Build this 300W high-power amplifier module

Playmaster 300 Watt Amplifier

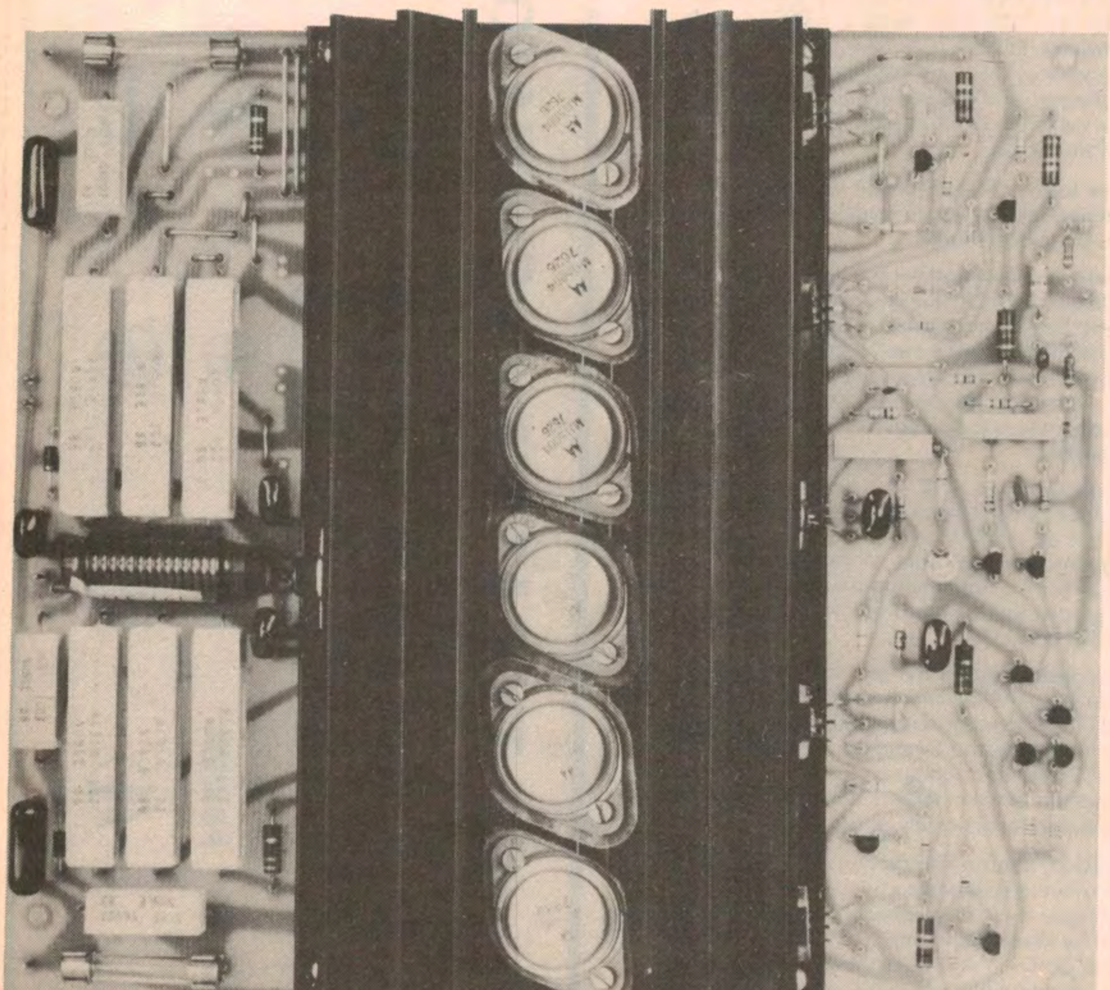
200 watts into 8 ohms, 300 watts into 4 ohms

Following Richard Tymerski's article last month on a philosophy for a high power amplifier, we present his 200-300 watt design. We have designed a printed circuit board which brings it all together in a rugged easy-to-build module. It can be built in either fully-complementary or quasi-complementary versions, so output transistor shortages should be no problem at all.

