ELECTRONICS AUSTRALIA

VIDEO, HIFI & COMPUTERS

JULY, 1982

AUST $2.00 NZ $2.50

100 WATT SUB-WOOFER AMPLIFIER

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High-power design uses Mosfet technology

100W sub-woofer power amplifier

Capable of up to 120 watts RMS into 4-ohm loads and up to 80 watts RMS into 8-ohm loads, this power amplifier module has been specifically designed for use as a sub-woofer driver amplifier in a tri-amped hifi system. It uses four power Mosfets for rugged, reliable operation.

by LEO SIMPSON

Since publishing the Playmaster Mosfet Stereo Amplifier in the December 1980 and January, February 1981 issues, Mosfets have gained an enviable reputation as rugged and reliable devices. The above amplifier has proved to be remarkably trouble-free but we have had a steady stream of requests for something more powerful but equally reliable.

So when we began development of this sub-woofer system, a Mosfet power module capable of around 100 watts into 8-ohm loads was our target. This has been substantially met although we shall talk more about the performance later in this article.

This new module is single channel only and incorporates the power supply circuitry including two 8000μF/75VW electrolytic reservoir capacitors which are surprisingly compact and efficient. Also provided on the module printed circuit board is a low-pass filter circuit which is identical in configuration to that published in our February 1980 issue, under the title, "Super-Bass Filter".

Since this module is intended as a sub-woofer driver in conjunction with an existing stereo amplifier, the power level in the sub-woofer should be directly in proportion to the signal level fed to the stereo speakers. In other words, the sub-woofer level should be directly under the control of the main volume control on the stereo amplifier. There are two ways of achieving this.

The first and most suitable way is possible if your stereo amplifier has preamplifier outputs. This would allow the left and right signals to be fed to the low pass filter via isolating resistors. (This method is also possible if you have a separate preamplifier/control unit and stereo power amplifier.)

The second and more practical method, for most owners of stereo systems, will be to take the signal directly from the drive to the left and right loudspeakers. Again, isolating resistors are used and the signal level adjusted by a common preset control. Thus, in our circuit, the left and right input signals are fed via 10kΩ resistors to a common 1kΩ preset shunt control.

Let us now discuss the power amplifier itself. This is almost identical in configuration to that of the Playmaster Mosfet Stereo Amplifier mentioned above and to that described in the original Hitachi literature on the power Mosfets. The power transformer is also the preferred type used in the above amplifier.

Since the Playmaster Mosfet Stereo Amplifier was stated to be only capable of delivering 55 watts RMS into an 8-ohm load with one channel driven, readers may wonder how the new amplifier manages to deliver up to 80 watts into an 8-ohm load and 120 watts into a 4-ohm load. And why do we entitle the unit a "100W Sub-Woofer Power Amplifier"?

Let's make it clear from the outset, that this amplifier configuration will not deliver 100 watts into an 8-ohm load with the specified transformer. Even under pulse power conditions with the supply rails rock-steady at ±50V the

Performance of prototype

POWER OUTPUT

4 ohms	120W (see text).
8 ohms	80W (see text).

FREQUENCY RESPONSE

Power amplifier	20Hz to 20kHz ±0.25dB.
Low pass filter	−3dB at 96Hz, slope 18dB/octave.

HARMONIC DISTORTION

See graphs.

HUM & NOISE

Power amplifier alone	−92dB ref 10W/8Ω input shorted. −103dB ref 10W/8Ω input open.
Amplifier and filter	−99dB ref 10W/8Ω input open all figures measured with bandpass filter 20Hz to 20kHz −3dB.

DAMPING FACTOR

At 1kHz ≥50.
At 30Hz ≥50.

STABILITY

Unconditional.

HOW IT WORKS:

The circuit of this sub-woofer amplifier is basically a low pass filter followed by a conventional power amplifier which uses four power Mosfets in the output stage.

Input signal is fed from the left and right channels of the main stereo amplifier in the system (from either the loudspeaker outputs or preamplifier outputs) via 10kΩ mixing resistors and then attenuated to the appropriate level by a 1kΩ shunt trimpot. The common mono signal thus obtained is then fed to the low pass filter which uses a single Fet-input op amp and three RC networks.

This combination active/passive filter gives a Butterworth response (maximally flat in the passband) and a −3dB point at 96Hz. This can be moved up or down in frequency by scaling the capacitor values (see the article). The filter has a gain of unity in the passband and an ultimate slope of 18dB/octave above the corner frequency (−3dB point).

Since the op amp has supply rails of ±15V its maximum output signal is far in excess of what can be handled by the following power amplifier. The op amp also causes negligible deterioration of the distortion and residual noise performance of the whole module.

The resulting sub-woofer signal has a maximum possible bandwidth (at the −3dB points) of 7Hz to 96Hz although, in practice, the low frequencies would rarely extend below 30Hz.

The output signal from the filter is fed via a 22μF bipolar capacitor (to ensure low distortion) to the amplifier input. A 1kΩ resistor and 27pF capacitor form a simple RF filter which is more important if the amplifier is to be used without the foregoing low-pass filter.

Two high voltage BC556 PNP transistors, Q1 and Q2, comprise the input differential pair. The "tail" of this differential pair is a 47kΩ resistor instead of the commonly found "constant current" transistor which is often used with amplifiers having lower supply rails.

