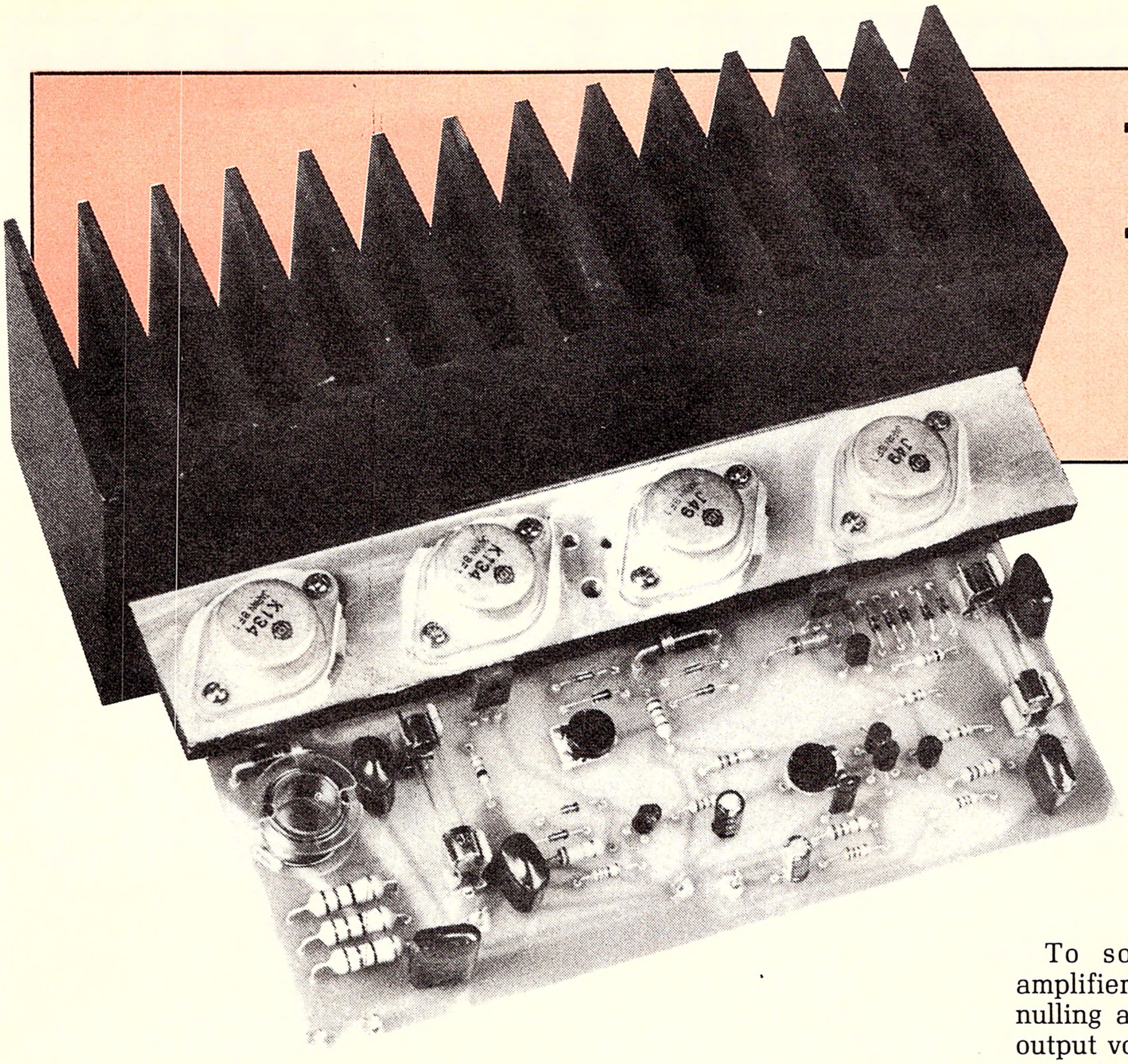
HIGH
AMP



The new amplifier can deliver up to 120 watts RMS into a 100V AC line. The large heatsink keeps the power Mosfets cool.

This rugged 120W Mosfet amplifier module is designed specifically to drive a 100V line transformer for public address applications. It can also be used as a stand alone module for guitar amplifiers and domestic stereo amplifiers.

By LEO SIMPSON & BOB FLYNN

Why is there any need to design an amplifier specifically to drive a line transformer? The answer is that a transformer presents a much more difficult load for an amplifier to drive than a normal loudspeaker.

For a start, the primary of a typical transformer will have a very low DC resistance which may be of the order of 100 milliohms (0.1Ω) or less. Second, transformers do not like direct current flowing in their windings; the resultant magnetisation causes distortion of the output waveform.

This means that any amplifier designed to drive a transformer must have a very low DC voltage at its output. Just consider what happens with a typical direct coupled amplifier which has a DC voltage at its output of say + 20mV. When a transformer with a primary resistance of 0.1Ω is connected, a current of 100 milliamps will flow through it. This will cause substantial magnetisation of the transformer core as well as increased power dissipation in the output transistors of the amplifier.

To solve this problem, the amplifier circuit must include a nulling adjustment so that the DC output voltage can be set to a very low value, say less than ± 5mV. The input differential transistor pair must also be thermally bonded together to ensure that the nulled output DC voltage does not drift away from zero as the temperature changes.

