AUDIO OUT

By Jake Rothman

MX50 power amplifier kit – Part 1

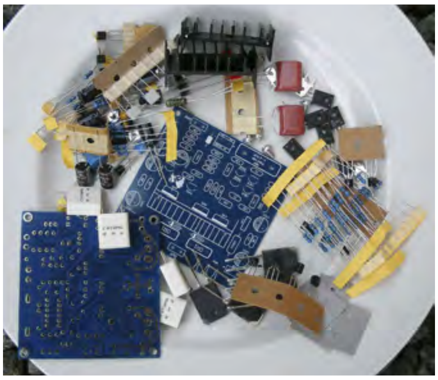

Fig.1. The MX50 kit – a lot of components for very little money.

Every so often, a bargain comes up online that's irresistible. This 50W stereo amplifier lets you make a posh power-amp for peanuts! It is advertised on eBay as the 'Douk Audio MX50 SE Dual 2.0 Channel Power amplifier Kit for DIY' from the seller Doukmall. The cost is £11.00 plus £2.99 postage. (There are other sources selling at higher prices, around £16.00.) I estimate this kit would cost at least £35 from normal UK suppliers. The catch is that the kit is just a bag of bits from Shenzhen, China (see Fig.1). There's no documentation, not even a circuit diagram, so you've got to know what you are doing. However, the design, PCBs and components are of such excellent quality, that the editor and I decided it was worth reverse engineering the design. This enabled the missing documentation to be generated so it could be easily built, even if the kits on eBay run out.

As an addition to my previous series on amplifier power supplies, we will use this module to show how to construct a stereo amplifier and dual-rail power supply for minimum distortion and noise.

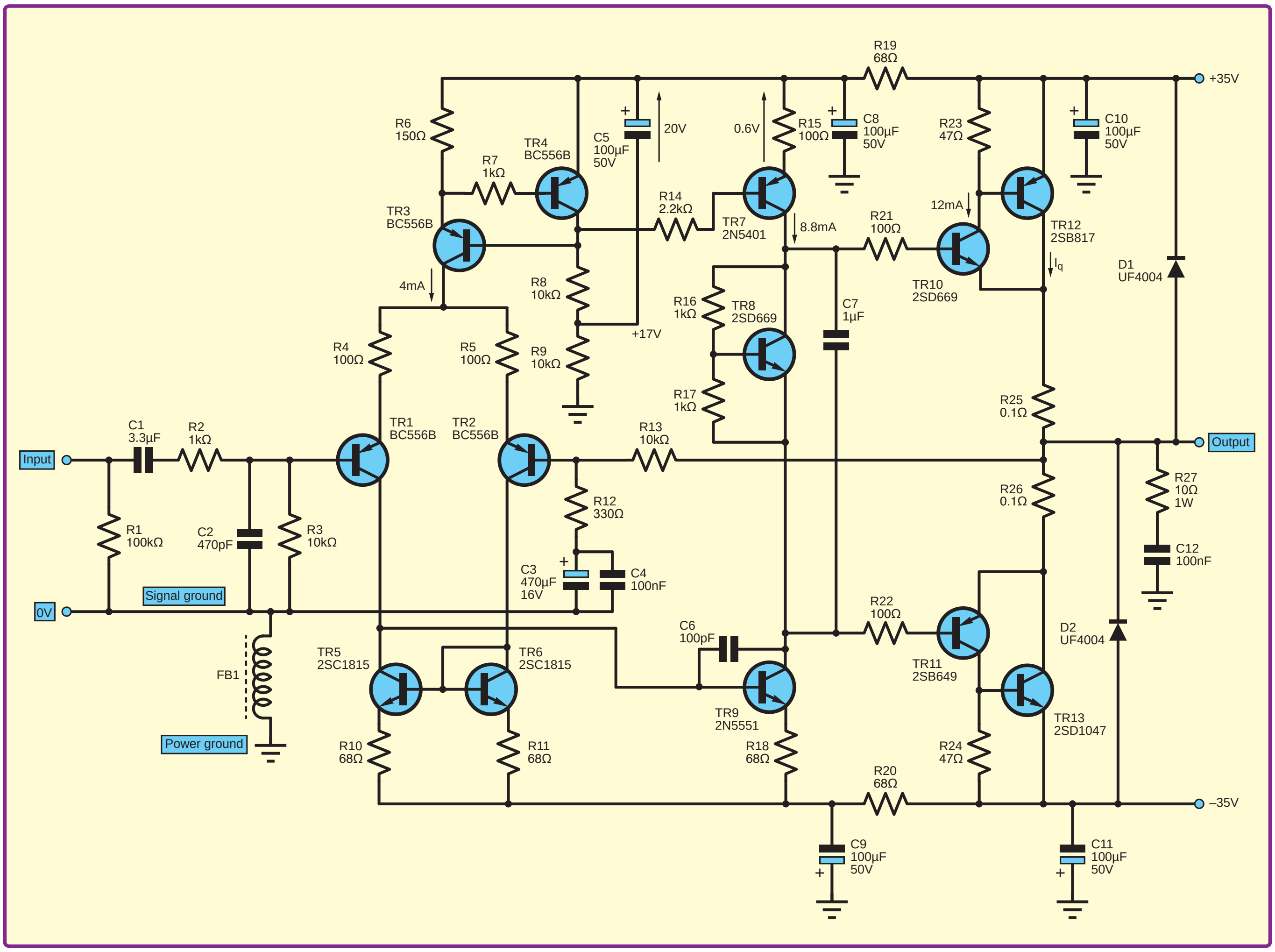

Fig.2. The MX50 circuit – another Douglas Self inspired design.

