An 'ultra-fidelity' MOSFET power amplifier module

Part 2

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In Part 1 the operation of the power amplifier was described and I discussed the reasons for the choice of the particular topology employed. In this article the construction of the power amp is covered in detail.

AN ASPECT of power amp design that is often given insufficient attention is the pc board layout and overall construction scheme. This is particularly important in the design of power amplifiers employing MOSFET-based output stages. The very high input impedance of the power MOSFET combined with its excellent high-frequency performance and slew rate makes this device particularly prone to oscillation if it is used incorrectly. This oscillation should, however, not be confused with the more common form of amplifier instability which is associated with a poorly controlled phase characteristic within the negative feedback loop. This is by far the most common form of instability in amps employing bipolar transistors in the output stage since the realatively poor high-frequency performance of these output devices limits the phase linearity of such designs.

The use of MOSFET output devices, on the other hand, greatly assists feedback loop stability. The type of oscillation to which power MOSFETs are prone does not involve the feedback loop and is substantially easier to control. In fact, the mechanism that causes the instability is one of interaction between the two n-channel MOSFETs, the 2SK176s, and their associated passive components. The cure for this problem is effected by the use of the low-value resistors R36-R39 and capacitor C13. In addition to these components, the layout of the pc board, particularly around the output stage, must minimise the inductances and certain critical inter-terminal capacitances. One area that is particularly critical for stable operation of power MOSFETs is the wiring to the gates and sources. The physical location of these components can be critical and it is for this reason that the power amp module has been designed so that the power MOSFETs are mounted onto a heatsink bracket and pc board which also contains the associated passive components.

The construction scheme must also facilitate the best possible heat transfer from the MOSFET output devices and bipolar drive transistors to the heatsink. As explained in Part 1, the AEM6000 design employs relatively large amounts of drive stage quiescent current to ensure low drive stage output impedance. This leads to considerable power dissipation in the drive stage, necessitating good heatsinking. As a result, the four drive transistors, Q15-Q18, and the two transistors used for the constant current sources, Q9 and Q10, have been bolted to the main heatsink bracket to ensure good heat dissipation. This arrangement also provides thermal coupling between the drive stage, its current source, and the output stage.

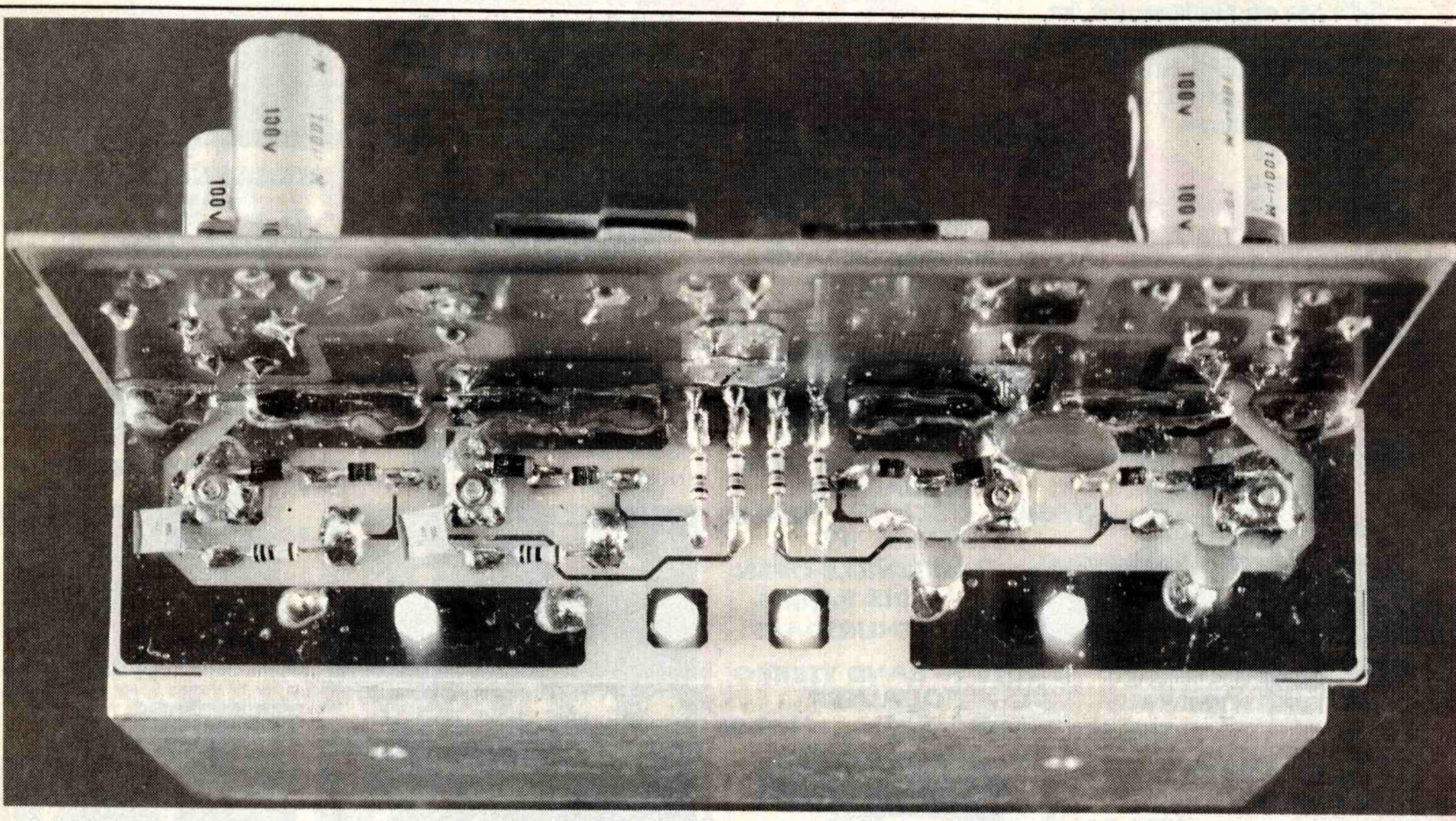
Although the concept of having all of the components, including the output devices, mounted on a pc board greatly assists repeatability of amplifier performance, it also tends to impose certain restrictions. A common construction scheme, for example, and one which we have used for various power amp modules in the past employs, an "L"-bracket in conjunction with a single pc board which contains all of the power amp components. The disadvantage with this scheme is that the pc board is mounted at right angles to the heatsink and can protrude a considerable distance into the chassis. In this case this was unacceptable, since it was decided to maintain the power amp chassis the same width as the AEM6010 preamplifier and to keep the chassis depth to a minimum. Accordingly, a different construction scheme was developed which has proven to be very effective.