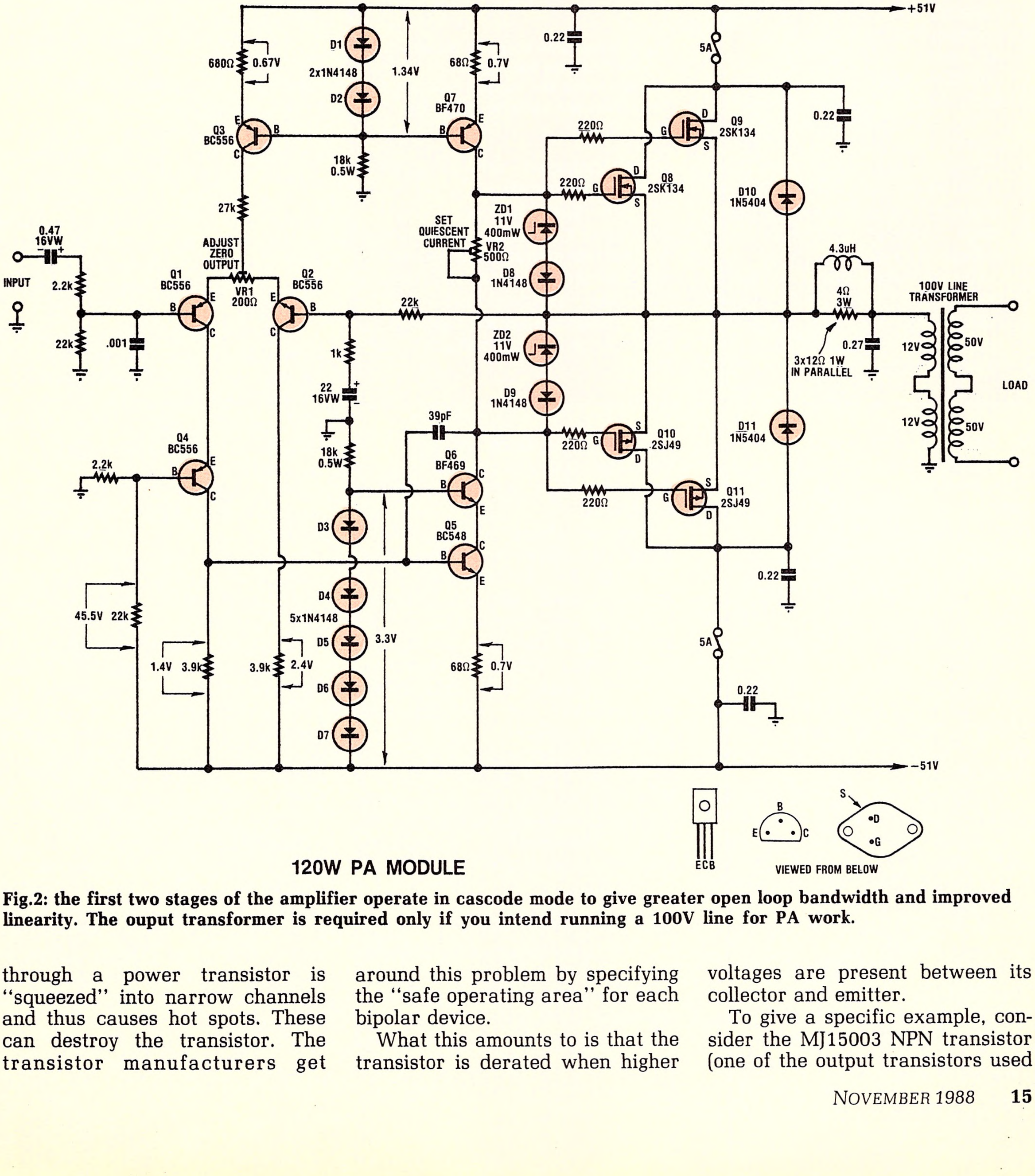
Another problem with a line transformer is that if the load on the secondary winding is disconnected or switched in level while substantial power is being delivered, very high spike voltages can be delivered by the transformer.

These high energy spikes can easily destroy bipolar transistors unless "flyback" diodes are connected across both halves of the output stage. Even if amplifiers do include these diodes and the spike voltages are thereby limited to the supply rails, the output stage is still not safe if bipolar transistors are used.

Second breakdown

The particular problem with bipolar transistors is "second breakdown". This is a mechanism whereby the current passing

POWER PA
LIFIER MODULE



120W PA MODULE

Fig.2: the first two stages of the amplifier operate in cascode mode to give greater open loop bandwidth and improved linearity. The ouput transformer is required only if you intend running a 100V line for PA work.

through a power transistor is "squeezed" into narrow channels and thus causes hot spots. These can destroy the transistor. The transistor manufacturers get around this problem by specifying the "safe operating area" for each bipolar device.

What this amounts to is that the transistor is derated when higher voltages are present between its collector and emitter.

To give a specific example, consider the MJ15003 NPN transistor (one of the output transistors used

Cascode Operation Explained

A cascode stage is one where two transistors are connected in series across the supply rail. In our diagram (Fig.2) we show an idealised schematic of a cascode stage. A reference voltage of, say, 4 volts is fed to the base of Q2. By emitter follower action, its emitter will be 3.4 volts and this will be the collector supply for Q1.

Thus Q2 maintains a constant collector voltage on Q1 and so eliminates any variations in gain which would otherwise occur if the collector voltage was able to fluctuate.

The varying collector current drawn by Q1 is the emitter current of Q2 which converts it to a voltage signal at its collector. Q2 can be regarded as a "grounded-base" stage because of the constant voltage at its base.

The combined effect of operating Q1 with a constant collector voltage and Q2 in a grounded-base mode gives a stage with much improved linearity and bandwidth compared with a single common-emitter stage.

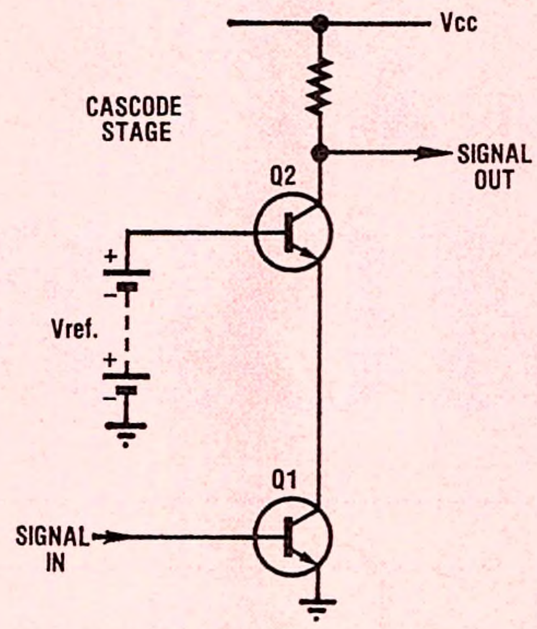


Fig.2: a cascode stage is formed by connecting two transistors in series across the supply rail. Note the reference voltage fed to the base of Q2.

In the past, cascode stages have been a feature of RF circuitry. Cascode stages were originally designed around valves. The word "cascode" is derived from the phrase "cascaded via the cathode", a reference to the cathode in a valve.

in the Studio 200 power amplifier). This device has a power rating of 250 watts, a maximum collector current rating of 20 amps and a collector voltage of 140 volts.

With a collector voltage of 50 volts you can pass 5 amps through the transistor (provided the case temperature is maintained at 25°C) and so obtain a power dissipation of 200 watts.

However, at a collector voltage of 100 volts you can only pass 1 amp safely through the transistor and thus it is derated to 100 watts dissipation.

Designers can cope with this situation provided they know what sort of load the amplifier is intended to drive. They can draw the load lines and select the transistor operating conditions so that the limits of the "safe operating area" are not exceeded.

The problem is, when the amplifier is intended to be used with a line transformer, it is much more difficult to predict the load characteristics. This means it is much more difficult to guarantee that the transistors will not be damaged by unsafe operating conditions.

This is where power Mosfets come into their own. They don't have to be derated for "safe operating area" because they don't have any tendency to internal hot spots. And if they are driven hard so that their temperatures are unduly elevated, they compensate automatically by reducing their transconductance.

In effect, they are just about unburstable. Their only weakness is that they can be damaged by excessive gate-to-source voltage. This can be prevented by connecting a suitable zener diode between gate and source.

New circuit design

With these thoughts in mind, we set out to design a new amplifier module which would be suitable for driving a 100V line transformer. It would use power Mosfets, have provision for nulling the DC output, flyback diodes across the output devices and so on.

