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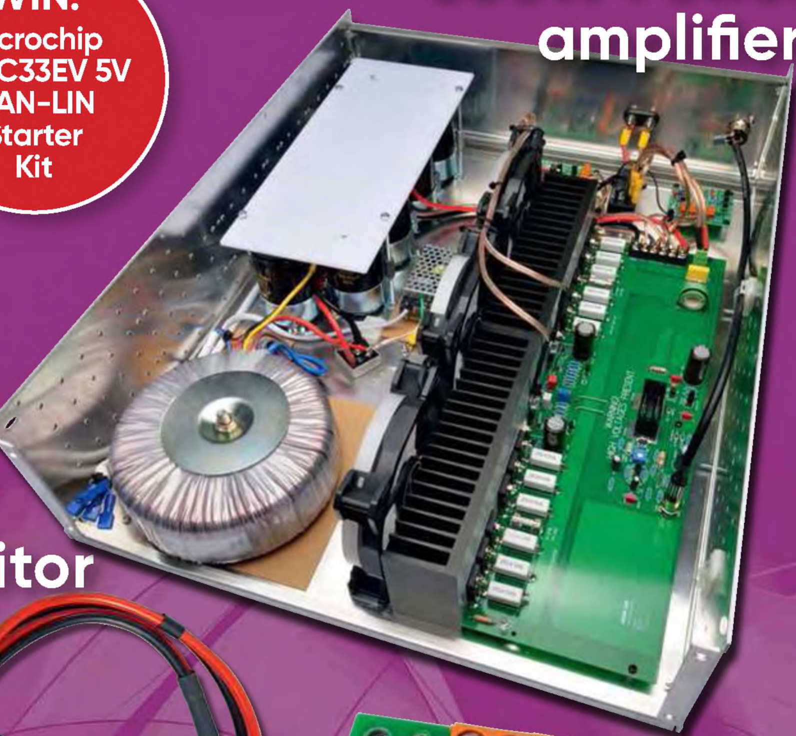

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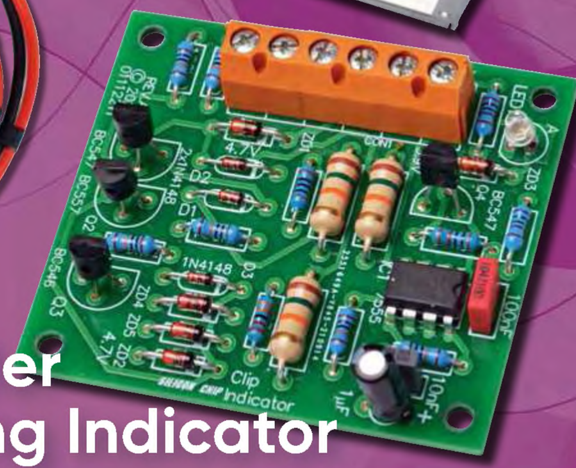

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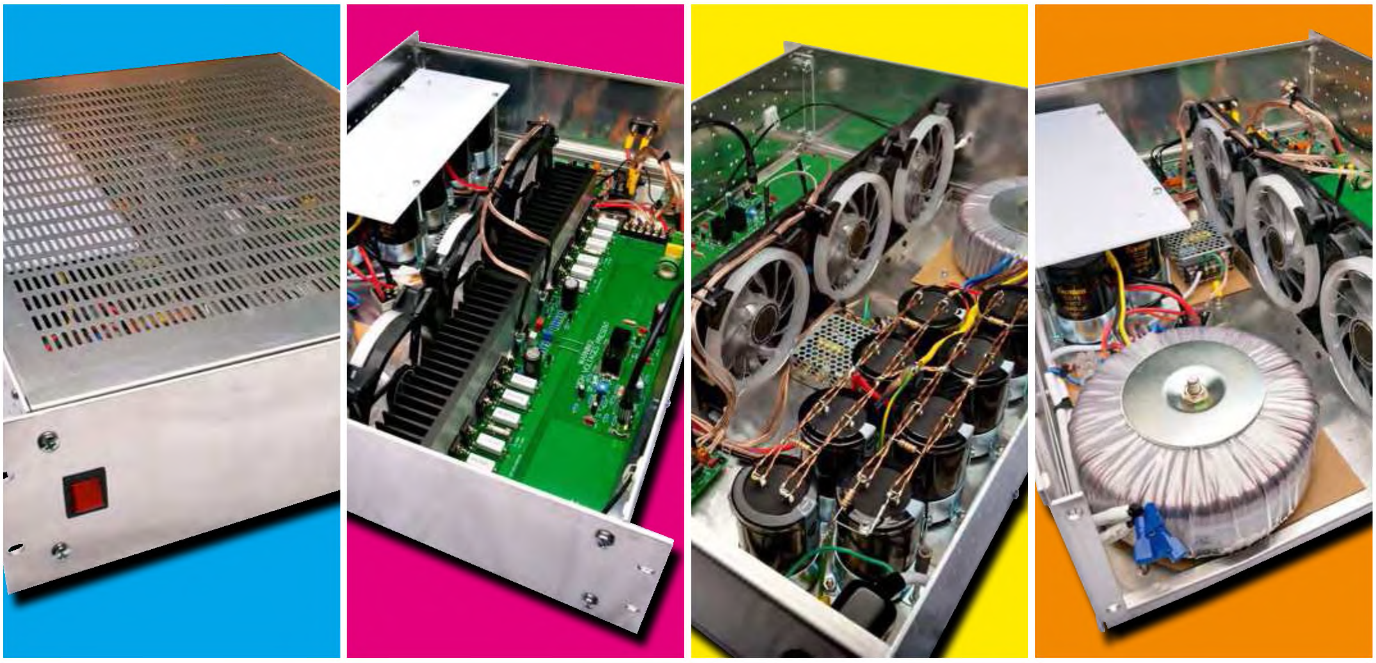
500 WATTS POWER AMPLIFIER

PART 1

BY JOHN CLARKE



This large power amplifier produces big, clear sound with low noise and distortion. It delivers 500W RMS into a 4Ω load and 270W into an 8Ω load. It has been designed to be very robust and includes load line protection for the output transistors and speed-controlled fan cooling that remains off until needed. With two of these, you could deliver 1000W into a single 8Ω loudspeaker. Good luck finding one that will handle that much power!

Features and Specifications

Output power	>500W into 4Ω, >270W into 8Ω – see Fig.3
Frequency response	+0, –0.1dB over 20Hz-20kHz (–3dB @ 97kHz) – see Fig.1
Signal-to-noise ratio	112dB with respect to 500W into 4Ω or 250W into 8Ω
Total harmonic distortion (4Ω)	<0.005% @ 1kHz for 1.5-350W – see Fig.2 and Fig. 3
Total harmonic distortion (8Ω)	<0.025% @ 1kHz for 2-270W – see Fig.2 and Fig.3
Input impedance	10kΩ || 4.7nF
Input sensitivity	1.015V RMS for 500W into 4Ω, 1.055V RMS for 270W into 8Ω
Power supply	±80V nominal from an 800VA 55-0-55V transformer
Quiescent current/power	94mA, 15W
Protection	DC fuses, dual-slope thermal tracking, SOA current limiting, output clamping diodes
Other features	output offset nulling, blown-fuse indicators, onboard power indicator

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Our 500W amplifier is big in several ways. It is physically big, requiring two heatsinks stacked end-to-end to keep the temperature under control. It requires a significant power supply using an 800VA transformer, and the amplifier and power supply fit into a three rack unit (3RU) rack case, again of rather large dimensions.

