Studio 350 Pow Amplifier Modu

Want an audio power amplifier with some real grunt? Want an audio power amplifier which is really quiet and has very low distortion? Here is the one answer for both desires. The Studio 350 is a rugged power amplifier module capable of delivering 200 RMS watts into an 8-ohm load and 350 watts RMS into a 4-ohm load, at very low distortion.

Pt.1: By LEO SIMPSON & PETER SMITH

OUR first approach on designing this amp was to decide on the target power output, given a likely supply rail. We decided to aim for 200 watts into an 8-ohm load. A few back-of-an-envelope calculations showed that we would need supply rails of about ±70V or a total of 140V.

Naturally, we would also want to drive 4-ohms loads and with those same supply rails we would expect to obtain around 350 watts. But how many output transistors and what type would be required? As you can see from the photos and circuit, we have used eight 250V 200W plastic power transistors: four MJL21193/4 complementary pairs. These are teamed with the high-performance MJL15030/31 complementary driver transistors.

In addition, we have used some high-voltage low-noise transistors in the input stage and highly linear high-voltage video transistors in the voltage amplifier stage. The net result is a rugged power amplifier with very low residual noise and distortion.

Load lines and power ratings

So why did we end up using eight 200W transistors in order to get just 200W into 8Ω and 350W into 4Ω? It might seem like over-kill but it is not. To work out the dissipation in a transistor, you need to draw the load lines. These show power dissipation in the active device (in this case, one half of the output stage, consisting of four transistors). The vertical axis is in Amps while the horizontal axis is Volts. The various load lines for our amplifier are shown in Fig.1.

For a start, we plotted the lines for 8-ohm and 4-ohm resistive loads and these are straight lines, showing all possible conditions. The two resistive lines start at the 70V mark on the horizontal axis, corresponding to the supply voltage applied across one half of the output stage (either the NPN or the PNP transistors). For the 4Ω load, the load line runs up to 17·5A on the vertical axis, corresponding to the current delivered if the active device was fully turned on (ie, 70V/4Ω = 17·5A).

Similarly, for an 8Ω load, the load line runs up to 8·75A on the vertical axis (ie, 70V/8Ω = 8·75A). These load lines show the instantaneous power dissipation at any possible signal condition (including an output short circuit).

Also shown on the diagram are two hyperbolas. One represents the maximum safe power (for one second!) dissipation of four parallel-connected MJL21193/94 transistors. Depending on the instantaneous voltage across the transistors, this can be more than 900W for low voltages, reducing to 720W at 80V, and ultimately to just 400W at 250V (not shown on the curve). This hyperbola represents the maximum dissipation the four

transistors can withstand under a non-repetitive one-second pulse, the so-called Safe Operating Area (SOA).

Since the resistive load lines are well below the one-second SOA hyperbola, you may think that the transistors are operating far below their maximum ratings and so they would be, if all they had to drive was resistive loads. Sadly, loudspeakers are not resistive; they can be resistive, inductive or capacitive, depending on the signal frequency. Usually they are inductive which means the load current lags the load voltage.

This has two effects. First, the voltage across the output transistors can go much higher than the half-supply value of 70V. Conceivably, it can run to the full supply voltage of 140V (or beyond, if driven into clipping on an inductive load). Second, the instantaneous power dissipation across the power transistors can go far in excess of that shown for a resistive load line.

To show this effect, we have drawn 8Ω and 4Ω reactive load lines which represent speakers with complex impedances of 5·6Ω + j5·6Ω and 2·83Ω + j2·83Ω, respectively. In the 8Ω case, the 5·6Ω represents the voice coil resistance while the j5·6Ω is the coil inductance. The resulting curved load lines extend well beyond 70V (to almost 110V) and also show instantaneous dissipation figures far in excess of that for the resistive load lines. In fact, you can see that in the case of the 4Ω reactive case, there is far less power margin to spare.

We have also drawn the de-rated power hyperbola (50°C) for four transistors on Fig.1 and as you can see, it touches the 4Ω reactive curve. Does this mean there is a problem? Well no, because the load lines show instantaneous power dissipation, not average or total power dissipation. As long as the load lines are below the SOA curve, everything is OK.

All of the foregoing is a shortened explanation of the process whereby we decided to use eight transistors. It shows that eight is a good conservative figure whereas six of these transistors would not be enough.

Finally, before we leave the discussion on load lines, we need to mention short circuit and overload protection. Apart from fuses, this amplifier circuit has no protection. We could have chosen to run with six power transistors if we had incorporated "load line" protection into the circuit. This uses a pair of transistors to monitor the output transistor voltage and current conditions and then limit the base drive signal when the load line is exceeded.