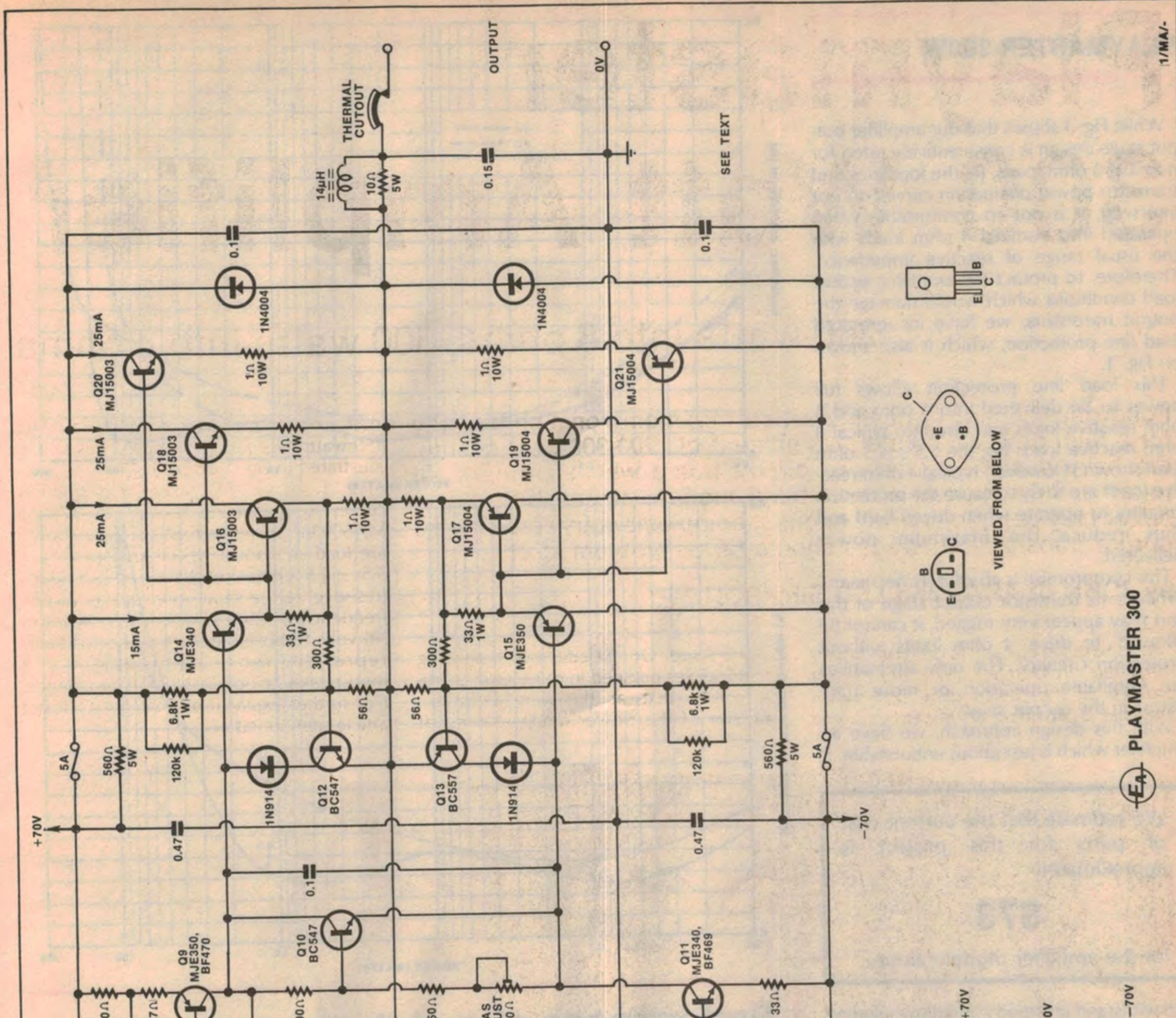
by JOHN CLARKE and LEO SIMPSON

As outlined in our article on "High Power Amplifiers" in October 1979, the biggest problem in the design of a high power amplifier is providing a sufficiently rugged output stage. Our calculations, following the principles outlined in our October article, show that at the very least, an amplifier of this power rating requires at least six output transistors, each rated at 150 watts dissipation or more. This fact is illustrated in Fig. 1 on page 57.

Fig. 1 shows the maximum dissipation curves for paralleled sets of 2N3773 or MJ15003/4 power transistors. Also shown are load lines for a typical loudspeaker at 5.5 ±j5.5 ohms (reactive) and 5.5 ohms (resistive, ie the same loudspeaker at low frequencies) when operated at a level of 40 volts RMS. Note that these loadlines represent those applicable to a loudspeaker of nominal 8 ohm impedance. (For further explanation, see our October article mentioned above).



This module will deliver up to 200 watts into an 8 ohm load and up to 300 watts into a 4 ohm load. Comprehensive protection is included. The circuit is at right.



PLAYMASTER 300
INPUT
OUTPUT
0V
THERMAL CUTOUT
SEE TEXT
+70V
-70V
5A
OFFSET ADJUST 100Ω
BIAS ADJUST 100Ω
7mA
25mA
15mA
Q1 BC547
Q2 BC547
Q3 BC547
Q4 BC547
Q5 BC557
Q6 BC557
Q7 BC547
Q8 BC557
Q9 MJE350, BF470
Q10 BC547
Q11 MJE340, BF469
Q12 BC547
Q13 BC557
Q14 MJE340
Q15 MJE350
Q16 MJ15003
Q17 MJ15004
Q18 MJ15003
Q19 MJ15004
Q20 MJ15003
Q21 MJ15004
1N914
1N4004
1N4752
33V 1W
14µH
10Ω 5W
VIEWED FROM BELOW
SUGGESTED POWER SUPPLY
JONES JT307
FERGUSON PF4363
240V
MDA2504
4000 75VW
10k 1W
47V
15V
CHASSIS
1/MA/-

PLAYMASTER 300W

While Fig. 1 shows that our amplifier output stage design is conservatively rated for nominal 8 ohm loads, (ie the loadlines and transistor power dissipation curves do not intersect), it is not so comfortable when operated into nominal 4 ohm loads with the usual range of reactive impedance. Therefore, to protect the amplifier against load conditions which would damage the output transistors, we have incorporated load line protection, which is also shown on Fig. 1.

This load line protection allows full power to be delivered into 4 ohm and 8 ohm resistive loads and also into typical 8 ohm reactive loads (eg the 5.5 ±j5.5 ohm load shown.) However, typical 4 ohm reactive loads are likely to cause the protection circuitry to operate when driven hard and thus reduce the maximum power delivered.

This compromise is absolutely necessary. While a six transistor output stage of this sort may appear very rugged, it cannot be allowed to drive 4 ohm loads without protection circuitry. The only alternatives are unreliable operation or more transistors in the output stage.

