Build the SC200...

New high performance amplifier module

- **200W into 4Ω**
- **0.001% distortion**

Part 3 – By NICHOLAS VINEN

In this third instalment, we provide the SC200's performance details. We also describe the required power supply, the testing and set-up procedure and how to build lower-power versions of the amplifier.

The SC200 is our new workhorse audio amplifier module, and while it doesn't have the extremely high performance of the very best designs, it's still more than comparable with most brand-name Hi-Fi amplifiers and it also has power aplenty. It's also easier to build and the parts cost significantly less than many SMD designs.

Fig.7 shows where the SC200 has the biggest advantage over a 14-year old design (the SC480) and that's in power output. The first thing you may notice is that below 10W, the total harmonic distortion of the SC200 is slightly higher than the SC480 but that's simply because it has more gain.

Since both designs use BC557 transistors at the input, their absolute noise figures are very similar, but since the SC200 delivers a lot more power, it needs more gain and this also amplifies the noise more.

Hence, while the SC200's signal-to-noise ratio relative to full power is 1dB better than the SC480, the noise at a particular power level will be slightly higher.

Having said that, at power levels above 10W the SC200 delivers significantly lower distortion. The SC480 runs into clipping at around 55W for 8Ω loads and 70W for 4Ω loads, while the SC200 delivers a clean output up to power levels of 135W for 8Ω loads and 200W for 4Ω loads.

Music power (ie, for short bursts such as percussion instruments) is even higher, at around 150W into 8Ω and 250W into 4Ω. So the SC200 has substantially more power output than the olde SC480.

Fig.8 shows distortion for the new SC200 and old SC480 designs at the same power level, into the same resistive loads and over the entire audible frequency band. We've used the plots for the TO-218 (plastic package transistor) version of the SC480 to be fair, since it is the more modern of the two designs that were originally presented, and it gave slightly better performance.

As you can see, the shapes of the distortion curves for both designs are very similar, but at the power levels used here, the SC480 has about 1/3 the distortion at all frequencies.

Note that we have filtered out some of the noise with a 30kHz bandwidth, to allow us to better see the harmonic distortion; the SC480 article doesn't state what bandwidth was used so it's difficult to make an 'apples-to-apples' comparison.

We have shown the projected high-frequency distortion with dotted lines, taking into account the fact that the limited bandwidth will filter out some of the higher harmonics for those frequencies.

Given that noise has less of an effect on the distortion measurements at higher frequencies, because it becomes a less significant proportion of the rising THD+N, this does suggest that the SC200 will have noticeably lower distortion at higher frequencies, at least into 8Ω loads, and should sound slightly better when driving 4Ω loads too.

Fig.9 compares the frequency response of both amplifiers at 10W into an 8Ω load. The frequency response of the SC480 is –1.8dB at 20Hz and –1.6dB at 20kHz. By comparison, the SC200's response is astonishingly flat at just –0.06dB at 10Hz and –0.13dB at 100kHz.

That more extended bass response will certainly be apparent if your CD player and your discs have very low bass signals (such as those from a pipe organ with 64-foot pipes!) and if your loudspeakers have the bass performance to match. At the other end of the spectrum, you will need young ears able to hear up around 20kHz and good speakers and program source to be able to notice the difference.

Power supply

In the power supply for the SC200 we rectify the output of a 40-0-40V toroidal transformer and feed it to a 6 × 4700µF capacitor bank to generate the nominal ±57V supply rails. The power supply PCB also carries optional circuitry to derive a ±15V preamplifier supply from a second 15-0-15 transformer, or a secondary winding on the main transformer.

The full circuit for the power supply is shown in Fig.10. This shows component values for the full-power rated supply, but also for a lower-voltage version which will reduce the power output slightly, to 75W into 8Ω loads and 110W into 4Ω loads.

There isn't a great deal to the power supply circuit. An external 35A bridge rectifier converts the AC from the transformer into pulsating DC, which is used to charge the two large capacitor banks. LED1 and LED2 act as bleeders, to discharge this bank after switch-off and also show when the supply is live.

A separate 1A on-board rectifier comprising diodes D1-D4 and two 2200µF capacitors converts the 15-0-15V AC output of the secondary windings to around ±20V DC, which is then fed to a pair of linear regulators to produce the ±15V rails for the preamplifier (or whatever other circuitry you need to power within the chassis).