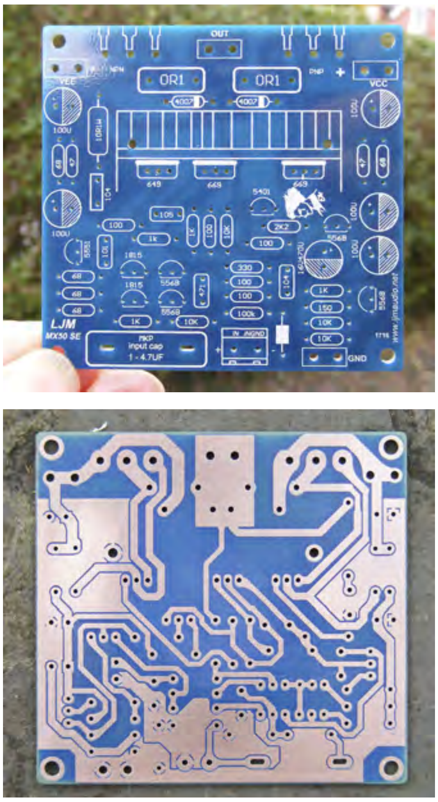

Fig.3 a) (top) The MX50 PCB, as supplied with component values, and b) (bottom) PCB track layout revealed after sanding.

Circuit

The circuit is clearly based on Douglas Self's Blameless 50W amplifier design, described in his *Audio Power Amplifier Design Handbook*, a distillation of years of research into the distortion mechanisms of the standard Lin circuit. Just like Baxandall and his tone control design, Self would have become rich if all amplifier manufacturers using his circuitry had paid him a small royalty. There are a few simplifications to his design (see the MX50 circuit in Fig.2) possibly to avoid copyright infringement. The main change being the omission of a buffer stage between the long-tailed pair (LTS) input stage and the voltage amplifier stage (VAS). This will make the distortion a bit higher. This is likely to be audibly insignificant because input stage distortion is subjectively much more benign than output stage distortion. Instead of an emitter-follower (EF) output stage, a complementary follower pair (CFP) stage is used. This configuration has slightly lower measured THD, but the distortion residue usually exhibits sharper spikes than the EF version, which may be more dissonant. The CFP stage does make the kit easier to build, because the temperature sensing V_{be} multiplier bias transistor can be mounted on the driver transistor heatsink on the board, rather than on the main output transistors.

The circuit has no quiescent current adjustment, just a 1kΩ resistor (R17) which gives a current that is safe at 10mA, but too low to be optimum. The driver transistor collector-load resistors, R23 and R24 are 47Ω rather than the normal 100Ω, which increases the driver dissipation, but this may give faster turn-off of the output devices. The lower-arm feedback capacitor (C3) is bypassed by a film capacitor (C4). This audiophile tweak was shown to be ineffective by the late Cyril Bateman. A couple of ultra-fast diodes (D1 and D2) have been placed across the supply rails to protect the output transistors from potentially damaging back EMFs from the speaker.

Short circuit

Do note that there's no short-circuit protection on this module; a possibly dangerous omission. One touch of the speaker leads, and bang! Possibly, this module is designed for use in active speakers where this should not happen, but it could happen in testing. I came across an active PA speaker where the aluminium wire voice-coil in the woofer had rubbed against the pole piece, causing a melted short-circuited voice-coil. I thought it could never happen! I've never seen it with a copper wire voice-coil though.

Hi-Fi designers often say no protection sounds better, but try telling that to a studio owner who's turning clients away because his monitoring system is burnt out. Adding short circuit protection is complex, involving a dozen components. Fuses will protect the transformer, PCB and most speakers, but bipolar transistor failure is much quicker and they usually blow before the fuses.