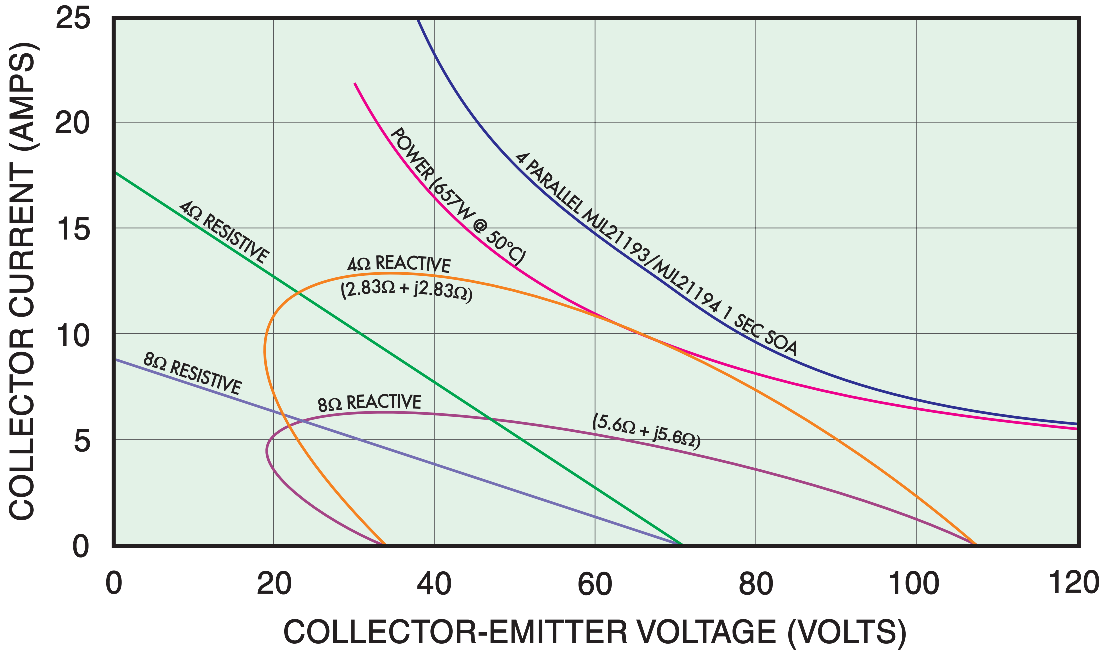


Fig.1: this diagram shows the resistive and reactive load lines for both 4Ω and 8Ω loads. Also shown are two hyperbolas. The blue curve shows the maximum safe operating area of four parallel-connected MJL21193/MJL21194 transistors, while the red curve shows the derated power curve for 50°C case temperature.

Such circuits can work quite well to protect the output stage but in practice their rapid switching action causes a burst of high frequency oscillation to be superimposed on the output signal. This means that not only do you get horrible distortion but the amplitude of the burst can be enough to overload and burn out tweeters if the overdrive situation persists.

Therefore, while we regard load line protection as important for PA amplifiers (which can easily have their output leads shorted), it is not desirable for a hifi amplifier. If you do short the outputs of this amplifier when it is under full drive, there will be a big spark and hopefully the only thing to be damaged will be the 5A fuses. If the fuses were increased in rating, the amplifier could ostensibly drive a 2Ω resistive load without damage, so we think the 5A fuses should provide adequate short circuit protection. Oh, but we don't recommend driving a 2Ω load!

Amplifier module

Two versions of this amplifier module are possible, both using the same PC board pattern. The one presented here employs a cast aluminium heatsink with an integral shelf which is convenient for mounting the power transistors. This heatsink is 300mm wide and the PC board itself is 240 × 136mm so the overall assembly is quite large.

The alternative approach is to mount the output transistors vertically on a single-sided or fan heatsink, in which case the PC board could be trimmed to 240mm wide by 100mm deep. This latter approach takes up less chassis space. Both approaches will be described in the constructional details to be presented next month.

Performance

As already noted, the Studio 350 delivers up to 200W RMS into an 8-ohm load and up to 350W into a 4-ohm load. Music power figures are substantially higher, around 240W into an 8-ohm load and 480W into a 4-ohm load. These figures apply only for the suggested power supply, which we will come to later.