The power supply PCB overlay is shown in Fig.11. The preamplifier regulator section at right can be cut off if you don't need it, or want to mount it elsewhere. The output of the bridge rectifier is connected via three spade quick-connect terminals, while two sets of DC outputs are provided on either side, making it easier to build a stereo amplifier.

Although we show a couple of wire links on this PCB, production boards should have WIDE top layer tracks joining those points, so fitting these wire links is not necessary. Check your board to verify this before starting assembly. The parts list for building the power supply is included later on in this article.

Lower-power amplifier module

If you want to build the lower-voltage power supply, using a 30-0-30VAC transformer which gives around ±42V DC, you need to make some slight changes to the amplifier modules.

The most important change is that the 22kΩ resistor between the collector of Q7 and ground (to its right on the PCB) must be changed to 15kΩ.

It's also a good idea to change the two 6.8kΩ resistors at the collector of Q6 (one to its left and one below VR2) to 4.7kΩ; however this is less critical and it will probably work OK with the original values.

Building the power supply

You'll need to build a power supply before you can test the amplifier module(s). Use the overlay diagram in Fig.11 as a guide to fit the components to the PCB, which is available from the *EPE PCB Service*, coded 01109111. Note that the power supply module kit is available from Altronics; Cat K-5168 (does not include transformer – you choose which one you want).

Assuming you do want the low voltage outputs, fit the four 1N4004 diodes (D1-D4), orienting them as shown. Then install the two 3-terminal regulators. You will need to bend their leads down by 90° so that they fit the PCB pads with the tab mounting hole lined up correctly. Attach each regulator to the board using an M3 x 6mm machine screws, shakeproof washer and nut, taking care not to get the two different types mixed up. Solder the leads *after* the screws have been tightened.

The two LEDs can go in next. These sit flush against the PCB with the flat side of the lenses oriented as shown on the overlay.

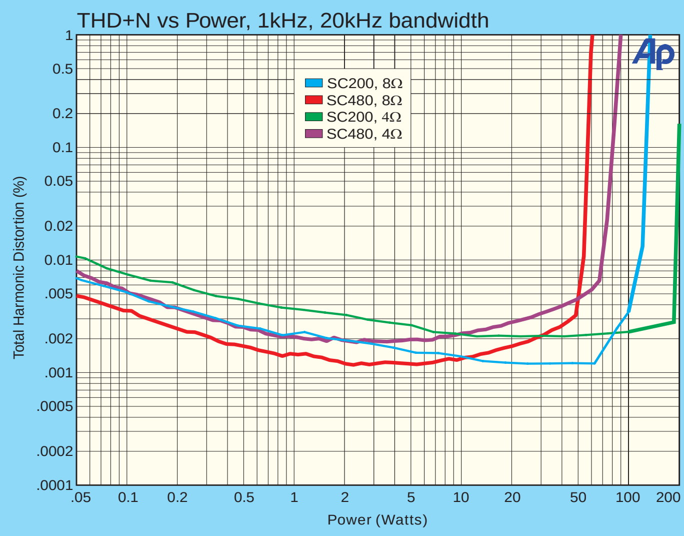


Fig.7: total harmonic distortion from 50mW up to 200W for the new SC200 amplifier, compared to the older SC480 design. Distortion is slightly higher below 10W due to the increased gain and thus noise, but significantly improved for powers above 10W and maximum power is much higher.

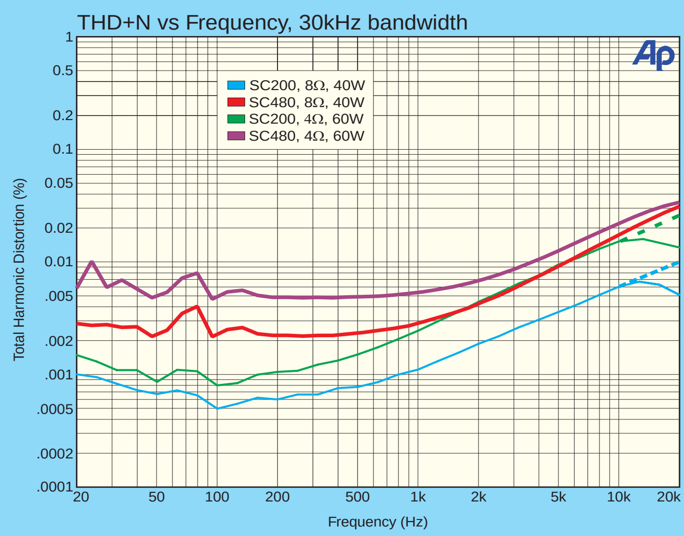


Fig.8: distortion versus frequency at 40W (8Ω load) and 60W (4Ω load). These power levels are the nominal output powers for the SC480 and this allows a direct comparison. As you can see, the distortion of the SC200 is lower, especially for 8Ω loads.

