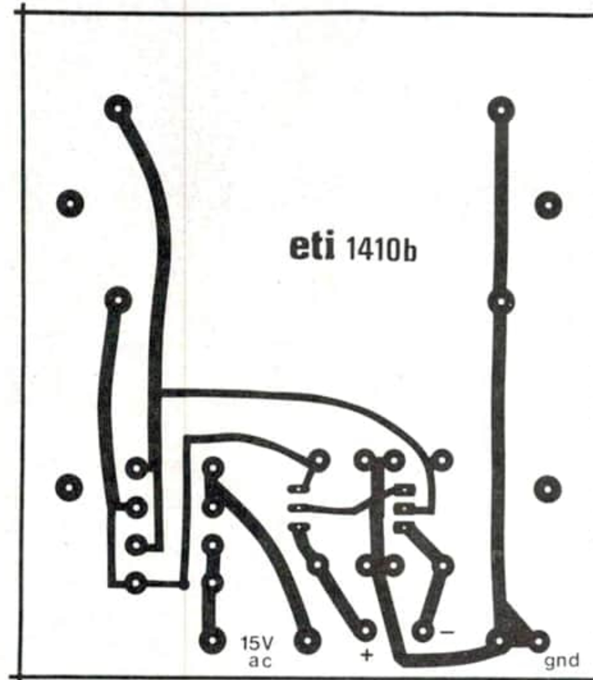
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150W BASS GUITAR AMP Part 2

Robert Irwin

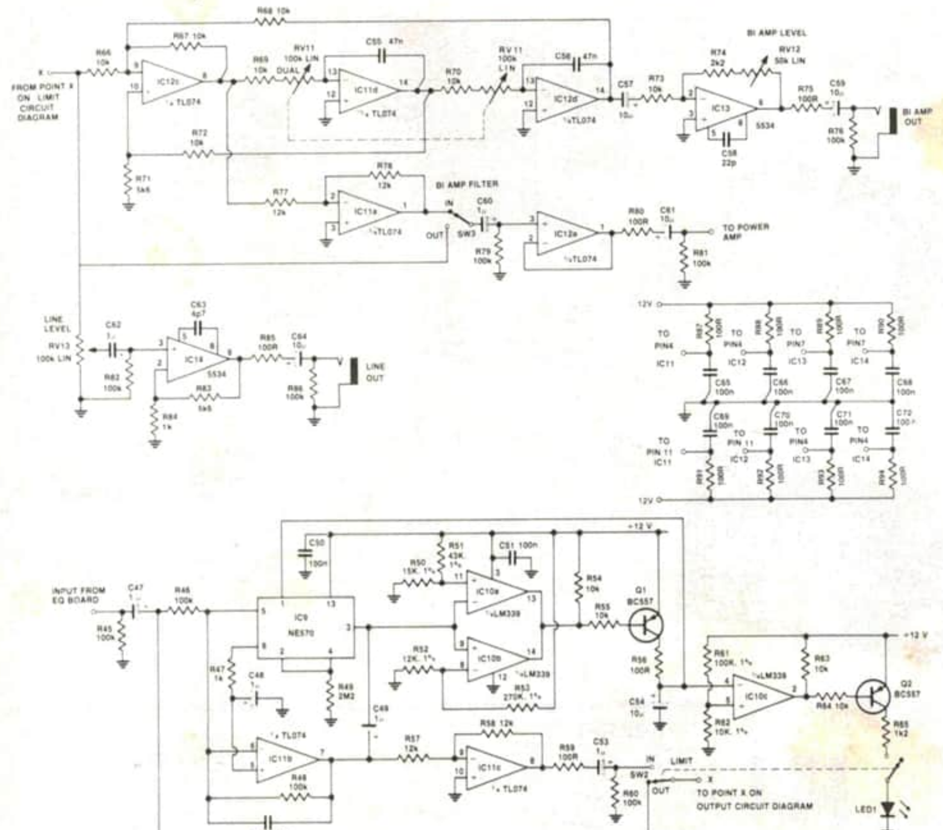
IN PART 1 the constructional details for the power supply board and input board were given. This article completes the picture, with details of the equaliser board and the output/limiter board, plus gives full constructional details for the complete amp.

Construction of the boards

The equaliser circuitry is contained on two boards, ETI-1410 c & d. The ETI-1410d board contains the main circuitry and the ETI-1410c board supports the six slider pots used for the adjustment of boost and cut. The construction of both boards is straightforward.

Start with the ETI-1410d. Solder in all the resistors first. The capacitors should be soldered in next but take special care to get the values in the correct place as these set the equaliser frequencies. Take care to get the orientation correct on the electrolytics and tantalums. Solder pins should be soldered into the holes for the input, output and power supply connecting leads as these will be connected after the board has been mounted and the underside will not be accessable for soldering.

The next step is to locate and solder in the ICs. This should be done with care as it is easy to bridge the tracks between IC pins with solder. Also take care to get the ICs the right way round. The only thing left to do on this board at the moment is to solder lengths of tinned copper wire (about 40 mm each) into the holes which will join to the board containing the sliders. These will be connected to the other board after both boards have been mounted in the case. The switch and pot shown on the circuit diagram are external to the board and will be attached with hookup wire at a later stage.

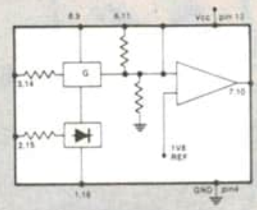


HOW IT WORKS ETI 1410e LIMITER/OUTPUT BOARD

This board has two main areas of circuitry, the limiter circuit and the output circuitry. They are independent of each other, so we can deal with them separately.

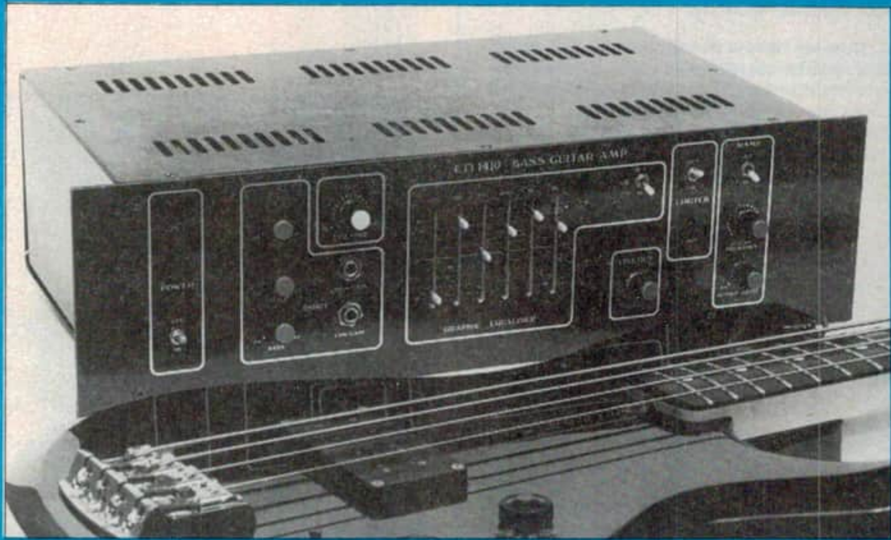
LIMITER

The heart of the circuit is the NE 570 Compander IC. This IC contains two identical gain control circuits which can be configured to produce a variety of compression and expansion type circuits. In this application only one of the circuits is used and this is configured as a hard limiter circuit designed to limit the output to a maximum of 1 V RMS.



The input from the EQ board is ac coupled by C47 and R45. The input is taken to an inverting amplifier stage formed by R46, R48 and IC11b (¼ of a TL074). Note that IC11b is used as a replacement for the internal op-amp incorporated on the NE570 chip which is not used here. Also incorporated in the feedback network of IC11b is the variable gain cell of the NE570 (pins 3 and 5) which is in paral-

bass guitar amp



The final part of this project looks at the operation of the sections not covered in Part 1. There are also full details of construction, powering-up and testing.

The ETI-1410c board contains only the six sliders. These should be soldered in at the top and bottom lugs only. The slider lugs will be connected to the main board once the boards have been mounted. Make sure that the sliders sit flush against the pc board and are sitting straight and square.

The final board left to construct is the limiter/output board (ETI-1410e). This is a relatively complex board and should be checked thoroughly for any bridged or broken tracks before you start. If all is well then start in the usual manner with the resistors and capacitors. After these have been soldered in, the eight links should be soldered in place. Tinned copper wire can be used for the links as they have been spaced far enough from other component leads so as not to be in danger of shorting.

Once again, solder pegs should be soldered in to the input, output and power supply holes. Solder in the ICs and transistors next; making sure that you get them the correct way round (note that the two NE5534's are the opposite orientation to the other IC's). An IC socket can be used with the NE570 in case it is necessary to replace it at some later date.

Once you have finished soldering in all the components, go back and double check that they are all in the right places and are the right way round. Once you are satisfied that all the boards are correct we can get on to the job of putting the thing together.

Constructional details

The prototype unit was mounted in a standard 19″ (424 x 250 x 140 mm) rack-mount, black anodised instrument case. This was supplied disassembled, but if you have one already built up then start by taking it apart. ▶

lel with the feedback resistor, R48.

C49 insures that the dc gain of the op-amp is not afected by changes in the variable gain cell. For small input signals less than 1 V RMS the variable gain cell is turned off and presents a high impedance which won't affect the gain of IC11b.

The gain for the signals less than 1 V RMS will be unity (set by R46 and R48). If the input signal rises above 1 V RMS a threshold level will be exceeded on the dual comparators formed by IC10a and IC10b. IC10a will detect positive going peaks and IC10b will detect negative going peaks. Pin 3 of the NE570 is internally biased to 1.8 Vdc so the threshold voltages for the positive and negative comparators are 3.2 Vdc and 0.4 Vdc respectively (since 1 V RMS represents a peak voltage of 1.4 V).