The circuit is as shown in Fig.1. It is suitable for use with or without a 100V line transformer. When used without a transformer, it will deliver 90 watts into 8Ω loads and 125 watts into 4Ω loads. The performance is fully detailed in the specification panel elsewhere in this article.

While most of the circuit is fairly standard, it does incorporate a feature which has not been seen in many published circuits to date. This involves cascode operation for the first two stages, a feature which gives improved linearity and better bandwidth.

Let us now describe the circuit in detail. Q1 and Q2 are PNP transistors connected as a differential input stage. The input signal is fed to the base of Q1 while the negative feedback signal is fed to the base of Q2. The total current through Q1 and Q2 is set by constant current source Q3.

Q3 is biased by diodes D1 and D2 so that it applies close to 0.67 volts across its 680Ω emitter resistor. This sets the current through Q3 at close to 1mA and so the current through Q1 and Q2 is 0.5 milliamps for each.

In a conventional direct-coupled amplifier, the signal from the collector of Q1 would be connected directly to the base of the following class-A driver stage transistor. In our circuit though, the signal from Q1 connects to the emitter of cascode transistor Q4 while the output signal appears at its collector and is then fed to the base of Q5.

Q5 and Q6 form a cascode class-A stage with Q7 operating as a constant current load. The base of Q7 is biased by diodes D1 and D2 (which also serve as reference voltage for Q3). With this bias voltage, the current through Q7, Q6 and Q5 is just over 10 milliamps.

Five diodes, D3 to D7, provide the base reference voltage for Q6 and thus set the collector-emitter voltage for Q5 at close to 2.6 volts. (To read how a cascode stage works, see the panel at the top of this page).

The output signal from the cascode stage is coupled directly to

Delving Into the Mysteries of the 100V Line

Why do public address amplifiers use 100V lines for speaker distribution? Does the speaker line operate at a constant 100 volts AC? How do you match a speaker to a 100V line?

These and other related questions cause a lot of confusion to people in and out of the public address field.

The big problem with public address systems is that the very long speaker leads can have considerable voltage losses if conventional low impedance speakers are used. Imagine the voltage loss in a pair of speaker lines 200 metres long with an 8Ω speaker. A 200 metre length of such cable will have a DC resistance of about 5.5Ω. This means that 40% of the power would be lost in the cable.

When you consider that a PA system in a large building may have tens of kilometres of speaker wiring running back to the amplifier, the resistance losses with conventional low impedance speakers would be intolerable.

The way around this problem is to feed the amplifier's output into a step-up transformer and then into the long speaker lines. Each speaker is then coupled to the line via a step-down transformer which usually has tap connections to vary the loudness from the speaker.

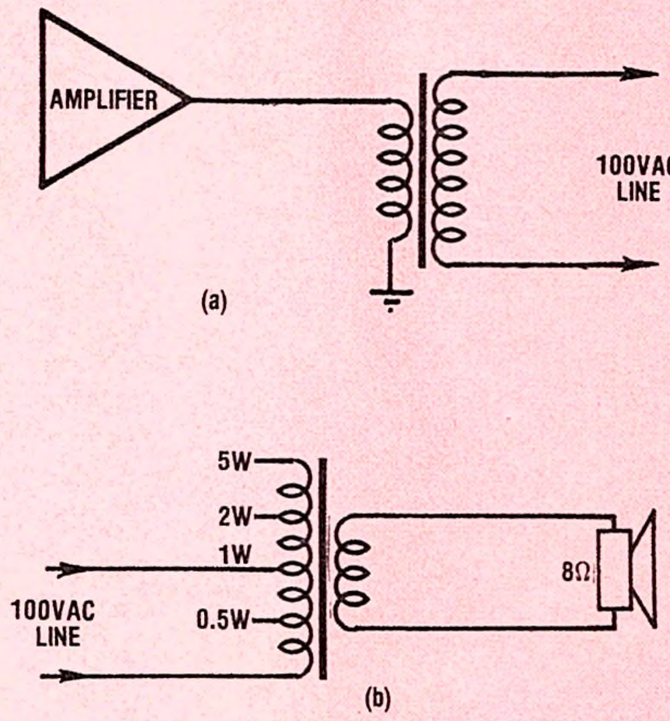


Fig.3: how the amplifier output is connected to give a 100V line. Each loudspeaker is connected to the line using a separate step-down transformer.

So how does the figure of 100 volts come into the picture? The assumption is that when the amplifier is running at full power, it will be delivering 100VAC to the speaker lines. This makes it easy for the PA system installer. Instead of having to calculate the total load impedance when all loudspeakers are connected, all he has to do is add up the power settings for every speaker connected and see that it is equal to or less than the power rating of the amplifier.

Consider a 100 watt power amplifier (with 100V line output). The installer can install any combination of speakers which give up to 100 watts. For example, he may have 50 loudspeakers all of which are connected via the "2 watt" primary tap on their individual step-down transformers.

So under the worst case conditions, when the attenuators (if fitted) on all speakers are set to maximum loudness, the maximum power delivered to each speaker will be 2 watts. Thus, provided no one modifies the installation, the loading on the amplifier will never be excessive (ie, too low in impedance).