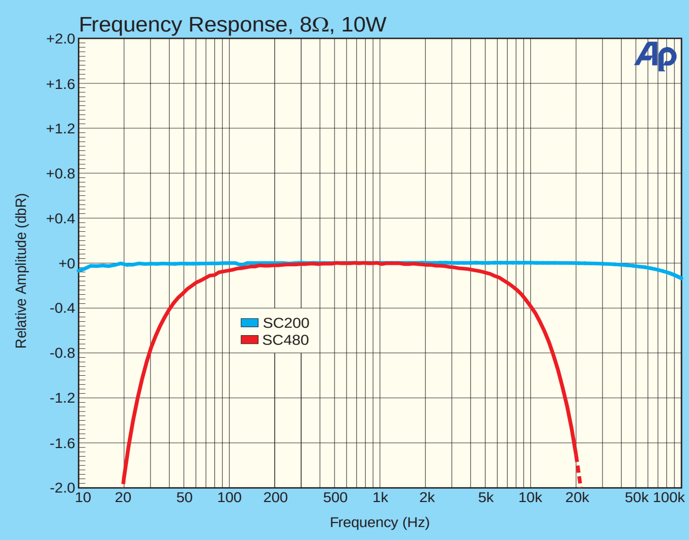


Fig.9: the frequency response of the SC200 is almost ruler-flat over the range of 10Hz-100kHz and should result in greatly extended bass, compared to the SC480.