It does deliver a prodigious amount of power. It is ideal for a public address system where high power can be necessary for sound reinforcement in a large venue. It is also well-suited to driving inefficient loudspeakers. As noted above, used in bridge mode, it could deliver just over 1000W per channel. Build two pairs for a sound system so massive, it would need to be plugged into two different mains power points!

Two of these amplifiers could also be the basis of an amazing stereo system for use in a large listening room.

You might think that a 500W per channel stereo system is just too much power. Whether that is true depends on what sort of music you like listening to and how efficient your loudspeakers are. If you like rock music with its somewhat limited dynamic range, then with this amplifier, you will be able to play it loud. That makes it ideal for music that just has to be loud to be enjoyed.

But please don't deafen yourself with the extreme sound levels possible with such a large amplifier. You might also need to provide ear protection for your neighbours!

It isn't just for rockers, either. Classical music requires lots of power as well. This is not because the performance is necessarily loud, but it allows the wide dynamic range in volume of concert hall performances to be replicated.

You want high power without distortion to produce the high peak volume levels of the performance, like massive kettle drum hits or pipe organ stings, with low noise from the amplifier so that it does not drown out the whisper-quiet passages.

Big power like this does not come easily. The amplifier uses 12 output transistors and they are all mounted on a 400mm-wide heatsink. The main circuit board is also significant at 402 x 124mm. The final installation within the 3U rack enclosure measures 559mm x 432mm x 133.5mm and weighs just over 12kg.

This article will concentrate on describing the *Amplifier Module* circuit. Over the next two months, we'll also give the full assembly details for this Module, plus describe a suitable power supply. Then we'll show you how to build the Module, power supply, speed-controlled fan cooling (which switches off at light loads), speaker protector and clip detector – all into an aluminium 3RU rack-mountable chassis.

Performance

The main performance parameters are summarised in the specification panel and Fig.1 to Fig.3. These indicate that just because a power amplifier delivers a lot of power, that does not mean that it cannot deliver high performance as well.

For one, the frequency response is ruler-flat from 20Hz to 20kHz, a mere 0.1dB down in response at 20kHz. Power into 4Ω is a genuine 500W. At typical power levels, between 1.5W and 350W, the total harmonic distortion plus noise (THD+N) is below 0.007% at 1kHz.

For an 8Ω load, maximum power is around 270W until the onset of clipping, with <0.004% THD+N at 1kHz at more typical power levels from 1W to 200W. Under ideal conditions, it's close to what we'd call 'CD quality' at around 0.002% THD+N.

As you can see from Fig.2, distortion rises somewhat with frequency; in fact, it's considerably lower than quoted above at more typical audio frequency ranges for most instruments of around 100-500Hz. Above 1kHz, distortion rises modestly, although it's still relatively low even by 10kHz, above which the filters in our test equipment start attenuating the harmonics.

The THD+N result of under 0.05% for 266W into 3Ω shows that the performance of this amplifier does not degrade significantly even under harsh conditions, driving lower load impedances than you'd expect to see with most high-power 4Ω loudspeakers.

Perhaps the most important aspect of this high-power amplifier is the very good signal-to-noise ratio of 112dB. This means that you can get a very high output level, including loud transients, without an annoying background hiss the rest of the time.

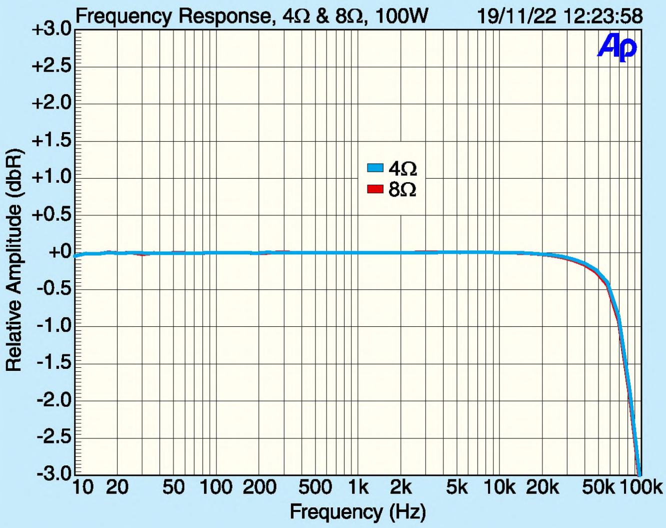


Fig.1: the frequency response of this amplifier is exceptionally flat, varying by less than 1/20dB between 20Hz and 20kHz. The upper –3dB point is just short of 100kHz. While the lower –3dB point is not visible in this plot, it's likely around 1Hz. An active subsonic pre-filter would be necessary to prevent over-extension if you're using this amp to drive a subwoofer directly.

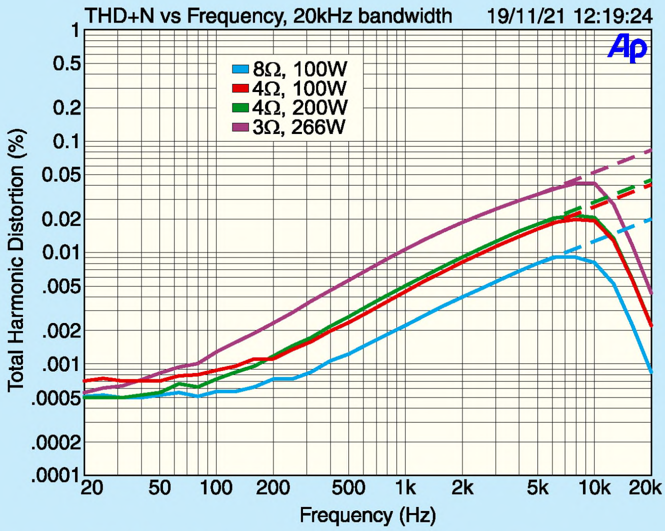
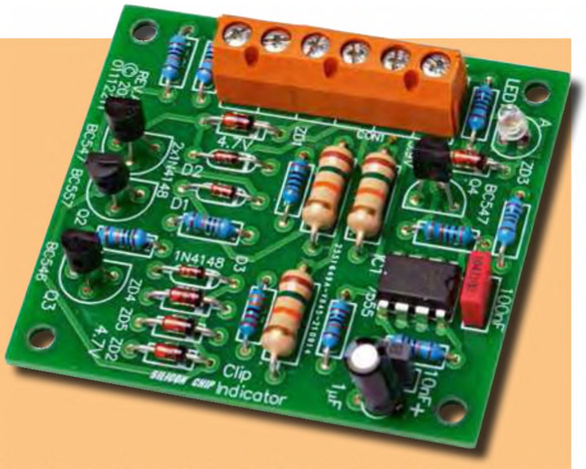


Fig.2: THD+N plots for 8W, 4W and 3W loads (two different power levels are shown for 4W) with 20Hz-22kHz bandwidth. You can see that the base distortion largely depends on the load impedance, and it rises steadily with frequency above about 100Hz. The 3W curve is mainly presented as a 'worst-case scenario' and shows that it can drive very low load impedances without too much difficulty.