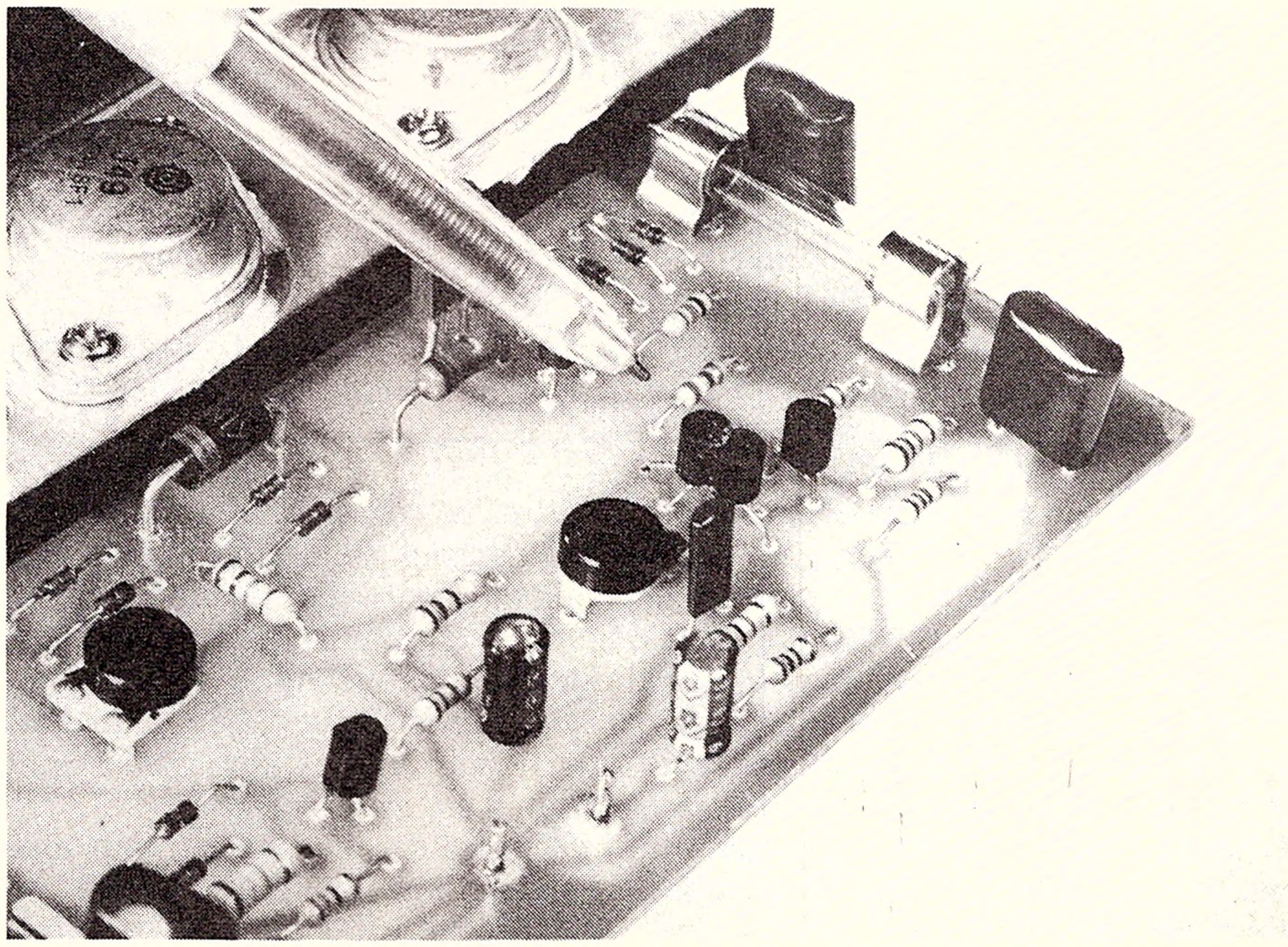
Remember that 100VAC will rarely, if ever, be present on the speaker lines. That only happens when the amplifier is driven to its maximum output.

In the past, many PA systems used 70V lines. This is exactly the same principle as the 100V line except that for a given power level, resistance losses in a 70V system will be twice that in a 100V installation.

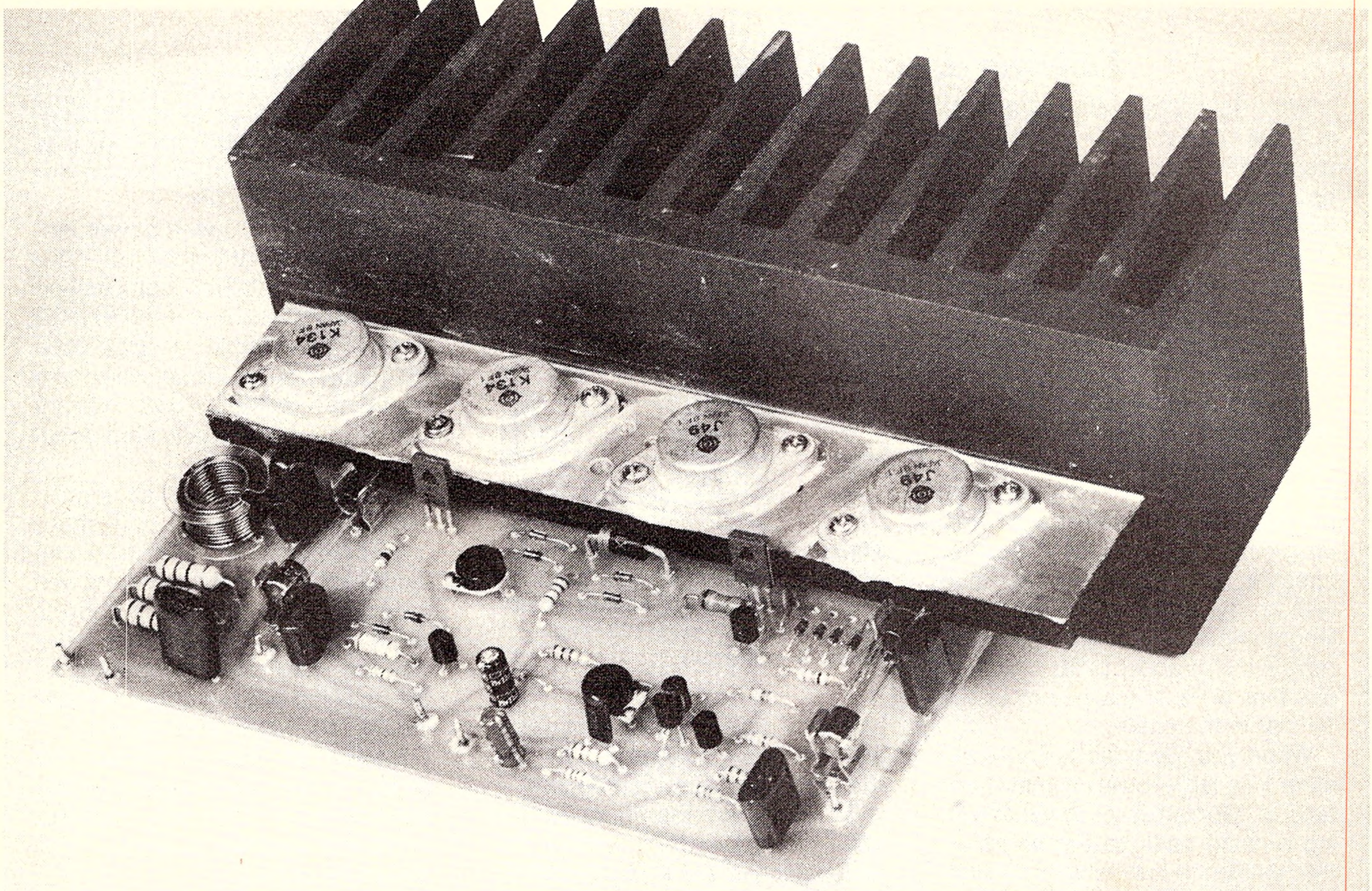
the output stage. A 39pF capacitor from the collector of Q6 to the base of Q5 rolls off the open-loop gain of the amplifier to ensure a good margin of stability.

Output stage

Four Hitachi power Mosfets are used in the output stage. They are connected in source follower mode (similar to emitter follower mode with bipolar transistors). The signals to the output stage are fed via 220Ω resistors to the gates of the Mosfets. These resistors also



Right: the pen is pointing to the two input transistors (Q1 and Q2) which must be thermally bonded together. This is done to minimise temperature drift of the output DC voltage.