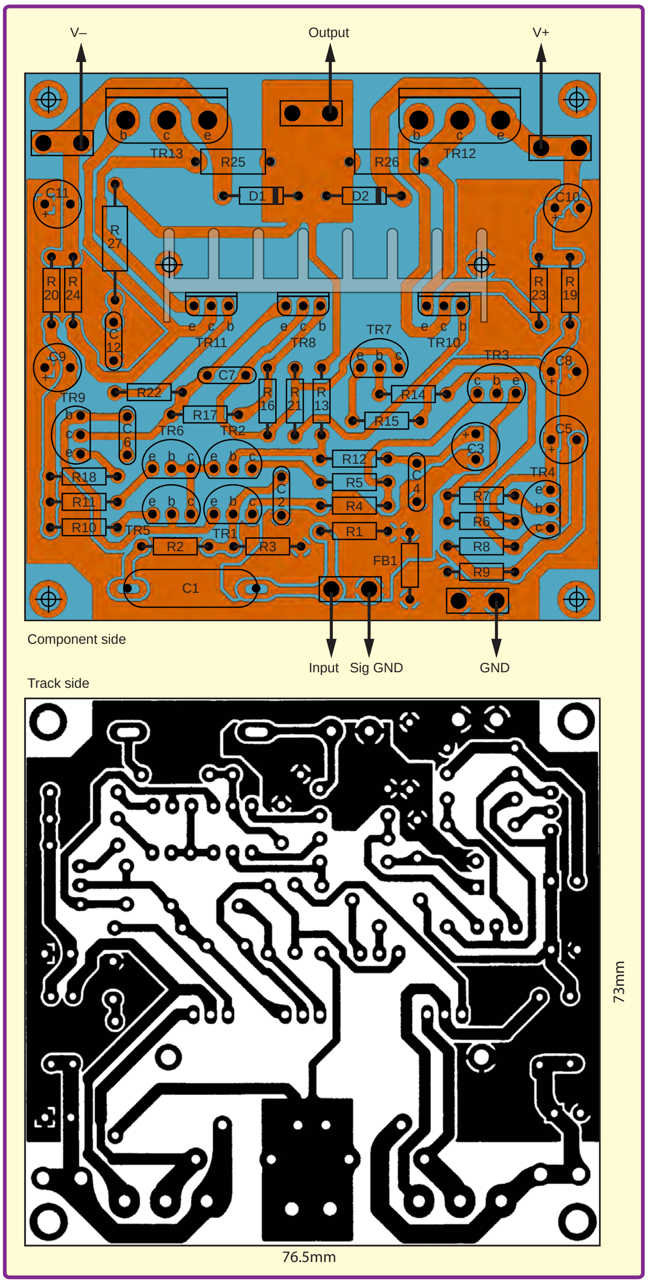

Fig.4 PCB overlay with component positions

Parts

Occasionally counterfeit parts are a problem with these sort of kits, but not here. The 140V 12A 100W output transistors are the proper KEC (Korean Electronics Company) devices derived from original Sanyo and Toshiba designs. I have never had any problems with KEC transistors, which I generally buy from Tayda. The electrolytic capacitors are Rubycon and Nippon Chemicon and all the other bits were fine. The PCB is a standard industrial-grade fibre glass, single-sided product of particularly neat and compact design with all the values clearly and accurately marked (see Fig.3a). It would be possible to build the amp from this information alone, which is the intention. I sanded off the blue silkscreen and solder resist on both sides (Fig.3a and 3b) to obtain the track layout, which is shown in Fig.4. This was also necessary to trace the circuit diagram, since those circulating on the web have errors.

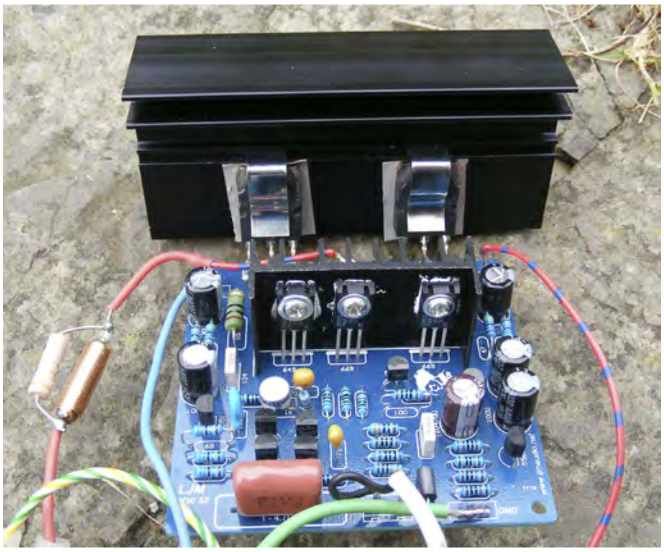

Fig.5. For low-power, a Rapid 3.3°C/W heatsink with clips suffices.

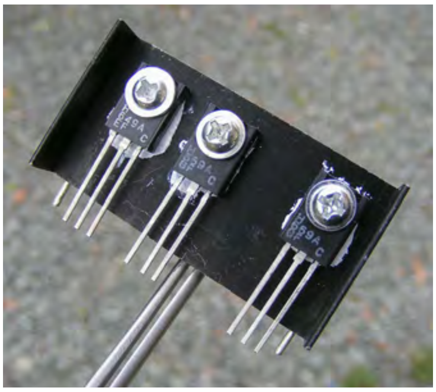

Fig.6. The driver transistors and bias transistor are mounted on a special small heatsink, which will be soldered to the PCB.