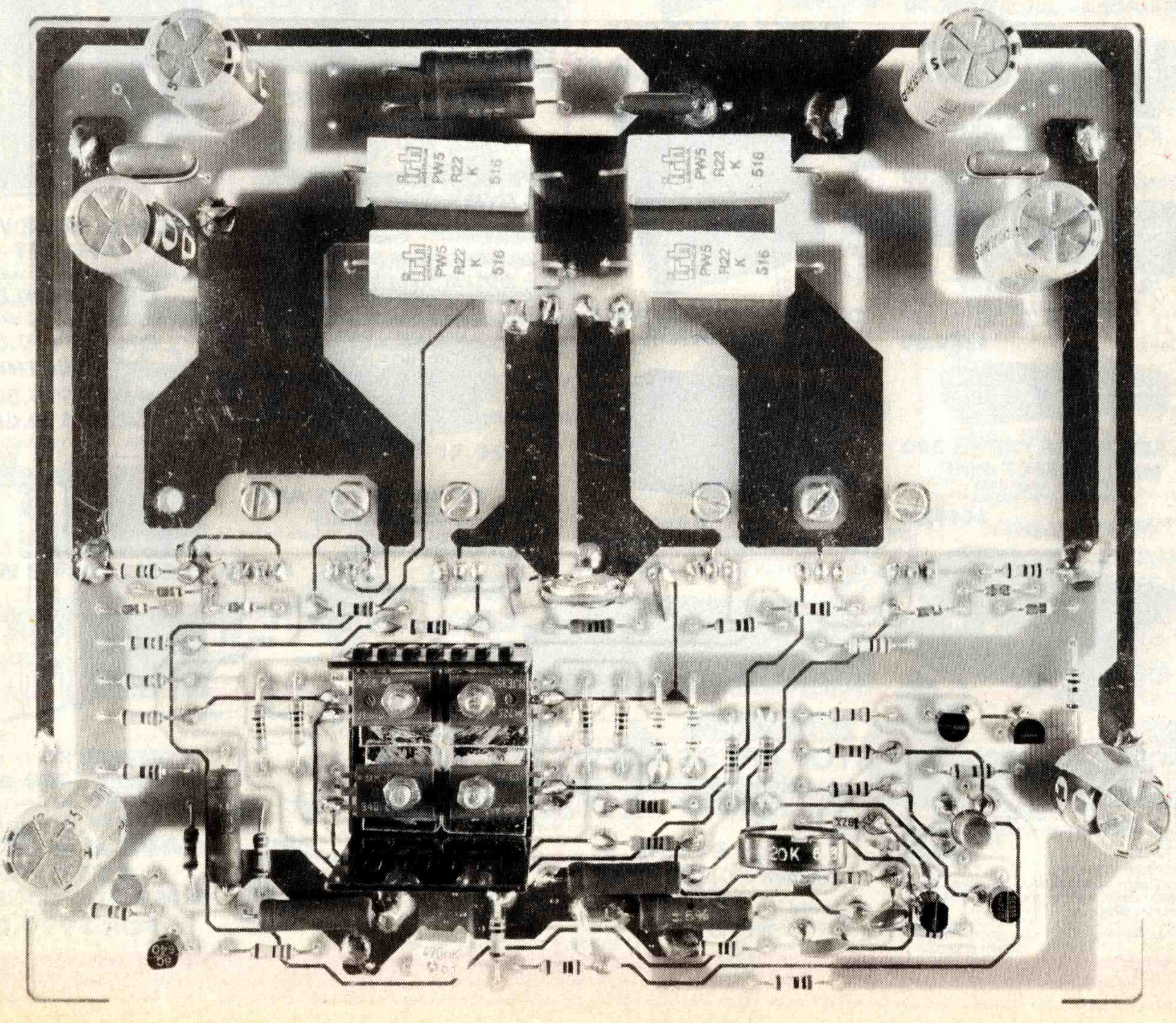
To overcome the problems of minimizing chassis volume occupied by the power amp module, an alternative construction scheme was developed which has proven to be very effective. This scheme uses a heatsink bracket with a "U"-shaped cross-section. As can be seen from the accompanying photographs, this allows the pc board to be mounted parallel to the heatsink. Furthermore, the module can be removed from the chassis in the event that servicing becomes necessary by removing the bolts through the heatsink.