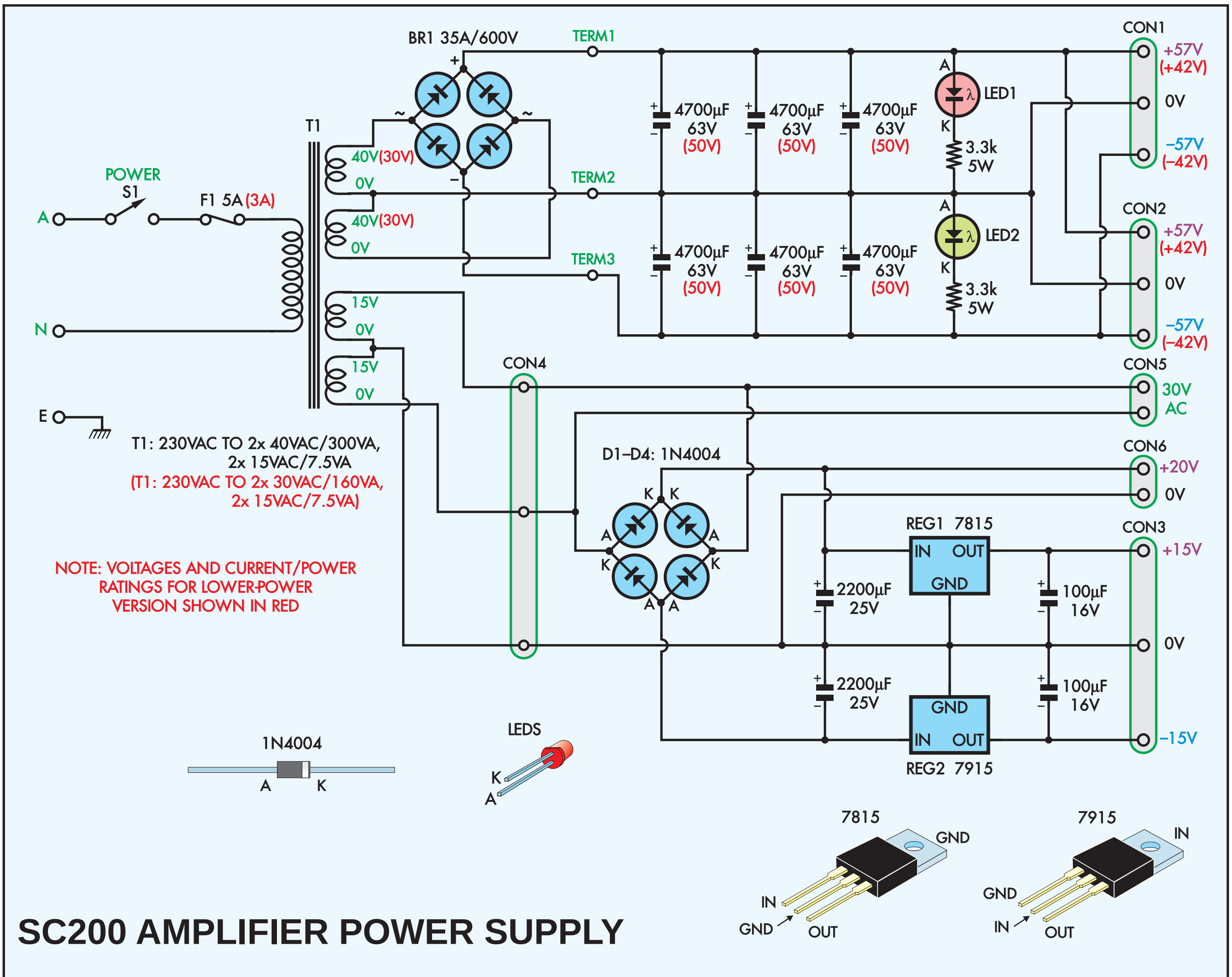


Fig.10: complete power supply circuit for the SC200. Depending on which transformer is used, the main DC rails are either ±57V, giving 135W into 8Ω and 200W into 4Ω, or ±42V, giving 75W into 8Ω and 115W into 4Ω.

Follow these with the two 3.3kΩ 5W resistors. These should be stood off the board by about 2mm, to allow the air to circulate beneath them for cooling (use a cardboard spacer during soldering).

The two 5-way screw-terminal connectors are made by dovetailing 2-way and 3-way blocks together. Be sure to fit these assemblies with the wire entry holes facing towards the adjacent edge of the PCB.

The two 3-way terminal blocks for the ±57V (or ±42V) outputs can then go in. Alternatively, instead of fitting these blocks, you can solder the DC supply leads directly to the PCB pads if it will be mounted right next to the amplifier modules.

The three quick-connect (spade) terminals are next on the list. If you are using PCB-mount connectors, simply push the pins through and solder them in place. It will take a while to heat the connectors so that the solder will 'take'. However, be careful not to overdo it, as the solder could 'wick' through the hole and onto the spade section.

If you are using 45° chassis spade lugs instead, screw them down tightly using M4 machine screws, nuts and washers – see Fig.12. If you can't get single-ended chassis lugs, cut one side off double-sided lugs.

Finally, fit the electrolytic capacitors, starting with the two 220µF units and finishing with the six large 4700µF units. Be sure to orient them correctly and make sure that they all sit flush with the PCB.

If building the lower power version, you'll probably need to crank out the capacitor leads to suit the board and it would also be a good idea to apply a little neutral-cure silicone sealant around the base of the capacitors so they aren't supported by the leads alone.

Cabling

Note that it's important to use the thickest wire you can easily fit into the terminal blocks and to keep the wiring as short and as tight as possible.

Each set of three wires from the power supply to the amplifier module should be tightly coupled by twisting them together and/or covering the bundle with a length of heatshrink tubing – ideally both.

Otherwise, the Class B currents flowing through the supply leads could couple into the amplifier module(s) and ruin the performance.

Be very careful when inserting the wires into the 3-way terminal block that you get the polarity right. Refer to the wiring diagram, Fig.13, and ensure your wiring polarity matches this. The 4-way pluggable connector for CON2 is used to run a pair of heavy wires to the speaker terminal (which should ideally be twisted together) from the terminals labelled Out and GND and optionally, two more to a headphone socket, labelled HP and GND.

