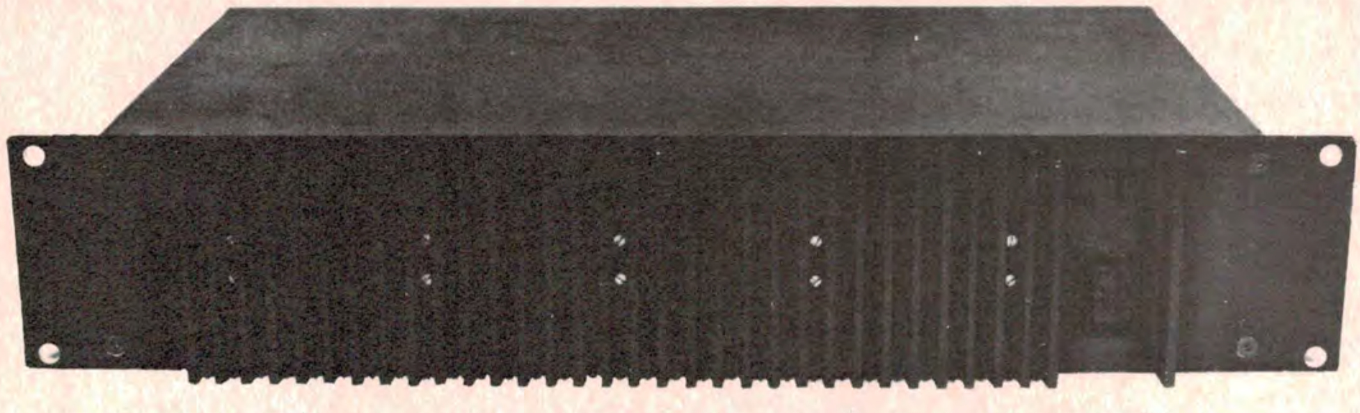


# Series 5000 MOSFET stereo amp

## This is it! A 100W/channel stereo power amplifier featuring 0.001% distortion.

**David Tilbrook**

IN LAST MONTH'S ISSUE we gave details for the construction of a stereo power amp module suitable for mounting to the ETI front panel heatsink. All that remains to complete construction of the 100 W/channel Series 5000 power amplifier is to assemble the chassis, build in a power supply and see to the earthing details.

Housing the Series 5000 Stereo Power Amplifier presented a few headaches. Heatsinking presented the biggest headache. Barry Wilkinson, once ETI's project manager, has a saying: "If you can't hide it, make a feature of it"! So we did. We designed a heatsink/front panel. It consists of a special aluminium casting, designed to conform to one of the standard 19-inch (430 mm) panel sizes. A chassis assembly is readily attached to the rear, consisting in this case of four 10 mm square-section aluminium bars, each about 230 mm long, supporting the rear panel.

Construction is clear from the photographs. A U-section aluminium top plate plus a flat bottom plate completes the case. Attach feet and you have a stand-alone unit.

The ETI heatsink/front panel will be available from kit and component suppliers as well as directly from us, via mail order. (See the end of this article.) We have designed it to be a 'universal' component and intend to use it in other projects in the future.

The power supply shown last month is suitable for a single ETI-477 module. Two of these could be used as independent supplies in the stereo amplifier but in the final assembly we have elected to use two power transformers to form a single, higher current power supply. The advantage normally associated with independent power supplies is the reduction of crosstalk between channels. In the case of the ETI-477 module however, the high supply rejection of the design reduces crosstalk to a level that is completely insignificant (i.e: around the noise level), so independent supplies offer no real advantage. On the other hand the use of two PF4361/1 power transformers in a single power supply yields a supply capable of more than 100 V at over 7 A continuous. On page 32 is the circuit diagram for the Series 5000 power amplifier. The Ferguson transformer specified has two, independent 35 V windings. These are connected in parallel to produce a single 35 V RMS winding capable of supplying 5 A RMS. The two transformers then have these secondaries connected in series to provide the centre-tapped supply. When paralleling the windings of a transformer it is essential that they are connected together in the correct way. In the Ferguson transformer the start of the two windings are the black and red wires which should be connected together to form one terminal connection. The finish of the windings are the orange and yellow wires. These are connected together to form the other terminal. If the windings are connected in any other way the power transformer will be damaged when switched on.

One terminal of each transformer is connected to the bridge rectifier, a 35 A type. The filtering for the power supply is done with two 8000 $\mu$F capacitors to form a total of 16 000 $\mu$F across each half of the dc supply rails. The resulting dc supply voltage should be approximately ±52 V, unloaded. At full power this will drop to around ±50 V. With a 10 V drop across the output devices the peak signal voltage before clipping is around 40 V, which gives 100 W into an eight ohm load. In reality, the voltage drop across the MOSFETs is not as high as this since the ETI-477 module uses two devices in parallel. The maximum output power of the prototype unit using the power supply shown was 112 W single channel and 105 W both channels driven.