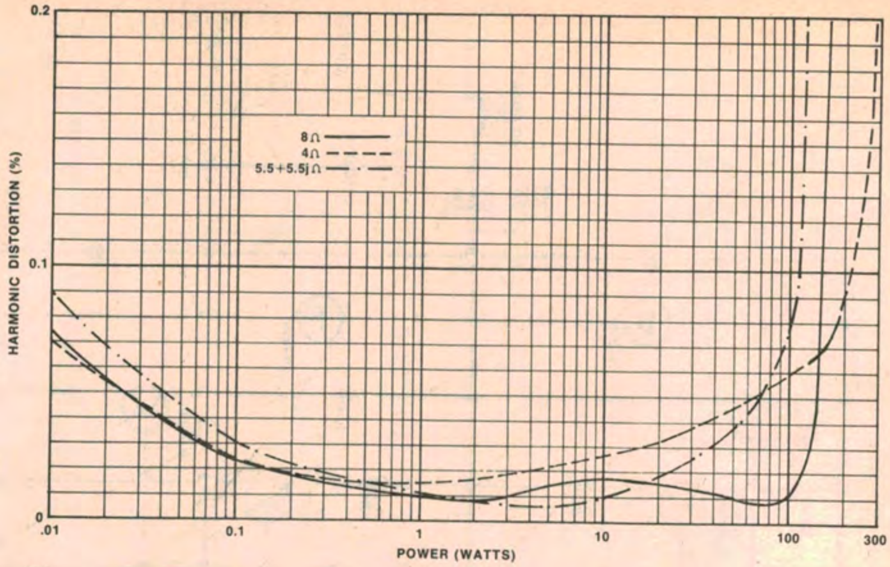
With this design approach, we have an amplifier which is just about unburstable. It will withstand any load condition including short circuits (for short durations).

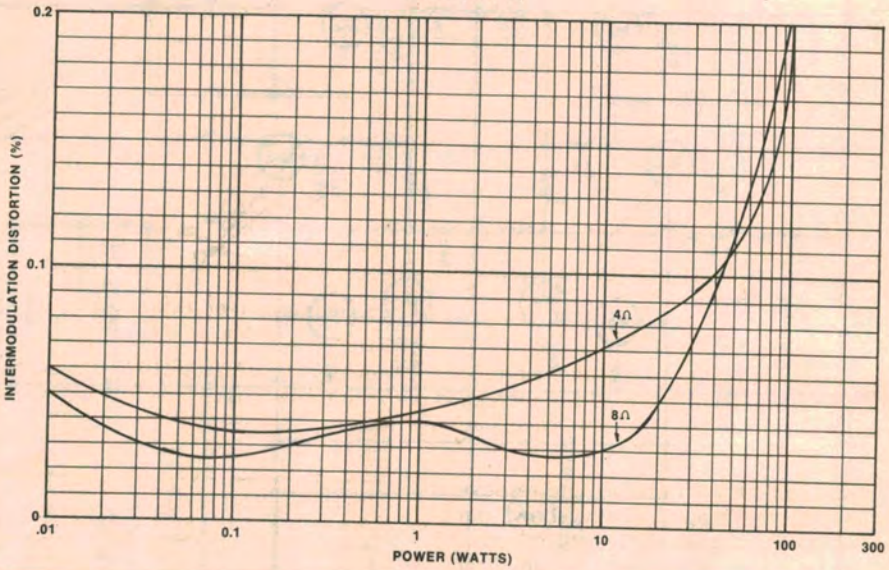
> We estimate that the current cost of parts for this project is approximately
>
> **$73**
>
> for the amplifier module alone.

Another very important criterion satisfied by this amplifier is stability. It is unconditionally stable. That means that it will not oscillate supersonically, regardless of the load connected to it. Many high power amplifier designs cannot make that claim! As a result, they sometimes do break into oscillation at supersonic frequencies which quickly causes them to overheat and fail.

Naturally, as indicated in the introductory article last month, the new Playmaster 300 has high performance in all other respects, including low transient intermodulation distortion. The performance specifications for the prototypes (quasi and fully complementary) are summarised in an accompanying table and graphs. Note that the curves for harmonic distortion also show the performance of the amplifier into reactive loads (5.5 ±j5.5 ohms). Note also that there is no appreciable difference in performance between the quasi and fully complementary versions.

Most amplifier manufacturers do not bother to quote distortion performance into real-life reactive loads because their designs often show up badly in com-





Performance of prototype

POWER OUTPUT

4 ohms	300W
8 ohms	200W

FREQUENCY RESPONSE

20 Hz to 20kHz -1dB

HARMONIC DISTORTION

see graphs

INPUT SENSITIVITY

1.5V for 47k input impedance

HUM AND NOISE

95dB with respect to 100W

DAMPING FACTOR

better than 100 for both complementary symmetry and quasi complementary symmetry versions at 1kHz and 30Hz.