Initial testing

If you're confident you've built the amplifier module correctly, it is possible to simply wire it to the power supply and fire it up. But we suggest a more prudent approach,

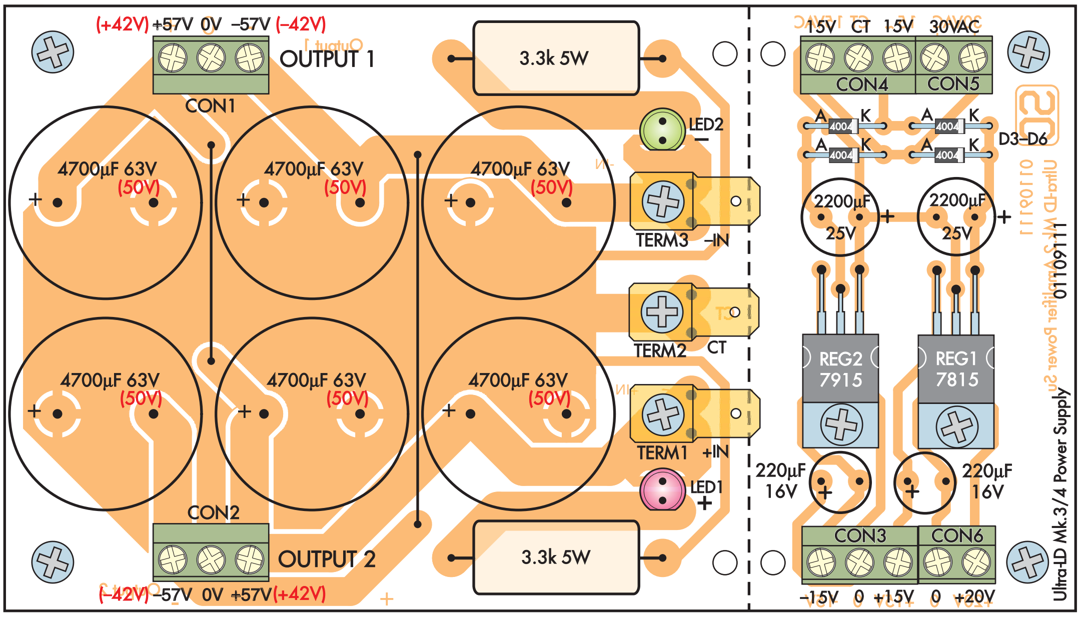


Fig.11: use this overlay diagram to help you build the power supply PCB. You can separate the two halves and even discard the right-hand section entirely if you don't need the ±15V output. The two links shown at left should be incorporated into the top layer of the PCB if you get it from *EPE*.

so it's much safer to first wire 68Ω safety resistors in series with the supply connections as this will reduce the chance of damage if something has gone wrong.

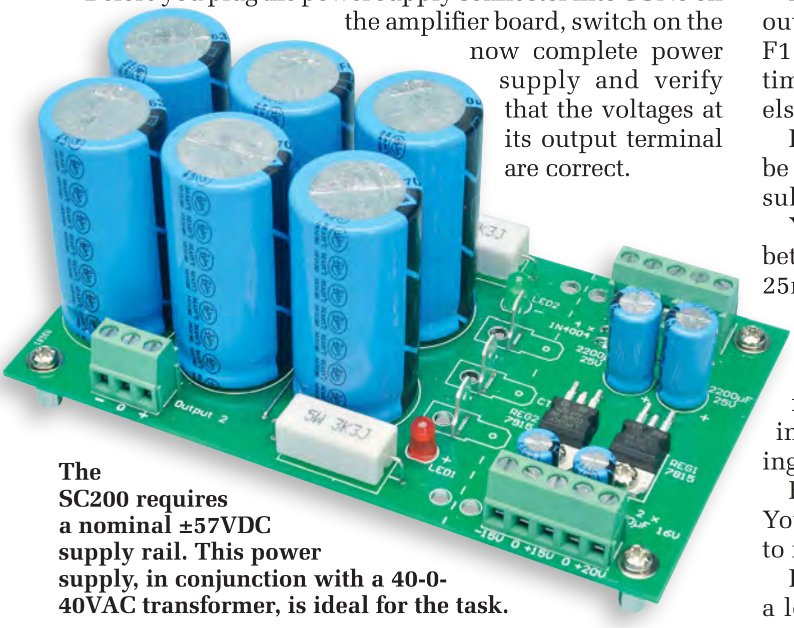
The easiest way to do this is to insert one lead of a 68Ω 5W resistor into each of the two terminals at either end of the block and do the screws up tightly, then similarly screw the other ends into a 3-way mains terminal block. You can use insulated wire or a 0.1Ω 5W resistor for the ground connection. This arrangement is shown in Fig.14.