During assembly, push the small signal transistors down onto the board as far as they will comfortably go before soldering the leads. The metal faces of the BF469/470 transistors (Q6 and Q7) go towards the heatsink.

function as "stoppers" to prevent spurious RF oscillation.

Zener diodes ZD1 and ZD2 plus diodes D8 and D9 prevent overdrive to the gates of the Mosfets. When the load is short circuited, these diodes limit the voltage between the gates and sources of the Mosfets to about ± 11.6 volts.

The quiescent current through the output stage is determined by the setting of the 500Ω trimpot, VR2. The 10mA current (via Q7 etc) through the resistance of the trimpot provides a voltage between the gates of the Mosfets to bias them on slightly when no signal is present. This is a normal feature of all class-B amplifiers and is used to minimise crossover distortion.

With Mosfets though, it is usual to set the quiescent current much higher than in an equivalent bipolar amplifier. The reason for this is twofold. First, Mosfets are even more non-linear at low currents than bipolars (contrary to what is written in some journals). Second, at a current of 100 milliamps, the transconductance (measured in amps per volt or "mhos") of the Hitachi Mosfets has a zero temperature coefficient. Hence, the total quiescent current for the output stage is set at 200mA.

This relatively high current also reduces any tendency to RF instability which can be a problem with power Mosfets if their quiescent current is set too low.

The high quiescent current is one disadvantage of Mosfets. It means they need a bigger heatsink and that they waste more power than an equivalent bipolar transistor amplifier.

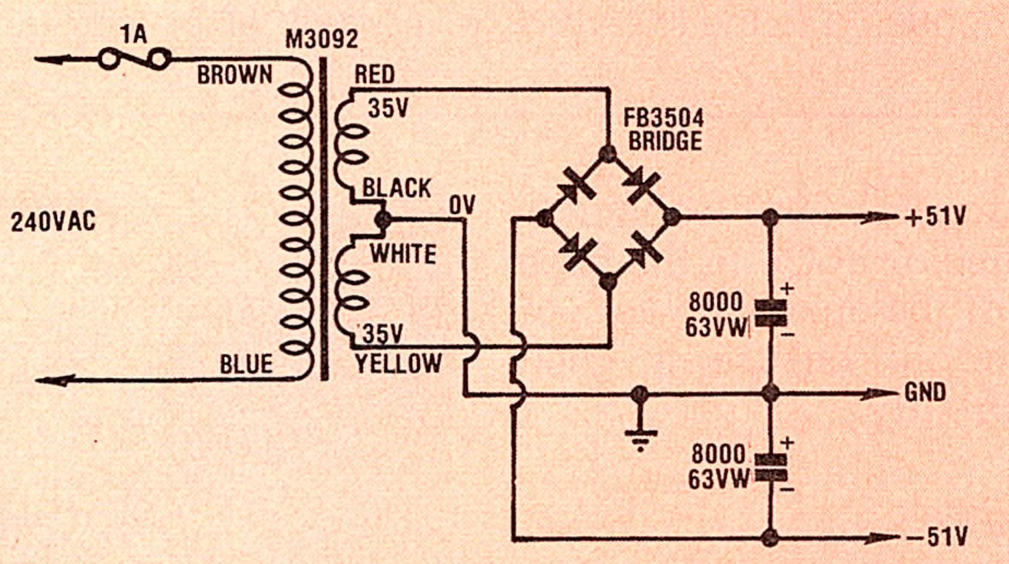


Fig.4: suggested power supply for the 120W PA module. Check the output rails before connecting them to the module.

Output stage protection

Apart from the zener diodes

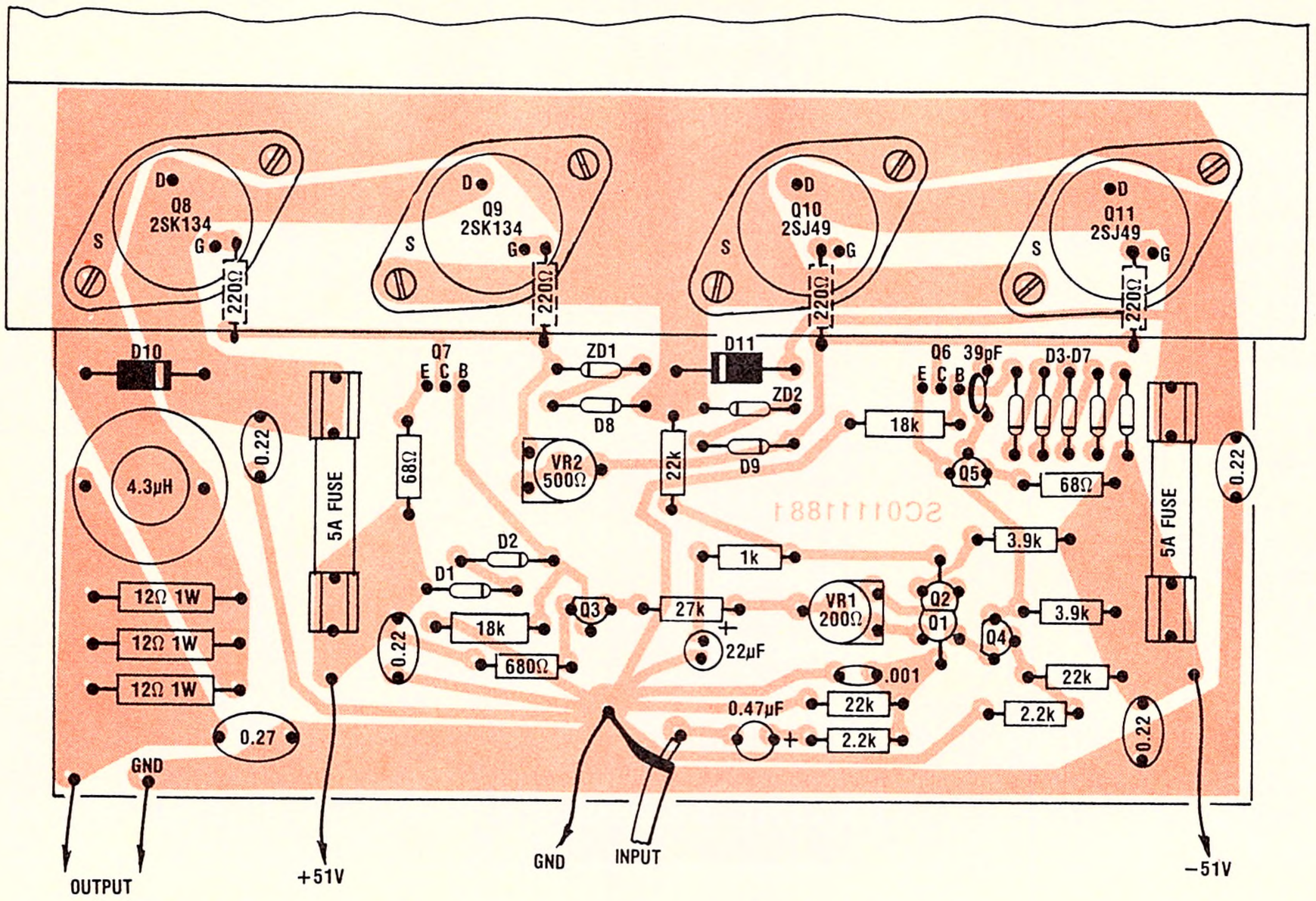


Fig.5: here's how to install the parts on the printed circuit board. Keep the component leads short and make sure that the Mosfet output transistors (Q8-Q11) are electrically isolated from the heatsink. The 220Ω resistors shown dotted are mounted on the copper side of the board.

already mentioned, the Mosfets also have have diodes D10 and D11 for flyback protection. These diodes safely clamp any spike voltages, generated by the load, to the positive and negative supply rails. To protect against short circuit loads, a 5A fuse is connected in series with the supply rails to the Mosfets.