The development of this construction scheme has taken some effort, with many of the earlier prototypes proving to be completely unaccaptable. One of the earlier schemes used the U-bracket as shown but with the MOSFETs mounted to the side of the U so that the MOSFET pins could be soldered directly onto the pc board. This scheme had the advantage that only one pc board was required. Unfortunately, the thermal conduction from the MOSFETs to the heatsink was entirely inadequate with the result that the output devices ran approximately 30 degrees Celcius hotter than the heatsink!

The final scheme settled upon employs two pc boards mounted at right angles to each other so that the output devices can be mounted on the base of the U channel in close proximity to the heatsink. The MOSFET gate and source pins protrude through the bottom of the channel and a pc board is bolted on that side, track side outermost, to provide connection to the MOSFET terminals. The source and gate components are mounted on the track side of this pc board, allowing layout to be optimised for minimum inductance, helping to ensure maximum stability and best possible transient performance. The connection between the two pc boards is made with a 'butt-joint', bridged by solder using adjacent low impedance tracks.

In Part 1 we included a photograph of one of the prototype pc boards developed during the design of this power amp. As can be seen from the photograph included here, which shows the final pc board design, the earlier design differs substantially. These two pc boards contain exactly the same circuitry, yet they differ markedly in their performance. The later design brings the four differential voltage amplifier devices, Q11-Q14, onto the one small heatsink so that these ▶


100V
100V


PW5
R22
K
516
20K

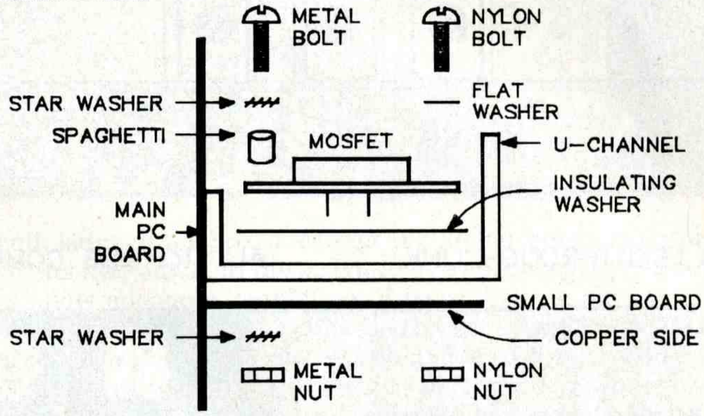
devices will track each other thermally. In the earlier design, this was not done and the amp suffered from significant drift of its output dc voltage. This problem stems from the fact that the npn and the pnp transistors forming the symmetric differential amplifier stage do not have equal power dissipation. Remember that the collectors of transistors Q3 and Q4 are at a voltage approximately 22 volts less than the positive supply rail and this means that the bases of the differential amp following then are also 22 volts below the positive rail. Transistors Q11 and Q12 will therefore drop around 21 volts between their collectors and their emitters, whereas transistors Q13 and Q14 will drop around 120 volts if the module is powered from a +/- 70 volt supply. This leads to a significant temperature difference between these two pairs of transistors which upsets the symmetry of operation and leads to the net dc output voltage.

Construction

It is wisest for the reasons discussed above to base the construction of this power amp on the two pc board designs given here. With this in mind, the construction is not difficult although the use of two pc boards does complicate things slightly.

Commence construction by preparing the heatsink bracket which is fabricated from a 158 mm length of 50 x 40 x 6 mm aluminium U extrusion. A detailed mechanical drawing has been included with this article. Ensure that all holes are clean and free of burrs that might otherwise pierce the insulating washers used with the output devices.

Mount the power MOSFETs to the heatsink bracket so that they are located in the U with their leads protruding through to the small pc board mounted flush against the other side of the aluminium bracket. Insulating washers must be used between the power MOSFETs and the heatsink bracket since the cases of the MOSFETs are connected internally to their sources which will be shorted to chassis if they not correctly insulated. The four mounting bolts closest to the main pc board are used to make the connections between the sources and the rest of the circuit. These bolts must make good contact with both the cases of the MOSFETs and the pc board but remain insulated from the heatsink bracket. To achieve this, star washers should be used beneath the bolt head and the nut and insulating spaghetti should be used covering that section of the bolt which passes through the heatsink bracket. The other four mounting bolts, those furthest away from the main pc board, must be insulated both from the MOSFETs and from the pc board. The easiest way to achieve this is to use nylon nuts and bolts although some care should be exercised not to overtighten these which can strip the nylon thread. Alternatively, metal bolts can be used with insulating washers fitted to both the top and bottom of the bolts. A detailed drawing showing the mounting of the output devices has been included here to clarify this aspect of the construction.