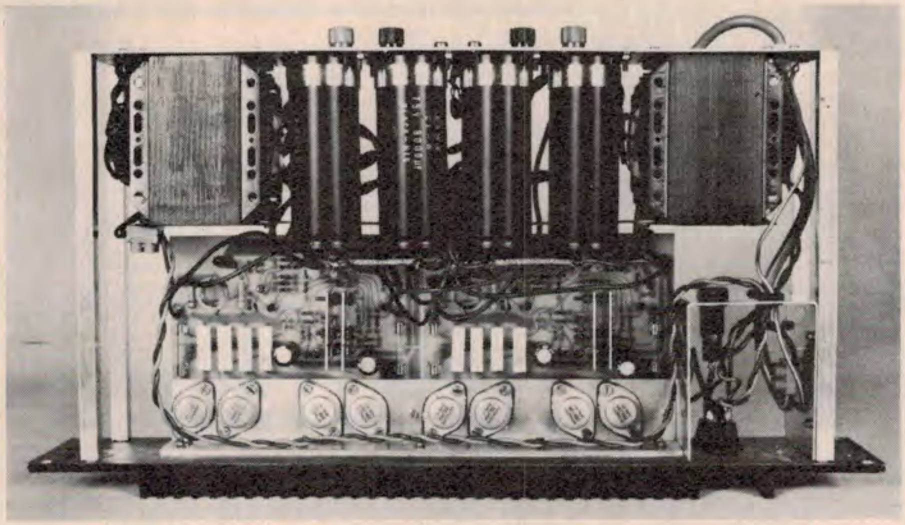
By far the biggest problem in the design and construction of any amplifier is that of earthing. If maximum performance is to be obtained from the ETI-477 modules great care must be taken to ensure complete isolation of high current earths from low current ones such as the input signal earth. If this is not done the large currents flowing in the speaker return earths, for example, will interact with the input and distortion results. Similarly, if the earth current from the electrolytic capacitors is allowed to interact with any low current signal earth the amplifier will have degraded hum figures and may even be unstable. The pc board layout has been designed to overcome these problems through the use of a *single-point* earthing arrangement. Earth lines from the output devices and power earth lines from the on-board electrolytic capacitors are kept separate until they reach the 0 V point on the circuit board.

The main input signal earth is the most critical.

The power amplifier will regard as a valid input any voltage difference between the input and the input earth terminals. So any hum present on this earth will be treated as an input and amplified accordingly. In order for the hum level to be inaudible from a 100 W power amplifier it must be at least 90 dB below the full output voltage, which is around 0.9 mV. Since the voltage gain of the ETI-477 is approximately 23, the equivalent input signal voltage is 0.9 mV/23 ≑ 39 uV! It is clear that even a *minute* hum level at the input will produce an audible hum at the output. To overcome this problem the input earth is isolated from the 0 V track on the circuit board by the 10 ohm resistor R3, shown on the ETI-477 circuit diagram in last month's issue. The input wiring to the module is done with a twisted pair of 10 amp hookup cable and the connection for the input earth is done at the input RCA sockets. This is shown in the circuit diagram for the Series 5000 amp assembly and in the wiring diagram on page 32. The 10 amp hookup cable is used instead of the more usual shielded cable, since in this application the lower resistance of the hookup cable results in better hum rejection.

The remaining earth problem is the possibility of hum loops caused by the fact that both the power amplifier and the preamplifier used to drive it must be connected to the same chassis ground point via their power cables. If the chassis of both the preamp and the power amp are connected to the 0 V point on their respective power supplies and the two 0 V points are connected together via the shielded cables between the preamp and power amp, a closed circuit is formed. Any hum currents induced into the earth lead of the three-core power cable, for example, can flow through the chassis of the power amp to the power amp 0 V point, down the shielded cable at the power amp input, to the 0 V point in the preamp and via the preamp chassis around the loop again. The presence of this hum current in the power amp input earth will be seen as an input by the power amp and output hum results. The cure is to open-circuit this loop so that hum current cannot flow in the input signal earth line. The best way to do this is to break the connection between the chassis of the power amp and the 0 V point on the power supply. In this way the power amp still has a valid earth reference at its input but the possibility of a hum loop is eliminated.

The disadvantage of this technique is that the chassis can no longer act as an effective shield to external electrical noise sources, but this problem can be overcome by capacitively coupling the chassis to the 0 V track at selected places in the power amplifier. The relatively high impedance of these capacitors at 50 Hz still maintains an effective open circuit to prevent the hum loop problem.



**Internal view of the amplifier showing general construction. Note the twisted lead running from the transformer at left, around the front panel, to the 'mains termination box' at front right. The two transformers are mounted using brass washers between the panel and their mounting brackets.**

The earthing procedure outlined above has consistently given good results both in the prototype Series 5000 amp and in numerous other power amps, and provides the power amplifier with good earthing that is not affected excessively by the earthing configuration used in the preamp.

## Construction

If you are using the ETI front panel heatsink it can be drilled at this stage according to the details shown on the front panel drilling diagram. This diagram assumes that the single double-length heatsink bracket is used (see last month's issue). The pc board assemblies can now be mounted to the front panel using 6 BA nuts and bolts. The heads of the 6 BA bolts should fit snugly between the heatsink fins. It is essential that there is good thermal contact between the heatsink bracket and the heatsink and for this reason the entire mating surface of the heatsink bracket should be coated in heatsink paste before bolting to the heatsink.