STABILITY

unconditional

SLEW RATE

70V/microsecond

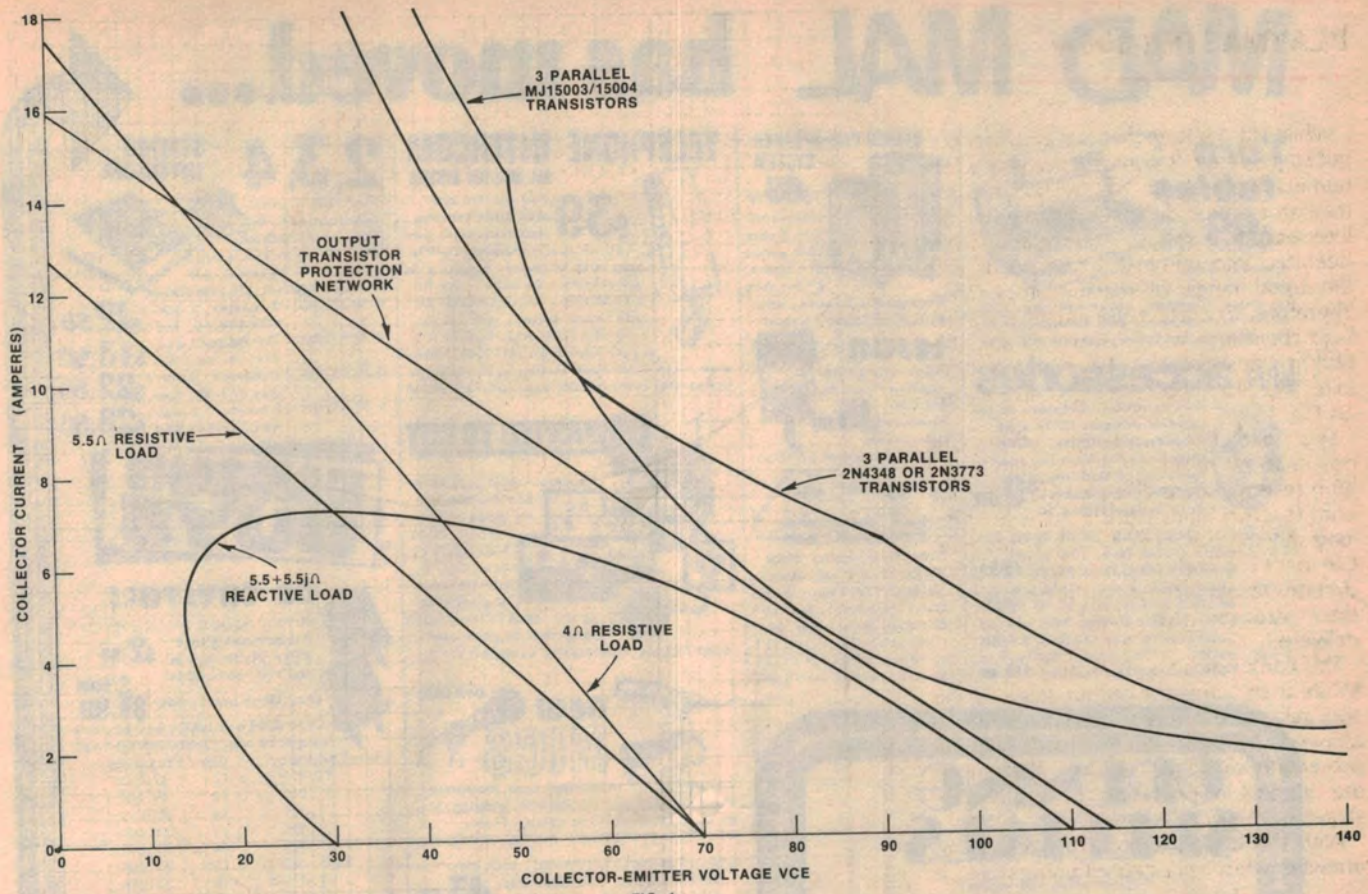


FIG. 1

This graph shows the juxtaposition of the safe operating areas of MJ15003/4 (× 3) and 2N3773 (× 3) parallel combinations of output transistors together with the load line protection of the amplifier. Also shown are the notional load lines for a 4 ohm load, and 5.5 ohms resistive and 5.5 ±j5.5 ohms reactive loads.

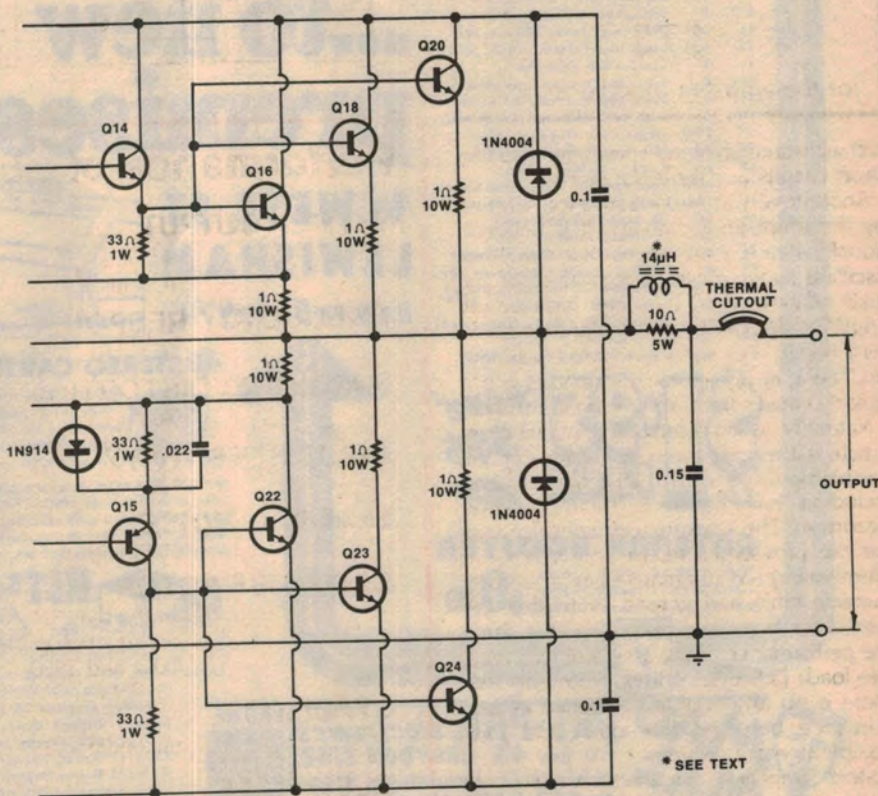
parison to their performance into resistive loads. As the graphs clearly show, our design performs well with reactive loads.