When a comparator threshold is exceeded then the comparator output will swing low and turn on the transistor Q1. This charges C54 through R56. As the voltage on C54 rises the variable gain cell is turned on due to the increase in voltage on pin 1 of the NE570. This has the effect of lowering the effective resistance of the variable gain cell which, in turn, increases the ac feedback on IC11b and lowers the ac gain. This will hold the output voltage to 1 V RMS regardless of how high the input voltage is.

IC10c is another comparator which detects the rise in voltage on C54 and turns on Q2 to supply current to the LED which indicates that limiting has occurred. R49 trickles a small amount of current through the variable gain cell so as to keep the capacitor C54 slightly biased on. This ensures a fast turn on time when the limit circuit is activated. The attack time of the limiting action is set by the RC time constant of R56 and C54. The component values shown given an attack time of less than 1 millisecond. This can be varied by varying R56. When the limit action is turned off (i.e: when the input falls below 1 V RMS) C54 discharges through an internal 10k resistor in the NE570. The components given give a release time of around 100 mS. To vary this you can vary the value of C54 but the value of R56 will have to be adjusted to give the correct attack time.

The positive input of IC11b is connected to pin 8 of the NE570 which is internally biased to 1.8 Vdc. This biases the op-amp output. R47 and C48 provide noise decoupling.

IC11c is configured as a unity gain inverter which is used to buffer the output and to put the output in phase wiht the input. C53 and R60 provide ac output coupling and R59 isolates any capacitive loading. The limiter circuitry can be bypassed using SW3.

OUTPUT

The output circuitry provides three separate outputs: line output, the bi-amp output and the power amp drive. The line out is provided by IC14, an NE5534 op-amp. This is configured as a non-inverting amp with a gain of 6.6 set by the equation:

$$Av = 1 + R83/R84$$

RV13 provides level control and C62 and C64 provide ac input and output coupling. C63 provides frequency compensation for the 5534.

IC12c, IC12d and IC11d form a state variable filter network. A state variable filter produces a highpass, lowpass and bandpass output all with the same cutoff frequency. Only the highpass and lowpass outputs are used here. The highpass output comes from the output of IC12c and is fed to an inverting buffer, IC11a. This gives the correct phase on the output. The output is then fed to IC12a which provides output drive to the main power amp. C61 provides ac coupling to the power amp.

The lowpass output is derviced from the output of IC12d and is ac coupled via C57 to an inverting amp stage formed by IC13. The gain is given by

$$Av = (R74 + RV12)/R75$$

This can be varied from 0.2 to 5.2 by varying RV12. The output of IC13 is ac coupled to the bi-amp output jack by C59 and R76. C58 provides compensation for the 5534.

The cutoff frequency of the filter network is given by:

$$F_c = \frac{\pi}{2}(RV11 + R69 \times C55)$$

For the values given this can be varied from 30Hz to 340Hz by varying RV11. The input to the power amp can be switched from bi-amp to the output of the limiter section by SW4.

Power supply noise de-coupling to all the IC's is accomplished by R87 to R94 and C65 to C72.

HOW IT WORKS ETI-1410c and 1410d EQUALISER BOARD

The equiliser board is an adaptation of the series 5000 ⅓ octave graphic equiliser published in the November 1982 issue of ETI. It incorporates selective filters in the feedback loop of an op-amp, to generate frequency selective gain.

Signals from the input board are fed to IC6c, which is connected as a buffer and provides a low driving impedance for the equiliser section. The input impedance is set to 10K by R20. RV4 provides a master control and feeds signals to IC8, an NE5534 op-amp which is connected as a non-inverting ac amplifier. The gain of this op-amp is set at 58 by the network R24 and R25. This can be altered if desired by changing R25. C48 is used to lower the effective gain at high frequency and thus prevent oscillation. C27 and C28 provide ac coupling. A switch, SW2, is provided to switch the equiliser in or out of circuit.

Figure 1 is the equivalent circuit of the graphic equiliser. The way it works is best understood by considering its behaviour with only a single frequency dependant circuit (labelled Z). If Z is a high impedance, then the op-amp will act like a simple unity gain voltage follower. However, if Z is low the circuit will exhibit both cut and boost depending on the position of RV. When the wiper of RV is in the centre position the input resistor forms a potential divider with half of RV. The other side of RV forms a potential divider with the feedback resistor. If both feedback and input resistors are the same value then the op-amp gain will be the inverse of the input attenuation, so the overall gain will be unity.

However, if the wiper is moved towards the inverting terminal, then the attenuation in the feedback loop will increase causing the gain of the op-amp to increase. At the same time the input attenuation will decrease, so adding to the overall increase in gain of the network. If the wiper is moved in the opposite direction, then a similar chain of reasoning shows that gain will decrease.

Thus we have a circuit that will give boost and cut when at resonance, and merely buffer any frequencies not at resonance. In the 1410 there are six impedances connected in parallel. Each one consists of a capacitor and a simulated inductor, the gyrator. The resonant frequency can be calculated in the traditional manner from

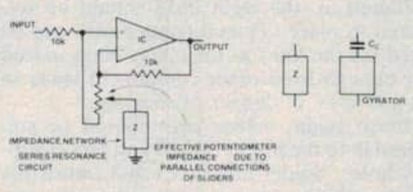
$$F = \frac{1}{2\pi\sqrt{LC}}$$

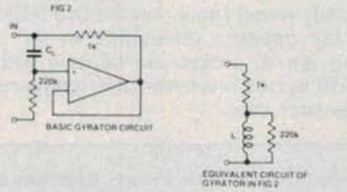
The general circuit of a gyrator can be seen in figure 2. It was used to avoid the necessity of winding up six coils of the appropriate inductance. The amount of inductance present can be calculated from:

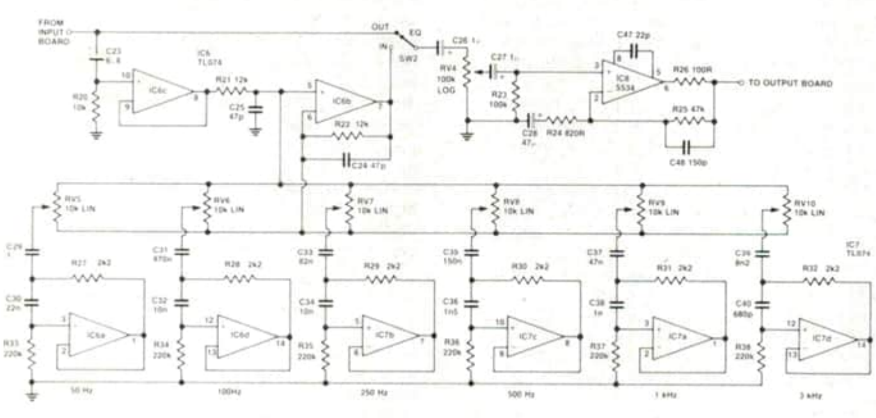
$$L = 2K2 \times 220K \times C1$$

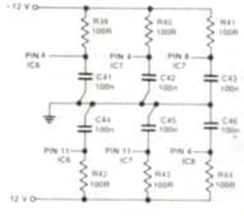
In the 1410 the gyrators are formed by IC6a, 6d, 7a, 7b, 7c and 7d plus their surrounding networks.

The power supply for all the op-amps is decoupled from the power supply noise by an RC filter network. This is formed by R39-44 and C41-46.









PARTS LIST ETI-1410c and d

Resistors

R20 .... 10k, ¼ Watt, 5%
R21, R22 .... 12k
R23 .... 100k
R24 .... 820R
R25 .... 47k
R26 .... 100R
R27, R28 . . . R32 .. 2k2
R33, R34 . . . R38 .. 220k
R39, R40 . . . R44 .. 100R
RV4 .... 100k log rotary pot.
RV5, RV6
. . . RV10 .... 10k lin 45 mm slider.

Capacitors

C23 .... 6µ8, 35 V Tant.
C24, C25 .... 47p ceramic
C26, C27 .... 1µ, 35 V electro.
C28 .... 47µ, 35 V Tant.
C29 .... 1µ Greencap
C30 .... 22n Greencap
C31 .... 470n Greencap
C32 .... 10n ceramic
C33 .... 82n Greencap
C34 .... 10n ceramic
C35 .... 150n Greencap
C36 .... 1n5 ceramic
C37 .... 47n Greencap
C38 .... 1n ceramic
C39 .... 8n2 ceramic
C40 .... 680p ceramic
C41, C42 . . . C46 .. 100n ceramic bypass
C47 .... 22p ceramic
C48 .... 150p ceramic

Semiconductors

IC6, IC7 .... TL074 quad op-amp
IC8 .... NE5534 op-amp

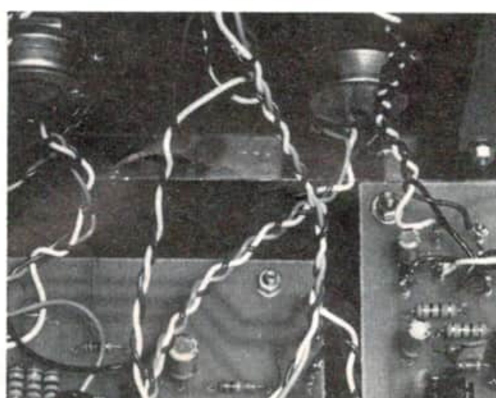
Miscellaneous

SW2 .... SPDT Toggle
ETI1410c and ETI1410d pc board.

General Parts

T1 .... Ferguson PF4361-1
Mains flex and plug, terminal block, DPDT mains toggle, NE2 Neon, six insulated stereo 6.5 mm sockets, 3AG panel mount fuse holder, 3AG in-line fuse holder, 3A 3AG fuse, 8A 3AG fuse, 42.5 x 25 x 14 cm rack mount case, seven small plastic knobs, ETI-1410 front and back panel, 300 mm length of radial fin heatsink, two 100n ceramic bypass caps, shielded hook-up cable, mains grommet, mains clamp, two solder lugs, eight 12 mm pc board spacers, hook-up wire, nuts and bolts, 4 rubber feet.