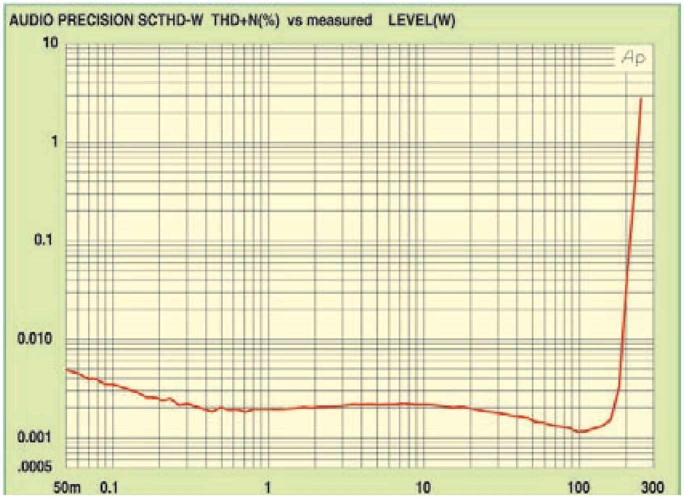


Fig.2: total harmonic distortion versus power at 1kHz into an 8-ohm load (10Hz-22kHz measurement bandwidth).

Fig.3: total harmonic distortion versus power at 1kHz into a 4-ohm load (10Hz-22kHz measurement bandwidth).

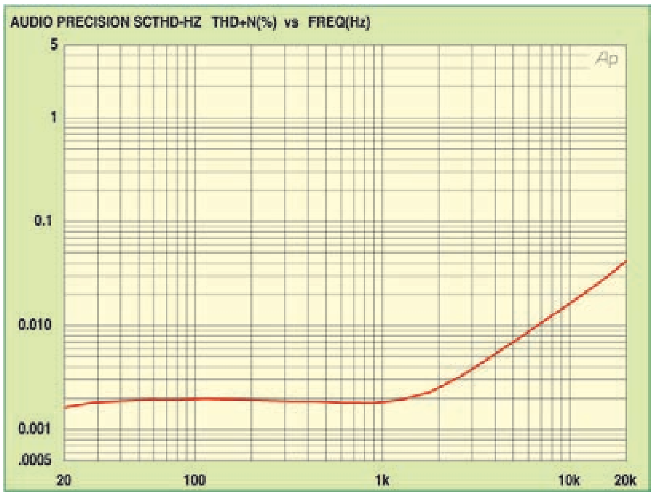


Fig.4: harmonic distortion versus frequency at 160W into an 8-ohm load (22Hz-80kHz measurement bandwidth).

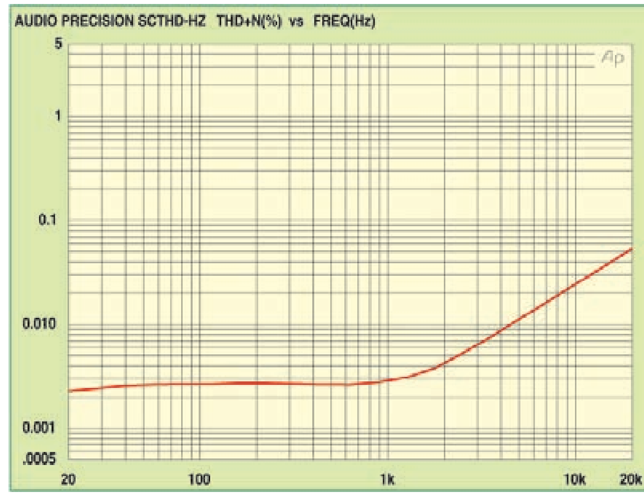


Fig.5: distortion versus frequency at 250W into a 4-ohm load (22Hz-80kHz measurement bandwidth).

Fig.2 shows the total harmonic distortion versus power at 1kHz into an 8-ohm load while Fig.3 shows distortion versus power at 1kHz into a 4-ohm load. As you can see, for an 8-ohm load, distortion is around 0·002% or less up to about 180W, rising to around 0·03% or thereabouts at 200W. At low powers, below 0·5W, the distortion figure rises but that is due to residual noise, not distortion. In reality, at low powers the distortion is well below 0·001%.

Similarly, for a 4-ohm load, distortion is around 0·0045% or less for powers up to around 280W, rising to 0·1% at around 350W. These figures were taken with a measurement bandwidth of 22Hz to 22kHz.

Fig.4 shows harmonic distortion versus frequency at 160W into an 8-ohm load while Fig.5 shows distortion versus frequency at 250W into a 4-ohm load. Both these curves were taken with a measurement bandwidth of 22Hz to 80kHz.

All of these distortion curves show a performance which is outstanding. This amplifier is also extremely quiet: –122dB unweighted (22Hz to 22kHz) or –125dB A-weighted. This is far quieter than any CD player!

Fig.6 shows the frequency response at 1W into 8Ω. It is 1dB down at 15Hz and 60kHz.

Circuit description

The full circuit is shown in Fig.7 and employs 17 transistors and five diodes.