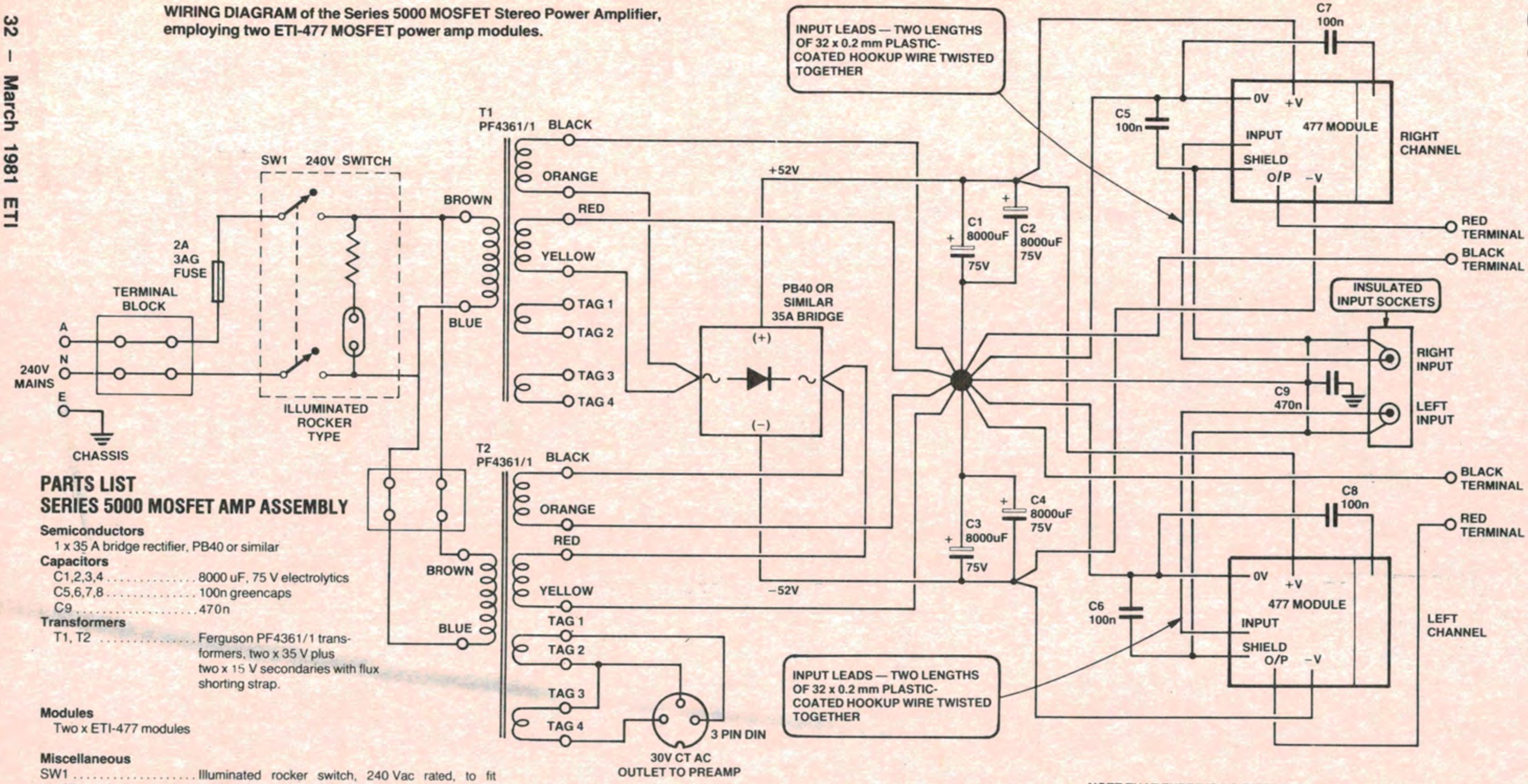
When you come to drilling the holes for the rack mounting bolts you'll notice dimples in the front of the casting indicating the hole centres. It would be preferable to use a drill press when drilling these holes as the rack standard leaves little room for error. If drilling by hand, drill a small pilot hole first.

The input wires to each module should be attached at this stage. We used a twisted pair of 32 x 0.2 mm plastic-coated hookup wire. This is superior to standard shielded cable for this application. The input wiring must be kept away from the 240 V wiring at the rear of the power switch. To achieve this the input wiring to both modules is taken to the left hand side of the amp, passing beside the left hand power transformer and then going to the input (see accompanying photographs).

The input leads to the left module should be around 250 mm long while those for the right channel module should be around 400 mm. This allows for trimming in the final assembly. The input 'earth' on each board has to be ac-coupled to the 0 V line on each board for the reasons discussed earlier. This is done by soldering a 100n greencap on the rear of each pc board, immediately beneath R3. The 'earthing bolt', which makes connection to the heatsink bracket, is assembled with a transistor mounting insulator on the underside of the pc board so that the bolt is insulated from the 0 V line on the pc board. A solder lug is placed under the nut. A 100n greencap is then soldered between this lug and the 0 V track adjacent. The accompanying photograph and drawing make this clear. ▶

**The 0 V track on each module pc board is 'earthed' via a 100n greencap to the earthing bolt, which is first insulated from the board using a transistor mounting insulator. (See also page 34).**

**WIRING DIAGRAM of the Series 5000 MOSFET Stereo Power Amplifier, employing two ETI-477 MOSFET power amp modules.**




## PARTS LIST
## SERIES 5000 MOSFET AMP ASSEMBLY

**Semiconductors**
1 x 35 A bridge rectifier, PB40 or similar

**Capacitors**
C1,2,3,4 .............. 8000 uF, 75 V electrolytics
C5,6,7,8 .............. 100n greencaps
C9 .................... 470n

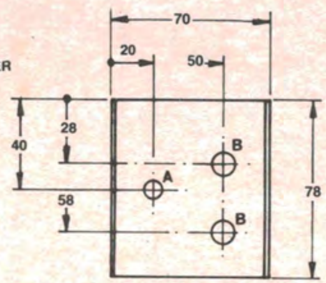
**Transformers**
T1, T2 ................ Ferguson PF4361/1 transformers, two x 35 V plus two x 15 V secondaries with flux shorting strap.