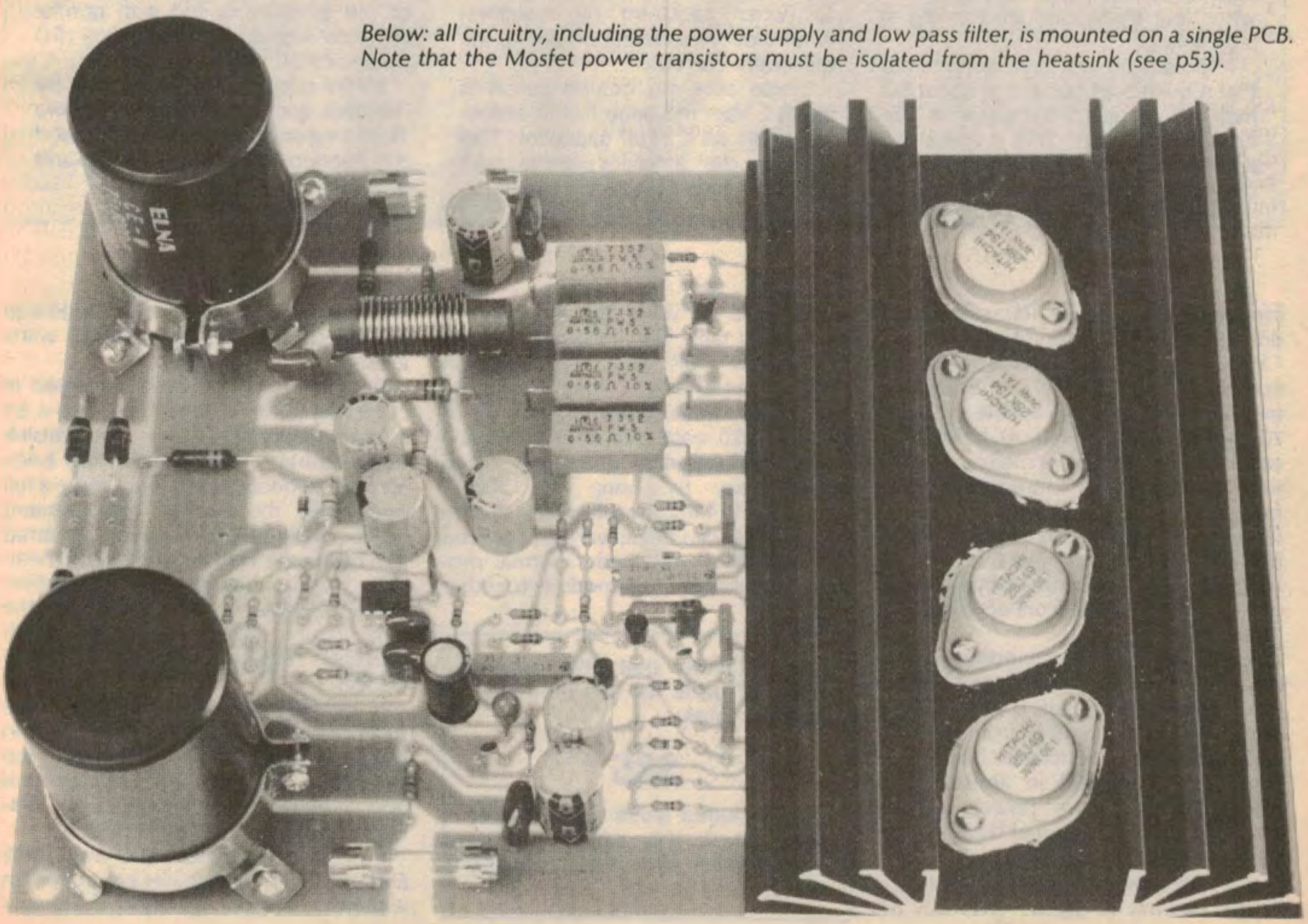
A trimpot (VR2) between the emitters of Q1 and Q2 allows minor balance adjustments to be made to the differential pair and thus obtain zero offset voltage at the output.

The input differential pair drives another differential pair, using NPN transistors Q3 and Q4 together with current mirror Q5. These transistors have a collector voltage rating of 250V and were designed specifically for class-B video stages in television receivers. As such, they are ideally suited to use as low distortion driver stages as they have a good gain-bandwith product of 100MHz or better and quite good beta linearity over their likely range of operating current.

The current mirror scheme for the second differential pair is a variation on the constant-current load which is often used for class-A driver stages in audio amplifiers. It has the effect of providing a higher gain from the stage, better gain linearity over the full voltage swing and gives a greater voltage swing than could be obtained from a simpler class-A stage with

Continued on page 46

Below: all circuitry, including the power supply and low pass filter, is mounted on a single PCB. Note that the Mosfet power transistors must be isolated from the heatsink (see p53).



HOW IT WORKS . . . continued

a boot-strapped resistive collector load.

The two differential stages provide all the voltage gain of the amplifier as the Mosfet output stage is run in source-follower mode (similar to emitter-follower mode for bipolar transistors). With the AC feedback disabled, the open-loop gain of the prototype amplifier was around 35,000 or 90dB.

Each of the four power Mosfets has a 0.56Ω/5W source resistor which helps ensure that each pair (of Mosfets) shares the load current equally. It also gives increased stability to the quiescent current setting. This is defined by the voltage between the gates of the complementary Mosfets and is adjusted by the 1kΩ trimpot which is wired as a variable resistor (VR3).