The frequency response of the amplifier is deliberately limited to -1dB down at 20kHz by the second-order low pass filter at the input stage. This is one of the measures to prevent transient intermodulation distortion. By any standard, the new Playmaster is very quiet. That figure of -95dB with respect to 100 watts into 8 ohms is equivalent to 0.5 millivolts RMS of residual noise at the output. To put it another way, if you put your ear right up to a typical loudspeaker connected to this power amplifier (with no signal connected at the input!) there is barely a whisper. . . .

All the amplifier circuitry, excluding the power supply, is accommodated on a large PCB measuring 218mm × 200mm, coded 80pa6. This also accommodates the large heatsink which is 200mm long and 105mm wide. This heatsink is adequate for typical program material peaking at full power but if the amplifier is intended for stage use, fan cooling will probably be required.

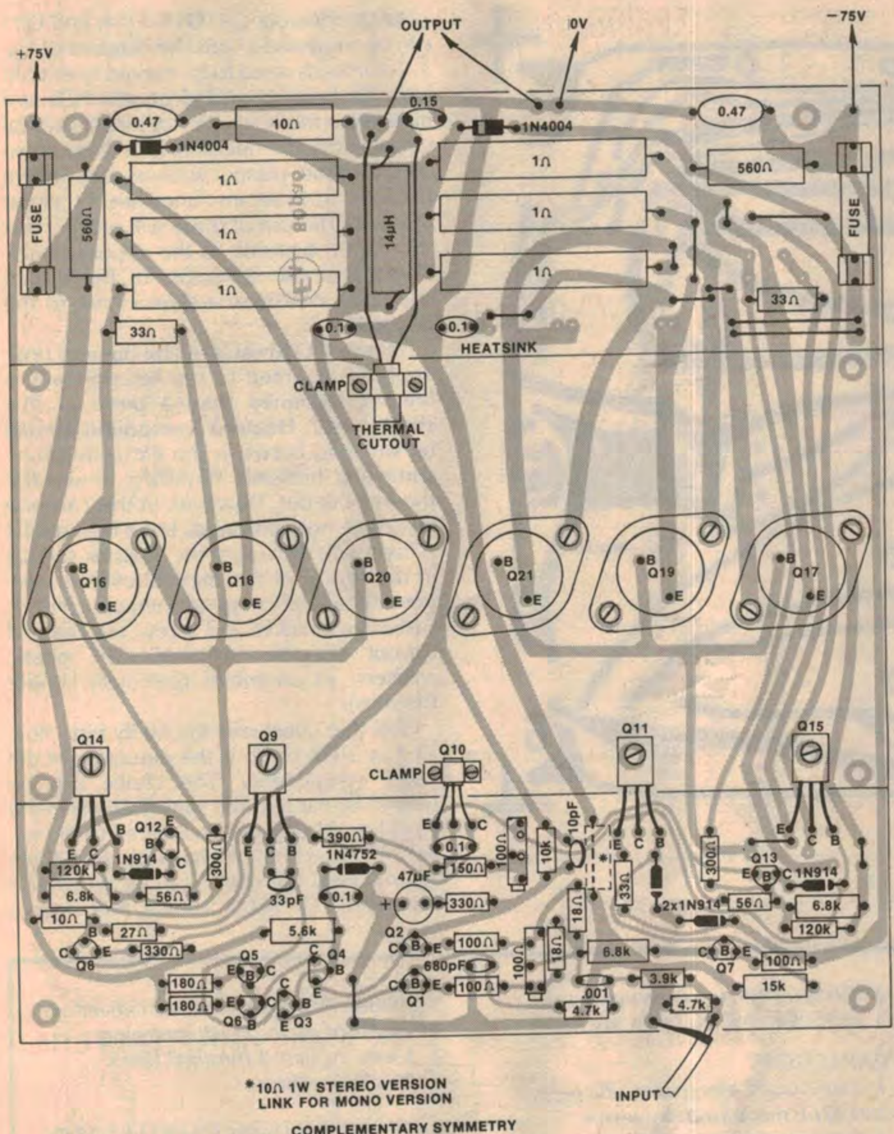
As well as having all six power transistors mounted on it, the heatsink also accommodates the four driver stage transistors, the Vbe multiplier transistor and a thermal cutout. (Unfortunately, at the time of writing, the thermal cutout is unavailable.)