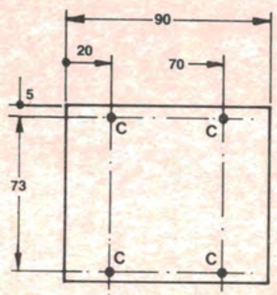
**Modules**
Two x ETI-477 modules

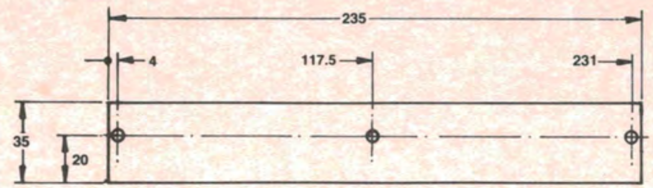
**Miscellaneous**
SW1 .................... Illuminated rocker switch, 240 Vac rated, to fit 22 x27 mm hole; 1 x 2A type 3AG fuse and fuseholder; 1 x 3-pin DIN socket; 2 x 2-way plastic terminal blocks; 2 x RCA sockets; 2 x red and 2 x black heavy duty screw terminals; clamp grommet and sundry rubber grommets; hookup wire; nuts, bolts etc; Heatsink/front panel, metalwork etc.

NOTE THAT THERE IS NO DIRECT CONNECTION BETWEEN CHASSIS AND 0V

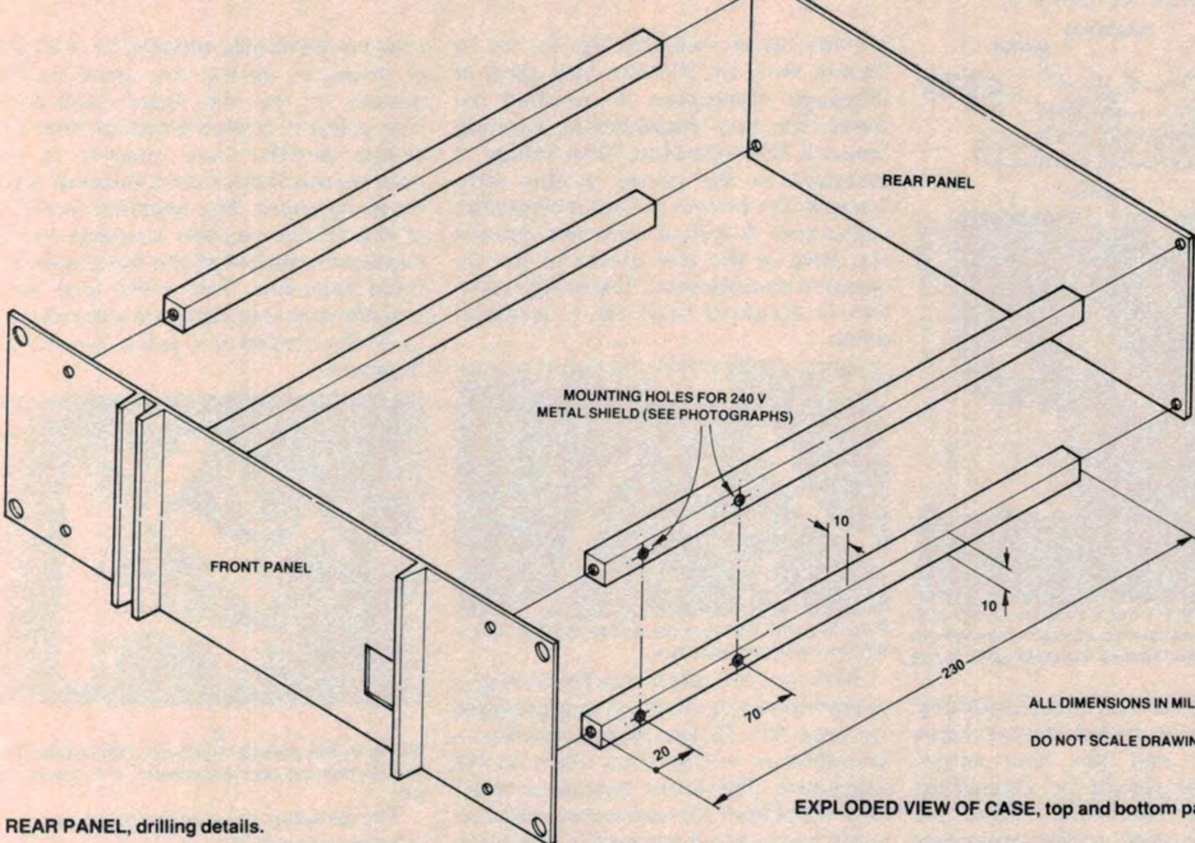
HOLES MARKED 'A' DRILL TO SUIT FUSEHOLDER
HOLES MARKED 'B' 10 mm DIA.
HOLES MARKED 'C' 3 mm DIA.
ALL DIMENSIONS IN MILLIMETRES
DO NOT SCALE DRAWINGS