There is a trade-off between the value of quiescent current and the amount of distortion produced at low power levels. While higher current settings will certainly give lower distortion values, the improvement that can be obtained is not commensurate with the great increase in heat dissipation which necessarily results when four transistors are running at high voltage.

Accordingly, we have determined that a quiescent current of about 30 milliamps in each transistor is the best compromise. This enables the heatsink to run at quite modest temperatures (warm but not hot) when program is being handled at low levels.

One hundred ohm resistors are connected in series with the gate of each Mosfet as "stoppers" to prevent parasitic oscillation.

We also experimented with the addition of small capacitors between gate and source of the 2SK134s (which have smaller gate capacitance) but found this tended to cause parasitic oscillation which was manifested as a rise in harmonic distortion at medium power levels.

No protection circuitry is incorporated in the output stage apart from fuses in the supply lines. While these do require that extra supply bypassing be added to compensate for the impedance of the fuse, it does mean that no fuse is necessary in series with the loudspeaker where its non-linearity can cause distortion.

Supply fuses also have the benefit of protecting against malfunction in the amplifier itself as could happen for example when a transistor fails or the wiper of the quiescent current setting trimpot goes open-circufit. The supply fuses also provide a convenient current monitoring facility (when replaced by resistors) when trouble-shooting or setting the quiescent current.

Single pole lag compensation is applied from the base to the collector of Q3 via a 27pF capacitor. This renders the amplifier stable with overall negative feedback applied.

Voltage gain of the power amplifier is set by the ratio of the 47kΩ and 2.2kΩ resistors at the base of Q2. The lower cutoff frequency is set by the 10μF capacitor in series with the 2.2kΩ resistor. This capacitor also sets the DC feedback at 100% so that the DC gain is unity.

A final refinement, which has been incorporated in recent Playmaster amplifiers, is the RLC network in the output. This is a rationalisation of the Zobel (RC) and LC networks often used in amplifiers and is based on a paper by A. N. Thiele and published in the September 1975 issue of "Proceedings of the IREE". This helps render the amplifier unconditionally stable, with the proviso that short circuits or large capacitive loads will blow the fuses.

Power supply circuitry is fairly simple. A centre-tapped transformer drives a bridge rectifier and two 8000μF/75VW capacitors to obtain unregulated supply rails of about ±50V at no signal. This drops to about ±46V when the amplifier is driven to full power (continuous) of about 70 watts into 8-ohm loads. If the supply rails are better regulated or the amplifier is fed with normal program signals, it will deliver 80 watts into 8Ω before clipping.

±15V supply rails are derived by resistors and zener diodes for the TL071 op amp. These are bypassed and decoupled by 68Ω resistors and 470μF/16VW capacitors.

module will not deliver 100 watts unless driven beyond the onset of clipping.

If you examine the power versus distortion curves you will see that the amplifier module is really only capable of about 70 watts RMS (continuous) before the onset of clipping. This is measured using the Ferguson PF4361/1 transformer and a regulated 240VAC mains supply. The difference in continuous power rating between this module and the previous Playmaster design comes about because of the use of parallel-connected output Mosfets.

These allow greater currents to be delivered to the load for a given voltage drop across each half of the output stage. Or to look at it from another angle, the transconductance of the output stage, expressed in amps/volt, is higher and so more power can be delivered for a given signal voltage from the driver stage.

Either way, the ultimate limiting factor in the amount of power that can be delivered is the value and regulation of the supply rails. The no-signal value of the supply rails with the Ferguson PF-4361 and a 240VAC input is close to ±50V. This drops to about ±46V when delivering 70 watts into an 8-ohm load.

If the regulation of the supply is improved, say by using the 300VA Ferguson PF4362 transformer, slightly more power can be delivered, at around 80 watts RMS. And under normal program conditions, the module together with the PF4361/1 transformer could also be expected to deliver about 80 watts RMS.

One other proviso must be noted in talking about these power measurements and that is the heatsink temperature. If the heatsink has been allowed to become very hot before a full power test, the resultant measurement will be significantly reduced compared to a test made with an initially cold heatsink. This is because the transconductance of Mosfets is reduced as the temperature rises — a factor which prevents thermal runaway in these devices.

By contrast, the gain of bipolar transistors normally increases with a rise in temperature and there is usually no significant difference in the maximum power output of a bipolar circuit between hot and cold measurements.

In order to guarantee 100 watts RMS (into an 8-ohm load) under any condition with this circuit configuration, the supply

We estimate that the current costs of parts for this module is approximately

$85

This includes sales tax but does not include the power transformer and other chassis parts.