Estimated price: $250-$280
including ETI-499 power amp module



Slider hookup. View behind the front panel, showing how the sliders for the eq board are hooked up. Note the use of twisted wires to RV4 and SW2 from the front left-hand end of the board.

ETI-1410e

Resistors

R45, R46, R48, R60, R76, R79, R81, R82, R86	100k, ¼ W, 5%
R47	1k
R49	2M2
R50	15k, 1%
R51	43k, 1%
R52	12k, 1%
R53	270k, 1%
R54, R55, R63, R64, R66, R67, R68, R69, R70, R72, R73	10k ¼ W, 5%
R56, R59, R75, R80, R85, R87, R88, R89, R90, R91, R92, R93, R94	100R
R57, R58, R77, R78	12k
R61	100k, 1%
R62	10k 1%
R65	1k2
R71, R83	5k6
R74	2k2
R84	1k
RV11	100k lin dual ganged rotary pot
RV12	50k lin pot
RV13	100k lin pot

Capacitors

C47, C48, C49, C53, C60, C62	1µ, 35V electro
C50, C51, C65, C66, C67, C68, C69, C70, C71, C72	100n ceramic bypass
C52	15p ceramic
C54, C57, C58, C61, C64	10µ, 35 V tant.
C55, C56	47n greencap
C58	22p ceramic
C63	4p7 ceramic

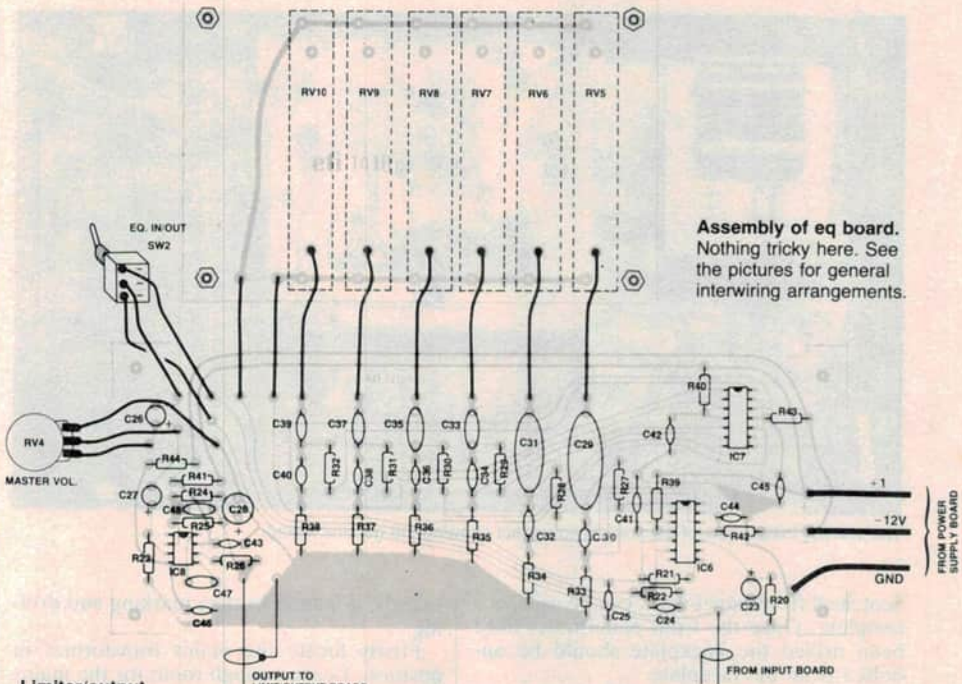
Semiconductors

IC9	NE570 compander
IC10	LM339 Quad comparator
IC11, IC12	TL074
IC13, IC14	NE5534
Q1, Q2	BC557
LED1	Red LED

Miscellaneous

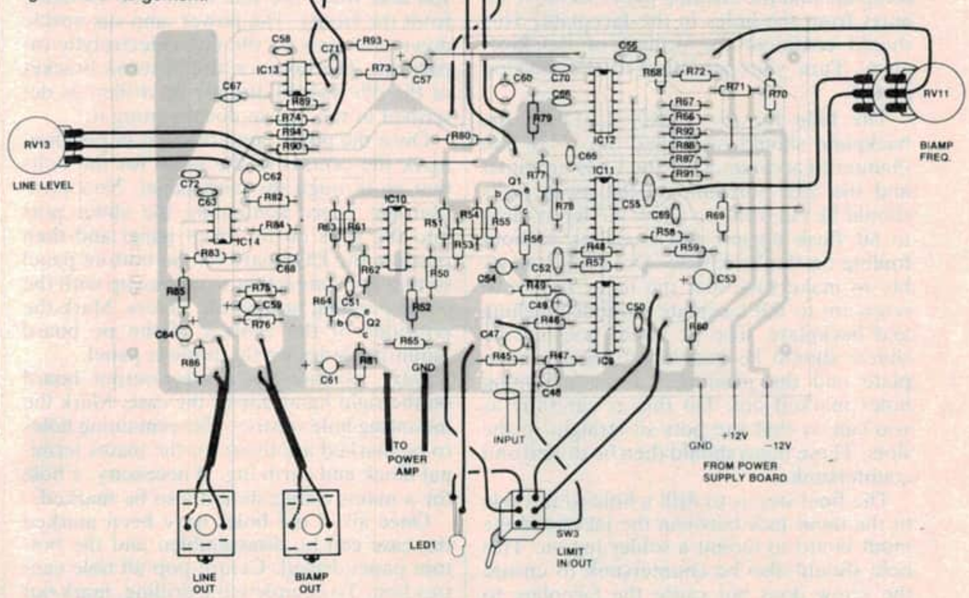
SW3	DPDT Toggle
SW4	SPDT Toggle

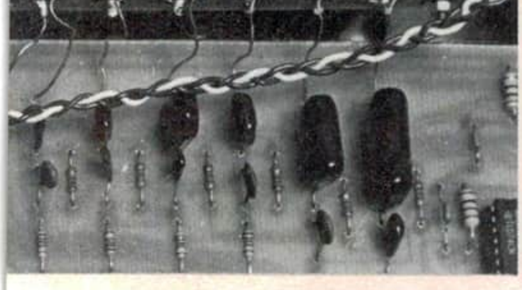
ETI-1410e pc board, 1 x 16 pin DIL IC socket, LED mounting Grommet.



Assembly of eq board. Nothing tricky here. See the pictures for general interwiring arrangements.

Limiter/output board assembly. Twisted wires are used to connect off-board components. See the pictures for the general arrangement.

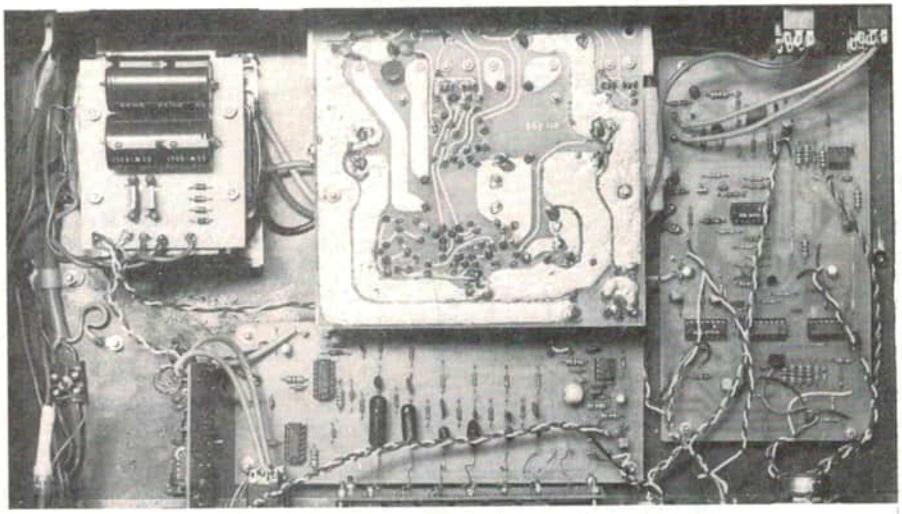




The first thing to do is to cut the slots for the sliders in the front panel. If you're handy with a drill and file then you can get into a bit of manual labour and, using a 3 mm diameter drill, drill a series of holes where the slots are supposed to go and then file away the intervening metal to form a nice, smooth, even, straight slot (or so the story goes!).

If your vocation doesn't lie in the metal-working field, then an alternative is to ring around the local engineering machine shops and see if you can get the front panel slots milled (thats what we did anyway). Note that the front of the case consists of two parts, the thick front panel and the backing plate. These should be bolted together and cut together to ensure that the holes line up accurately.

After the slots have been cut the rest of the front panel holes should be drilled. This can be done from the drilling diagram or the ▶



The works! Inside view of the completed project showing the general layout.

Scotchcal front panel mask can be used as a template. Once the front panel holes have been drilled the backplate should be unbolted from the faceplate.

To complete the metalwork on the front panel, the back of the holes for the input gain, bass and treble on the faceplate should be countersunk with a very large drill. This is to allow room for the nuts that screw on to the miniature pots to sit between the faceplate and the backing plate. Remove all burrs from the holes in the faceplate. This should complete the drilling of the faceplate. Turn your attention to the backing plate.

The hole for the LIMIT LED on the backplate should be drilled out to 10 mm diamter to accommodate the LED grommet and the area surrounding the input jacks should be cut away to allow the input jacks to sit flush against the faceplate without fouling on the backplate. Do a trial assembly to make sure that the input jacks can screw on to the faceplate without touching and backplate. The pc board housing the sliders should be positioned on the backplate and the positions of the mounting holes marked out. Do this as carefully as you can so that the pots sit straight in the slots. These holes should then be drilled and countersunk.