Two of our other projects: the Cooling Fan and Loudspeaker Protector (February 2023) and Amplifier Clipping Indicator (this issue) are both used in the 500W Amplifier.

Circuit details

The full circuit diagram is shown in Fig.4. Aside from the large number of output transistors, the circuit is similar in configuration to many of our previous amplifiers, including the Ultra-LD Mk.2 (August and September 2010).

One major difference is the addition of safe operating area (SOA) protection for the output transistors. This helps prevent damage to them if the amplifier is short-circuited or presented with a load that exceeds their safe operating area (SOA). This is not just protection against a short circuit; it works over the entire operating range of the amplifier.

We've heard it stated in the past that SOA protection degrades the performance of an amplifier, but we tested this one with it in-circuit and disconnected, and we couldn't measure any differences. So you don't need to be concerned about its impact on sound quality.

The supply rails are ±80V or 160V in total. This high voltage requires rugged transistors, particularly the output and driver transistors, which need a large SOA. We could have used the NJL3281D/NJL3282D ThermalTrak transistors as used in previous amplifiers. However, we would have needed 12 of these transistors per side or 24 in total to ensure it was robust.

The ThermalTrak transistors have two main advantages: good linearity and each device includes a separate diode for biasing. The diode within the transistor package allows the quiescent (idle) current to be controlled accurately with temperature variations. Unfortunately, the sheer number of these transistors required would make the amplifier impractically large and expensive, so they are unsuitable.

Instead, we are using MJW21196/MJW21195 transistors, with only six required per side, thanks to their generous SOA curves.

The input signal is AC-coupled via a 47μF non-polarised electrolytic and high-frequency stopper components, ferrite bead FB1 and a 22Ω resistor to the base of transistor Q1. The 22Ω input resistor and 4.7nF capacitor constitute a low-pass filter with a –6dB/octave roll-off above 1.5MHz.

Q1 is part of the input differential pair of Q1 and Q2, which are Toshiba 2SA1312 PNP low-noise transistors.

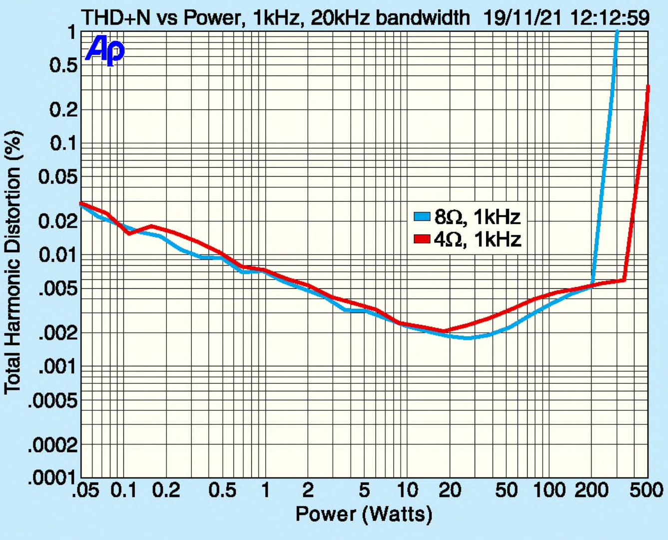
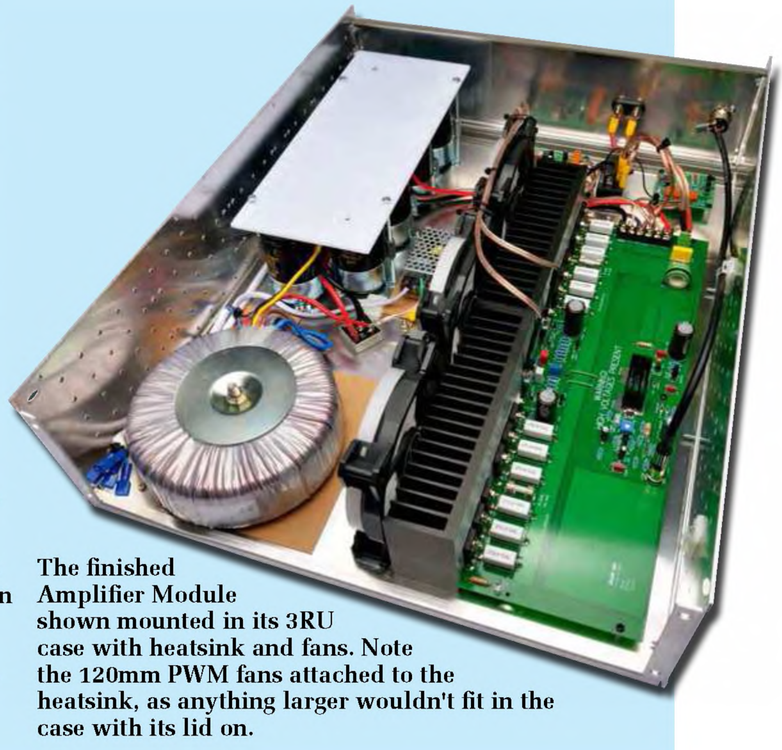
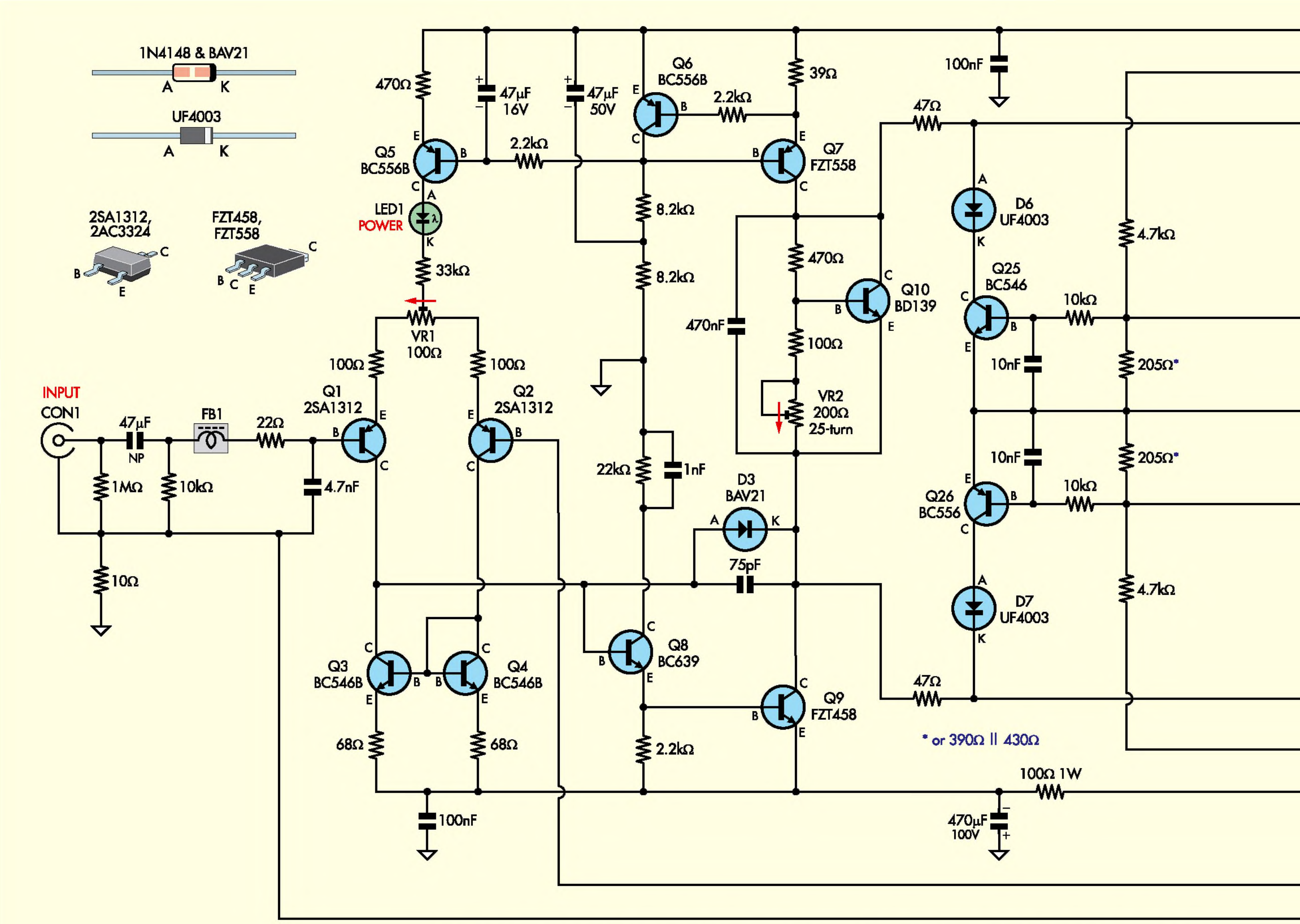