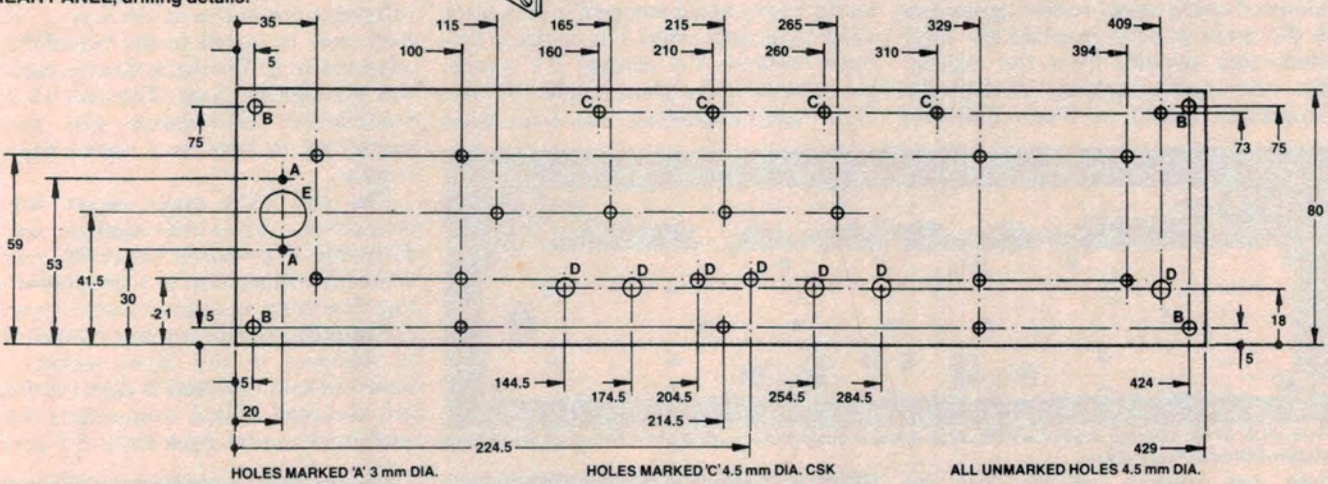




DRILL ALL HOLES 4.5 mm
ALL DIMENSIONS IN MILLIMETRES
DO NOT SCALE DRAWINGS




EXPLODED VIEW OF CASE, top and bottom panels not shown.

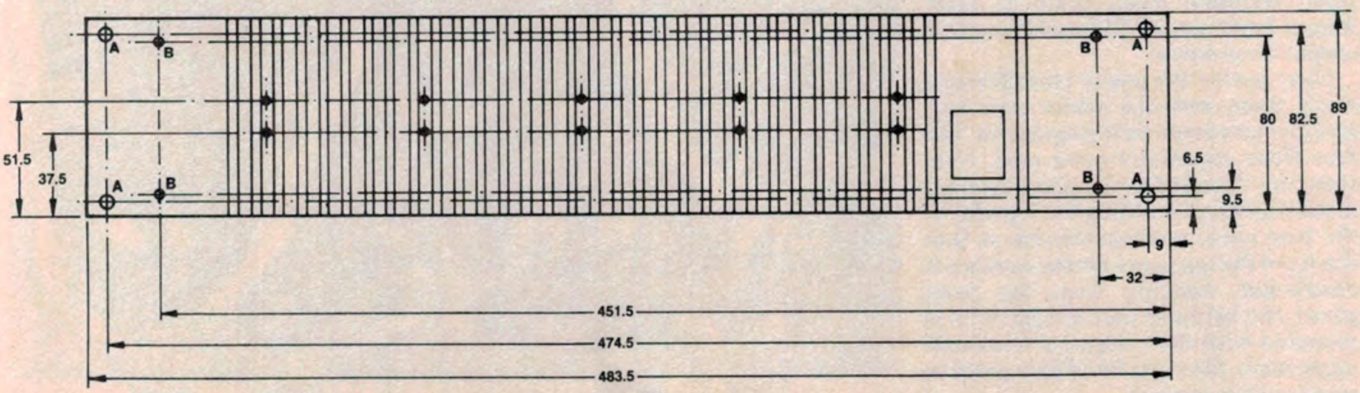
REAR PANEL, drilling details.




HOLES MARKED 'A' 3 mm DIA.
HOLES MARKED 'B' 5 mm DIA.

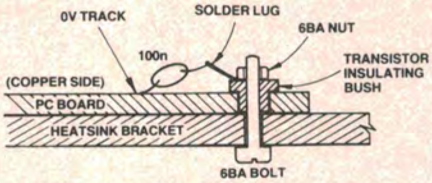
HOLES MARKED 'C' 4.5 mm DIA. CSK
HOLES MARKED 'D' DRILL TO SUIT
HOLES MARKED 'E' DRILL TO SUIT DIN SOCKET

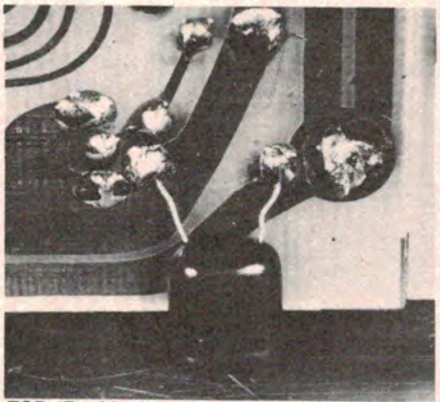
ALL UNMARKED HOLES 4.5 mm DIA.
ALL DIMENSIONS IN MILLIMETRES
DO NOT SCALE DRAWINGS




HOLES MARKED A 8 mm DIA.
HOLES MARKED B TO TAKE 2BA COUNTERSUNK BOLT

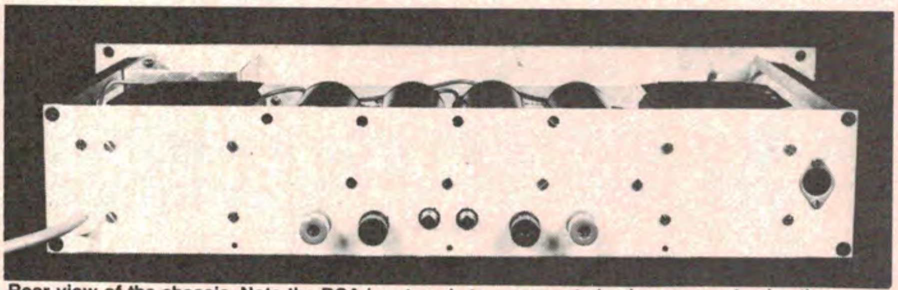
HEATSINK/FRONT PANEL drilling details.