The final step is to drill a hole to the side of the input jack between the jacks and the input board to mount a solder lug on. This hole should also be countersunk to ensure the screw does not cause the faceplate to stand off from the backplate when it is mounted.

At this point it is advisable to re-assemble the case so that the layout of the boards can be seen. The picture of the inside layout will give you a general idea of where the boards are positioned. Note that the power amp board is positioned upside down and that the power supply board is mounted on top of the transformer. Once you have familiarised yourself with the position of all of the boards, it is time to start marking and drilling.

Firstly locate the mains transformer in position. Leave enough room for the mains fuse and cable. The transformer should be about 30 mm from the back panel and about 30 mm from the side. Mark the positions of the mounting bolts for the transformer and centre-pop them. Next, position the power amp board. This should be 150 mm from the left hand side (looking from the front). The power amp sits upside down and rests on the large electrolytic capacitors. The holes on the heatsink bracket of the 499 should already be drilled as described in the article documenting it.

Once the power amp board is in position, mark the centres of the holes for the bolts that go through the back panel. Now position the board containing the slider pots into the slots on the front panel and then position the EQ board on the bottom panel so that the connecting wires line up with the corresponding lugs on the sliders. Mark the positions of the centres of the pc board mounting holes on the bottom panel.

Next, position the limiter/output board on the right hand side of the case. Mark the mounting hole centres. The remaining holes to be marked are those for the mains terminal block and earth lug. If necessary, a hole for a mains clamp should also be marked.

Once all of the holes have been marked the case can be disassembled and the bottom panel drilled. Centre-pop all hole centres first. To complete the drilling, mark out the positions of the mains fuse and mains grommet and also the four output jacks. The output jacks should be kept so far to the right hand side (looking from the front of the amp) as possible and the Scotchcal back panel label should be used as a template to get the spacing. Drill the back panel holes. Note that if a locking type mains grommet is used then the hole will have to be drilled slightly smaller and filed out to the correct shape.

The heatsink specified is a 300 mm length of radial-fin extruded aluminium. This should be located in the centre of the back panel with the top edge of the heatsink flush with the top edge of the back panel. Be sure that the heatsink won't foul any of the output sockets. Once in position the centres of the holes should be marked using the previously drilled holes in the back panel. The holes in the heatsink should now be drilled. This should complete all the drilling needed.

Now for the fun part! The wiring up. Firstly, though, the Scotchcal front panel label should be attached to the faceplate. Drill small pilot holes at the centres of all the holes to give yourself something to line up with. If you don't have the steady hand of a microsurgeon then the best method is to peel the backing paper from the Scotchal and then run water over the back of the label. Also, run water over the faceplate. The Scotchcal can then be applied to the faceplate and the water allows you to move the label into position. Once in position, press the Scotchcal firmly into place and squeeze out the excess water with a soft, dry cloth. The front panel should be left for a few hours to dry and stick properly. After it has dried, press it down firmly once again to make sure that it has stuck.

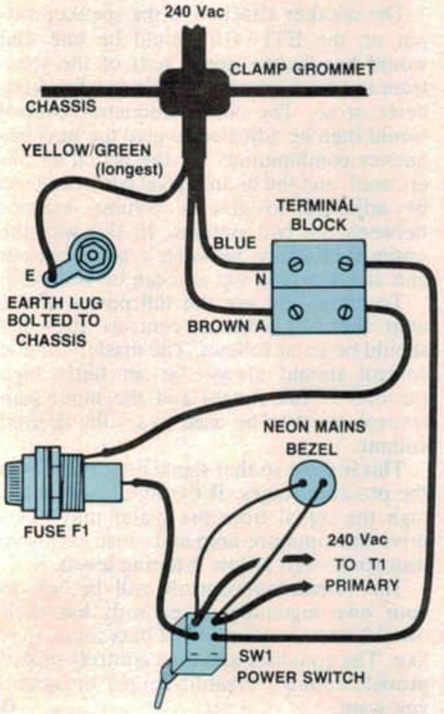
The input board should be bolted onto the frontpanel backplate. The pc board with the sliders should also be mounted to the backplate with 25 mm long countersunk bolts. Put the bolts through the holes in the backplate and then screw a nut on tight to hold the bolt in position. Place 12 mm spacers on the bolts and then bolt the pc board into position. The body of the pots should be standing a few millimetres off the backplate and the sliders should run smoothly and straight in the slots. The solder lug should be bolted in position next to the input jack hole. The case can now be reassembled.

The mains transformer should be mounted next. It should be mounted so that the input and output wires come out at the bottom of the transformer. This leaves the 15-0-15 V winding lugs facing up for easy access. The fuse holder can be mounted on the back panel and the power switch on the front panel. The mains cord and grommet can now be inserted and the mains wiring should be done in accordance with the mains wiring diagram. The mains input goes straight to the terminal block and the earth is connected to the chassis solder lug. It should be arranged so that the earth wire will be the last to break if the mains cord is somehow pulled out.

From the terminal block the active wire is taken to one side of the mains fuse. The other side of the fuse is connected to one pole of the mains switch. The neutral is taken from the terminal block straight to the other pole of the switch. The two outputs from the switch are then connected to both the primary of the transformer and the mains bezel. Make sure that the mains

NOTE: The front panel artwork is too large to reproduce in the magazine. Photostat copies may be obtained by sending an A4-sized stamped, addressed envelope to **ETI-1410 Artwork Photostats, ETI Reader Services, PO Box 227 Waterloo NSW 2017.** If you want positive or negative same-size film transparencies, the complete set costs $20 or front panel film only costs $10 from **ETI-1410 Artwork Sales, ETI Magazine, PO Box 227, Waterloo NSW 2017.** Make out your cheque or money order to 'ETI Artwork Sales' and ensure you ask for positives or negatives as you require. The printed circuit board and rear panel artwork are on page 156.

Power wiring. General arrangement for the mains power wiring. If you don't use a clamp grommet, use an ordinary grommet in the rear chassis backdrop and a cable clamp inside on the chassis bottom.

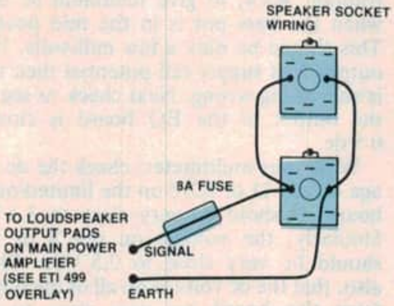


switch and bezel are both firmly screwed in place and will not come loose during operation. Be very careful when wiring up the mains side of the transformer since mains voltages are lethal.

All exposed terminals should be protected with heatshrink insulation to prevent anyone accidentally coming in contact with mains voltages. The mains cord should also be securely attached so that it won't come out even when pulled. Carefully double and triple check your mains wiring to make sure you haven't made any silly mistakes like connecting the active to the chassis. This completes the mains wiring.

The secondary of the transformer can now be connected to the power amplifier. Referring to the overlay for the ETI-499 MOSFET module on page 27 of the March 1982 issue of ETI, the two 35 V lines shown correspond to the yellow and black wires from the PF4361/1 transformer secondary.

Output jacks. Wiring up the speaker output jacks. Note the use of an in-line type fuse.

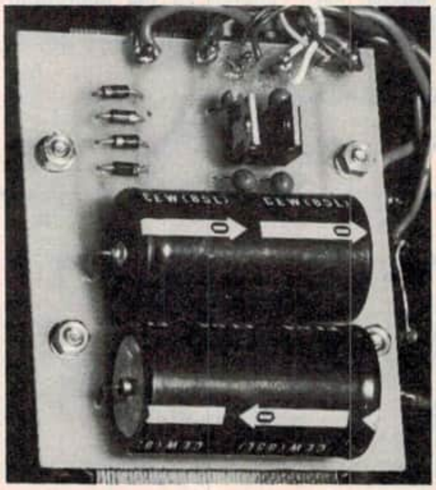


The orange and red wires are connected together and form the centre-tap connection on the board. At this time it is also advisable to connect good lengths of heavy duty hookup wire to the input and output holes on the power amp board. Colour code these and write down which is which so that you will know where to connect them later.

Note that an in-line fuse is used in the speaker output line. Before finally turning the power amp board topsy turvy and bolting it to the back panel you should carefully follow the power-up procedure given in the article. Be careful that none of the components or tracks of the power amp are shorting to the case when you are doing this and also make sure that the wires connected to the output terminals don't touch anything.

Once the power amp is set up OK you can then turn it off and pull out the plug. The power amp board and heatsink can now be bolted to the back panel. Heat conductive silicon grease should be liberally smeared between the power amp heatsink bracket and the backpanel as well as between the backpanel and heatsink. Securely fasten these bolts.

The next step is to bolt the power supply board to the top of the transformer. A nut is used as a spacer to lift the board off the



Power supply. The power supply board (see Part 1) is mounted on top of the PF4361/1 transformer. The supply connections to the ETI-499 MOSFET module should be heavy duty hookup wire.

transformer and ensure that the top of the transformer doesn't short out any of the tracks on the underside of the board. Once the board is mounted the 15 Vac should be connected. The transformer has four lugs which are the connections for the two 15 V windings. The two centre terminals should be connected together and a wire taken to the earth of the pc board. The two outside windings should be hooked up to the ac input of the power supply board.

The unit can now be plugged in again and turned on. Measure the voltage on the outputs of the regulators to earth. You should get +12 V and −12 V dc respectively. If you don't then turn off, pull out the plug and double check all the wiring and components. Once you get the correct voltages you are ready to proceed. WARNING: Make sure that, from now on, whenever you are poking around on the inside of the case that the mains plug is pulled out of the wall socket. We don't like losing readers!