An RLC network is connected between the amplifier output and the line transformer (or loudspeaker load if the transformer is not used). This network serves two purposes. First, it ensures stability of the amplifier under all loading conditions, including large shunt capacitances. Second, it effectively decouples the amplifier from the load and connecting lines at very high frequencies.

This stops large RF signals picked up by the loudspeaker lines from being fed back to the input of the amplifier (via the feedback components) and being detected in Q2. Thus, it helps stop RF breakthrough.

Similarly, at the input of the amplifier, there is quite a savage low pass filter which attenuates any extraneous RF signals before they get to the base of Q1.

The voltage gain of the amplifier is set by the 22kΩ and 1kΩ resistors at the base of Q2. These set the voltage gain to 23. The low frequency response is set mainly by the 0.47μF input coupling capacitor, giving a – 3dB point at about 20Hz. This could have been set for a lower frequency but this would cause problems of distortion and loading with the output transformer.

DC nulling

As mentioned before, it is most important that the DC voltage at the output of the amplifier be as close to zero as possible. To ensure this, the two input transistors are thermally bonded together so that any temperature drift will be minimised. As well, the 200Ω trimpot VR1 allows the output voltage to be set close to zero; ie, to less than ± 1mV.

Power supply

The suggested power supply (Fig.4) for the amplifier module uses a 300VA toroidal transformer with a centre-tapped 70V secondary winding (ie, 35 volts a side). This feeds a 400V 35 amp bridge rectifier and two 8000μF 63VW electrolytic capacitors.

100V line transformer

The recommended 100V line transformer was supplied by Altronics of Perth, as were the supply components. The transformer is a toroid with a rating of 160VA. It has been designed to present a 4Ω load to the amplifier. It has two prinmary windings and two secondary windings. The method of connection to the amplifier is shown on the circuit of Fig.1.

No feedback is applied around the transformer but even so the performance is very good, both as far as frequency response and harmonic distortion are concerned. Full details are shown in the specifications panel.

Construction

The wiring layout of Mosfet amplifiers is very critical so the printed board is a crucial feature of the design. The printed board

PARTS LIST

1 PCB, code SC01111881, 95 x 163mm
1 cast aluminium heatsink with integral bracket, 195mm wide by 66mm high; Jaycar Cat. No. HH-8550 or equivalent L-shaped bracket and heatsink
4 3AG fuseclips
2 5A 3AG fuses
6 PC pins
1 plastic coil bobbin, 12mm diameter x 11mm long; Siemens B65672-B-T1 or equivalent (or 4.3μH air-cored choke; see text)
4 TO-3 transistor mounting kits

Semiconductors
2 2SK134 Mosfet transistors
2 2SJ49 Mosfet transistors
4 BC556 PNP transistors
1 BC548 NPN transistor
1 BF470 PNP transistor
1 BF469 NPN transistor
9 1N4148, 1N914 small signal diodes
2 11V 400mW zener diodes
2 1N5404 3A silicon diodes

Capacitors
1 22μF 16VW PC electroyltic
1 0.47μF 16VW PC electrolytic
1 0.27μF metallised polyester (greencap)
4 0.22μF metallised polyester (greencap)
1 .001μF metallised polyester
1 39pF ceramic

Resistors (0.25W, 5%)
1 x 27kΩ, 3 x 22kΩ, 2 x 18kΩ 0.5W, 2 x 3.9kΩ, 2 x 2.2kΩ, 1 x 680Ω, 4 x 220Ω, 2 x 68Ω, 3 x 12Ω 1W, 1 x 500Ω trimpot (Bourns Cermet horizontal mount, 0.2 x 0.4-inch), 1 x 200Ω trimpot (Bourns Cermet horizontal mount)

Transformers and Power Supply Parts
1 300VA power transformer, 70V centre-tapped, Altronics Cat. M-3092 or equivalent
1 160VA 100V line transformer, Altronics Cat. M-1124
1 35-amp bridge rectifier, Altronics Cat. FB-3504
2 8000μF 63VW electrolytic capacitors
1 1A fuse and fuseholder

measures 163 x 95mm and is coded SC 01111881. It is meant to be used with a large heatsink. The one shown in our illustrations is from Jaycar (Cat. HH-8550).

As an alternative, the board could be used with a heavy gauge aluminium angle bracket and a large extruded heatsink. The heatsink must be reasonably large to keep the amplifier as cool as possible, for long term reliability.

Assembly of the board is a straightforward matter but it should not be hurried. First, you should closely inspect the board to see if there are any shorted tracks or open circuits in the copper pattern. These should be fixed before proceeding further. The PCB component diagram is shown in Fig.5.

Fit the small components first, such as the resistors and diodes. Make sure that you don't confuse the small diodes (1N914s) with the 11V zeners. The fuse clips, trimpots and small transistors can be mounted next. Q1 and Q2 should be mounted so that their flat faces are touching. When you have soldered them in place, put of drop of superglue between them and squeeze them together.

Note that all the transistors should be pushed close down onto the PCB before soldering (see photo).

The 4.3μH choke at the output of the amplifier is wound with 19.5 turns of 0.8mm enamelled copper wire on an 11mm plastic bobbin. Two layers of wire are wound on so that the start is at one side and the finish is at the other side of the bobbin. Bend the start and finish leads at 90° and scrape off the enamel coating before soldering the choke to the board.