**TOP: 'Earthing' the 0 V track on each module (C7, C8). LOWER: Capacitors C5, C6 mount beneath R3 on each module and couple the input earth to the board 0 V.**

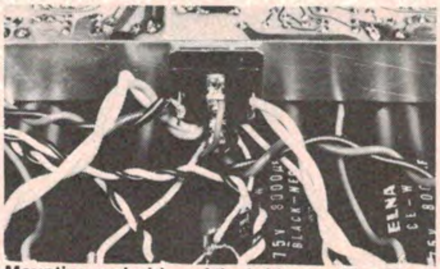
Next step is the rear panel assembly. Once the panel is drilled, the two input RCA sockets and the four output terminal posts should be assembled. Note that the two RCA sockets are mounted using small rubber grommets in the holes so as to insulate the outer connection (shield) from the chassis. See the accompanying photograph. Grommets having a 6 mm diameter hole are perfect for the job. Alternatively a two-way insulated RCA input terminal panel could be used. Mount the three-pin DIN socket next (ac output for preamp).



**Rear view of the chassis. Note the RCA input sockets are mounted using grommets plus the preamp supply DIN socket at right.**

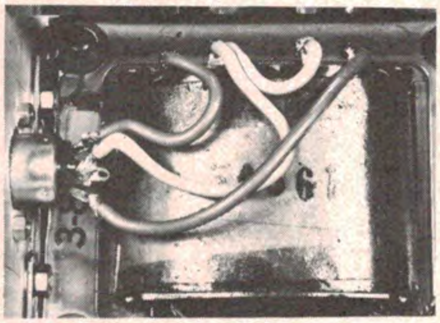
Next mount the power transformers. Place them with the solder terminals and primary leads facing *outwards*. The four filter capacitors come next. Note that the four holes for the capacitor mounting brackets along the top edge of the rear panel are countersunk so that the lip of the top panel for the case is not obstructed. Looking from the front panel, the left hand pair of capacitors is mounted with their negative terminals uppermost, the right hand pair positive terminals uppermost.

To mount the bridge rectifier, and provide some heatsinking for it, a 35 mm wide by 235 mm long strip of 20 gauge aluminium is mounted between the two transformers, running beneath the capacitors. The bridge is mounted in the centre of this strip towards the bottom so that it clears the capacitors. A bolt at each end secures the strip to the end cheeks of the respective transformers. The bridge rectifier is mounted with its + terminal down.



**Mounting and wiring of the bridge rectifier. The + terminal is uppermost here.**

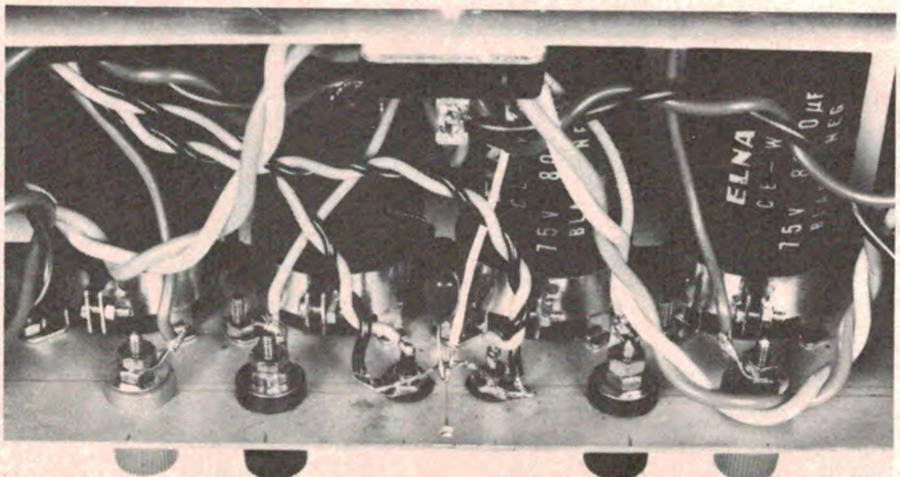
Now you can commence the wiring (a complete wiring diagram is reproduced on page 32). Do the bridge rectifier — transformer wiring first. Then do the capacitors. The lower terminals of all four capacitors are connected together using heavy braid stripped from a piece of RF type coax cable. The centre of this buss becomes the central 0 V return point (refer to the photograph). The two right hand capacitors also have their positive terminals bridged by a length of braid, as do the two negative terminals of the left hand capacitors. The positive output terminal from the bridge rectifier then connects to the positive terminal of the innermost right hand capacitor. The negative terminal of the bridge rectifier connects to the negative terminal of the innermost left hand capacitor. Two wires from each transformer secondary are wired directly to the central 0 V point (see wiring diagram).



**Wiring of the preamp ac supply DIN socket. The transformer tags are numbered 1, 2, 3, 4 from the left.**

The preamp ac supply output socket (oh yes, a preamp is on the way . . . Ed.) may now be wired to the transformer adjacent to it. Wiring is clearly seen in the photograph here. The two 15 Vac transformer secondaries are series connected to provide a centre-tapped supply.

The two RCA input socket shield connections are wired together and a 470n/250 V greencap capacitor wired from this connection to a panel ground lug. The latter is secured under a nut on the capacitor mounting bolt immediately adjacent to the input sockets. A separate earthing lead is then run from the common shield connections from each input socket, back to the 0 V point.