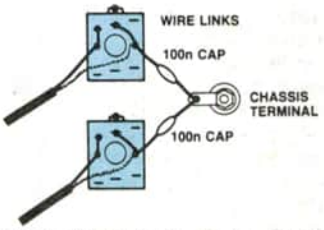
Bolts should now be put through the mounting holes for the two other pc boards and nuts screwed on to secure them. Place the equaliser board temporarily in position. Note the approximate distance from the master volume pot to the appropriate connection points on the pc board and cut suitable lengths of hookup wire. You will need to allow more wire than the actual distance since the wires will need to be twisted together.

Remove the board and solder the hookup wire to the pc board (if you have used solder pins for the connection points then you can mount the board permanently now). Once you have twisted the wire together and have the length right you can solder the wires to the pot (make sure you get them the correct way round). Repeat this procedure for the EQ IN/OUT switch and then do the same for the three pots, LED, and two switches connected to the limiter/output board.

Once all the pots and switches have been connected, the two boards can be mounted on the bolts using 12 mm spacers and bolted down. The wires connecting the slider pot board to the EQ board can now be attached and all the pots and switches mounted onto the front panel. The LED should be mounted using a standard LED mounting grommet.

The next step is to tackle the inter-board wiring. First, take three pieces of hookup wire and connect the +12 V, -12 V, and earth outputs from the power supply board to the appropriate pins on the input board. These should be twisted together. Do the same for the power supply connections to the EQ board and the limiter/output board. At this stage, if a CRO and signal generator are handy, the operation of each board can be checked individually. If not, then continue and live in hope!

Shielded cable should be used to make the connections between the output of the input board and the input of the EQ board and similarly between the EQ board and limiter/output board. Note that the shield is ▶



Input jacks. Wiring the input jacks. The inputs are shorted with no plug inserted.

connected *at one end only* since the earth connection between boards is already made by the power supply wiring. The input to the power amp should be left disconnected for the moment.

The only remaining connections are those to the input and output jacks. These should be wired as shown in the accompanying diagrams. Note the wire links used on the input sockets. This is done so that when there is no plug in the socket the input terminal is shorted to ground.Note also that 100 nF caps are connected from the input signal ground to the chassis. Once the input and output sockets have been wired they can be mounted and connected to the appropriate terminals. This then completes the construction.

Powering-up and testing

Without a signal generator and CRO there isn't a lot of testing you can do. The first thing to do though is, with the input to the power amp disconnected, switch on and measure the voltages at the power supply input pins to all the boards. These should all be within 0.1 V of +12 V or -12 Vdc. If the voltage regulator ICs start getting really hot at this point then there is probably a short somewhere on one of the boards. Take off the power supply leads to all of the boards and connect them back one board at a time to try to isolate which board has the short. Remove this board and check it thoroughly. NOTE: Make sure you always switch off at the wall socket before making any adjustments to the circuit.

Once the power supply wiring checks out look at the output (pin 6) of IC5. Set the trimpot, RV4, to give minimum dc offset when the bass pot is in the mid position. This should be only a few millivolts. If the output is at supply rail potential then there is something wrong. Next check to see that the output of the EQ board is close to 0 Vdc.

With your multimeter, check the dc voltage on pin 11 of IC10 on the limited/output board. It shold be very close to 3.1 Vdc. Similarly, the voltage on pin 8 of IC10 should be very close to 0.5 Vdc. Check, also, that the dc voltage on all of the outputs from this board are very close to 0 V. Switch the limiter switch to the IN position and ensure that the LED doesn't light.

If everything checks out OK then switch off, connect the power amp input to the appropriate terminals on the limiter/output board and insert a three amp fuse into the fuse holder in the speaker output line. Connect up a speaker and, with all the volume controls down, switch on. If no smoke comes from anywhere and the speaker is still intact then there is a reasonable chance that everything is fine. If so then turn off, replace the 3 A fuse in the speaker line with an 8 A one and plug in your bass (note that the mains power fuse must still be 3 A type).

Turn the amp on, turn up the volume a little and try a few notes. If you hear those mellow, bassy tones carressing your ears then all is well and you're on the way to rock 'n' roll stardom!

Hints on using it

All the controls are fairly self-explanatory with the possible exception of the bi-amp controls. To obtain the best sound from a bass it is often desirable to split the signals into a high end and a low end. This then allows the low and high frequencies to be driven by separate amp/speaker combinations, each tailored to the appropriate frequency range.

The bi-amp filter incorporated into the output board of the 1410 acts like a crossover which separates the signal into high frequencies and low frequencies. The crossover point (whether the signal is considered high or low) is set by the CUTOFF FREQUENCY control on the front of the amp. The high frequencies are sent to the internal power amplifier and the low frequencies are directed to the BI-AMP OUT socket at the rear of the amp.

A typical way to set up a bi-amp system would be as follows. The BI-AMP OUT would be connected to the input of an external power amp (which should be of a higher power than the 150 watts of the internal amp). A speaker, attached to the external power amp, should be particularly suited to the very low end of the audio spectrum i.e: 20 Hz to around 300 Hz.

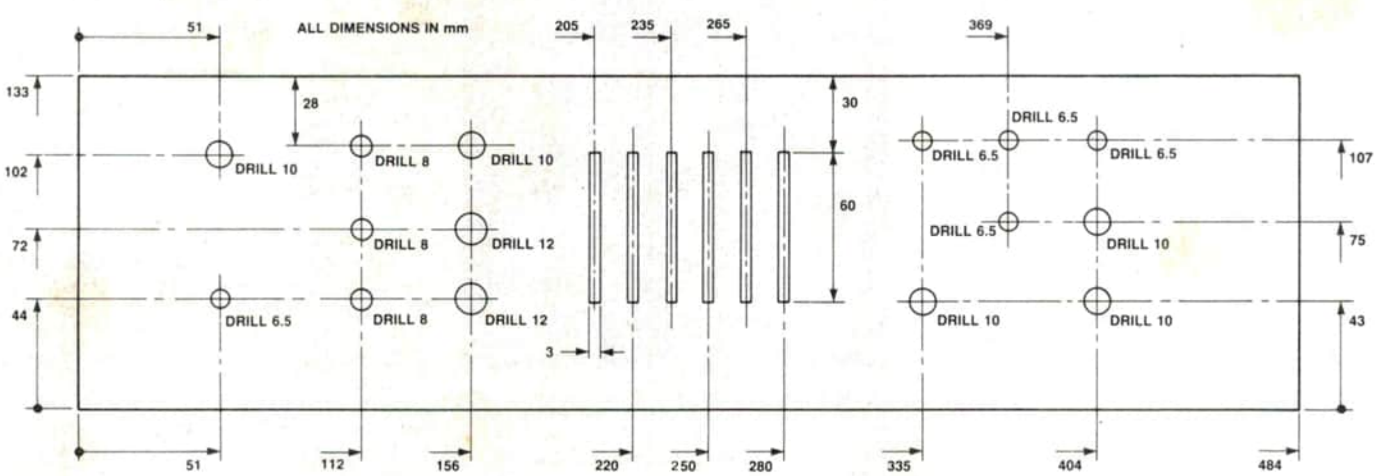
The speaker attached to the speaker output on the ETI-1410 should be one that would handle the upper part of the spectrum i.e: from around 300 Hz to a few kilohertz or so. The cutoff frequency control would then be adjusted to give the best frequency combinations for the actual speakers used, and the bi-amp level control would be adjusted to give a volume balance between the two systems. In this way the optimum balance between a good bottom end and a cutting top end can be achieved.

To effectively use the full power of the amp the two volume controls provided should be set as follows. The master volume control should always be set fairly high (around ¾ full range) and the input gain control can then be used to set the desired volume.

This is done so that signal does not clip in the pre-amp stages. If the input gain is too high the signal from the guitar may overdrive the input pre-amp and cause excessive distortion even at low listening levels.

The remaining controls will be left to your own ingenuity. Everybody has their own idea about what sort of bass sound they like. The equaliser and tone controls should provide enough versatility to get the sound you want. ●

Front panel. Complete drilling details for the front panel to suit the case specified.



General purpose 150 W MOSFET power amp module

Here's a high power, general purpose power amplifier module for guitar and PA applications employing rugged, reliable MOSFETs in the output.

David Tilbrook

Geoff Nicholls

SINCE publishing the ETI-477 MOSFET amp in the January, February and March 1981 issues, we have received a continued demand for a general-purpose MOSFET power amp module suitable for guitar or PA applications. The ETI-477 can of course be used but is unnecessarily complex for this purpose. To fill this demand we have developed the ETI-499 module. It produces similar power levels to the ETI-477 (i.e: around 100 W RMS into an 8 ohm load or around 150 W into a 4 ohm load when used with the Ferguson PF4361/1 transformer), but has been designed with constructional simplicity as the foremost consideration. The power supply circuitry is included on the pc board so that the only connections to the board are from the power transformer, input sockets and output terminals. This greatly simplifies construction and installation and ensures that all power supply wiring is done with the necessary high current handling capability. In all transistor amplifiers, but especially with MOSFETs, the resistance between the main filter capacitors and the output devices must be kept as low as possible if low distortion and stability are to be ensured.

The circuit used in the ETI-499 is a development from one published in the Hitachi application notes for these MOSFETs. The original circuit used very high-gain bipolar driver transistors developed especially by Hitachi for use as MOSFET drivers. Unfortunately these devices are at present unavailable in Australia. Since these are an extremely fast device, replacement by more common bipolars limits the open loop bandwidth and causes the amplifier to be unstable. The main departures from the Hitachi circuit are therefore to ensure a stable design with common transistors.

We used the BF469 and BF470 as drivers. These are a complementary video output pair supplying good slew rate and V_{ceo} figures at a reasonable price. The resulting power amp module is fast and stable, with distortion figures completely adequate even for many high fidelity applications. The module is easy to construct and capable of withstanding continued clipping or full-power operation for extended periods when provided with a suitable heatsink.