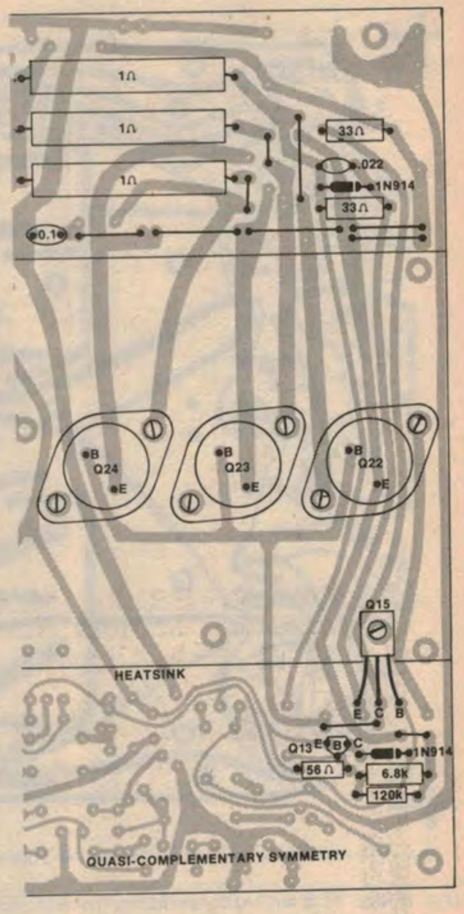
Ten-turn preset pots are provided for



QUASI-COMPLEMENTARY SYMMETRY

This is the alternative quasi-complementary output circuit using 2N3773 transistors.





At left is the component layout diagram for the PCB while above is a section of the PCB showing the alterations necessary to implement the quasi-complementary version using all NPN output transistors.

precise and easy adjustment of quiescent current and output offset voltage. If unavailable, conventional trimpots can be substituted. Onboard fuse protection of the amplifier is also provided, as well as fixed resistors for monitoring the quiescent current.

A casual glance at the PC pattern overlay will reveal many links. These were not provided to make life more difficult, but to allow two versions of the amplifier possible; namely the complementary symmetry and quasi complementary symmetry configurations mentioned above. The complementary symmetry version output stage has NPN/PNP complementary pairs, while the quasi has all NPN transistors.

Construction of the amplifier module should begin with drilling the holes for the components to suit the diameter of the component leads. The links are 16 gauge tinned copper wire and consequently require an appropriate hole size.

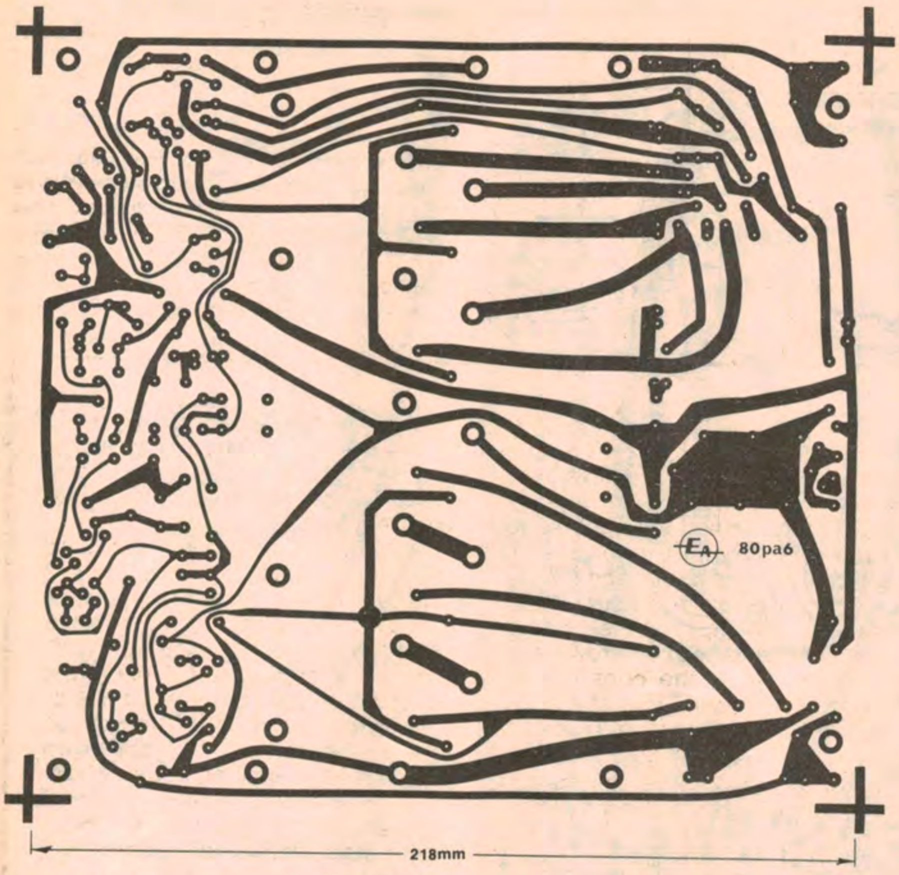
The heatsink can now be clamped into position and the four mounting holes for each corner of the heatsink drilled from the PCB side using the marked copper holes as a guide. Temporarily bolt the heatsink into position making sure the heatsink is centred above the TO-3 mounting holes.

The remaining holes in the heatsink can now be drilled. The holes for the bracket mounting of Q10 and the thermal cut-out are also marked with the copper pattern and should be drilled now as well. After drilling, remove the heatsink and deburr all the holes, particularly the transistor holes, since even a small whisker of metal can pierce the mica washers.

With all drilling operations completed, the links may be inserted. Those in the output stage use 16-gauge tinned copper wire while those links in the input stages can use thinner wire.

Now the power transistors and heatsink can be assembled. Follow the drawing of Fig. 2 to assemble the insulating components. The bush surrounding the bolt is a standard mounting bush with the integral washer removed with a razor blade. These washers can be used so do not throw them away. With a smear of heatsink compound on each surface of the mica washer, transistor and heatsink, tighten up the screws and solder the nuts to the copper. It is a good idea not to solder the base and emitter leads yet, just in case the insulation is faulty and the transistor has to be removed.