The advantage of doing it this way is that you can easily monitor the current flowing through the resistors with a DMM (in volts mode) and the leads are unlikely to short together, as long as they are carefully arranged initially.

The other side of the terminal block is wired to the DC outputs of the power supply. This will need to be built and wired up inside an earthed case. The simplest solution is to build the power supply into the case that you intend to use for your final amplifier, and simply run an extra-long 3-way lead out of the case for testing purposes.

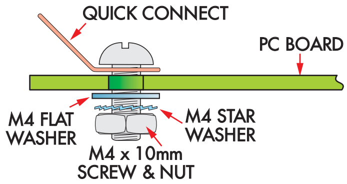
Don't skimp on this arrangement; make sure all the mains wiring is properly insulated and anchored for the tests. Once you have verified the module(s) are working you can then mount them in the case and complete the amplifier. Refer to the notes on putting the power supply together later in this article (under the 'Chassis Assembly' heading).

Before you plug the power supply connector into CON3 on the amplifier board, switch on the now complete power supply and verify that the voltages at its output terminal are correct.



The SC200 requires a nominal ±57VDC supply rail. This power supply, in conjunction with a 40-0-40VAC transformer, is ideal for the task.

Fig.12: if using the chassis-mount spade terminals on the power supply board, fit them as shown here.



The exact DC voltages will vary depending on your mains supply, but for the full power version, you should get something like 54-57V or 39-42V for the low-power version. Be especially careful to check for the correct polarity.

Switch off and wait for the LEDs on the power supply board to go out before connecting the module. Then connect a DMM set to measure volts across each safety resistor using alligator clip leads. If you don't have two DMMs, monitor one resistor. If you don't have alligator clip leads, you will have to hold the probes in place after switching power on.

Wind VR1 fully anti-clockwise and set VR2 to its halfway position using a small jeweller's screwdriver. Ensure F1 and F2 have not been fitted, then switch power on and check the onboard LEDs and the DMM readings. You should see LED1 (blue) light up along with LED 2 and 4 (red). LED6 may flicker initially, but should not stay on. Check for a reading of just under 1V across each of the safety resistors and verify that the two readings are close in value.

Assuming it's OK, switch off and wait for the LEDs to go out, which will probably take a couple of minutes. Then fit F1 and F2, switch back on and re-check everything. This time LED3 and LED5 (green) should light up but not much else should have changed.

If it does, then the output stage is suspect, eg, it could be an isolation failure on one of the output transistor insulating washers.

You can now check the output offset voltage, measuring between Out and GND on CON2. It should be less than 25mV and is usually about 10mV. Be careful not to short the two pins together!

Now rotate VR1's screw clockwise slowly while monitoring the voltage across a safety resistor. At first nothing should happen but eventually it will rise. This indicates that the Vbe multiplier is working; stop turning VR1.

Rotate VR2 and check that the offset voltage changes. You can trim it close to 0mV now, although you will need to make the final adjustment later.

If you have a scope and signal generator, you can feed a low-level signal into the amplifier (<250mV RMS) and

Parts List – SC200 Power Supply

1 PCB, available from the *EPE PCB Service*, coded 01109111, 141 × 80mm
4 3-way PCB-mount terminal blocks, 5.08mm pitch (CON1-4)
2 2-way PCB-mount terminal blocks, 5.08mm pitch (CON5-6)
3 PCB-mount or chassis-mount spade connectors
3 M4 × 10mm machine screws, nuts, flat washers and shake-proof washers (if using chassis-mount spade connectors)
4 M3 × 9mm tapped nylon spacers
10 M3 × 6mm machine screws
2 M3 shake-proof washers and nuts

Semiconductors
1 7815 regulator (REG1)
1 7915 regulator (REG2)
4 1N4004 1A diodes (D1-D4)
1 5mm green LED (LED1)
1 5mm yellow LED (LED2)

Capacitors
6 4700µF 63V [50V*] electrolytic
2 2200µF 25V electrolytic
2 220µF 16V electrolytic

Resistors
2 3.3kΩ 5W

Additional parts
1 300VA 40-0-40V + 15-0-15V transformer *OR*
1 160VA 30-0-30V + 15-0-15V transformer*
1 35A 400V chassis-mount bridge rectifier
1 chassis-mount IEC mains input socket with fuseholder and fuse
Various lengths mains-rated heavy duty hookup wire
Various spade crimp connectors Cable ties, heatshrink tubing * for lower power version

check that the output signal looks clean. Note that with the safety resistors in-circuit, it won't drive a load, nor will it handle high-swing or high-frequency signals.