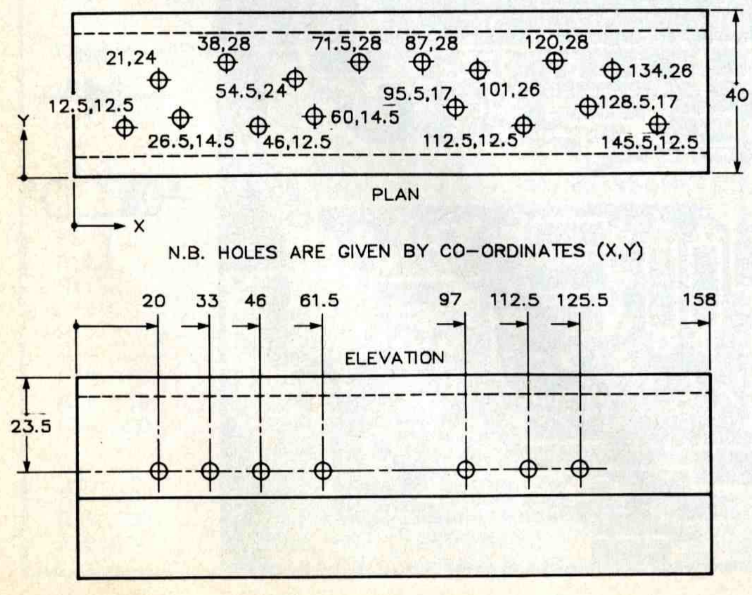


The next step is to mount the passive components to the track side of the small MOSFET pc board. This can be done after mounting the main pc board but it is easier at this stage. Follow the component overlay included here. Several of these components are mounted across adjacent tracks so some care should be exercised to ensure that they do not short to any of these intervening tracks.

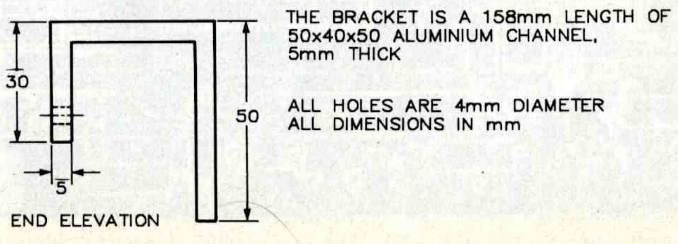
Once this is complete the assembly can be mounted to the main pc board. This is accomplished by first mounting the six flat-pack transistors to the underside of the heatsink bracket so that the leads can pass through the main pc board to its components side. Once again, these devices must be insulated from the heatsink bracket using insulating washers. Be carfeul not to confuse the MJE340 and MJE350 types. Bolt the devices into place using the same bolts to hold the main pc board to the heatsink bracket. The main pc board must be mounted the correct way around so that the area marked with the rectangular border is adjacent to the heatsink bracket. Before tightening these mounting bolts line up the two pc boards so that their adjacent copper tacks mate correctly. Once this is achieved, the bolts can be tightened and the two pc boards soldered to each other by running a fillet of solder along the copper tracks, ensuring that a good connection is made to both boards.

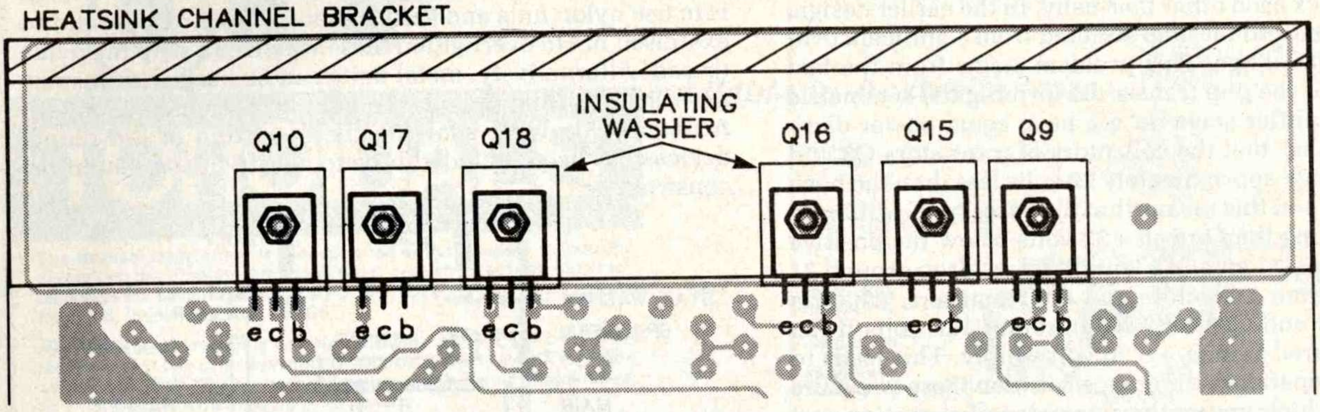
The leads to the six-flat pack devices can now be soldered. Some of these require soldering to both sides of the main pc board. Be careful not to introduce any solder bridges across the adjacent leads of these devices. Soldering to the bottom side of the pc board can be a little difficult since this requires working between the heatsink bracket and the main pc board. A reasonably fine soldering iron tip will greatly assist to ensure freedom from solder bridges in this area.