Assembly

As with all amplifier modules, a heatsink and mains transformer are not included and must be provided by constructors. In the spirit of economy, these can be obtained cheaply from radio rallies and scrapped old amps, since they don't wear out (they are expensive if bought new from UK distributors). The ideal heatsink would be 1°C/W if continuous high power is needed. For Hi-Fi use at moderate volumes, it can be quite a bit smaller, such as the 3.3°C/W unit shown in Fig.5. Mica washers and heatsink compound will be needed, I find this messy but much more effective than the silicone rubber washers provided. The driver heatsink is a special item which will have to be replaced by a strip of aluminium or copper if not available. Remember to mount the heatsink and tighten the transistor mounting screws *before* soldering to prevent stress on the joints, as shown in Fig.6. No insulating washers are needed with the fully insulated transistors supplied, although a bit of heatsink compound is necessary. Spade terminals were provided, but these were too loose a fit on the board and replaced with wire loops. The emitter resistors R25 and R26 are the radial-mount ceramic-box type. These cannot be inserted fully because diodes D1 and D2 get in the way. The solution is to insert the two together and push the diodes over before soldering. A close-up of the finished PCB is shown in Fig.7.

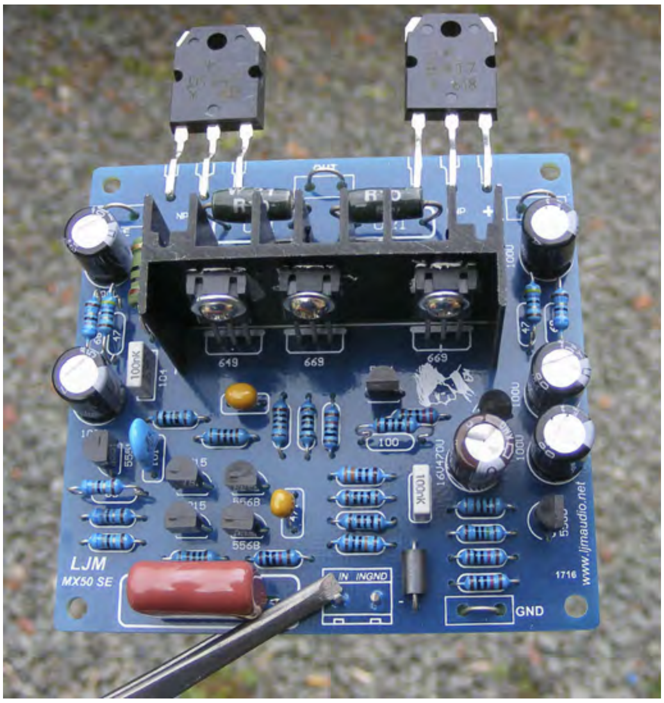

Fig.7. (right) The finished MX50 PCB.

Next month

In *Part 2*, next month, I will move on to consider the power supply and wiring, various potential improvements and explain how to test the finished amplifier.

AUDIO OUT

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MX50 power amplifier kit – Part 2

Last month, I introduced the excellent MX50 power amplifier kit. This month, it's time to look at the power supply, some possible improvements and testing.

Power supply and wiring

The dual power supply is the same as a single-rail system except there are two smoothing capacitors with an extra node for the negative rail, as shown in Fig.8. The kit provides a ferrite bead to link the signal ground and dirty ground on the board to reduce RF interference. Since the hum loop problem in stereo amps is low frequency, this would not be effective and a 10Ω resistor is inserted. A photo of the stereo amplifier test bed shown in Fig.9 illustrates a recommended physical arrangement that gives no hum. If the transformer used has a significant hum field, use the heatsink as a screen between it and the boards.

Improvements

Since there is no VAS buffer, the gain of the VAS transistor TR9 is important. The supplied 2N5551 transistors have an H_{fe} of around 130. The loading on the input stage and the overall open-loop gain is reduced by the inclusion of an emitter resistor (R18). An audiophile Japanese transistor, such as the 2SC3071 (H_{fe} = 600) could be used here, and may improve HF distortion. It made no difference at 1kHz. C3 could be replaced by a non-polarised electrolytic to reduce LF distortion. The most important improvement would be to add an I_q adjustment. A 50kΩ trimmer in series with an 8.2kΩ can be wired in parallel across R17. Later, this can be replaced with a fixed resistor. In my case, I used 22kΩ for one channel and 18kΩ for the other.