Quiescent current adjustment

Switch off, wait for the LEDs to go off and remove the safety resistors. These can now be soldered across a pair of blown fuses to make handy resistor fuse adaptors; see the adjacent photo. Fit these in place of F1 and F2 and wire up the power supply direct this time, as shown in Fig.13.

Given that the earlier tests were successful, it's unlikely anything will go wrong at this stage, but it's still a good idea to have the safety resistors in place of the fuses initially. These limit the current through the output stage to about 840mA if there is a fault. Note that the 68Ω resistors will quickly burn out under such circumstances (since they would be dissipating over 40W).

Now use the following procedure to set the quiescent current and trim out the offset voltage.

STEP 1 – check that the safety resistors are installed and that their leads can't short to any adjacent parts (note: do NOT connect the loudspeaker to the amplifier during this procedure).

STEP 2 – connect a DMM set to volts across one of the safety resistors (alligator clip leads are extremely handy in this situation).

STEP 3 – turn trimpot VR1 fully anti-clockwise. This can take as many as 25 turns but it will continue to turn even so. Many (but not all) multi-turn trimpots click when they are at the end-stop. If in doubt, check the resistance across it – it should be about 1kΩ.

STEP 4 – check that the power supply is off and that the filter capacitors are discharged (LEDs off!), then connect the ±57V supply to the module. Check that the supply polarity is correct, otherwise the amplifier will be damaged when power is applied.

STEP 5 – apply power and check the voltage across the 68Ω resistor. It should be less than 1V (it may jump around a bit). If the reading is over 10V, switch off immediately and check for faults.

STEP 6 – using an insulated adjustment tool or a small flat-bladed screwdriver, slowly adjust the trimpot clockwise. Be careful not to short any adjacent components.

STEP 7 – after a few turns, the resistor voltage should stabilise and start to rise. Continue until it reads around 6V. It may drift a little but should be quite steady.

STEP 8 – switch off, wait for the capacitors to fully discharge (LEDs off) and replace the safety resistors with 6.5A fuses.

STEP 9 – connect a DMM set to volts between TP5 (to the upper left of D3) and TP7 (lower right of D3). If you have fitted PC stakes you can use alligator clip leads, otherwise you may need to get someone else to hold the probes in place while you perform the following steps.

STEP 10 – reapply power and check that the DMM reads close to 4.4mV. If necessary, readjust trimpot VR1 to bring the voltage close to this figure.

STEP 11 – now check the voltage between TP3 and TP7. The reading should be similar. Do the same check with TP4/TP7 and TP6/TP7. This verifies that all the output transistors are working and sharing the load current more or less equally.

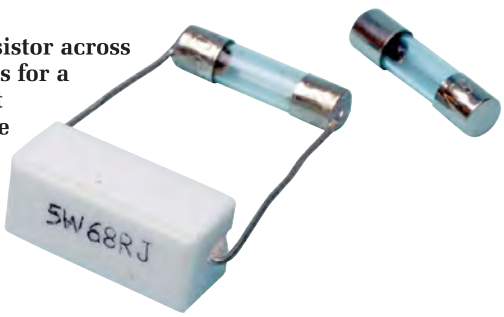
STEP 12 – adjust VR2 until the voltage across the output pins is less than 0.5mV. This is easier to do if you screw a couple of bits of wire into the top two connections of the pluggable terminal block for CON2 and clip a DMM across it using alligator clip leads. Be extra careful not to short the output terminals together! Note that this is a trial-and-error process because you will probably find each time you remove the screwdriver from VR2, it will take several seconds for the output voltage to stabilise. You will need to make very small adjustments towards the end of the process.

It's a good idea to recheck the quiescent current (ie, between TP5 and TP7) after the amplifier has been idling for a few minutes with the lid on. If the reading is more than 5mV, readjust VR1 anti-clockwise to bring it back below this figure. The stability is such that it should stay below this figure but it's a good idea to check.

That completes the adjustments. Note, however, that if you wish to repeat the above procedure (ie, with the 68Ω resistors in place), you will first have to reset VR1 to minimum (ie, fully anti-clockwise). If you don't do this, the amplifier may latch up when power is reapplied and could burn out the safety resistors.