The remainder of the components mount on the top side of the main pc board in the usual fashion. Start by soldering the resistors and capacitors in place. Those components with tracks on the top side of the pc board should be soldered on ▶



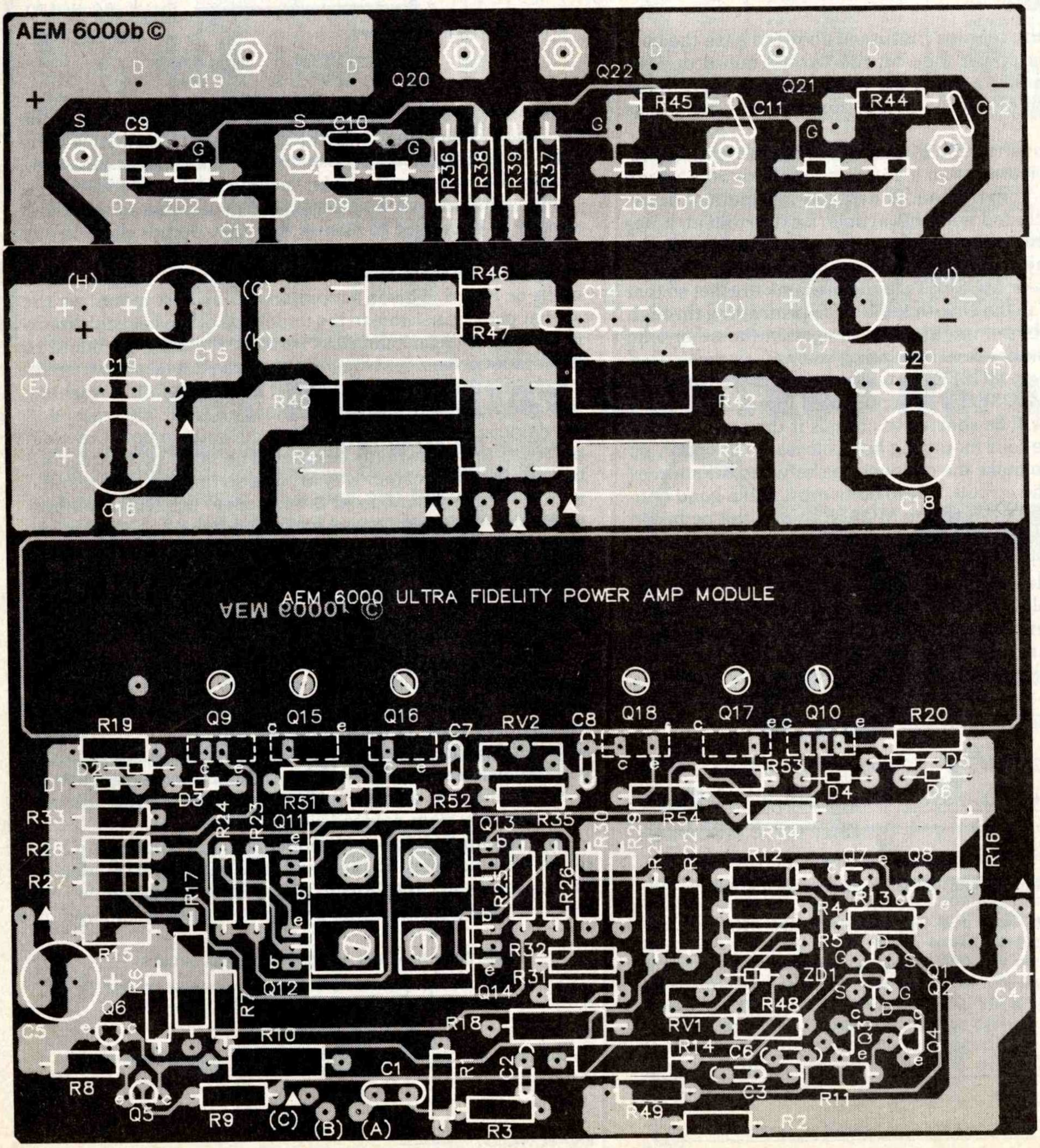
AEM 6000 HEATSINK BRACKET DRILLING DETAILS