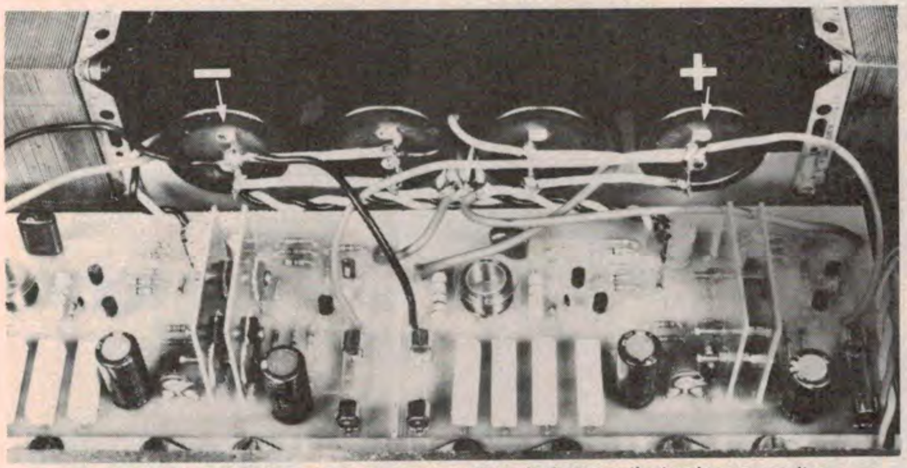
**Input RCA socket wiring. Note which direction the twisted pair leads from these sockets are dressed.**

The two speaker negative terminals, mounted either side of the input RCA sockets, are individually wired to the central 0 V point next.

Incidentally, if you're worried that the + terminal of the bridge rectifier may short to the bottom panel, bend it in a little and sleeve the connection.

The four 10 mm square aluminium bars may now be attached to the rear panel assembly. There are two 'upper' bars and two 'lower' bars and don't forget that the bars at the right hand end are drilled to take the mains termination and fuse assembly. The front panel assembly (with the two modules mounted) can be attached now. We placed 4 BA steel washers between the front panel and the four bars to accommodate the depth of the top cover we used, but this may be unnecessary in your case.

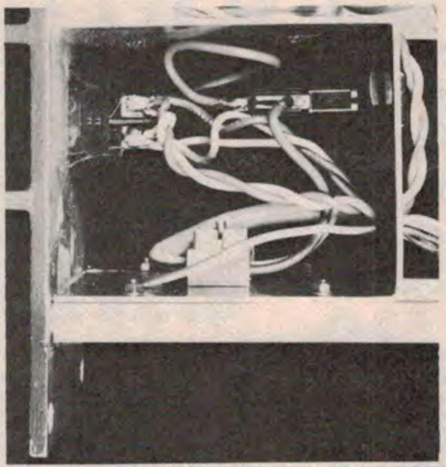
With the chassis assembled and tightened up, the wiring may be completed. Do the power supply to module wiring first. *We recommend you use 32 x 0.2 mm plastic-coated hookup wire;* anything less will probably degrade performance. The negative rail of each board connects to the uppermost (negative) terminal of the left hand




Wiring of the four filter capacitors. Note the common 0 V point between the two inner capacitors.

capacitor, while the positive rail of each board connects to the uppermost (positive) terminal of the right hand capacitor. This is visible in the photograph of this portion of the assembly. *Use separate leads; do not connect one board to the other, then to the capacitors.* The 0 V rail of each board is wired, *using separate leads,* to the central 0 V point, visible between the two innermost capacitors. Each speaker output lead is wired to its respective output terminal.

Now we come to the 240 Vac wiring. The mains switch is a DPDT illuminated rocker type that has a push-in,



The 'mains termination box', showing general assembly and wiring.

snap-lock mounting arrangement. There are several makes available and these fit the 22 x 27 mm hole provided in our panel. If you prefer something different an escutcheon may be fitted in this section of the panel. We noticed that the rocker switch sold by Dick Smith stores (cat. no. S-1506) has snap-lock flutes designed to hold the switch to a thinner gauge panel. You will need to trim them — carefully — to get this switch to fit our panel.

A U-shaped sub-assembly is mounted behind the mains switch, secured to the adjacent bars which run between the front and rear panels. This mains cable terminates at a two-way plastic terminal block mounted on the outer side. The mains fuse holder is mounted on the rear side. Also on the rear side are two grommetted holes. The lower and larger one provides an entry for the mains cable. The mains cable itself enters the cabinet via the back panel, secured with a clamp grommet (see rear photograph). The smaller, upper hole provides passage for the mains earth lead, which returns to an earth lug on the rear panel. The ac wiring to the transformer primaries also passes through this hole.

The active (brown) mains lead is wired to one pole of the mains switch via the fuse. The neutral (blue) is wired to the other pole of the mains switch. A twisted pair is taken from the mains switch terminals to another two-way plastic terminal block mounted on the left hand transformer. This cable is routed around the front panel, secured with cable ties held by several of the module heatsink bracket bolts. The right hand transformer is wired directly to the output terminals of the mains switch, the wires passing through the smaller grommetted hole.

That should complete the wiring. But, before proceeding to test the amplifier, *check all your wiring thoroughly.*

## Getting it going

Having satisfied yourself that all is well, remove the fuses on each pc board, arm yourself with a multimeter, hold your breath ... and switch on. Assuming no disasters occur, measure the supply rail voltages. They should be around 52 V. If you have previously set up your modules then you can replace the four fuses and proceed with listening tests. Before replacing the fuses allow sufficient time for the electrolytic capacitors to discharge. This will take several minutes.

The general set-up procedure was discussed on page 32 of the January issue.

Once you have completed the set-up procedure, your amplifier is ready for listening tests.

The top and bottom covers can be screwed in place once you've confirmed all is well. We recommend you use aluminium for these items as steel plates will react with the field of the transformers and produce quite a loud hum.

We trust you enjoy your Series 5000 Stereo Power Amplifier.

The second project in the Series 5000 range will be a high quality control preamp that is already in the prototype stage.