SPECIFICATIONS — ETI-499

Power output
150 W RMS into 4 ohms
100 W RMS into 8 ohms
(at onset of clipping)

Frequency response
20 Hz to 20 kHz, +0 −0.5 dB
10 Hz to 60 kHz, +0 −3 dB
(measured at 1 W and 100 W levels)

Input sensitivity
1 V RMS for full output

Hum
−98 dB below full output

Noise
−114 dB below full output

Total Harmonic Distortion
0.006% at 1 kHz
0.03% at 10 kHz
(measured at 12 W level)

Stability
Unconditional — tested to full output driving 3.5 uF short circuit at 10 kHz.

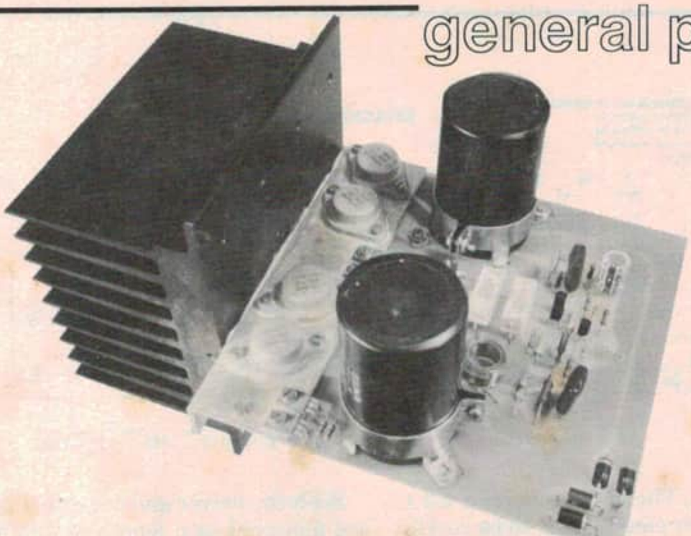
Why MOSFETs?

The power MOSFET is a relatively recent development and offers several distinct advantages over the more common bipolar transistor. To understand these differences it is helpful to look at some of the characteristics of bipolar output transistors.

Most power amplifiers employ bipolar transistors in a common-collector or emitter-follower configuration. The relationship between the output signal voltage and the input signal voltage is a function of the load impedance and the forward transfer admittance of the particular device. Forward transfer admittance is commonly given the symbol y_{fs} and its non-linear characteristic gives rise to distortion in the output stage. With bipolar transistors, the greatest non-linearity occurs for low input voltages, typically between 0 V and 0.6 V. Once outside this voltage range the forward transfer admittance is high and quite linear. So most of the distortion generated in a bipolar output stage occurs at low signal voltages and is called *crossover distortion* (for a more detailed explanation of crossover distortion refer to the article on the ETI-477 power amp module published in January 1981).

The most common method used to overcome this problem is to make use of bias current. A fixed voltage of around 0.6 V is applied to the bases of the output transistors so that the applied signal voltage does not have to operate the transistor over the most non-linear region. However, a problem arises with this technique because this voltage must be controlled extremely accurately. Even 0.5 V in excess of the correct voltage will saturate the output devices, probably destroying them. Furthermore, as the output devices heat up due to normal operation, the bias voltage must be decreased to maintain the same operating conditions. This is very difficult to do accurately enough, so the power amp is often running either with insufficient bias current or is dangerously close to destruction.

The problem occurs because the bipolar transistor has a positive temperature coefficient. This means that as the



temperature of the device is increased the collector-emitter current will increase if the base-emitter voltage is held constant. The increased current causes further heating and a further increase in current. This condition is called *thermal runaway* and results in the destruction of the output device.

Another problem with conventional bipolar output transistors is speed. The techniques used in the construction of these devices to ensure broad SOAR characteristics (SOAR stands for Safe Operating ARea) usually conflict with those to ensure high speed. Since the output transistors must handle the largest currents they are usually the slowest devices in the amplifier and determine the maximum signal slope that can be handled by the amplifier before distortion results. Distortion generated by this mechanism is called *slew-induced distortion* and *transient intermodulation distortion*. Once unnecessarily high signal slopes have been removed by a suitable filter at the input of the power amp the only solution is to increase the slew rate of the output devices.

One of the major advantages of power MOSFETs is their extremely high speed. When driven correctly the MOSFETs used in this project can switch a current of around 2 A in 30 nanoseconds! This is roughly *100 times* the speed of commonly available bipolars. Another advantage of MOSFETs is their very high input impedance. Unlike the bipolar transistor, they are a voltage-controlled device and require only enough drive current to overcome their input capacitance. Probably their most important advantage over bipolar transistors, however, is that *they have a negative temperature coefficient.* Heating causes an increase in the resistance of the device, so MOSFETs are inherently self-protecting. If one part of the device attempts to conduct more current it heats up more than the surrounding region, increasing its resistance, which distributes current over the rest of the device. Similarly if several devices are used in parallel, the negative temperature coefficient will ensure that all devices share current equally. In guitar and PA applications the negative temperature coefficient of MOSFETs provides the amplifier with unprecedented reliability, and the high speed helps to eliminate the problem of slew-induced distortion.

On the other hand a disadvantage with MOSFETs arises from their relatively low forward transconductance when compared to a good bipolar transistor. Although the transconductance of bipolars is highly non-linear when the base emitter voltage is below 0.6 V, it increases dramatically once outside this region. The MOSFET, although not as non-linear for small voltages, never achieves the forward transconductance of the bipolar transistor. The distortion generated by the power MOSFETs is therefore higher than that of bipolar transistors and must be reduced to acceptable limits through the use of negative feedback. This is not a real problem, however, since the high input impedance eliminates at least one stage of a conventional bipolar amplifier design. This allows a simpler circuit with fewer active devices and consequently improved stability margins, allowing greater levels of overall negative feedback before oscillation results.

Construction

Construction of the ETI-499 is relatively simple, since all the components mount on the pc board, including the output transistors and power supply components. The design of a good pc board pattern is often as difficult as the design of the original circuit! This is especially true for power amplifiers or any circuit in which both large and small currents are involved. The problem of large currents occurs because of voltage drops across earth return paths, destroying the integrity of earth reference points for small signal currents. To overcome this problem, the pc board must be designed to ensure the ▶

HEATSINKING

The heatsink will need to dissipate around 100 W when the module is run at full output for lengthy periods. A heatsink with a thermal capacity of around 0.65°C/watt is recommended if free-air cooling is contemplated. A 152 mm length of Philips 65D6CB will do nicely (cost — around $30). Alternatively, the module may be mounted on one of the ETI-designed Series 5000 heatsink panels. In fact, two modules may be mounted on a Series 5000 heatsink panel. The panels are available at some suppliers or direct from us (see page 49).

If fan-forced cooling is contemplated, then a heatsink rated at 1.2 to 1.5°C/watt should be used. A 225 mm length of commonly available extruded 'fan' type heatsink will do the job. This type of heatsink is flat on one side, the other side having two sets of fins fanning out from a central channel. A suitable length will set you back about $10. A fan will set you back around $20 to $30, unless you have one lying around.

Compensation capacitors are required for the two 2SK134 output MOSFETs (Q8 and Q9) to equalise the input capacitances between the n-channel and p-channel output devices. They are mounted under the board as shown here. Solder lugs are placed on top of the mounting nuts and held with another nut each. C6 and C7 mount from these to the pads shown, while C7 mounts between them. Note the resistors mounted under the board also.

validity of the earthing arrangement. If at all possible, the pc board published should be used, as departures from this design could seriously affect amplifier performance.

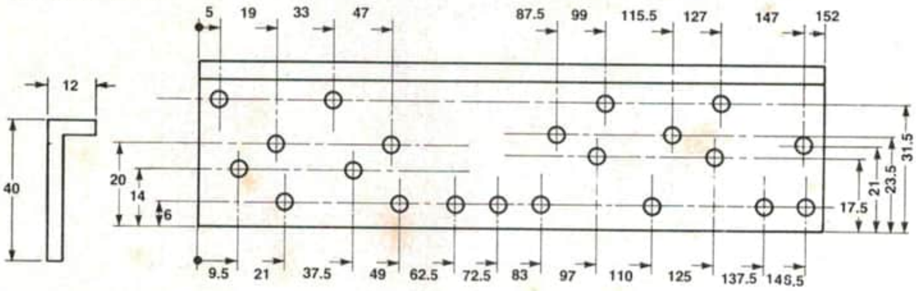
Commence construction by soldering all the resistors onto the circuit board with the exception of the four 0R22 output resistors. These effectively connect all the sources of the MOSFETs together and make it difficult to locate faults in the mounting of the MOSFETs. Solder the 1 W resistors slightly above the circuit board since these can become hot under certain conditions. The components marked with an asterisk on the circuit diagram are mounted on the rear of the pc board. They should be mounted close to the MOSFETs. Do not solder the resistors to the rear of the circuit board at this stage. These are best left until after the MOSFETs have been mounted.

Solder the capacitors onto the circuit board with the exception of those on the rear of the board and the two large electrolytics. The 100u capacitor C3 is the only other electrolytic, so be careful with the orientation of this component. The capacitor is marked to indicate which of its leads are to be connected to a positive or negative voltage. Check the correct orientation on the overlay diagram. This also applies to the diodes and zener diodes used in the circuit, which can be mounted next.

Both the driver and power transistors are mounted on a length of aluminium angle extrusion, which is bolted to the pc board by bolts through the transistor mounting holes. This is shown in the accompanying diagrams. The extrusion is used to conduct the heat generated by the output and driver transistors to the heatsink, which will also be bolted to the extrusion. If you purchase the mod-

ALL 4 mm DIA.
MATERIAL 40 x 12 x 3 ALUMINIUM ANGLE EXTRUSION
Drilling details for the heatsink bracket assembly. All dimensions are in millimetres. Suitable aluminium angle stock is available from Alcan Handyman stores.