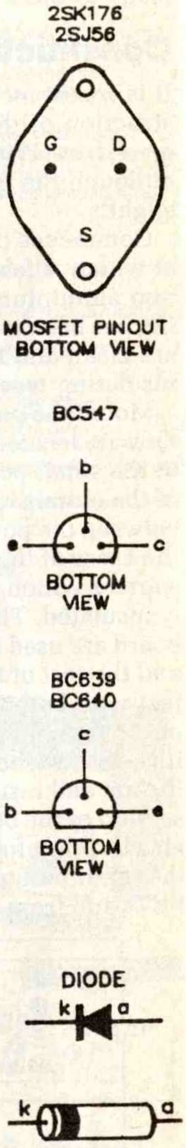


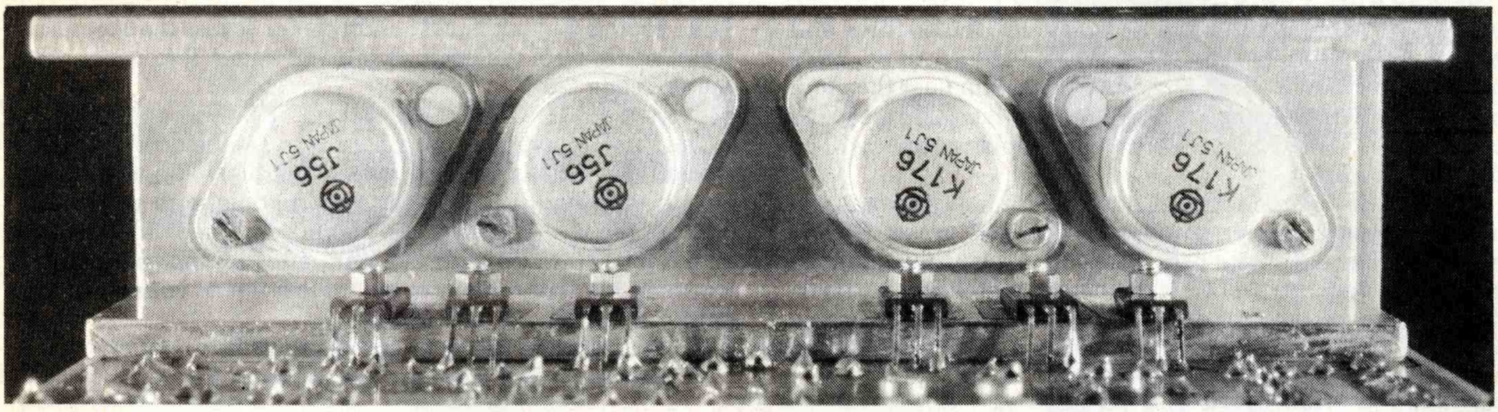


▲ FEEDTHROUGH LINK

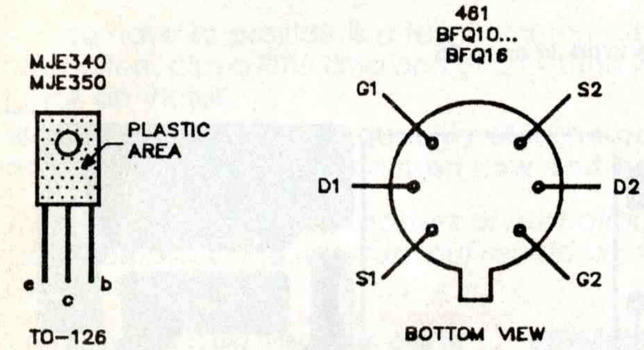
ALL TOPSIDE COMPONENT PADS MUST BE SOLDERED







COMPONENT PINOUTS



AEM 6000 PARTS LIST

Semiconductors

Q1, Q2	ECG461 or equiv.
Q3, Q4	BC639
Q5	BC640
Q6	BC557
Q7	BC639
Q8	BC547
Q9	MJE350
Q10, Q11, Q12	MJE340
Q13-Q16	MJE350
Q17, Q18	MJE340
Q19, Q20	2SK176
Q21, Q22	2SJ56
D1-D6	1N914 or equiv.
D7-D10	100V, 1A fast recovery
ZD1	12V, 400 mW zener
ZD2-ZD5	12V, 1W zener

Resistors all 1/4W, 5% unless noted.

R1	100k
R2	10R
R3	1k
R4, R5	220R
R6, R7	33k, 1%
R8	180R, 1%
R9	3k3
R10	10k, 1W
R11	1k
R12	2k7
R13	120R, 1%
R14	10K, 1W
R15, R16	10R
R17, R18	10k, 1W
R19, R20	220R 1% *see below*
R21-R26	100R, 1%
R27-R30	680R, 1%
R31, R32	100R, 1%
R33, R34	33R, 1%
R35	100R
R36-R39	270R
R40-R43	0R22, 5W
R44, R45	22R
R46, R47	22R, 1W
R48	47k
R49	1k
R50	not used
R51-R54	10R
RV1	20k
RV2	200R

Capacitors

C1	470n MKP else MKT (see text)
C2	1n MKP else MKT
C3	47p ceramic
C4, C5	100μ/100V RB electro.
C6	15p ceramic
C7, C8	18p ceramic
C9, C10	330p KP else ceramic
C11, C12	33p ceramic
C13	220n MKP else MKT
C14	22n MKP else MKT
C15-C18	100μ/100V RB electro.
C19, C20	100n MKP else MKT

Miscellaneous

PC boards, AEM6000, AEM6000B; AEM6000 heatsink; wire; four T03 mounting kits; thermal paste; nuts & bolts; heatsink bracket.

* R19, R20 are 150R to 270R, depending upon the number of output devices employed. In the case of the module as described (i.e: four output devices) use 220R 1%.

Expected cost: $110-$125

both sides of the board. Mount the higher power resistors so that they stand off the pc board by approximately 1-2 mm to allow adequate ventilation. Ensure that the electrolytic capacitors are mounted with the correct orientation. These are polarised devices and will be damaged if the module is powered-up with these incorrectly inserted. The diodes and small transistors can be soldered next, leaving mounting of the small heatsink until last. This should be drilled according to the drilling details given elsewhere, once again being sure to clean the holes of burrs that may cause problems with the insulating washers. The heatsink is held in place by the bolts used to secure the four flat-pack transistors to the pc board. The transistors must be insulated from the heatsink, and therefore from each other, by the use of insulating washers. After bolting these devices into place solder their leads, as before, on both sides of the pc board.