Check the insulation of each transistor from the collector (case) to heatsink with an ohm-meter as you finish mounting each one. If there is a short circuit, repair the fault immediately as it is difficult to find the fault when they are all assembled. Retighten down the transistors after the heatsink compound has time to spread under pressure and recheck the insulation.



This is the PCB artwork, reduced to half size.

Now transistors Q9, Q11, Q14, and Q15 can be mounted as per the diagram of Fig. 3. Their leads need to be curved over to fit into the holes provided on the PCB and make sure the leads do not make physical contact with the heatsink. Bolt them down and use the plastic washers, that were removed from the insulating bushes, under the nuts. The use of these will prevent any short from heatsink to the copper tracks. Check that the collectors of these transistors do not show a short circuit to the heatsink.

Transistor Q10 can now be put into position and mounted to the heatsink with a bracket fashioned from a piece of thin sheet metal. Heatsink compound should be smeared between the flat of the transistor and heatsink. (Similarly, mount the thermal cut-out. However, in this case the lip on the heatsink needs to be filed until it is flush with the rest of the heatsink surface in the region of the thermal cut-out position, to enable a good surface contact. Fashion a bracket and screw the thermal cut-out to the heatsink. Use plastic washers, as described previously, under the nuts).

Well that concludes the fiddly bits. Now all that is left to do is the mounting of the other components. The choke can be wound by hand to the specifications in the parts list and the wire coils glued to the ferrite or held with heat shrink plastic tubing. Alternatively the choke can be purchased from Radio Despatch Service, 569 George

PARTS LIST

- *1 PC board 218mm × 200mm coded 80pa6*
- *1 heatsink, Dick Smith cat 3426 or Thermalloy 6169, 200mm long*
- *1 14uH choke, 19 turns of 16 gauge wire on Neosid F14 ferrite 40mm × 10mm diameter.*
- *1 thermal cut-out, 10A, 95 degrees (if available)*
- *4 fuse clips, Swan (McMurdo) FC1 part No 1397-01-18*
- *2 5A 3AG fuses*
- *6 TO-3 mica washers*
- *4 TO-126 mica washers*
- *12 insulating bushes*
- *1 200mm length of 16 gauge tinned copper wire*

SEMICONDUCTORS

- *4 1N914 silicon signal diodes*
- *2 EM404, 1N4004 400PIV 1 amp silicon diodes*
- *1 33V 1W zener diode, BZX61, C33, 1N4752*
- *4 BC557 PNP transistors*
- *7 BC547 NPN transistors*
- *2 MJE350 PNP transistors*
- *2 MJE340 NPN transistors*
- *3 MJ15003 NPN power transistors*
- *3 MJ15004 PNP power transistors*

CAPACITORS

- *1 47uF/10VW electrolytic PC type*
- *2 0.47uF metallised polyester*
- *5 0.1uF metallised polyester*
- *1 .001uF metallised polyester*
- *1 680pF ceramic*
- *1 33pF ceramic*
- *1 10pF ceramic*

RESISTORS

(¼w unless other specified, 5% tolerance)

2× 120k, 1 × 15k/1W, 1 × 10k, 3 × 6.8k/1W, 1 × 5.6k/1W, 2 × 4.7k, 1 × 3.9k, 2 × 560 ohm/5W, 1 × 390 ohm, 2 × 330 ohm, 2 × 300 ohms, 2 × 180 ohm, 1 × 150 ohm, 3 × 100 ohm, 2 × 56 ohm, 1 × 33 ohm, 2 x 33 ohm/1W, 1 × 27 ohm, 2 × 18 ohms, 1 × 10 ohm, 1 × 10ohm/5W, 6 × 1 ohm/10W, 2 × 100 ohm vertical trim pots or 2 ten-turn miniature ceramic trim pots.

PARTS LIST FOR POWER SUPPLY

- *1 Transformer, Ferguson PF 4363, Jones JT 307 or 94VAC, CT at 3A.*
- *1 bridge rectifer MDA2504, 400 PIV, 25A.*
- *2 4000uF/75VW electrolytic capacitors*
- *1 length of mains cord, and plug*
- *1 3-way insulated terminal block*
- *2 10k/1W resistors*

PARTS FOR QUASI-COMPLEMENTARY SYMMETRY VERSION

OUTPUT TRANSISTORS

- *6 NPN silicon power transistors, MJ15003, 2N3773 or 2N4348*

EXTRAS

- *1 1N914 silicon signal diode*
- *1 .022uF metallised polyester capacitor*
- *1 33 ohm/1W resistor*

MISCELLANEOUS

Aluminium for transistor and thermal cut-out brackets 4mm × 4mm approx, heatsink compound, PC stakes, nuts, bolts, washers, solder etc.

NOTE: Resistor wattage ratings and capacitor voltage are those used for our prototype. Where voltage ratings are not quoted, they should be 100V or more. Components with higher ratings may be used provided they are physically compatible.

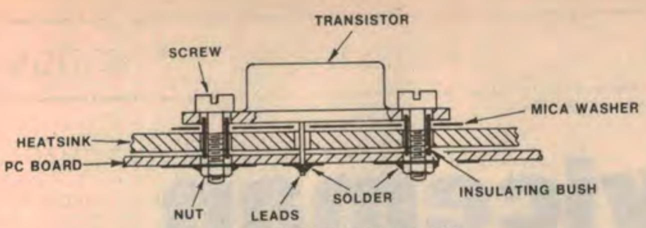


FIG. 2 : TO-3 MOUNTING METHOD

These two diagrams show the transistor mounting details.