The input signal is coupled via a 1µF bipolar capacitor and a 2·2kΩ resistor to the base of Q2. Q2 and Q3 are a differential pair using Hitachi 2SA1084 low-noise transistors which have a collector-emitter voltage rating of 90V, necessary because we are using 70V rails. Transistor Q1 and diodes D1 & D2 make up a constant current source running at about 1mA to set the current through the differential pair at 0·5mA each.

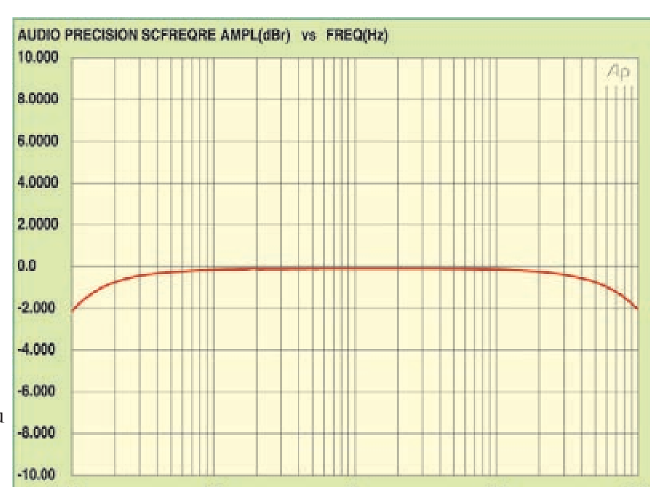
Trimpot VR1 in the emitter circuit to the differential pair is provided to adjust the offset voltage and thereby trim the output DC voltage very close to 0V (within a millivolt or so). This is largely academic if you are driving normal 4-ohm or 8-ohm loudspeakers but is particularly desirable if you intend driving electrostatic speakers which usually have a high voltage step-up transformer with very low primary resistance.

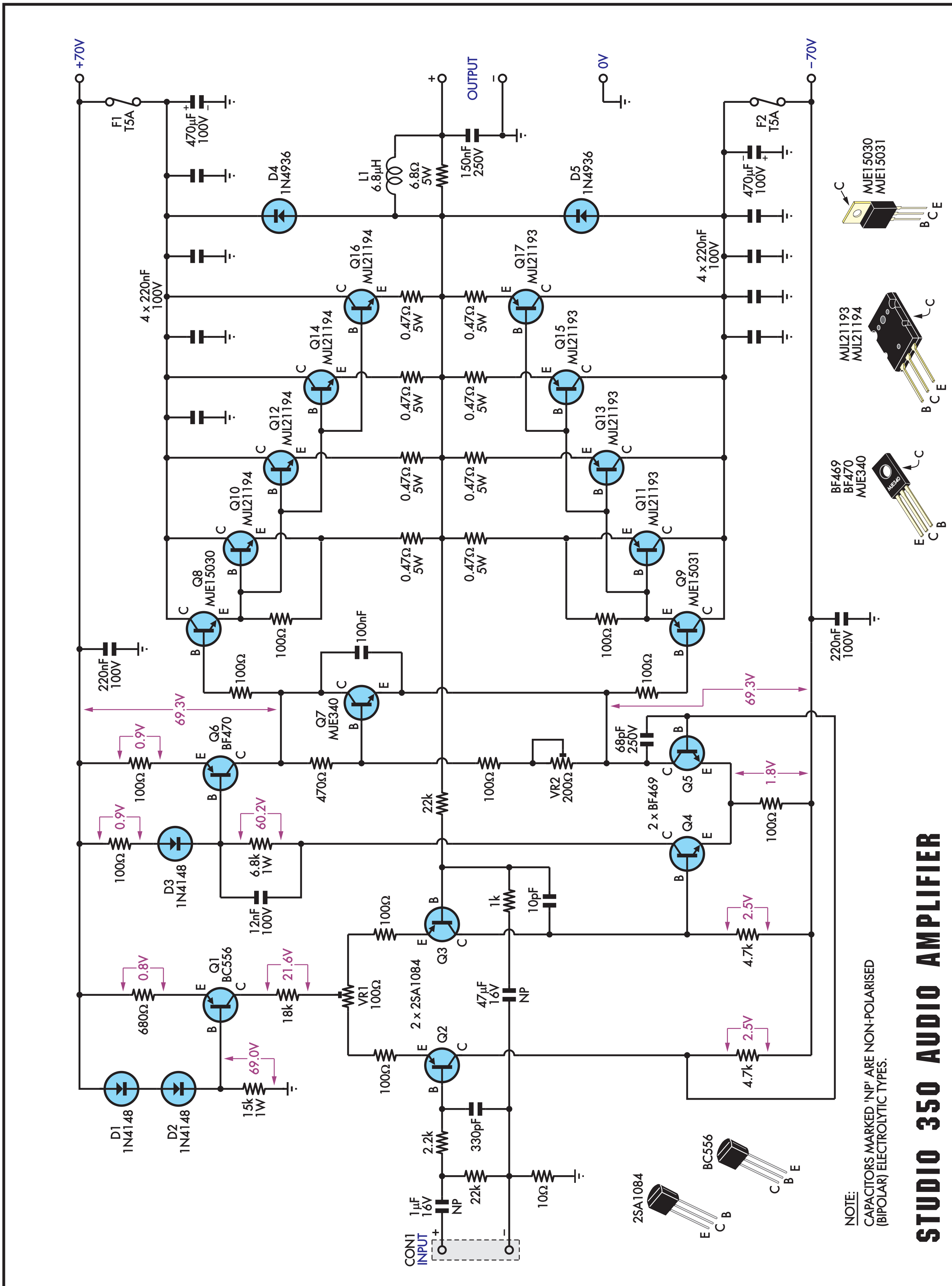
The same comment applies if the amplifier is used to drive 100V line transformers. Just to explain that, if you have a transformer primary resistance of 0·1Ω and a DC output offset from the amplifier of just 20mV, the resulting current through the transformer will be 200mA! Not only will this magnetise the core and degrade the transformer's performance, it will also result in additional power dissipation of 14W in one half of the amplifier's output stage. This is not good! Hence, trimpot VR1 has been included.