Fig.3: THD+N vs power at 1kHz. Distortion starts to rise above 350W for 4Ω loads but it delivers 500W without gross distortion (and even more on a short-term basis). The performance is pretty good in the middle power range, from a few watts to a couple of hundred watts; it will give 'CD quality' into 8Ω up to about 200W. Double the numbers on the horizontal axis and check the 4Ω curve for 8Ω bridged performance!



The finished Amplifier Module shown mounted in its 3RU case with heatsink and fans. Note the 120mm PWM fans attached to the heatsink, as anything larger wouldn't fit in the case with its lid on.



500W Amplifier

Fig.4: the main difference between this amplifier and our last few designs is the sheer number of output devices (six pairs) and the addition of SOA/load line protection circuitry. This protection circuitry is based on voltage references REF1 and REF2, transistors Q25 and Q26 and the associated resistor network, including the series of 3.3kΩ resistors connected to the emitter of each output transistor.

These are responsible for the very low residual noise of the amplifier.

2SA1312 transistors are becoming somewhat challenging to get, but we have secured a good supply for our readers as we couldn't find any suitable alternatives – see the parts list for our sourcing recommendation.

(*Editor's note – the practice of manufacturers discontinuing components with no direct replacement is very frustrating, and it has bitten us several times.*)

The bias resistor for Q1 and the series feedback resistor to the base of Q2 are set to a relatively low value of 10kΩ to minimise signal source impedance and thereby reduce thermal noise. The 10kΩ input resistance and the 47µF input capacitor provide a low-frequency roll-off at 0.34Hz.

The amplifier gain is set by the ratio of the 10kΩ and 220Ω feedback resistors at the base of Q2. This gain is 46 times (33dB), while the 2200µF capacitor sets the low-frequency roll-off (–3dB point) in the feedback loop to 0.33Hz. The relatively high gain helps to keep the amplifier stable and makes the input sensitivity reasonable at around 1V RMS for full-power output.

Coupling capacitors

The high-value electrolytic capacitors for the input coupling (47µF) and feedback (2200µF) networks eliminate any effects of capacitor distortion in the audio pass-band and also minimise the source impedance.

To explain, if we use a smaller input capacitor at say 2.2µF, its impedance will be 1447Ω at 50Hz. This will only have a small effect on the audio frequency response but represents a substantial increase in the source impedance at low frequencies. By contrast, the 47µF input capacitor we used has an impedance of only 67.7Ω at 50Hz.

This also means that the voltage across these capacitors is minimal compared to the audio signals, so the inherent non-linearity of electrolytic capacitors does not matter.

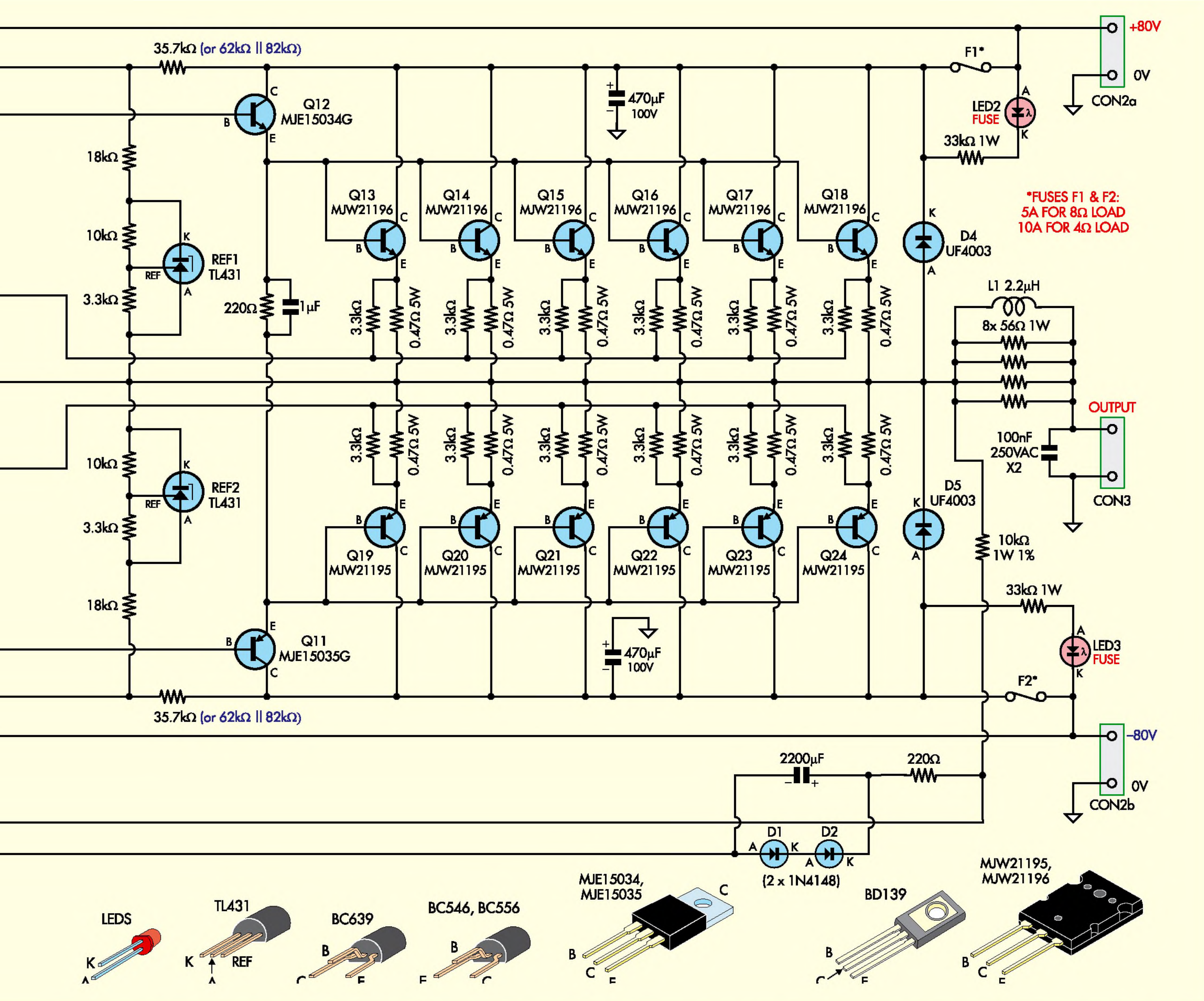
Diodes D1 and D2 are included across the 2200µF feedback capacitor as insurance against possible damage if the amplifier suffers a fault where the output is pulled to the –80V rail. In this circumstance, the capacitor would have a significant reverse voltage.