## Performance

The objective of this project has been to design a power amplifier module of the highest possible performance. Ideally the power amp should produce an amplified version of its input signal and contribute no sound of its own. In order to design a practical amplifier that will come as close as possible to this ideal, it is necessary to 'define' limits on the input signal characteristic and then ensure that the power amp exceeds these limits.

The problem of amplitude overload cannot be eliminated, since no practical power amplifier has access to infinite supply voltage. In order to overcome this problem, the ETI-477 module has been designed to handle in excess of ±50 V rails, giving it a conservative power rating of 100 W RMS into 8 ohms. The output stage has been designed so that the MOSFETs will not operate outside their safe operating area on any load in which the effective series resistance does not drop excessively below 8 ohms.

Similarly, since no power amp has an infinite slew rate or infinite frequency response, the input signal has been limited by a passive input filter. It can be easily demonstrated by experiment that the introduction of a passive filter that does not excessively affect the frequency response within the audio passband will not affect the sound of the input signal. This filter will define a maximum possible input slope. It is therefore only necessary to design the amplifier with a slew rate that exceeds this by a sufficient margin to ensure freedom from slew-induced distortion. Since the amplifier is operated below its slew rate limit, the application of negative feedback will decrease distortion produced as a result of the signal slope approaching the slew rate (TIM).

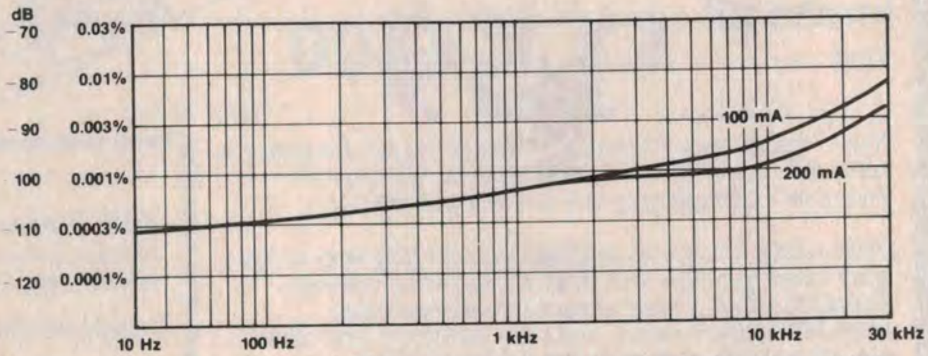
Differential pairs have been used throughout the design to form not only the input stage but also the voltage gain stage. This ensures that the distortion characteristics of the input and voltage gain stages are low enough so that the open loop characteristics of the amplifier will be determined by the output stage. The improved frequency and phase linearity of the differential pair make it considerably easier to ensure that the amplifier meets the Nyquist stability criterion. Another advantage of the differential pair is its relatively high supply rejection, a parameter which is often not given sufficient attention in power amp design.

Careful control of the feedback loop and the use of a passive filter/load on the output of the module, coupled with the design points mentioned above, have yielded an amplifier with particularly low dynamic distortion characteristics. An amplifier that has been designed with these objectives in mind will automatically have low THD and TID figures. The ETI-477 is no exception, with a THD at 1 kHz and 10 W RMS of less than 0.001%, rising slightly to around 0.003% at 10 kHz (top end distortion figures are a function of bias current). It should be remembered, however, that obtaining low THD figures should not be the prime objective of a good power amplifier design, but results from the reduction of dynamic distortion mechanisms already discussed.

### QUIESCENT CURRENT SETTING

With the quiescent current of each module set at 100 mA (1 V across 10 ohm resistors inserted across the fuse holders) the heatsink temperature will rise to typically 40°C after warm up. In use it will rise perhaps a further 30° or more, depending on programme material.

If you wish the unit to operate a little cooler, the quiescent current can be set to 75 mA on each module — adjust each RV1 for 0.75 V across 10 ohm resistors inserted across the fuse holders.




**This graph shows the measured distortion versus frequency for two values of quiescent current in the output stage.**


**The measured frequency response of the amplifier (single module). Roll-off points are defined by the input filter (low end) and output compensation network (high end).**

The ETI-477 module has been tested exhaustively and all prototypes have performed with negligible differences.

When attempting to measure distortion figures as low as these, great care must be taken with the earthing arrangement to the test equipment. The amplifier module will give its lowest distortion figures only when measured with respect to the correct earth. It may be necessary to remove the connection between mains earth and signal earth inside some distortion analysers. This problem will not arise when the amplifier is connected to a loudspeaker. This condition is not unique to the ETI-477 module, but will occur whenever an alternative earth path is provided to the output signal earth.

The subjective performance of the 477 module has confirmed for me the validity of the basic design approach. The sound is clean with no sign of the aggressive high frequency performance common to many transistor amplifiers. There are some amplifiers that give the subjective impression of being 'over-smooth'. By this I mean that the amplifier on first listening sounds clean and unobtrusive. Further listening tests reveal, however, that these amplifiers lack detail, and complex sounds like a symphony orchestra tend to become a single mass of sound rather than being rendered as single instruments. The ETI-477 does not suffer from this problem. When connected to my system (ETI Series 4000 Four-way Loudspeaker, Nakamichi MC1000 moving coil cartridge, Linn Sondek turntable, Stax tone arm, ETI-473 MC head amp), the result is one step closer to a system that has no sound of its own. ●

### SERIES 5000 HEATSINK/FRONT PANEL

This will be available through a variety of suppliers and we suggest you check your usual source for price and availability. However, if you are unable to obtain one locally you may order it direct from us.

Cost is $42.50 each, post paid within Australia. Send your cheque or money order, to cover the number you require, to:

**Series 5000 Heatsink/Front Panel**
**ETI Magazine**
**15 Boundary St**
**Rushcutters Bay NSW 2011**

Please allow up to four weeks for delivery.