A suggested short-circuit protection circuit is shown in Fig.10. It senses the voltage across the emitter resistors and shuts down the amplifier by removing the bias from the current sources. It also

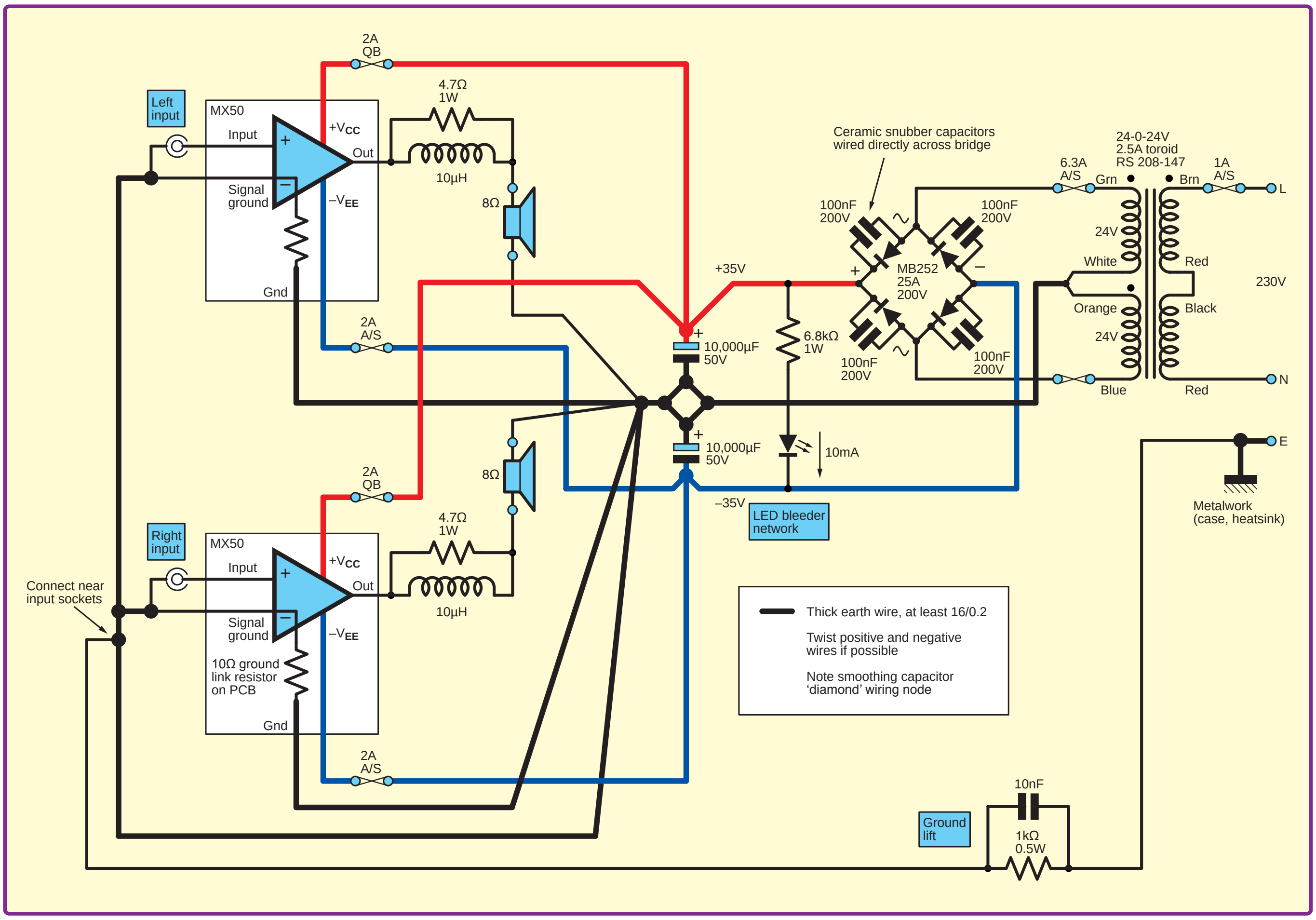

Fig.8. A suggested wiring diagram for all stereo dual-rail power amplifiers and entirely appropriate for the MX50. Remember to insert 10Ω ground-lift resistors in the FB1 position.