BRACKET DRILLING DETAILS



PARTS LIST — ETI-499

Resistors .... all ½ W,5% unless stated
R1,R2 .... 100k
R3,R11 .... 1k
R4,R5,R18-R21 .... 220R
R6,R7 .... 3k9
R8 .... 22k
R9 .... 680R
R10 .... 10k
R12,R15,R16,R17 .... 100R
R13 .... 33k
R14 .... 10k 1 W
R22-R25 .... 0R22 W
R26 .... 4R7 1 W
R27 .... 1R 1 W
RV1 .... 100R preset
RV2 .... 250R preset

Capacitors
C1,C9 .... 220n greencap
C2 .... 2n2 greencap
C3 .... 100u/25 V electrolytic
C4 .... 33p ceramic
C5 .... 6n8 greencap
C6,C8 .... 330p ceramic
C7 .... 47n greencap
C10,C11 .... 100n greencap
C12,C13 .... 8000u/75 V electrolytic

Semiconductors
Q1,Q2,Q3 .... BC546
Q4,Q5 .... BF470
Q6,Q7 .... BF469
Q8,Q9 .... 2SK134 Hitachi MOSFET
Q10,Q11 .... 2SJ49 Hitachi MOSFET
D1-D4 .... 1N914
D5-D8 .... 1N5404
ZD1,ZD2 .... 12 V 400 mW zener

Miscellaneous
ETI-499 pc board; plastic bobbin (from P26/16 potcore or similar); 5 A fuse (speaker fuse, not mounted on pc board); fuse holder; 1 m of 0.8 mm enamel-covered copper wire; 155 mm length of aluminium extrusion, 40 mm x 12 mm, for use as the heatsink bracket; assorted nuts and bolts, hookup wire, etc; two solder lugs.

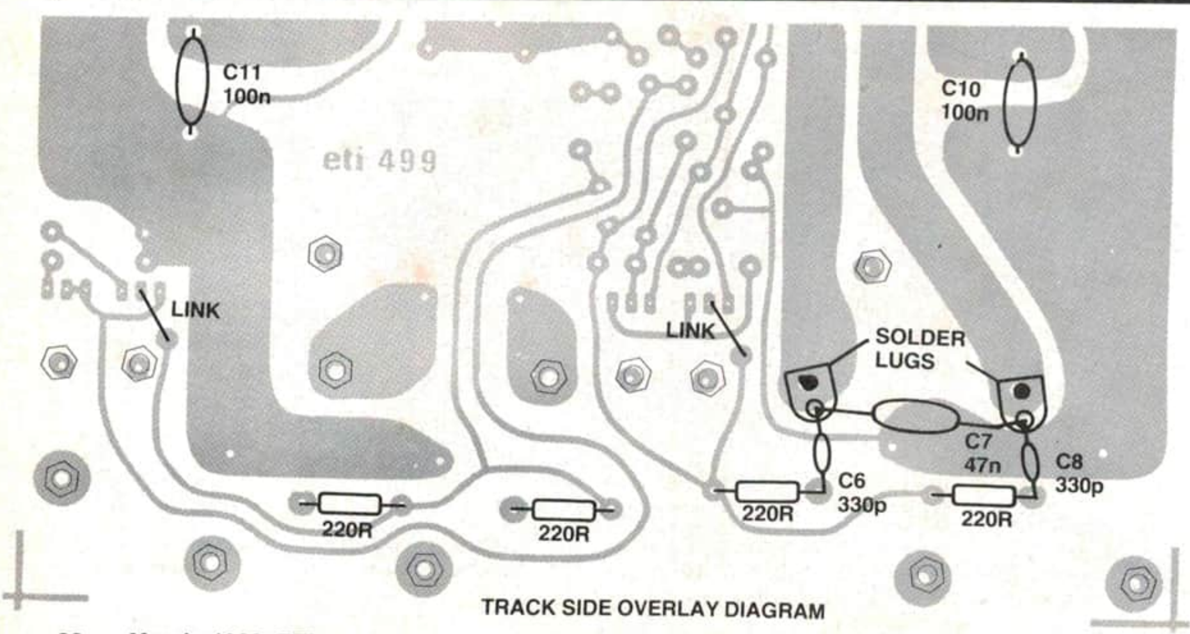
Price estimate

We estimate the cost of purchasing all the components for this project will be in the range:

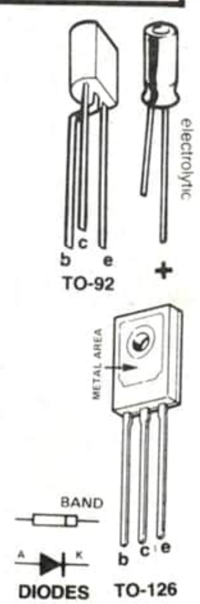
$75-$85

(heatsink & transformer extra)

Note that this is an **estimate** only and **not** a recommended price. A variety of factors may affect the price of a project, such as — quality of components purchased, type of pc board (fibreglass or phenolic base), type of front panel supplied (if used), etc — whether bought as separate components or made up as a kit.



TRACK SIDE OVERLAY DIAGRAM

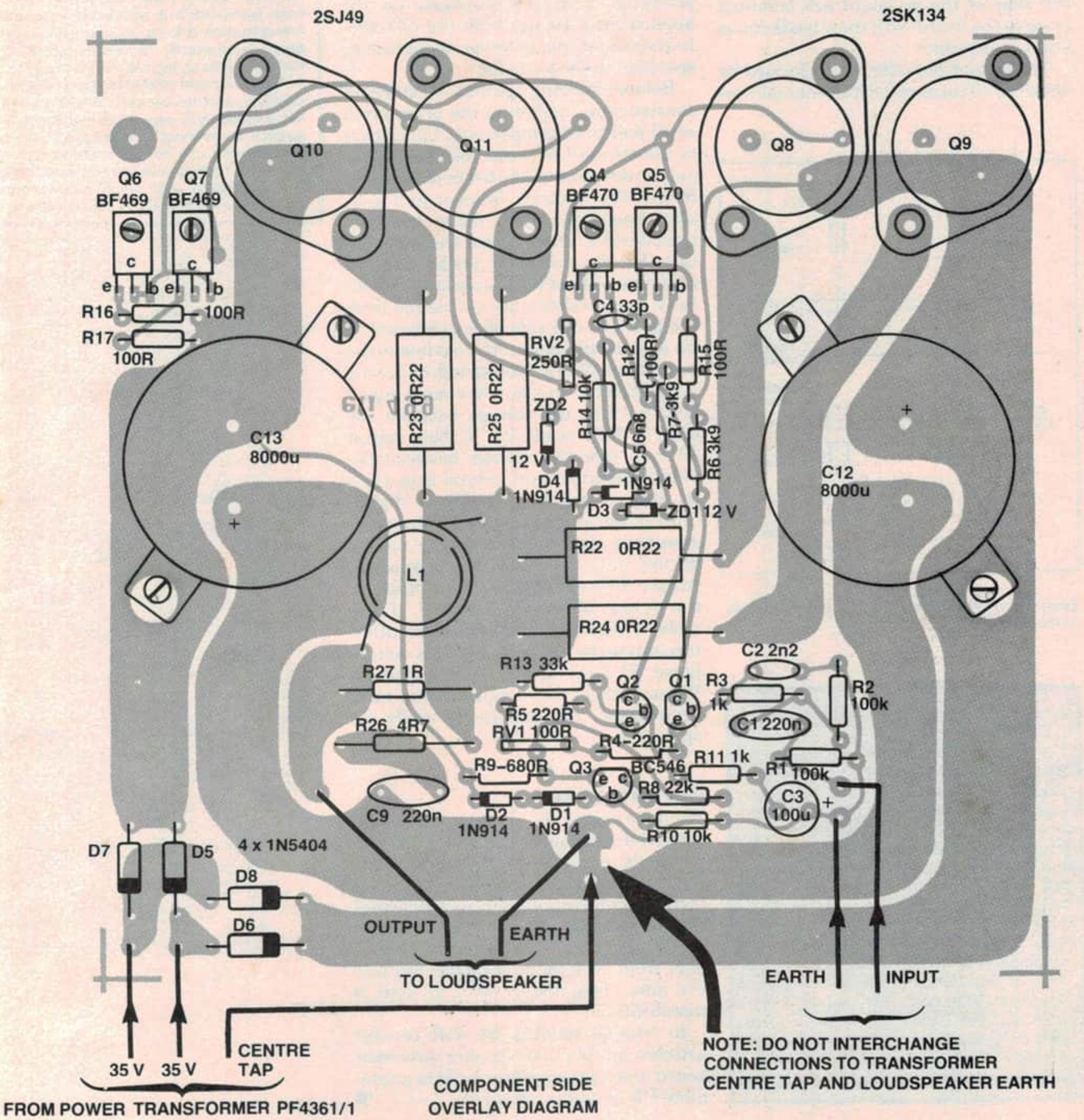


ule in kit form from one of the kit suppliers who support our projects, this bracket should be supplied drilled, ready to mount the transistors. If not, drill all the necessary holes before proceeding further. Make certain the holes are free of burrs or shavings that might otherwise cut through the transistor insulating washers. This is best done with a couple of twists of an oversize drill (i.e: around 13 mm diameter).

The bolts holding the MOSFETs in place also serve to make electrical connections to the cases of the devices. These bolts must be insulated from the heatsink bracket, which will be at earth potential. This is done with the use of short insulating sleeves cut from a length of 'spaghetti' insulation. Use a small quantity of heatsink compound on both sides of the transistor insulating washers to ensure good thermal contact. Insert the sleeves in the holes of the heatsink bracket and mount the four MOSFETs as shown in the accompanying diagram.

The four driver transistors can now be mounted. Again, use transistor insulating washers between the metal sides of the transistors and the heatsink bracket, although insulating sleeves are not necessary.