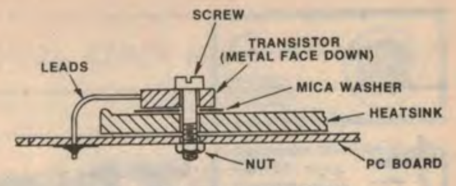


FIG. 3 : TO-126 MOUNTING METHOD

St, Sydney.

When mounting the 5W and 10W resistors, solder them with at least 1mm spacing above the PCB to allow cooling and to avoid their charing the board. Take care in orienting the polarity-conscious components such as the diodes, transistors and electrolytic capacitor.

Finally, the use of PC stakes is recommended for the external connections, allowing easy access to the terminals with a meter.

A suitable power supply is required before the amplifier offset and quiescent current adjustments can be set. This is shown on the circuit diagram but we shall discuss its construction next month. Before proceeding with the discussion of adjustments, note that the power supply voltages are **dangerous,** as a total of 140 volts DC is present. Under the right circumstances (or wrong, depending on your point of view) this high voltage power supply could deliver a **lethal** shock. In other words, it could kill you. So be very careful. Remember that the high voltage is present on the cases of the output transistors.

10k/1W resistors are connected as "bleeders" across the 4000uF electrolytic filter capacitors to dissipate the voltage when the power is removed.

The setting up procedure is rather simple. Firstly set the offset pot to about the centre position and the quiescent current (bias) pot to maximum resistance. Without the fuses present, apply power to the module and quickly check the voltage across the fuse clips (560 ohm resistors). If the voltage across each pair of fuse clips is less than say about 50V, then all is well; if the total power supply voltage is impressed across the fuse clips, then it is possible that there is a short from the output transistors to the heatsink.

If all is well, measure the voltage between the amplifier output and power supply common, and adjust this voltage with the offset trimpot until the voltage is as close to zero as your meter will read. Now adjust the voltage across the fuse clips with the bias trim pots until a 50V reading is obtained. The voltage should be similar across each of the fuse clips. This setting corresponds to a 25mA current through each output transistor.

With the fuses in position, the current can be rechecked provided a meter that can read 25mV is used. By measuring the voltage across each emitter resistor, the current can be determined. The current should be 25mA in four of the resistors and 40mA in the emitter resistors of Q16 and Q17. This extra current is from the current flow in Q14 and Q15.

Next month we shall give details of how to mount the module in a 19-inch rack mounting chassis, together with power supply, fan cooling and loudspeaker protection circuitry.

HOW IT WORKS:

While the large number of transistors in this amplifier may make the circuit seem unduly complex, it is really quite straight-forward. The circuit is basically a direct-coupled amplifier with differential input stage, class-A driver stage with constant-current load, and with output transistors and drivers working in class AB emitter-follower configuration.

Right at the input is a second-order (12dB/octave) filter comprising two resistors and two capacitors. This filter reduces the maximum slew rate of the input signal to a value which ensures freedom from TIM, as mentioned elsewhere in this article.

Q1 and Q2 make up the differential input stage, in conjunction with Q3 and Q4 operating in cascode configuration. In effect, the bases of Q3 and Q4 are referenced to +33V by the zener diode and grounded to AC. So, regarded in isolation, Q3 and Q4 can be considered as grounded-base stages which transfer the signals appearing at the emitters to their collectors.

The main virtue of the cascode configuration is that it reduces the collector voltage to Q1 and Q2 so that readily available low voltage transistors can be used. Apart from that, the cascode configuration also gives an extended frequency response to the input stage, as does the emitter degeneration due to the common resistors in the emitter circuits of Q1 and Q2.

Q5 and Q6 form a "current mirror" for the input transistors Q1 and Q2 and so improve their linearity. Q8 is the constant current "tail" for the input stage, providing a high "common mode" rejection ratio and so minimising the amplifier's response to the hum content on the balanced supply rails.

Output from the input stages is coupled to Q9, which in conjunction with its constant current load, Q11, functions as a class-A driver. Q8 protects Q9 against excessive loading which may occur when the protection circuits operate. Q10 is a "Vbe multiplier" which sets the quiescent bias for the output stages and provides thermal stability.

Eight transistors make up the complementary symmetry output stage which operates in class AB emitter follower mode. Class AB means that the amplifier works in class B mode at higher power levels while the fixed bias from Q10 provides class A operation at low signal levels. Q16 to 21 work in current-sharing mode, with large emitter resistors to make sure that they do, in fact, share the load current equally.

Q12 and Q13 provide the load line protection for the output stage. Their associated resistors monitor the voltages and currents through transistors Q16 and Q17, and act to bypass the signal to the output if the output transistor operating conditions transgress the designated load line, shown on Fig. 1. In this way, the output transistors are prevented from operating in unsafe "areas" where over-dissipation or secondary breakdown could occur.

The diodes connected in series with Q12 and Q13 prevent these transistors being reversed-biassed and bypassing the drive signal, during normal operation.

The diodes across the output stages are also part of the protection circuitry, preventing "spike" voltages developed by rapid turnoff of output transistors from causing damage.

The 560 ohm resistors across the fuses are there for convenience only, for the initial setting up procedure and also for troubleshooting fault conditions which would otherwise blow fuses.