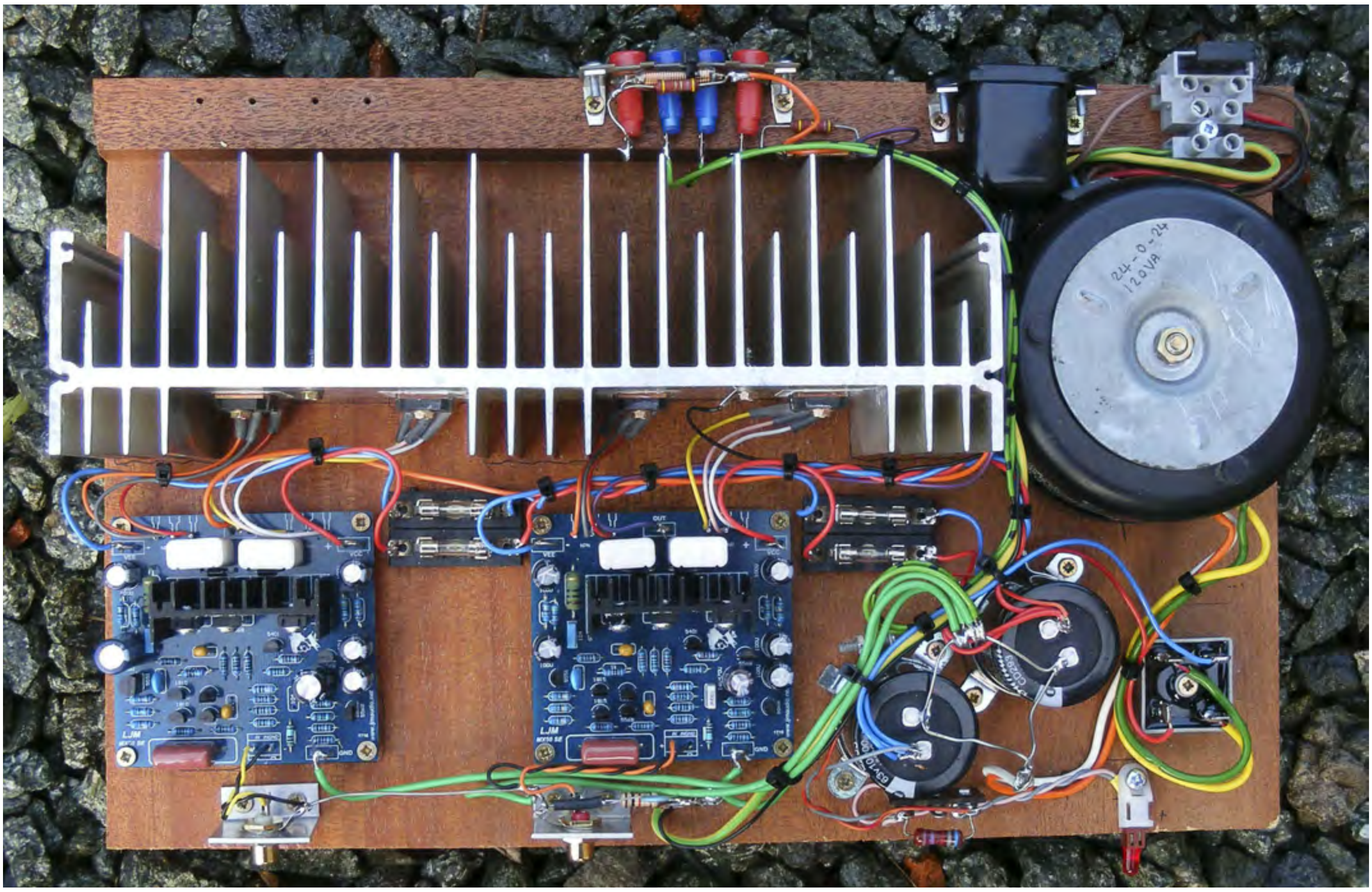

Fig.9. The completed MX50 amplifier test bed built on a wooden board. This helps with evaluating optimum layout for a given case, since it is much easier to chop and change screwing into wood rather than drilling metal.

provides a switch-on delay, useful for suppressing thumps from a proceeding circuit. This can be assembled on a small piece of stripboard and retrofitted to the amp, as shown in Fig.11. With this particular amplifier configuration it's best to make the positive rail fuse smaller than the negative rail fuse, because when it blows the amp is turned off with no offset. If only the negative rail fuse blows, a full positive offset occurs. If a 1N4004 diode is connected from V– to ground this offset reduces to 3V and the capacitors are protected from reverse polarisation. I used a 2A quick-blow fuse for the positive and a slow-blow type for the negative. An already-very-low hum can be reduced below the noise floor by increasing C9 to 470µF. The hard-wired amp shown with the inputs shorted had 2.5mV of noise on the outputs, one of the lowest I've ever measured.

A debatable 'improvement' is to use lateral MOSFETs, such as the 2SJ162 and 2SK1058, which can survive momentary shorts – replace TR12 and TR13 respectively. Gate resistors will have to be added and the bias voltage ramped up. The distortion will go up, the output will go down and they cost five-times more than bipolar transistors. However, the reliability can be around five-times better according to *The Audiophile's Project Sourcebook* by Randy Slone.