Once all the transistors have been mounted on the heatsink bracket use a multimeter to check for any short circuits to the heatsink bracket by measuring the resistance from the case of each MOSFET, and from the centre lead of each driver transistor, to the bracket. The measurements should show open circuit on all transistors. If a short does exist the transistor should be ▶

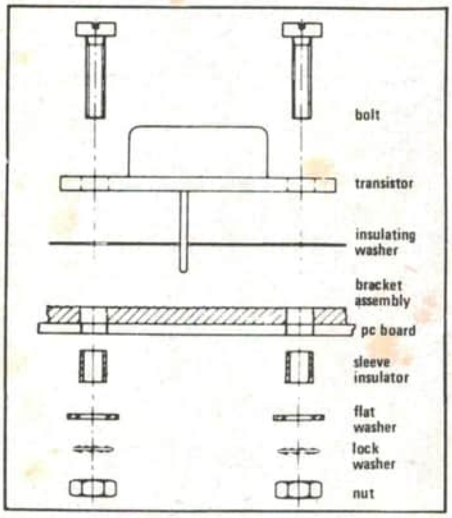


COMPONENT SIDE OVERLAY DIAGRAM

removed and remounted, possibly with a new insulating washer. Finally, solder the leads to the transistors.

Once the MOSFETs and drivers have been mounted, the remainder of the components can be mounted on the pc board, including the small signal transistors and the components on the rear of the pc board. Mount the two 8000u electrolytic capacitors last; be sure to bolt the capacitors down, however, before soldering the lugs. Mount the four 0R22 resistors now, leaving around 5 mm between the resistor and the board. Ensure that all components mounted on the rear of the pc board are mounted close to the board with their leads cut as short as possible.

The output inductor, L1, is formed by winding 20 turns of 0.8 mm enamel wire around a 14 mm former. The plastic bobbins supplied for use with the P26/16 potcores are ideal for this purpose.



Exploded view of how to mount the output devices to the bracket and pc board.

Powering up

Supply fuses have not been included on the pc board because the resulting resistance necessitates the use of a second set of electrolytic capacitors close to the output devices. To protect the loudspeakers in the case of failure of the power amp a fuse should be used in series with the loudspeaker cable. We will shortly be publishing a loudspeaker protector, with the emphasis on PA applications, for use with the ETI-499. In the meantime, however, use a fuse as specified in the parts list.

Before powering up check all stages of construction, including the orientation of all polarised components. Check that no shorts exist between the cases of the output devices and the heatsink bracket. Mount the heatsink bracket to a suitable heatsink, again using heatsink compound to ensure good thermal contact. Do not connect a loudspeaker at this time. Adjust RV1 to centre and RV2 fully counterclockwise, as viewed from the positive rail side of the pc board. If all is in order, connect the module to the power transformer and switch on. Using a multimeter on the 1 V range, adjust RV2 so that the voltage between the ends of RV2 reads 0.8 V. Now adjust RV1 so that the voltage between the output terminal and ground is as close to zero as possible. Ideally, a digital multimeter should be used for this measurement since most analogue meters do not have the necessary resolution. Adjust RV1 to achieve a dc voltage on the output of less than 10 mV, if possible. If your multimeter does not allow measurement of voltages this small, leave RV1 set at the centre position. When both of these adjustments have been made, the module is ready for operation.

Performance

We have tested the prototype into both inductive and capacitive loads and at all times *it performed impeccably.* The sound is clean and smooth with no sign of the harshness sometimes experienced with transistor power amps. The high speed of MOSFETs helps to ensure freedom from slew-induced distortions and the amp clips cleanly with no sign of instability.

In coming months we will present articles on the loudspeaker protector board and a preamplifier to form a complete PA or guitar amplifier. ●

SOME CAPACITORS AREN'T . . .

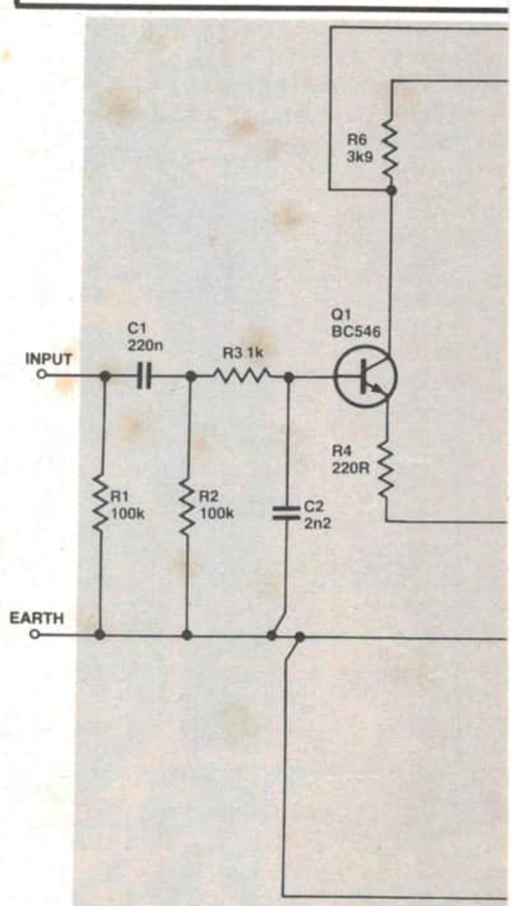
For the R26-C29 network to provide an effective high frequency load to the output stage it is imperative that C9 (220n greencap) have low self inductance. From experience, we have found Elna type greencaps and Philips polycarbonates meet this requirement. High frequency instability, if not outright oscillation, may result if this requirement is not met.

To a lesser extent, the same applies to C7, C10 and C11. Note that C7 ac-couples the sources of Q8 and Q9 together, so that the self inductance of the source ballast resistors R22 and R24 is no longer important, preventing high frequency instability in this section of the output stage brought about by the inductance of the wirewound ballast resistors.

HOW IT WORKS — ETI-499

The circuit is a development from one published in Hitachi's application notes for these MOSFETs. The original circuit uses driver transistors designed by Hitachi for use as MOSFET drivers. Unfortunately these devices are not available in Australia at the present time, so most of the differences are to ensure stability and low distortion with a more readily available driver. We have used the BF469, BF470 complementary video output pair as used in the 477 module. These transistors provide the necessary speed so as not to degrade the performance of the output transistors.

One of the most difficult stages in the development of an amplifier module of this type is the pc board design. Separation of the large currents flowing to the electrolytic capacitors from signal earth is absolutely imperative if low distortion is to be obtained. An earlier pc board using exactly the same circuit gave distortion figures as high as 1% when driven into 8 ohms at around 10 W RMS! The problem was simply interaction between charging currents to the electrolytic capacitors and the earth reference to the input differential pair. For best performance use the pc board design published with this article and pay special attention to all earth and supply connections. In particular ensure that the connections to the



centre point of the transformer and the loudspeaker earth are soldered into the correct positions on the pc board. Although these two points are immediately adjacent on the pc board they are *not* equivalent electrically due to the slight resistance of the board. If these wires are connected the wrong way around the distortion will be increased possibly by as much as 20-30 dB!

Transistors Q1 and Q2 form an input differential pair. Their function is to compare the output signal with the input signal and drive the voltage amplifier transistors in the driver stage with the necessary correction signal, sometimes called the error voltage or error signal. The base of Q1 is held at ground potential by resistor R2. Capacitor C1 in conjunction with R2, R3 and C2 forms an input filter, which defines the upper and lower 3 dB points of the amplifier. This filter therefore restricts the maximum possible signal slope capable of being driven to the input of the differential pair. This is an essential function since it eliminates slew-induced distortions such as TIM, provided that the rest of the power amp has a slew rate in excess of this limit. For a more detailed description of slew-induced distortions and their remedies see the articles on the 477 MOSFET module published in January, February and March 1981.

The gain of the differential pair is around 17, so most of the open loop gain is done by the driver transistors Q4 and Q5, and their associated current mirror formed by Q6 and Q7. The series RC network C4, R12 ensures stability of the amplifier by decreasing the gain of the driver stage at very high frequencies, while keeping the phase shift produced within 90°.

As stated above, transistors Q6 and Q7 form a current mirror. The purpose of these devices is to ensure the current through the two driver transistors remains identical. At the same time the very high impedance represented by Q7 on the collector of Q5 ensures high open loop gain, and consequently low distortion through the relatively large amount of negative feedback available. RV2 varies the voltage between the gates of the output MOSFETs and therefore the amount of bias current through the output transistors. If the voltage across this preset is set to around 0.8 V the bias current will be approximately 80 mA, which is about right. If the bias current is decreased completely by turning RV2 fully away from the MOSFET end of the board, the MOSFFTs will remain off until a signal is fed to the input. This is pure class B operation and results in the coolest operation of the power amplifier. The disadvantage, however, is that a slight increase in distortion, called crossover distortion, will result. In PA or guitar applications this is not a problem, so the amplifier can be used in this mode without hesitation.

The diodes D3, D4 and the zener diodes ZD1 and ZD2 ensure that the voltage between the gates of the FETs and their sources never exceeds 12.6 V, the most common cause of MOSFET failure.

Capacitors C6 and C8 equalise the capacitive input characteristics of the MOSFETs and make it considerably easier to correctly stabilise the output stage. Capacitor C7 brings the sources of the two 2SK134 MOSFETs to the same potential at high frequencies, and overcomes possible problems that might otherwise be caused by inductance in the source resistors R22 and R24.

The four resistors R22-R25 help to match the differences between the characteristics of the different output devices.

The passive filter network formed by R26, C9 ensures that the module always has a load at high frequencies. If the amplifier is tested with large high frequency sinewaves this resistor will become extremely hot, but this does not indicate a fault condition. The inductor L1 and the resistor R27 help to ensure total stability into capacitive loads, such as when driving extremely long loudspeaker leads.