PARTS LIST

1 PC board 228 × 170mm, code 82pa7
1 heatsink, single sided 170mm long, Thermalloy 6169, Ritronics, or equivalent
1 14μH choke, 19 turns of 16 gauge enamelled copper wire close wound on Neosid F14 ferrite 40mm × 10mm diameter
4 fuse clips, Swann Electronics FC1
2 5A 3AG fuses
4 TO-3 mica washers
8 insulating bushes

SEMICONDUCTORS
1 1N4148, 1N914 silicon signal diode diode
2 15V, 1W zener diodes
4 1N5404 silicon rectifier diodes
1 TL071, LF351 Fet-input op amp
2 BC556 PNP transistors
2 BF469 NPN transistors
1 BF470 PNP transistor
2 2SK134 power Mosfets
2 2SJ49 power Mosfets

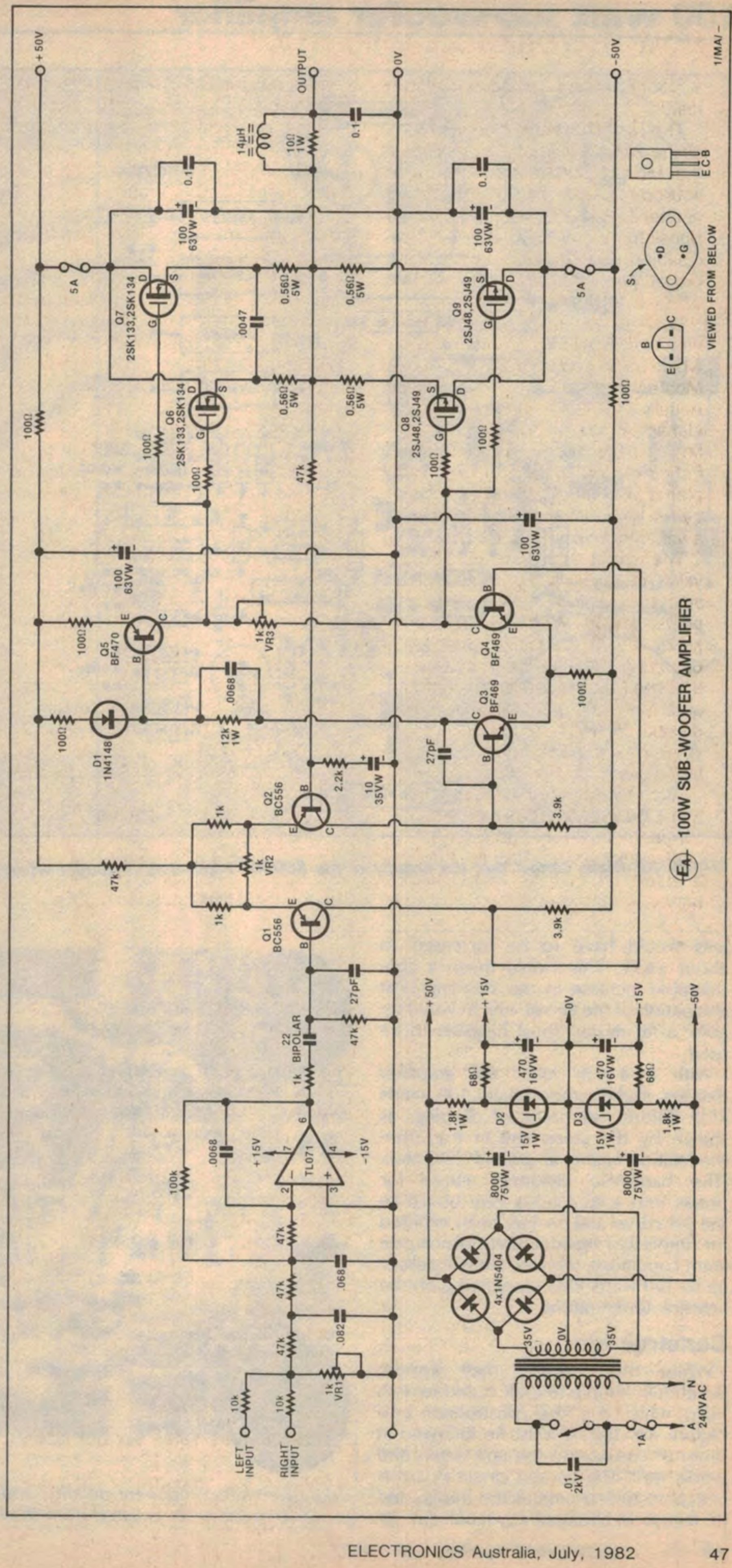
CAPACITORS
2 8000μF/75VW electrolytics (with mounting brackets)
2 470μF/16VW electrolytics
4 100μF/63VW electrolytics
1 22μF/50VW bipolar electrolytic
1 10μF/35VW tantalum or low leakage electrolytic
3 0.1μF greencap (metallised polyester)
1 .082μF greencap
1 .068μF greencap
2 .0068μF greencap
1 .0047μF greencap
2 27pF ceramic