We use two diodes instead of one to ensure that there is no audio distortion due to the non-linear effects of a single diode junction at the maximum feedback signal level of about 1V peak. This prevents diode conduction under normal operating conditions.

Voltage amplification stage

Most of the amplifier's voltage gain is provided by Q9, fed via emitter-follower Q8 from the collector of Q1. Together, these transistors form the voltage amplification stage (VAS). Q8 buffers the collector of Q1 to minimise non-linearity.

Q9 is operated without an emitter resistor to maximise gain and also maximise its output voltage swing.



Maximum voltage swing is required from the voltage amplifier stage to obtain as much power as we can from the output stages.

Current mirror

The collector loads of Q1 and Q2 are NPN transistors Q3 and Q4 which operate as a current mirror. Q4 acts as a sharp cutoff diode, providing a voltage at the base of Q3 equal to the base-emitter voltage drop of Q4 (about 0.6V) plus the voltage drop across its 68Ω emitter resistor.

If Q2 draws more than its share of emitter current from Q5, the voltage at the base of Q3 increases, so Q3's collector current also rises. This forces Q1 to pull a bit more current and stops Q2 from taking more than its fair share. As Q3 mirrors the current of Q4, Q1 is provided with a collector load that has a higher impedance than would otherwise be the case.

The result is increased gain and improved linearity from the differential input stage.

Similarly, the collector load for Q9 is a constant-current load comprising transistors Q6 and Q7. Interestingly, the base bias voltage for constant current source Q5 is also set by Q6. Q5 is the constant current tail for the input differential pair of Q1 and Q2, and it sets the current through these transistors. LED1 is connected to this circuit as a 'free' power-on indicator.

The reason for the somewhat complicated bias network for Q5, Q6 and Q7 is to produce a major improvement in the power supply rejection ratio (PSRR) of the amplifier. Similarly, the PSRR is improved by the bypass filter network consisting of the 100Ω 1W resistor and 470μF 100V capacitor in the negative supply rail.

Why is PSRR so important? Because this amplifier runs in class-AB, it pulls large asymmetric currents from the positive and negative supply rails. The currents are asymmetric in the sense that it's pulling from one or the other at any given time; the waveforms will be a similar shape for a sinewave, just time-shifted compared to each other.

So, for example, when the positive half of the output stage (Q13 to Q18) conducts, the current waveform is effectively the positive half-wave of the signal waveform; ie, rectification occurs. Similarly, when the negative half of the output stage (Q19 to Q24) conducts, the current is the negative half-wave of the signal.

So we have half-wave rectification ripple of the signal superimposed on the supply rails, as well as the 100Hz ripple from the power supply itself. And while the PSRR of an amplifier can be very high at low frequencies, it is always worse at high frequencies. If these ripple voltages can get into the earlier stages of the amplifier, they will cause distortion, so we need to minimise them there.

Diode D3 is included to improve recovery performance when the amplifier is driven into hard clipping. It makes the recovery from negative

Parts List – 500W Amplifier Module (to build one)

1 double-sided, plated-through PCB coded 01107021, 402 x 124mm – see bottom of page
2 200mm-wide heatsinks **[Altronics H0536]**
2 small PCB-mounting heatsinks **[Jaycar HH8516]**
12 TOP-3 silicone insulating washers
3 TO-220 silicone insulating washers
2 insulating bushes for the TO-220 transistors
4 M205 fuse clips (for F1 and F2)
2 fast-blow ceramic M205 fuses (5A for 8Ω load, 10A for 4Ω load) (F1, F2)
1 ferrite bead (FB1) **[Jaycar LF1250, Altronics L5250A]**
1 6-way PCB-mount screw terminal with barriers (CON2) **[Altronics P2106]**
1 2-way pluggable vertical terminal socket (CON3) **[Altronics P2572, Jaycar HM3112]**
1 2-way pluggable screw terminal (CON3) **[Altronics P2512, Jaycar HM3122]**
1 vertical PCB mount RCA (phono) socket (CON1) **[Altronics P0131]**
1 pot core bobbin for L1 **[Altronics L5305, Jaycar LF1062]**
1 2m length of 1.25mm enamelled copper wire (for winding L1)
1 60mm length of 0.7mm diameter tinned copper wire (links)
12 M3 x 20mm panhead machine screws
5 M3 x 15mm panhead machine screws
6 M3 x 6mm panhead machine screws
17 M3 hex nuts
12 M3 steel washers
6 M3 tapped 9mm spacers
2 transistor clamps **[Altronics H7300, Jaycar HH8600]**
1 15mm length of 25mm diameter heatshrink tubing (for L1)
1 60mm length of 1mm heatshrink tubing (for the wire links)
1 small tube of heatsink compound/thermal paste

Semiconductors
6 MJW21196 250V 16A NPN transistors (Q13-Q18) **[element14 1700966]** •
6 MJW21195 250V,16A PNP transistors (Q19-Q24) **[RS 790-5410]** •
1 MJE15035G 350V 4A PNP transistor (Q11) **[Mouser 863-MJE15035G]** •
1 MJE15034G 350V 4A NPN transistor (Q12) **[Mouser 863-MJE15034G]** •
1 FZT558TA 400V 300mA PNP transistor (Q7) **[RS 669-7388P]** •
1 FZT458TA 400V 300mA NPN transistor (Q9) **[RS 669-7326]** •
2 2SA1312 120V 100mA low-noise PNP transistors (Q1,Q2) •
3 BC546 65V 100mA NPN transistors (Q3, Q4, Q25)
1 BC639 80V 500mA NPN transistor (Q8)
3 BC556 65V 100mA PNP transistors (Q5, Q6, Q26)
1 BD139 80V 1.5A NPN transistor (Q10)
2 1N4148 75V 200mA signal diodes (D1, D2)
4 UF4003 200V 1A ultra-fast switching diodes• (D4-D7)
1 BAV21 250V 250mA low-capacitance switching diode• (D3) **[RS 436-7846]**
2 TL431 programmable voltage references, TO-92 (REF1, REF2) **[element14 3009364]** •
1 5mm green LED (LED1)
2 5mm red LEDs (LED2, LED3)