Powering-up

Before attempting to power up the module, make some preliminary checks with a multimeter and give the entire module a close visual inspection. Power amplifiers often fail somewhat spectacularly if a mistake has been made and the result are often expensive to repair. Check that the MOSFETs are correctly insulated from the heatsink bracket by checking the resistance from the cases of the devices to the bracket. If a short circuit is found, unbolt the device and rectify the problem. Apply the same test to all of the flat-pack transistors, checking for shorts between their centre leads and the heatsinks to which they are mounted.

If all is well, the module can be connected to a power supply. The recommended power supply rail voltages for the module lie in the range from +/- 50 V to +/- 75 V.

Connect the power supply to the module using the two 10R series resistors shown in the circuit diagram of the test power supply. These resistors help to minimise damage to the module in the event of a fault being present when the module is powered-up. Most serious faults will result in these resistors being burnt out immediately upon powering-up. These resistors also serve the purpose of enabling the quiescent current to be measured by measuring the voltage drop across them. Use a heavy gauge multistrand hookup wire, such as 32 x 0.2 mm as a minimum, to wire-up the moduleto the positive and negative supplies. Note that the module is connected to the 0 V on the power supply at two different points. The main connection is from the 0 V point closest to the output terminal on the module. This connection should be made ▶

NOTES & ERRATA regarding Part 1.

The earth connection to capacitor C5 in the circuit diagram is shown as 'clean earth'. This should be shown as 'noisy earth'.

The values of resistors R19 and R20 are shown in the circuit diagram incorrectly as 150R. These should be 220R as specified in the parts list.

using heavy gauge wire, like that used for the positive and negative supply rails. The second connection can be made using lighter gauge wire to the 0 V connection near the module's input. The reasons for having these two separate earth connections, called "clean earth" and "noisy earth", will be detailed in Part 3.

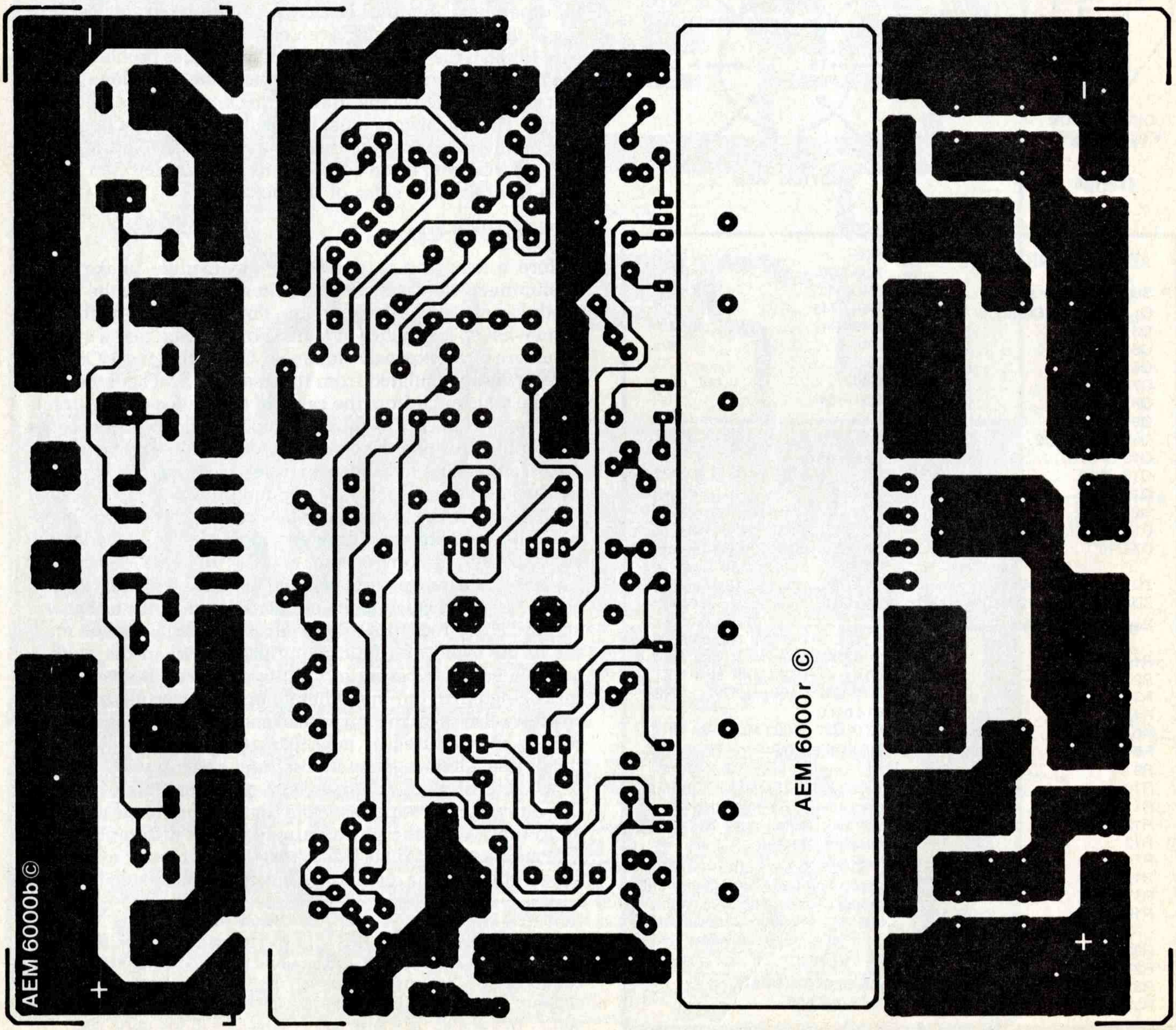
Once all of the connections have been made between the module and the power supply, ensure that preset RV1 is turned to the centre and preset RV2 is turned fully counterclockwise, then apply power to the unit. Watch for any signs of excessive power dissipation in the two 10R resistors (smoke!). Should problems arise, switch off and trace the fault. If all is well, connect a multimeter across the 10R resistor in series with the positive rail and adjust RV2 so that the meter reads 2.6 V.