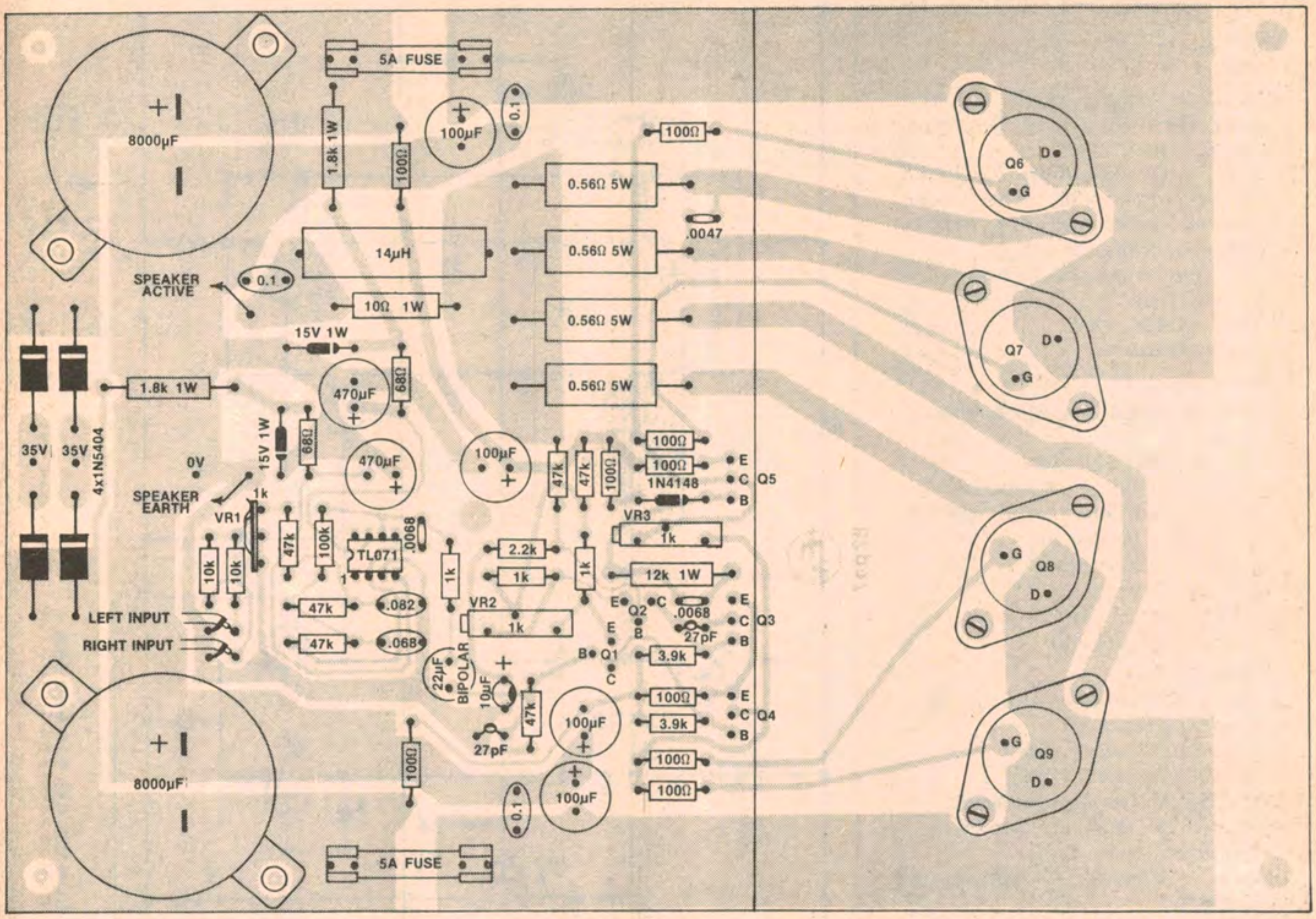
RESISTORS (¼W, 5% tolerance)
1 × 100kΩ, 6 × 47kΩ, 2 × 10kΩ, 2 × 3.9kΩ, 1 × 2.2kΩ, 3 × 1kΩ, 9 × 100Ω, 2 × 68Ω

OTHER RESISTORS
1 × 12kΩ/1W, 2 × 1.8kΩ/1W, 2 × 220Ω/5W (for set-up adjustment), 1 × 10Ω/1W, 4 × 0.56Ω/5W, 2 × 1kΩ multi-run trimpots, 1 × 1kΩ vertical trimpot

MISCELLANEOUS
Heatsink compound, PC stakes, screws, nuts, washers, solder.

CHASSIS PARTS
1 chassis to suit (eg, Playmaster Twin 25)
1 transformer, Ferguson PF4361/1, 70V CT
1 SPST mains toggle switch
1 .01μF/2kV ceramic or 250VAC metallised dielectric capacitor
1 3-way insulated terminal block
1 solder lug
1 1A fuse and fuseholder
1 mains cord, plug and cord clamp





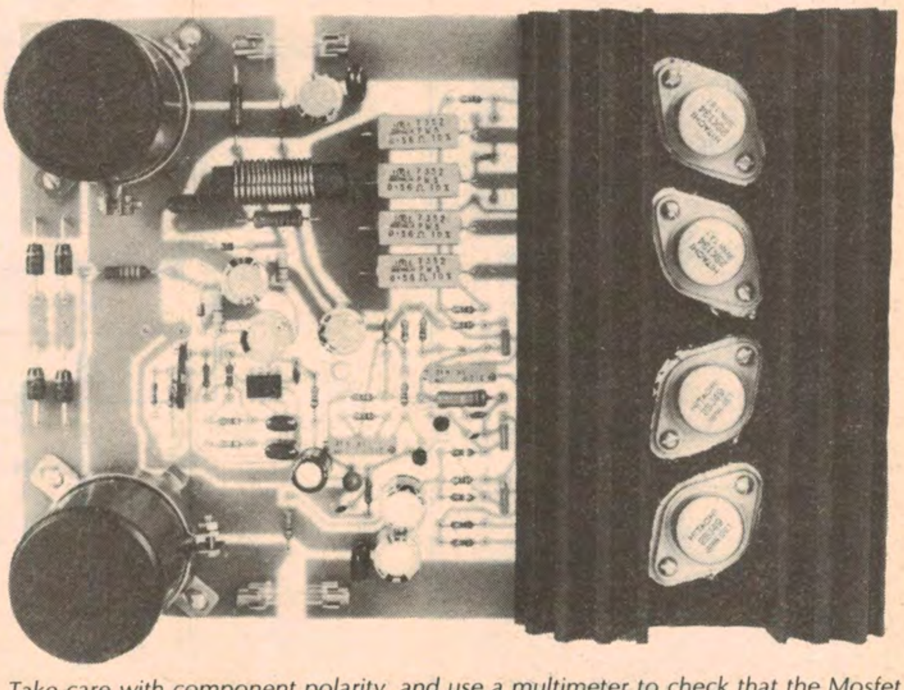
WARNING: Make certain that the polarity of the 8000uF capacitors is correct when they are installed.