Signals from Q2 & Q3 drive another differential pair, Q4 & Q5, which have a "current mirror" as their collector loads. The current mirror comprises diode D3 and Q6, essentially a variation of a constant current load, which ensures high linearity in Q5. Q4, Q5 and Q6 are BF469 and BF470 types which are high-voltage (250V) video transistors, selected for their excellent linearity and wide bandwidth (F_t is 60MHz).

Q7 is a "V_{be}-multiplier", so-called because it multiplies the voltage

Fig.6: this graph shows the frequency response at 1W into 8Ω. It is just 1dB down at 15Hz and 60kHz and is virtually flat between those frequencies.





STUDIO 350 AUDIO AMPLIFIER

Fig.7: the circuit uses eight high-quality audio output transistors to give a rugged design with low distortion. The voltage readings on the circuit were taken with no input signal.

Performance

Output Power	200W RMS into 8Ω; 350W RMS into 4Ω
Music Power	240W into 8Ω; 480W into 4Ω
Frequency Response	-1dB at 15Hz and 60kHz at 1W (see Fig.6)
Input Sensitivity	1·75V for 200W into 8Ω
Harmonic Distortion	Typically 0·002% at normal listening levels (see graphs)
Signal-to-Noise Ratio	-122dB unweighted (22Hz to 22kHz); -125dB A-weighted, both with respect to 200W into 8Ω
Damping Factor	75 at 10kHz, with respect to 8Ω
Protection	5A supply fuses (see text)
Stability	Unconditional

between its base/emitter to provide a floating voltage reference to bias the output stage and set the quiescent current. Quiescent current is needed in all class-B amplifiers, to minimise crossover distortion. In fact, this amplifier displays no trace of crossover distortion.

We use an MJE340 transistor for Q7 even though a small signal transistor could easily handle the task. The reason for using a power transistor is that its package and junction does a better job of tracking the temperature dependent changes in the junctions of the output power transistors and thereby gives better overall quiescent current control.

The driver transistors are the high performance MJE15030 and MJE15031 made by On Semiconductor (previously Motorola). These have a minimum current gain-bandwidth product (F_t) of 30MHz. These drive the paralleled output stage MJL21193/94 transistors which themselves have a typical F_t of around 6MHz.

Each of the power transistors in the output stage has a 5W wirewound emitter resistor of 0·47Ω. This relatively high value has the disadvantage that it causes a slight reduction in power output but this has been done to provide improved current sharing between the output transistors – an important factor in a high-power design.

Although not shown in the photographs, one of our prototypes used non-inductive wirewound emitter resistors. These have been recommended in some past designs in magazines, in order to minimise secondary crossover distortion effects. Our tests showed no benefit in this design (probably because of the PC board layout) and so they are not specified – ordinary wirewound emitter resistors are OK in this design.

Two 1N4936 fast recovery diodes are reverse-connected across the output stage transistors. Normally, these do nothing but if the amplifier is driven into clipping when driving highly inductive speakers or transformers, the diodes safely clamp the resulting back-EMF spikes to the supply rails.

Negative feedback

Overall negative feedback is applied from the output stage via the 22kΩ resistor to the base of Q3. The voltage gain is set by the ratio of the 22kΩ resistor to the 1kΩ resistor also connected to the base of Q3. This gives a voltage gain of 23 (+27dB). The 47µF bipolar capacitor in series with the 1kΩ resistor sets the −3dB point of the frequency response to about 3Hz. The other factor in the amplifier's low frequency response is the 1µF bipolar input capacitor.