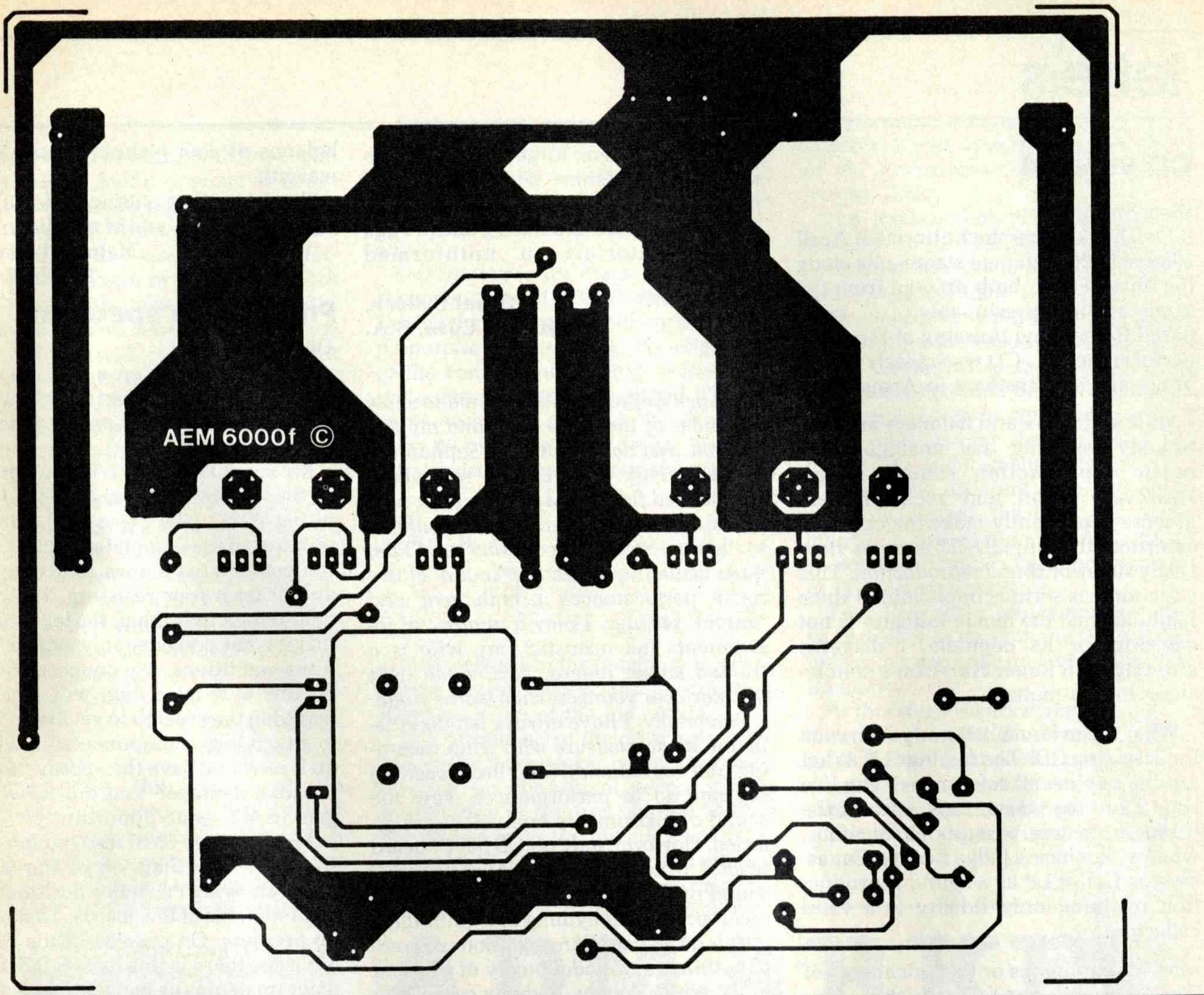
The final adjustment necessary is to set the dc output offset voltage. This is done by measuring the voltage from the output terminal of the power amp module with respect to 0 V. Set the multimeter to the 200 mVdc range, if available, or the lowest dc range it has and, after letting the module warm up for about five minutes, adjust the dc voltage on the output to within 20 mV of zero.

Your module is ready to go!

AEM6000 pc board artwork

More pc board artwork is on p. 95

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