rails would have to be increased to about ±65V. This would mean a considerable increase in the standing heat dissipation of the circuit which would require a far more robust heatsink to be used.

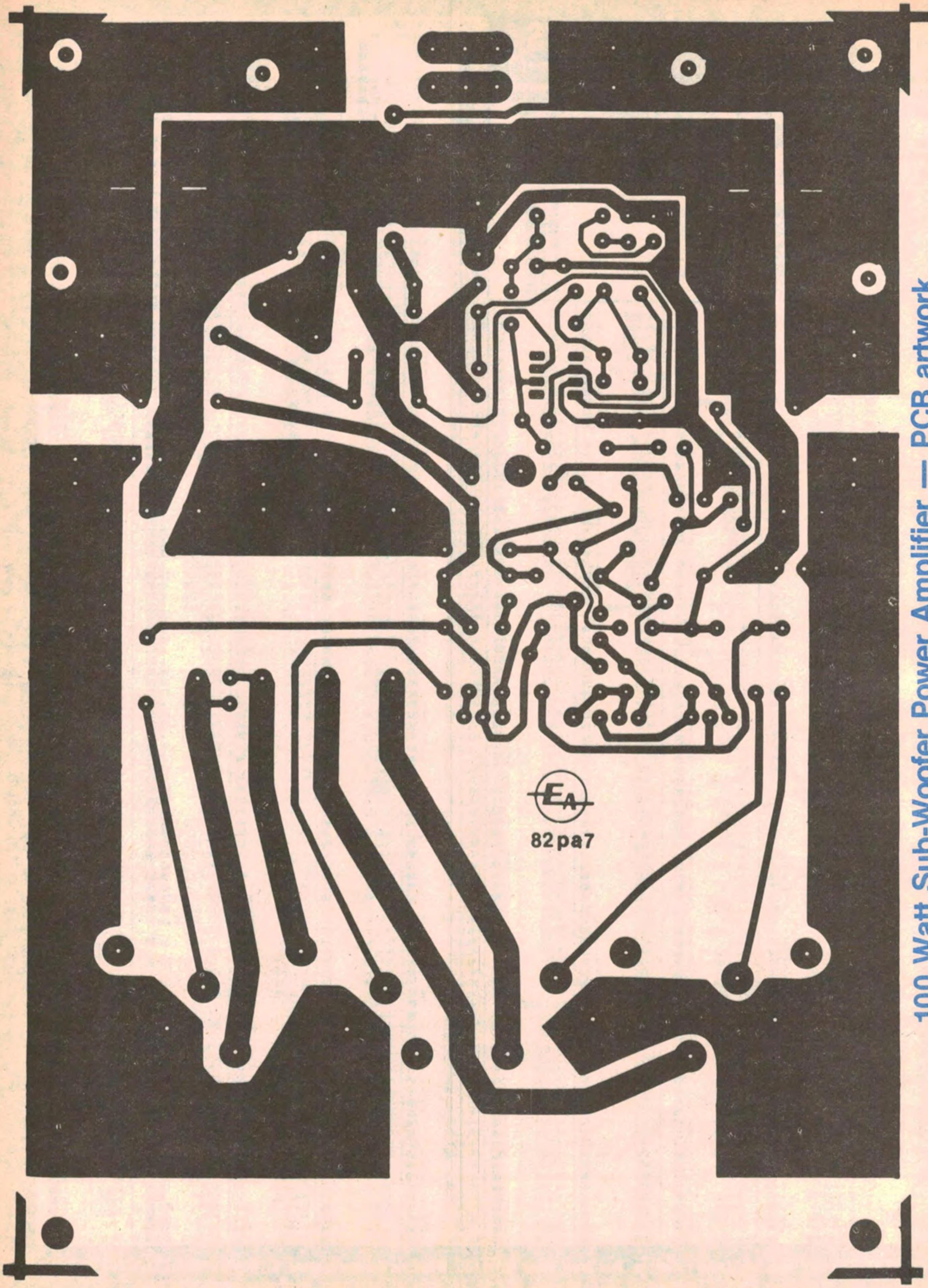
With a 4-ohm load, the amplifier delivers slightly more than 100 watts RMS before the onset of clipping, as shown by the steep rise in the intermodulation figures at around this value. (The harmonic distortion curve for power into a 4Ω load is very similar to the IM curve and so has been omitted for simplicity.) Again, under normal program conditions, the module will deliver up to 120 watts RMS, depending on the heatsink temperature.