We have used non-polarised (NP) capacitors for the input and feedback coupling instead of conventional electrolytic capacitors because the low voltages present in this part of the circuit are insufficient to polarise conventional electrolytics. Incidentally, some readers may disagree with our choice of electrolytics in the signal path but the alternative of plastic dielectric capacitors is not very attractive; they are large and expensive and unavailable, in the case of 47µF. Nor do we think that electrolytic capacitors, properly used, are the cause of high distortion

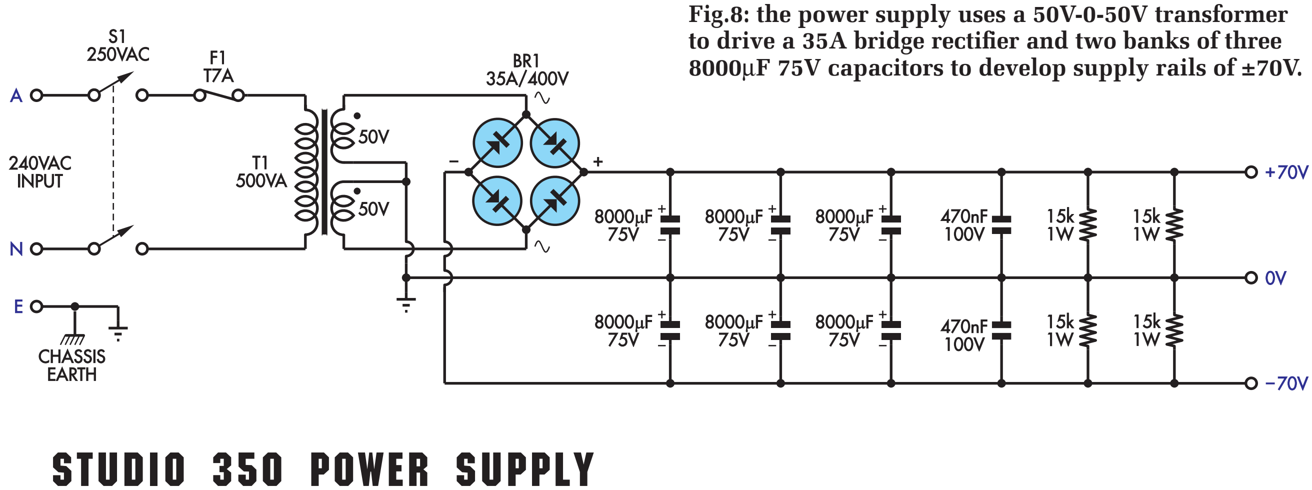
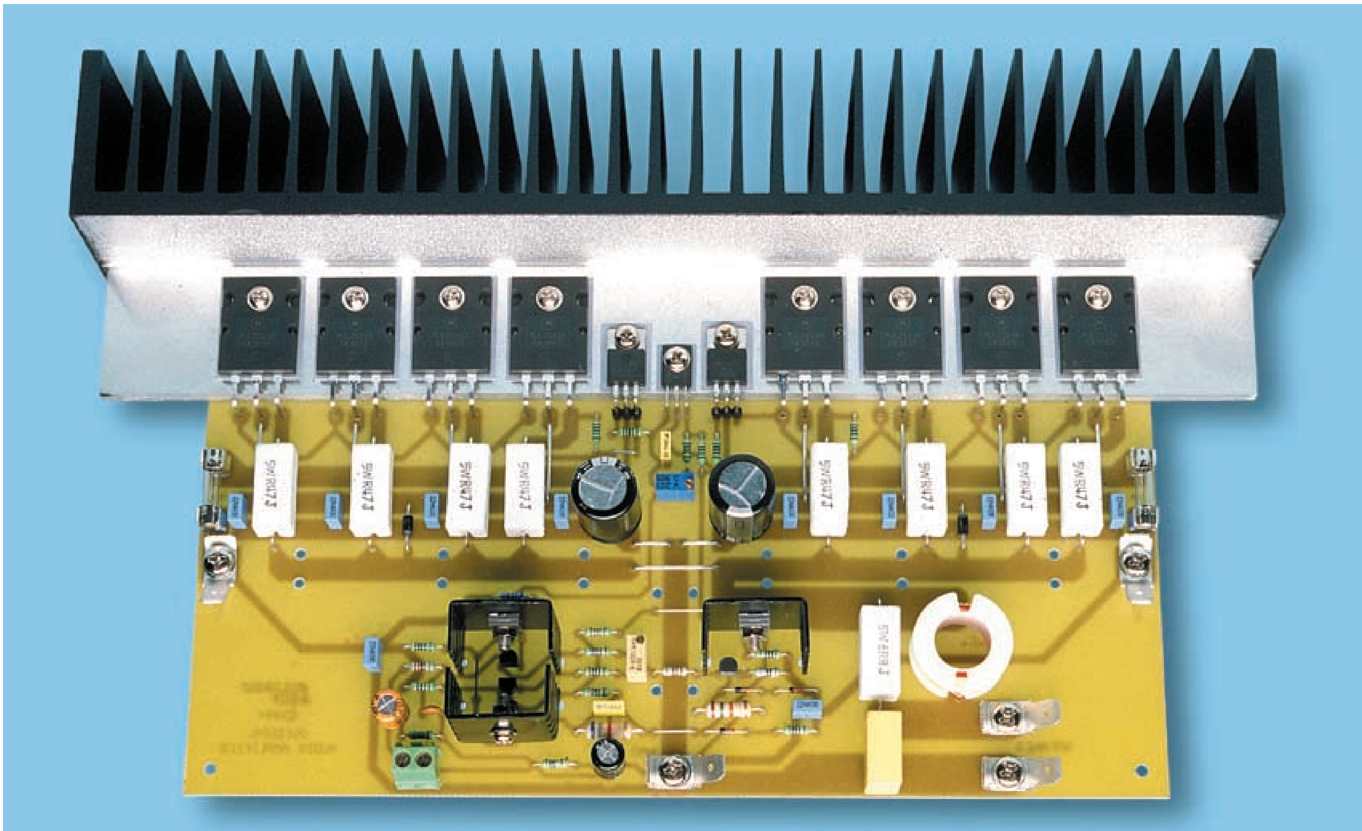