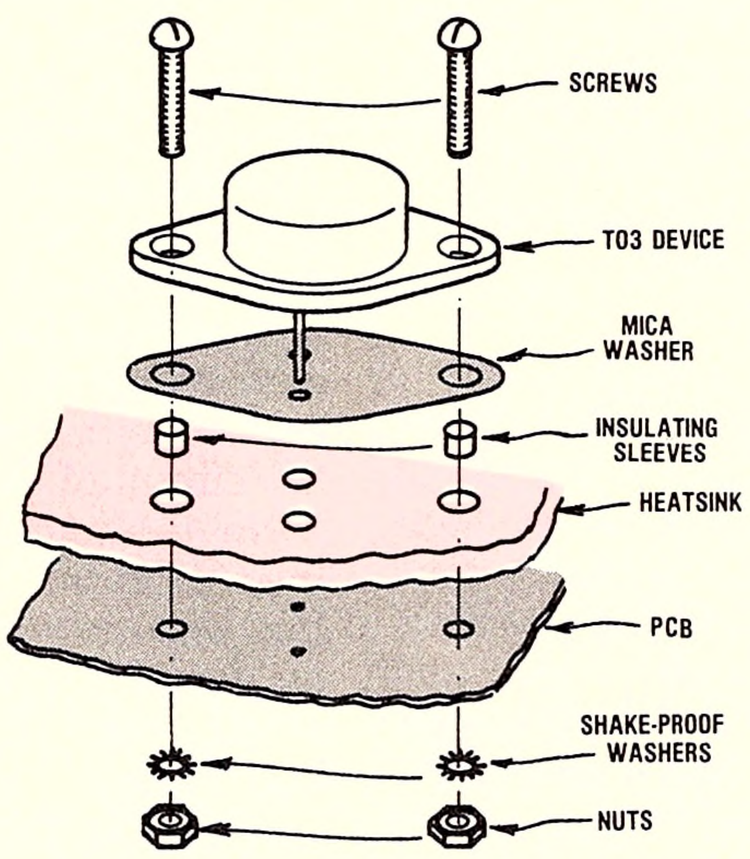
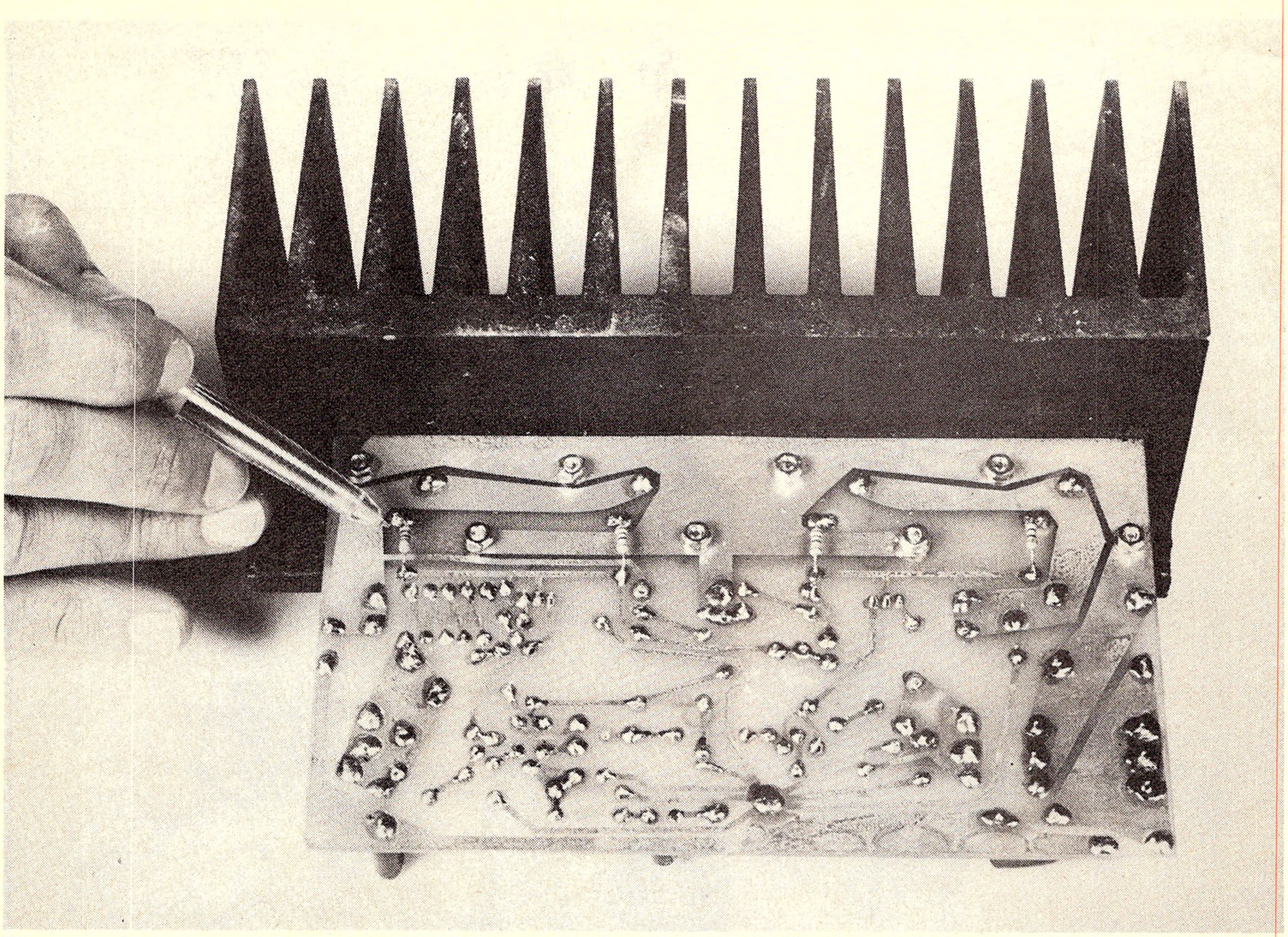


Fig.6: this diagram shows how the Mosfet output transistors are mounted on the heatsink. Use your multimeter to check for shorts between the case and heatsink as each transistor is mounted. The nuts should be soldered to the PC pattern after assembly to ensure reliable contact.

Heatsink assembly

The four Mosfet power transistors are mounted on the heatsink but with their leads soldered to the printed board. The assembly is as shown in Fig.6. We used 5mm fibreglass tubing for the insulating bushes. Smear all the mounting surfaces of the Mosfets and the heatsink with heatsink compound before assembly.

The transistors are mounted to the heatsink using 12mm 6BA



The pen points to one of the four 220Ω resistors mounted on the copper side of the board. Mount the resistors so that they are 2-3mm proud of the board while keeping their leads as short as possible.

Performance of Prototype

Power Output (RMS)	125 watts into 4 ohms; 90 watts into 8 ohms; 120 watts into 100V AC line
Frequency Response	20Hz to 50kHz (−3dB) without line transformer; 20Hz to 23kHz (−3dB) with line transformer
Input Sensitivity	1.1V into 22kΩ input impedance
Harmonic Distortion	⟨0.1% from 20Hz to 20kHz
Signal-to-Noise Ratio	−111dB unweighted (20Hz to 20kHz); −119dB A-weighted
Damping Factor	⟩50 for 8Ω loads
Stability	Unconditional

screws and nuts. Solder the nuts to the PCB pattern after assembly to ensure reliable contact. Alternatively, if the nuts are nickel plated or stainless steel, use lockwashers.

As each transistor is mounted, use your multimeter (set to a low "ohms" range) to check that its case is insulated from the heatsink.

If the meter does indicate a short, remove the transistor and check carefully for metal swarf around the mounting holes.