Construction

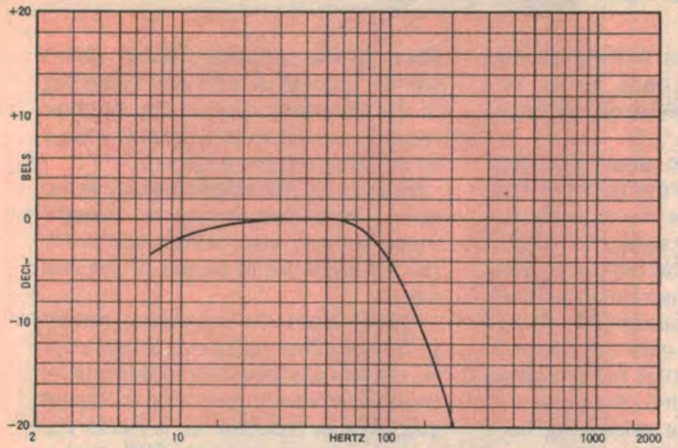
While this module may appear delightfully simple to look at and easy to build, which it is, the construction procedure we suggest must be followed in order to ensure that the unit works and works well. The printed circuit board is critical to the success of the design and its layout is arranged to avoid any in-



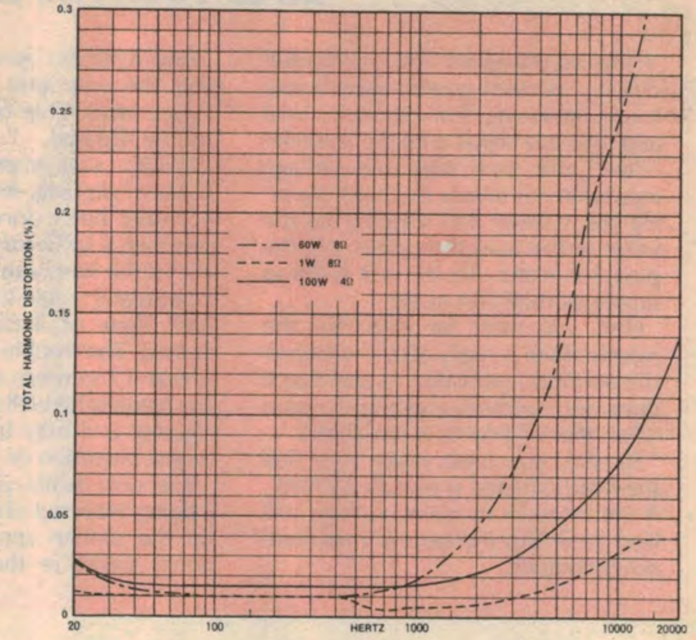
Take care with component polarity, and use a multimeter to check that the Mosfet power transistors are isolated from the heatsink.



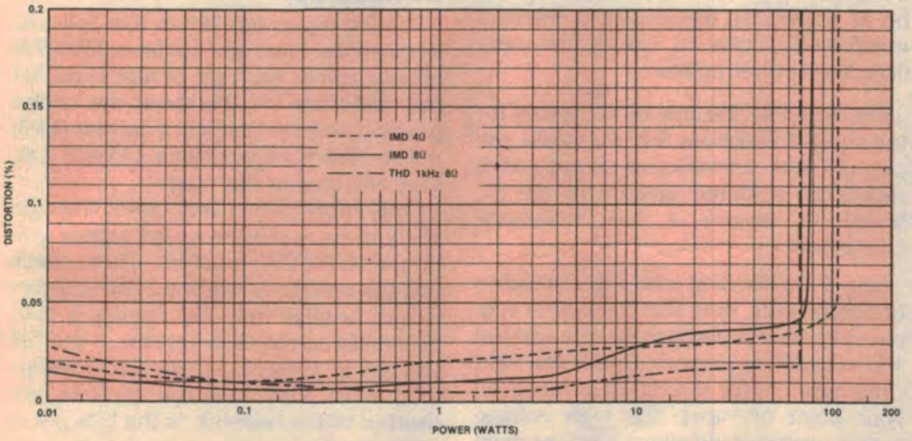
100 Watt Sub-Woofer Power Amplifier — PCB artwork



Above is the frequency response curve of the low pass filter stage, while at right are the distortion versus frequency curves for the power amplifier stage.



Below: power output versus distortion for the power amplifier stage. Maximum output is 70W RMS continuous into 8 ohms.



teraction between output and input currents.

All the amplifier circuitry, including the power supply components, is accommodated on a large PC board measuring 228 × 170mm and coded 82pa7. This also accommodates the heatsink for the four Mosfet transistors. The single-sided heatsink is 170mm long and 105mm long and is adequate for typical program material peaking at full power.

If you intended using the amplifier module in a more rigorous application such as for stage use, a much bigger heatsink or fan cooling will have to be employed.

Multi-turn trimpots are provided for adjustment of quiescent current and output offset voltage. We have not made provision for single turn trimpots in these positions as they are considerably more difficult to adjust.

We assume that kitset suppliers will provide drilled heatsinks but if they do not, you should use the copper pattern of the PCB as a template for marking the heatsink hole positions.

Make sure that the heatsink is completely deburred before mounting it and the output transistors on the PC board. Follow the drawing of the heatsink assembly cross-section to assemble the insulating washers and bushes. The bushes surrounding the mounting bolts are standard mounting bushes with the integral washer removed (with a razor blade). These washers are used later so do not throw them away.