Fig.8: the power supply uses a 50V-0-50V transformer to drive a 35A bridge rectifier and two banks of three 8000µF 75V capacitors to develop supply rails of ±70V.



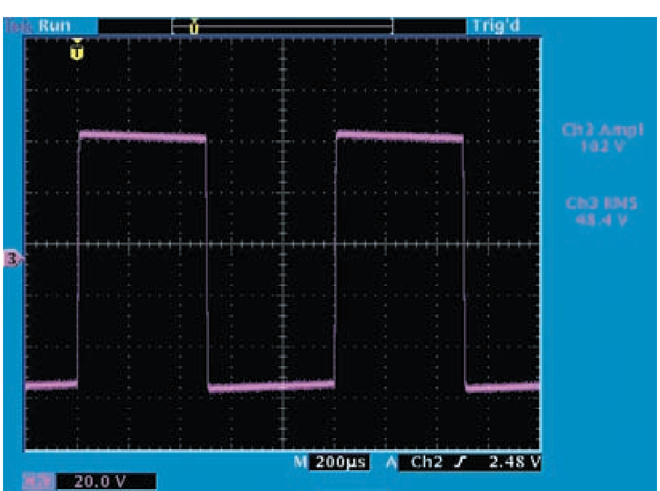
This view shows the fully completed audio amplifier module. The construction details are in next month's issue.

in audio circuits; there's no evidence of it in the case of this circuit.

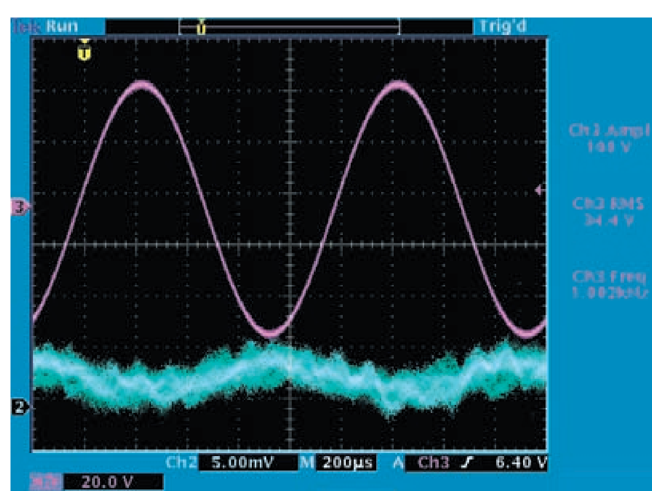
The 330pF shunt capacitor and 2·2kΩ resistor in series with the input signal constitute an RC low-pass filter, rolling off the high frequencies above 200kHz. The 68pF capacitor between Q5's base and collector rolls off the open loop gain to ensure stability with feedback applied.

Note that this capacitor can be ceramic or polystyrene but must have a rating of at least 250V. This is because the signal at this part of the circuit can be as high as 45V RMS (127V peak-to-peak). Other capacitor types (such as monolithics) are definitely not recommended.