After the nuts have been tightened and soldered, the gate and source leads of the Mosfets can be soldered to the PCB pattern. The four gate resistors are then soldered in place, on the copper pattern side of the PC board.

Install these four resistors so that they just sit proud of the PCB (see photo for details).

Now closely inspect all your work for correct assembly and soldering. Make sure there are no blobs of solder bridging out tracks. As a final check on your work, connect your multimeter (set to a low "ohms" range) and test for shorts between the supply rails and the 0V rail. There is a trap here — flyback diodes D10 and D11 will show a low resistance for one connection of the multimeter and a high resistance for the reverse connection.

Assuming that you have wired up the power supply, check the voltage on the two supply rails before mak-

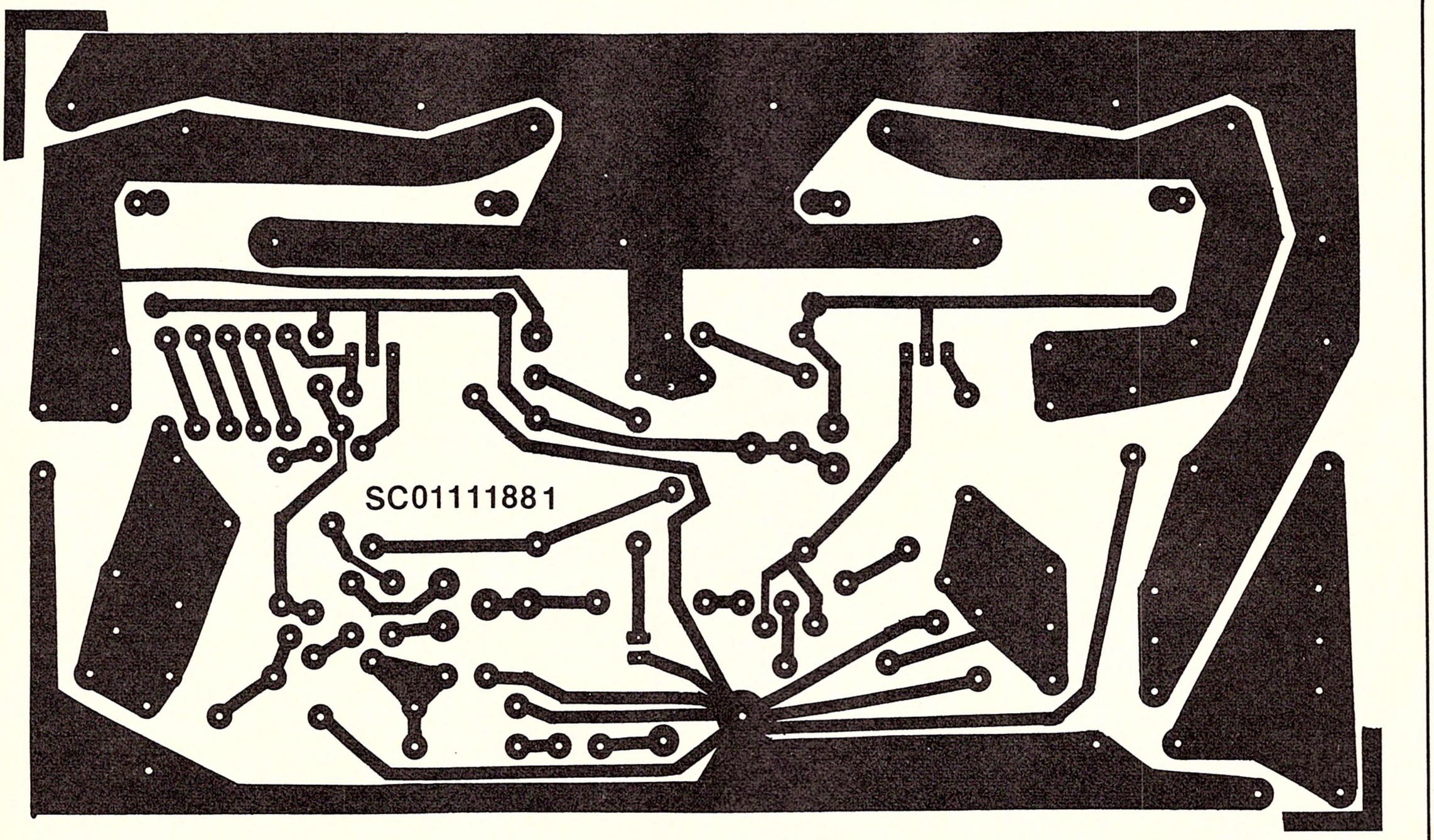


Fig.7: the full size PC pattern. The wiring layout is critical so the PCB pattern is a crucial feature of the design.

ing connections to the amplifier board. The supply rails should be close to ±50V DC. Switch off and wait for the 8000μF capacitors to discharge to below 5V before hooking the supply up to the amplifier.

Caution: remember that the power supply puts out a total of 100 volts DC. This is a potentially dangerous voltage. Make sure you don't come in contact with it.

Setting up

Now remove the negative supply fuse from its clip and connect a multimeter set to measure up to 1A across it. **Do not connect a load or the output transformer to the amplifier at this stage.**

The output stage quiescent current can now be set. Rotate the 500Ω trimpot (VR2) fully anticlockwise and apply power. Now rotate the 500Ω trimpot for a current of 200mA.

Switch off the power supply and wait for the voltage across the supply capacitor to drop. The multimeter can now be removed from circuit and the 5A fuse replaced in the negative supply line. Reapply power and measure the DC voltage at the output of the amplifier. Rotate trimpot VR1 to set it to zero; ie, to less than ±1mV.

Leave the amplifier with power connected for an hour or so and then check the settings for DC output and quiescent current. Reset if necessary. It is normal for both settings to drift slightly.

Now you can connect the 100V line transformer or the loudspeakers and check for the presence of hum or any other signal. With no signal applied the amplifier should be absolutely quiet. Touching your finger to the input should cause the speaker to emit a small "blurt". With that, your amplifier is ready for work.

Footnote: a complete PA amplifier based on this new module will be published in a future issue of SILICON CHIP. SC

What is Transconductance?

While the gain of bipolar transistors is specified as a simple ratio of collector current to base current (and known as beta or h_{fe}), the gain of Mosfets and V-fets is referred to as transconductance. This is because a fet (field effect transistor) is a voltage controlled device; a signal of several volts into the gate gives a drain-source current of several amps.

Hence, a Mosfet varies its conductance (the reciprocal of resistance) in proportion to its gate signal.

The gain of a Mosfet is specified in terms of amps per volt or in the old unit of conductance, Mho (which is "Ohm" spelt backwards and still used by American semiconductor manufacturers). The new unit for conductance is the Siemen (used by European and Japanese manufacturers).

For the 2SK134 (N-channel) and 2SJ49 (P-channel) devices, the transconductance is typically 1 Siemen (ie, 1 amp per volt) at a drain current of 3 amps and a drain-source voltage of 10V.