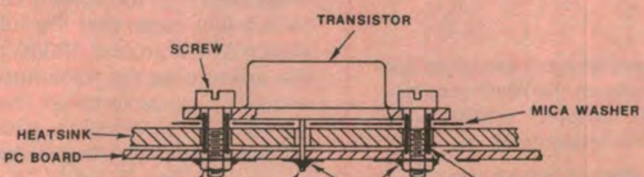
With a smear of heatsink compound on each side of the mica washer, assemble each transistor onto the heatsink and PC board, tighten up the screws and solder the nuts to the copper. It is a good idea not to solder the source and drain leads yet, just in case the insulation is faulty and the Mosfet has to be removed.

Check the insulation of each Mosfet from the source (case) to heatsink with an ohmmeter 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 the Mosfets after the heatsink compound has time to spread under pressure and recheck the insulation.

With those checks complete, solder the drain and gate leads of the Mosfets and then proceed with assembling the other smaller components onto the PC board.

When mounting the 5W resistors, solder them with at least 1mm spacing above the PCB to allow cooling and to avoid their charring the board. Take care in orienting the polarity-conscious com-

Power Mosfet mounting method



DOES YOUR AMPLIFIER GIVE 100W?

How do you verify that an amplifier delivers its rated power? Superficially it is quite simple. Just connect a load and feed in a signal until the amplifier "clips" and then take the voltage measurement across the load. Squaring the voltage and dividing by the value of the load then gives you the power in watts. Ah, but is it really as simple as that? Not at all!

First, you must be sure that the resistive load is really 8Ω (or whatever the nominal load value is) and that it does not overheat and rise in value when the full power is dissipated.

Second, you must make sure that the mains voltage is exactly 240VAC. A 5% increase in mains voltage will lead to a 10% increase in maximum power output.

And it almost goes without saying that the voltmeter must be as accurate as possible because any error will be squared.

Thirdly, you must determine the onset of clipping. In the past this has normally been done by visually inspecting a CRO for signs of "flattening" of the sinewave at the peaks. The input signal would then be backed off until signs of flattening just disappeared. The trouble with this method is that it can mean that the amplifier can actually be well into the region of clipping and may be producing harmonic distortion of 1% or 2%

The only really consistent way of judging the onset of clipping is to look for the sudden appearance of additional spikes in the distortion products of the amplifier. These spikes will be consistent with any flattening of the sinewave output. The method requires access to a distortion bridge or audio spectrum analyser.

By ignoring the methodology listed above and just taking a "rough" measurement, your results can easily be 20% or more in excess of the real value.

Finally, does the maximum power of the amplifier reduce as it heats up? As explained elsewhere in this article, the "onset of clipping" for a Mosfet amplifier is reduced as it heats up, due to reducing transconductance. This effect is quite significant and can easily reduce the power output by more than 10% (after taking all the above effects into account).

ponents such as the diodes, transistors and electrolytic capacitors.

Wind the 14μH choke to the specification in the parts list and clean the ends of the winding before tinning and soldering the unit to the PC board.

Make sure the holes for the 8000μF capacitors are correctly positioned and of the right size. The bracket for the negative supply capacitor must be rotated to fit the board mounting holes. Make sure that polarity is correct as you install these capacitors as it is not possible to check once the capacitors are in place. If you apply reverse voltage to large capacitors such as these they will be wrecked and will spray nasty vapour all over the place!

The securing screws for the capacitor mounting brackets must be isolated from the PC pattern otherwise they will be at ±50V. Use the insulating washers mentioned above to isolate the nuts from the copper pattern.

Finally, while the use of PC stakes for the input connections is permissable, the output and transformer connections should be soldered directly to the PC board to ensure a low resistance connection.

Before proceeding with the discussion of adjustments, note that the power supply voltages are dangerous, as a total of 100 volts DC is present. Under the right circumstances (or wrong, depending on your point of view), this high voltage power supply could give a nasty or even lethal shock. So be very careful and treat this module with the respect it deserves.

Setting up

The setting up procedure is as follows: Remove the fuses and solder a 220Ω/5W resistor across each set of fuse clips. Set the offset pot VR2 to about the centre position and the quiescent current (VR3) pot to minimum resistance. Do not connect any load at this stage.

Now apply power and check that the ±50V rails are present on the supply side of the 220Ω/5W resistors. Then check that the voltage across the 220Ω resistors is zero or quite low. The reading should be similar across each resistor. If the full voltage is present across the fuseclips then it is likely that the Mosfets are shorted to the heatsink or the bias pot is open-circuit.

Now adjust the bias trimpot (VR3) to obtain 13 volts across each 220Ω resistor. This coincides to a total of 60mA quiescent current in the output stage or 30mA for each Mosfet. If you have a digital multimeter you can check that each Mosfet is sharing the quiescent current equally by checking the voltage across each 0.56Ω/5W resistor. It should be about 17mV.

Adjust the offset trimpot for zero voltage at the amplifier output. This can more easily be done with a digital multimeter but if you do not have one you can first do a coarse check with your multimeter on its lowest voltage range. Then switch to the lowest current range (which will mean that the full scale sensitivity is now around 100mV) and repeat the adjustment for minimum voltage. It should be possible to set the voltage to be less than or equal to ±20mV.

Next month we will give details of how to mount the module in a suitable chassis and team it with a sub-woofer enclosure.