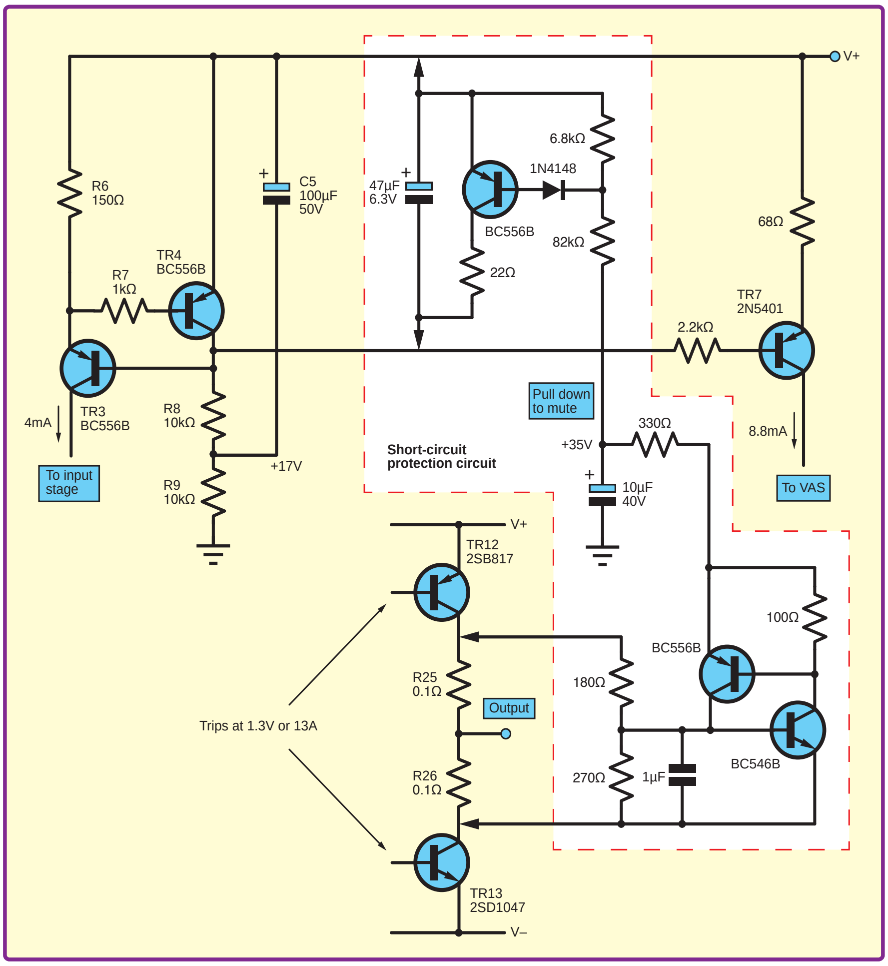

Fig.10. A suggested short-circuit protection system, which is not too complicated to add. It is inspired by the system used on the Mission Cyrus 1 amplifier.

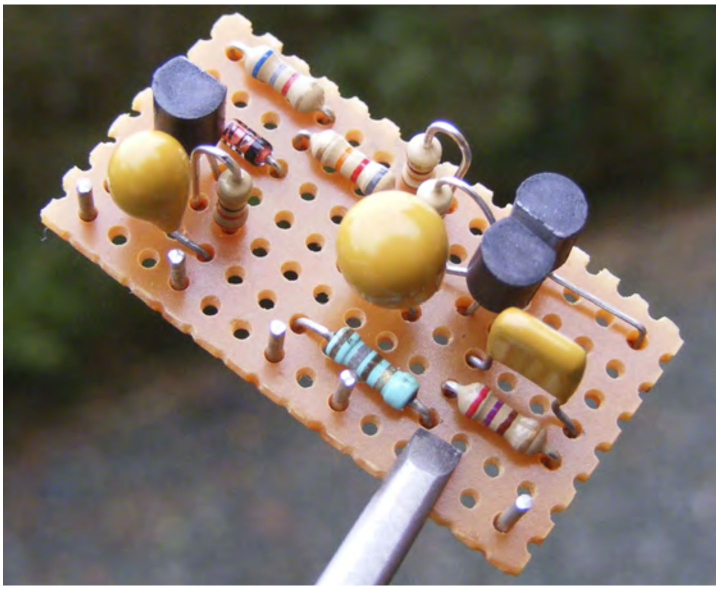

Fig.11. The short-circuit protection circuit is easily built on stripboard.

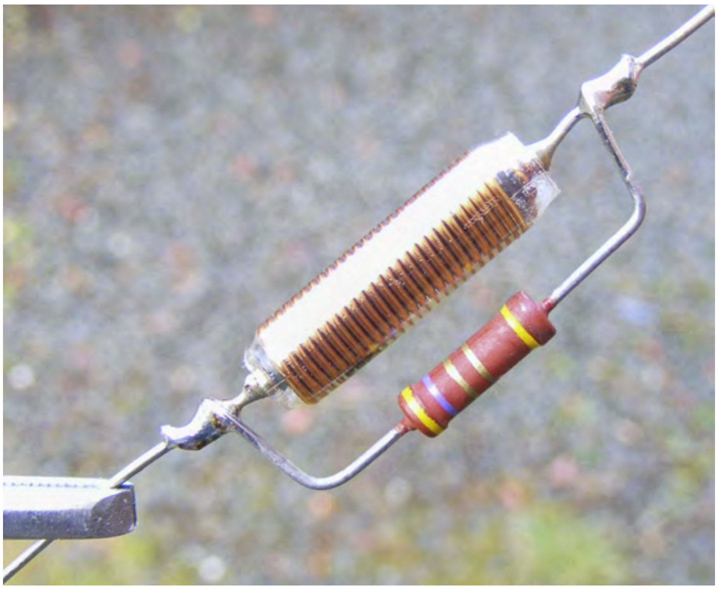

Fig.12. An LC network should be inserted at the output pin if driving high capacitance loads, such as fancy plaited speaker cable.