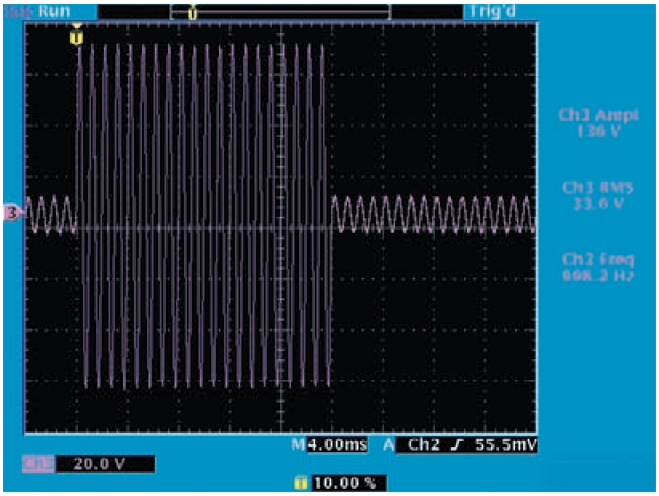
The output signal to the loudspeaker is fed via an RLC filter consisting of a 6·8µH choke, a 6·8Ω wirewound resistor and a 150nF 250V capacitor. This very well-proven filter network was originally developed by Neville Thiele and published in the September 1975 issue of the *Proceedings of the IREE*. The filter has two benefits: ensuring stability of the amplifier with reactive loads and as an attenuator of RF and mains-interference signals which are



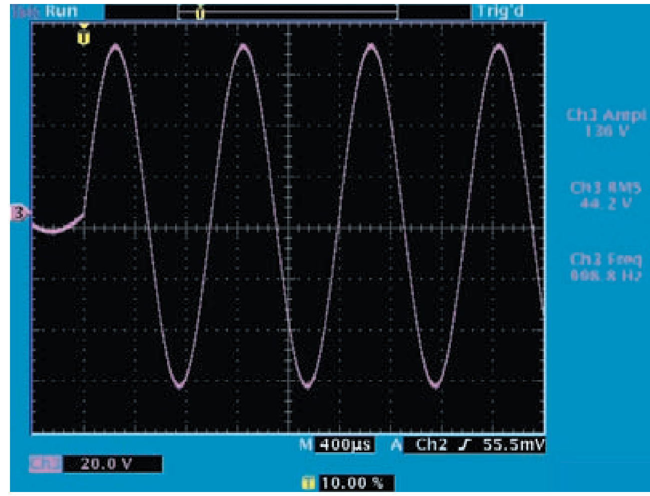
Scope1: this waveform shows the excellent square wave response of the amplifier, taken at 1kHz and 102V p-p into 8Ω. This equates to a power output of about 300W RMS.



Scope2: these waveforms show a 150W sinewave at 1kHz and the resulting total harmonic distortion waveform (ie, noise and distortion) which is at about 0·0015%.



Scope3: this is the pulse waveform used to measure music power. Note the excellent stability of the amplifier, particularly the recovery after the pulse.



Scope4: the same waveform as in Scope3, but with the scope switched to a faster timebase. In this case, the amplifier is delivering over 240W RMS into an 8-ohm load.

inevitably picked up by long loudspeaker leads.

Power supply

Fig.8 shows the power supply and as you can see, we've "gone for broke" on this one. It's a vital part of the performance package and unfortunately, with all those big electrolytic capacitors, is likely to be more expensive than the amp module itself. The consolation is that the same power supply could be used for a stereo version with two amplifier modules, provided the power transformer was uprated.

The 500VA transformer used has two 50V windings which are connected together to form a centre tap. This transformer drives a 35A bridge rectifier and two banks of three 8000µF 75V capacitors to develop ±70V supply rails. The 470nF capacitors are used to provide high frequency bypassing, while the 15kΩ 1W resistors are used as "bleeders" across the electrolytic capacitors.

PC board topology

Finally, the PC board has been laid out using distortion-cancelling topology. It also has "star" earthing whereby all earth currents come back to a single point on the board. This careful separation of output, supply and bypass currents avoids any interference with the signal currents and the distortion that this could cause.

As far as the "distortion cancelling" technique is concerned, this involves laying the copper tracks so that the magnetic fields produced by the asymmetric currents in the output stage are cancelled out, as far as possible. These asymmetric currents (think of them as half-wave rectified output signals) and their resultant magnetic fields induce unwanted distortion signals into the input stage transistors Q2 and Q3.

This approach is very worthwhile and constructors will not have to worry about whether the performance of their module is as good as the prototype featured here. As long as you follow closely the wiring layout in the construction article next month, you can expect the results to be very good indeed. ***EPE***