Capacitors
1 2200μF 16V or low-ESR 10V electrolytic
3 470μF 100V electrolytic **[element14 3464457]**
1 47μF non-polarised (NP/BP) electrolytic
1 47μF 50V electrolytic
1 47μF 16V electrolytic
1 1μF 100V MKT polyester
1 470nF 100V MKT polyester
2 100nF 100V MKT polyester
1 100nF 250V AC metallised polypropylene X2-class
2 10nF 100V MKT polyester
1 4.7nF MKT polyester
1 1nF 100V MKT polyester
1 75pF 200V COG **[Mouser 80-C315C750JCG or 80-C325C750KAG5TA]** •

Resistors *(all ¼W, 1% thin film unless specified)*
1 1MΩ
2 35.7kΩ • (or 2 82kΩ and 2 62kΩ)
1 33kΩ
2 33kΩ 1W 5% (carbon type OK)
1 22kΩ
2 18kΩ
5 10kΩ
1 10kΩ 1W 1% thin film **[Yageo MFR1WSFTE52-10K]** •
2 8.2kΩ
2 4.7kΩ
14 3.3kΩ
3 2.2kΩ
2 470Ω
2 220Ω
2 205Ω • (or 2 430Ω and 2 390Ω)
3 100Ω
1 100Ω 1W 5% (carbon type OK)
2 68Ω
2 68Ω 5W 5% wirewound (for testing purposes)
8 56Ω 1W 5% (carbon type OK)
2 47Ω
1 39Ω
1 22Ω
1 10Ω
12 0.47Ω 5W 5% wirewound
1 100Ω single-turn top-adjust trimpot (VR1) **[Altronics R2591]**
1 200Ω multi-turn top-adjust trimpot (VR2) **[Altronics R2372A]**

The parts list for the power supply, chassis, wiring etc will be presented in an upcoming issue.

UK readers – kit of parts for the 500W Power Amplifier

This is a large project with hard-to-find parts, especially the transistors. We normally supply the PCB and then readers source components using the Parts List. However, for this project constructors should buy kit SC6727 from Silicon Chip in Australia: **www.siliconchip.com.au/Shop/20/6727**

The UK's 2021 VAT/import regulations mean it is not worthwhile for Silicon Chip to sell to UK customers for purchases under AUD250 (plus p&p), but the size of this project means this restriction does not apply. **Note: UK purchasers will be liable for import duty and VAT.**

The parts supplied in the kit are detailed on the Silicon Chip website and include: the 500W amplifier module PCB; set of hard-to-get parts for the 500W amplifier module, including most of the semiconductors (marked with red dot above); Clipping Indicator PCB; Fan Controller/Speaker Protector PCB with programmed microcontroller, plus three 4-pin PWM fan headers.

voltage clipping as clean and fast as that from positive voltage clipping, improving signal symmetry and reducing ringing under these conditions. For this role, we are using a BAV21 diode with a low capacitance of 2pF at 1MHz so that it doesn't affect sound quality.

Feedback and compensation

As mentioned, the feedback components at the base of Q2 set the closed-loop gain of the amplifier. The bottom end of the feedback network is connected to ground via a 2200µF electrolytic capacitor. As this reduces DC gain to unity, the amplifier output offset voltage is dramatically lower than it would otherwise be (by a factor of 38 times).

The 75pF compensation capacitor connected between the collector of Q9 and the base of Q8 prevents oscillation by limiting the slew rate.

The 22kΩ resistor in Q8's collector limits the current through Q9 under fault conditions. Should the amplifier output be shorted, it will try to pull the output either up or down as hard as possible, depending on the output offset voltage polarity.

If it tries to pull it up, the output current is inherently limited by the 15mA current source driving Q9 from Q7. However, if it tries to pull down, Q9 is capable of sinking much more current. The 22kΩ resistor limits Q9's base current and therefore, its collector current and dissipation. The 1nF parallel capacitor is required to keep its AC collector impedance low, improving stability.

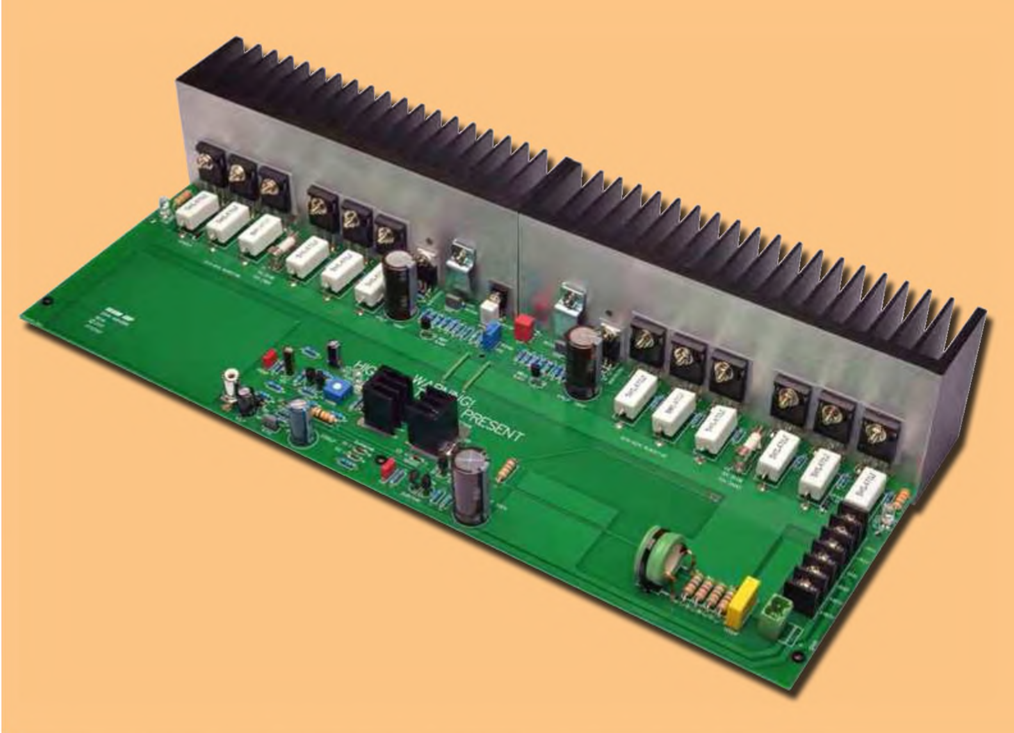
Driver stage

The output signal from the voltage amplifier stage Q9 is coupled to driver transistors Q11 and Q12 via 47Ω resistors. The 47Ω resistors act as stoppers to help prevent parasitic oscillation in the output stage. They are also needed to allow the load line protection circuitry to override the drive from the VAS.