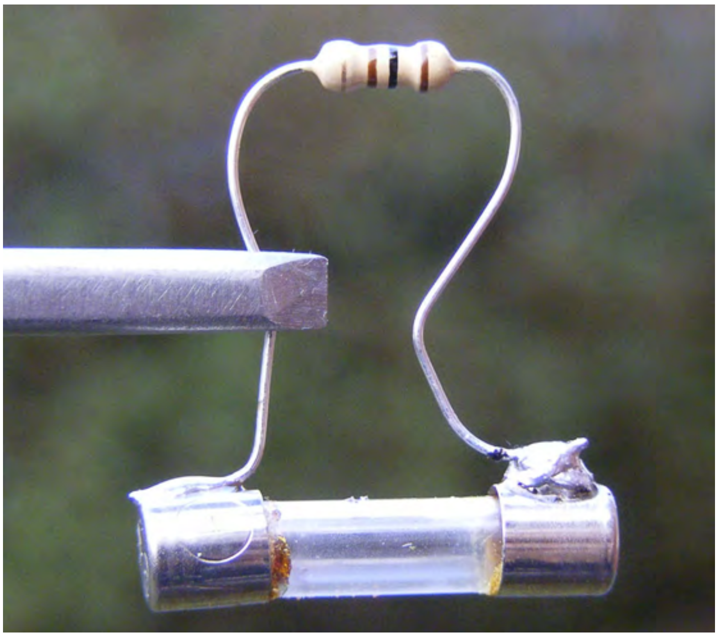

Fig.13. One of my special power amplifier test techniques is to solder 100Ω resistors across blown fuses and insert these into the fuse holders for current limiting with added smoke signalling.

There is no output inductor to prevent oscillation with long high-capacitance speaker leads, but this can easily be added. The 10µH inductor with a 4.7Ω resistor in parallel, as shown in Fig.12, will suffice.

Voltage variations

A safe maximum-rail voltage for the transistors supplied would be ±37.5V, which would equate to a transformer of 28V-0-28V. These are hard to obtain and the nearest available would be 25V-0-25V. With a 24-0-24V 2.5A 120VA transformer and adequate heatsinking, the amp delivered $58V_{pk\text{-}pk}$ or $52.5W_{rms}$ into 8Ω at 1kHz. The rail voltage at this power was ±31.5V, meaning there was a total loss of 5V. 1.6V of this was across the decoupling resistors R19 and 20. If high-power 4Ω running is contemplated, it would be worthwhile doubling-up the output transistors. If you must use 4Ω speakers, drop the transformer voltage to 22V-0-22V. Remember, distortion with class AB amplifiers triples going from 8Ω to 4Ω loads. If lower power, say around 20W into 8Ω is acceptable, cheap transistors such as TIP3055s, BC182s, BD139s and their respective complements could be used with 18-0-18V or 15-0-15V transformers. This would be a good starting point for students and beginners.

Testing

Discrete transistor power amplifiers are notoriously intolerant of errors, often resulting in instant destruction of the output and driver transistors. With no current limiting, a PCB can even catch fire. Use a power supply with a current limit set to 300mA for initial testing if available, or put 100Ω resistors in series with the power lines. I solder these resistors to blown 20mm fuses, as shown in Fig.13, which can then be easily inserted/removed.

Never connect a load to a transistor amplifier when powering up for the first time. Use small fuses in the amplifier power supplies, say 100mA or resistors, and if they don't blow, check for DC off-set on the output, which should be less than 20mV.

Next, check the I_q is correct, it should be just over 15mA. This equates to 3mV across the emitter resistors, easily measured by putting the meter probes onto the output transistor collector metal tabs. Note that this drifts down as the amplifier warms up. All the MX50s I measured gave values of around 1.2 to 1.5mV and therefore had too low an I_q. Visible crossover glitches were present at 11kHz and above. These disappeared when I trimmed the I_q. Note these could only be seen on an analogue scope, you won't see them on a standard digital unit with 8-bit resolution.

Next, connect a signal generator set to 1kHz sinewave on the input and hook up an oscilloscope to the output and check for oscillation and distortion. If all is well, bring up to clipping. If this is okay, connect a load resistor and allow the output to just clip briefly, again checking for problems. Read off the peak-to-peak voltage to calculate the power output. Finally, test with music and other difficult signals.

It's a bargain!

For those looking for a low-cost entry into high-quality discrete amplification that beats the sound quality of chips, and is almost as good as the Self design, the MX50 is ideal. I've just bought 10 for my audio engineering BSc students. Luckily, they have proper dual-rail bench power supplies that will shut down if there's a short, so hopefully there will be no fireworks.