Q10 sets the DC voltage between Q7 and Q9, and this determines the quiescent current and power in the output stages. It provides a bias of about 2.3V or so between the bases of Q7 and Q9 so that they are always slightly conducting, even without an input signal.

Q10 is a 'V_{BE} multiplier', multiplying the voltage between its base and emitter by the ratio of its collector-emitter and base-emitter resistances. While trimpot VR2 varies the resulting collector-emitter voltage, it is actually adjusted to set the quiescent current through the output transistors.

It is important that the bias voltage produced by Q10 changes with the temperature of the output stage transistors. As the output transistors become hotter and their base-emitter voltages reduce, Q10's collector-emitter voltage should also drop, so that the quiescent current is the same or less as at lower temperatures, averting the danger of thermal runaway.



The first part of our 500W Amplifier series focuses on describing how the Amplifier Module works; assembly and testing will be handled in later parts.

Output stage

The amplifier's output stage is effectively a complementary symmetry emitter follower comprising six NPN transistors (Q13-18) and six PNP transistors (Q19-Q24).

Each output power transistor has a 0.47Ω emitter resistor, and this more-or-less forces the output transistors to share the load current equally. The emitter resistors also help to stabilise the quiescent current to a small degree, and they slightly improve the frequency response of the output stage by providing current feedback.

Output offset adjustment

DC offset adjustment is provided by the 100Ω trimpot (VR1) between the emitters of the input pair, Q1 and Q2. VR1 adjusts the current balance between the input pair, and this causes the DC offset at the output to vary. The trimpot is set to make the DC offset as close to 0V as possible; it should be possible to keep this within ±5mV.

This is generally a good figure to keep low, but it's especially critical if using the amplifier to drive a step-up transformer for 100V line operation. That's because the DC resistance of the transformer primary is much lower than that of a loudspeaker voice coil, so significant DC can otherwise flow through it.

Load line protection

It is crucial to prevent the output transistors from operating beyond their Safe Operating Area (SOA). A high-power amplifier like this is quite likely to see abuse, being driven beyond its limits at times.

Fig.5 shows plots of collector current versus collector-emitter voltage (V_{CE}) for the six-per-side paralleled MJW21196 and MJW21195 output transistors. Of the two types, the MJW21195 (PNP) has the lower SOA curve, with a lower current allowed beyond 150V than the complementary MJW21196, so that is the curve we've plotted (the solid green line).

The SOA curve is based on a transistor junction temperature of 150°C and a case temperature of 25°C. That is not a very practical case temperature to maintain, especially when the transistors are dissipating significant power.

The actual transistor case temperature depends on the dissipation, the thermal resistance of each transistor's junction to its case (0.7°C/W) and the case-to-ambient thermal resistance, which is determined by the heatsink and fans. Having a large heatsink with fan-forced air greatly helps to keep transistor temperatures low.

At elevated temperatures, it is essential to ensure the transistors are not operated beyond their maximum power rating, 200W at 25°C, reducing by 1.43W per °C. This power rating curve can further reduce the power they can handle beyond that imposed by the SOA secondary breakdown area.

We plotted both the 25°C case temperature power curve (green curve) and the 50°C case temperature power curve (mauve curve). While a total of

1200W is available with the six 200W transistors at 25°C, only 985W is allowable with a 50°C case temperature.

The curves assume that each of the six parallel transistors share the current equally, a fair assumption since each has a relatively high-value emitter resistor. If one of the power transistors tends to take more than its share of load current, the voltage drop across its emitter resistor will be proportionately higher. This will throttle the transistor back until its current comes back into line with the others.

The blue and red curves show resistive 8Ω and 4Ω loads (straight lines) that assume the load is purely resistive. In practice, this is not true for loudspeakers as there is a considerable reactive impedance in a practical loudspeaker that causes its resistance to vary with frequency.

The curved blue and red lines show the load impedance curves assuming that the resistive and reactive impedances are equal. The plots show the worst-case impedance that occurs over the operating frequency range.

A close-up of the front-end circuitry of the 500W Amplifier Module.

For example, for a 4Ω speaker, we plot the curve with a 2.83Ω resistance and 2.83Ω reactive impedance that's 90° out of phase with it ('j' is like 'i' in mathematics, the imaginary unit of value $\sqrt{-1}$, forming a complex impedance value).

Calculation of the total impedance can be visualised as the two impedances forming two sides of a right-angle triangle with the hypotenuse length equalling the total, which in this case is either 4Ω or 8Ω.

These plots are for a rather severe amplifier load. Typically, a loudspeaker will not exhibit such a load, but we want to ensure the amplifier will not be damaged by designing for worst-case loads.

Note how the curved impedance plots encroach quite a bit closer to the SOA curve than the purely resistive loads. Note also that at elevated temperatures, the allowable dissipation curve comes close to the 4Ω reactive impedance plot, especially around the 60V to 100V V_{CE} region. At case temperatures above 50°C, the allowable transistor dissipation could possibly be exceeded.

The two protection lines on the graph prevent this. The dashed green line is for a transistor case temperature of 25°C, while the dashed mauve line is for a 50°C case temperature. The lines show the points on the graph where the output transistors are protected by reducing their base drive should the load reach the protection line.

The protection lines shift closer to the 4Ω impedance curve with increasing temperature. Also, the protection lines have a dual slope with one straight line between the Y-axis and the small circle (dot), and the second line between that dot and the X-axis. Note that where the line meets the X-axis, it must be at least the total supply voltage (160V) to prevent spurious limiting near zero output current.

As the temperature rises, the voltage at the zero current axis reduces. However, even the 50°C curve meets the axis above 160V, at 165V. If the amplifier gets significantly hotter, perhaps beyond 60°C, the output will probably get cut off, but maybe that is not a bad thing, as it's a sign that the cooling system might have failed.

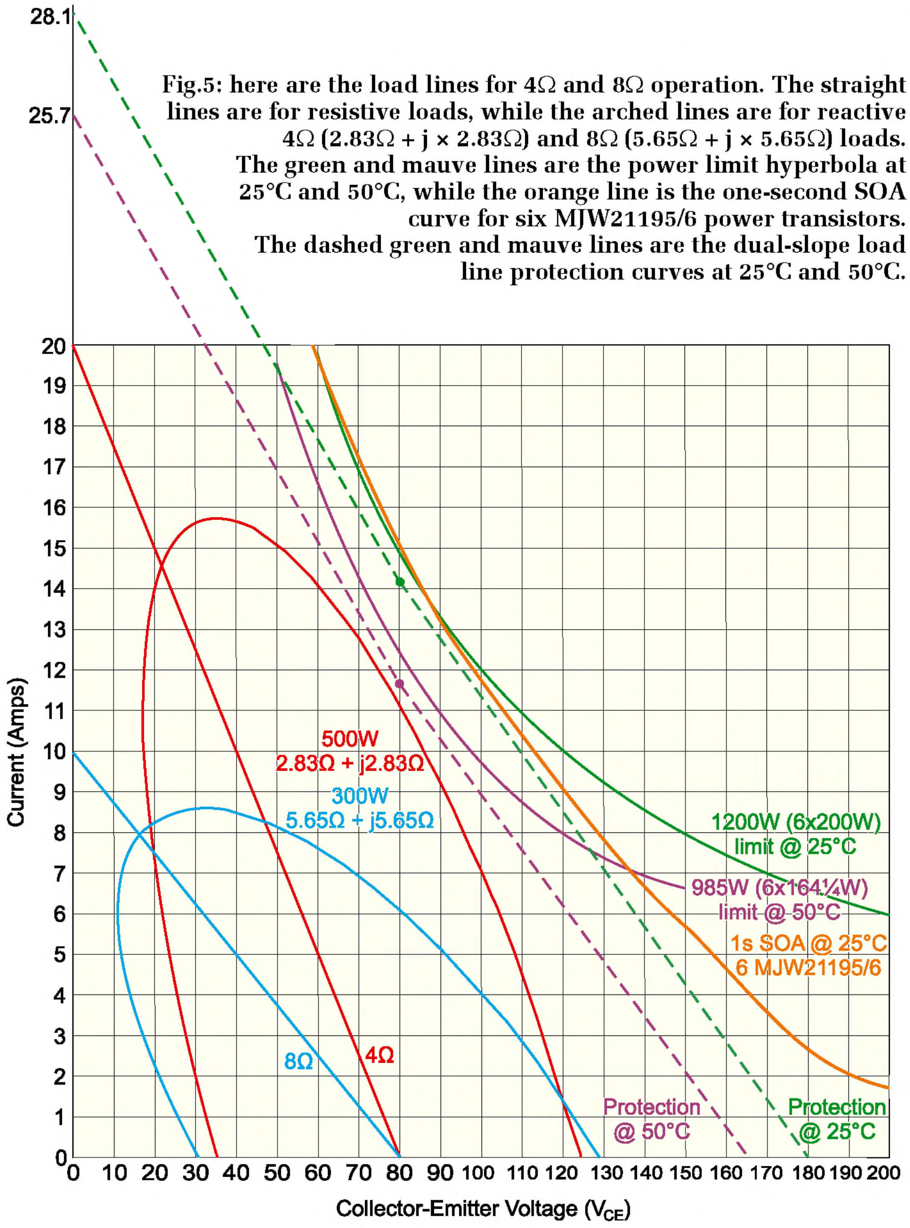


Fig.5: here are the load lines for 4Ω and 8Ω operation. The straight lines are for resistive loads, while the arched lines are for reactive 4Ω (2.83Ω + j × 2.83Ω) and 8Ω (5.65Ω + j × 5.65Ω) loads. The green and mauve lines are the power limit hyperbola at 25°C and 50°C, while the orange line is the one-second SOA curve for six MJW21195/6 power transistors. The dashed green and mauve lines are the dual-slope load line protection curves at 25°C and 50°C.

While the difference between the two slopes in the protection curve is subtle, this is necessary to more closely follow the power rating curve and hence prevent the protection curve at 50°C and beyond from encroaching on the 4Ω impedance curve at a V_{CE} of around 70V.

SOA protection circuitry

This dual-slope foldback protection scheme is based on the research paper titled, *The Safe Operating Area (SOA) Protection of Linear Audio Power Amplifiers* by Michael Kiwanuka, BSc (Hons) Electronic Engineering, which you can view at: **https://bit.ly/pe-apr23-soa**

The supply voltage, output voltage and current through the output transistors are all monitored to provide load-line protection over the entire voltage and current ranges of the amplifier.

Transistors Q25 and Q26 and diodes D6 and D7 provide the protection feature. Q25 (NPN) can shut off the MJW21196 transistors, while Q26 (PNP) acts on the MJW21195 transistors. The diodes are included to prevent Q25 and Q26 from shunting the drive signal when they are reverse-biased. This happens for every half-cycle of the signal to the driver transistors.

The circuits around Q25 and Q26 are essentially identical.

Normally, Q25 and Q26 are biased off and play no part in the amplifier's operation. However, if the load encroaches upon the protection curve, Q25 and/or Q26 switch on to throttle back drive to the output transistors, limiting the output current and protecting the transistors. This also protects against short circuits.

Transistor Q25 and Q26 are mounted on the amplifier's heatsink so that the protection circuit curves shift with temperature as required.

In more detail, the voltage across each 0.47Ω output stage emitter resistor is monitored via a set of 3.3kΩ resistors. These voltages are averaged (equivalent to being summed) at the base of Q25 or Q26. Resistive dividers formed from pairs of paralleled resistors provide output voltage and supply voltage monitoring by feeding extra current into these summing points.

Effectively, what these dividers do is make it so that as the voltage across a set of output resistors reduces (either due to reduced supply voltage, or the output swinging closer to that rail), the protection circuitry becomes more insensitive and requires a higher output current to be triggered. Similarly, as the V_{CE} increases, the trip current decreases, forming the 'curves' shown in Fig.5.

The dual slope in the protection circuit is created by voltage reference REF1 for the positive half of the circuit and REF2 for the negative half. The bias current to operate these devices comes via 18kΩ series resistors. REF1 and REF2 are adjustable voltage references, with the 10kΩ and 3.3kΩ resistors setting the voltage across them to 10V.

The protection circuit relies on the base-emitter voltage of Q25/Q26 being around 0.6V at 25°C. This voltage drops to 0.55V at 50°C, so these transistors switch on with less applied voltage at higher temperatures. This shifts the protection line downwards with elevated temperature, following the downward movement of the output transistors' power rating curve.

Diodes D4 and D5 between the amplifier output and supply rails are also part of the protection circuitry. They absorb any large spikes generated by the loudspeaker's inductance when the protection circuit cuts the drive to the output transistors. D4 and D5 are fast recovery diodes, included to ensure their operation at high frequencies and high power.

These diodes are even more critical if driving a line transformer as its primary inductance is likely to be significantly higher than any loudspeaker load.

The finished case is simple, with only a power button and clipping indicator LED on the front and audio input/output and power socket on the back.

Output RLC filter

The remaining circuit feature is the output RLC (resistor-inductor-capacitor) filter, comprising a 2.2µH air-cored choke, eight paralleled 56Ω resistors (giving 7Ω) and a 100nF capacitor. This output filter effectively isolates the amplifier from any large capacitive reactance in the load, thereby ensuring unconditional stability.

It also helps attenuate any RF signals picked up by the loudspeaker leads and stops them from being fed back to the early stages of the amplifier, where they could cause RF breakthrough.

Fuse protection

The output stage supply rails are fed via fuses F1 and F2 from the +80V and −80V main power supply rails. These provide 'last-ditch' protection to the amplifier, limiting the damage in the case of a severe fault. The recommended fuses are ceramic types. LED2 is a blown-fuse indicator for F1 and LED3 for F2. They light up if the fuse is blown as it isn't always obvious, especially with ceramic types.

Next month

The following article next month will have the full module construction details, including the heatsink drilling and instructions for winding inductor L1.

In the June issue, we'll show you how to build a suitable power supply, mount it and the *Amplifier Module* in the chassis, and wire it all up along with the *Fan Controller*, fans, *Speaker Protector* and *Clipping Indicator*.

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