Troubleshooting

If there's a fault in the module, a likely symptom is either excessive voltage across the safety resistors or the amplifier output voltage is pegged near one of the ±57V supply rails.



Soldering a 5W resistor across a blown fuse makes for a handy way to limit current through the amplifier's output stage during testing and adjustment.

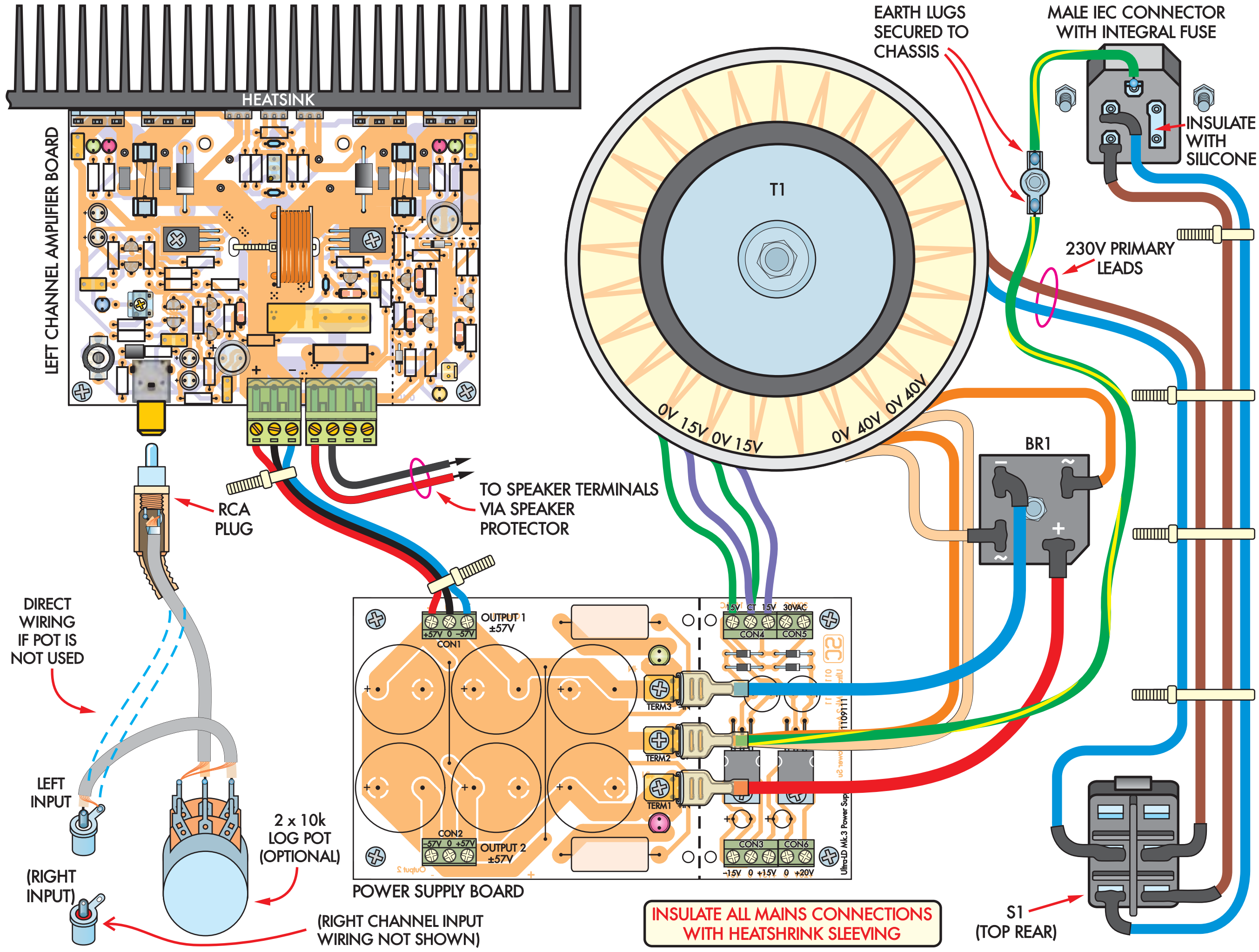


Fig.13: this shows how to wire up the amplifier module, power supply, volume control and signal input. This should give you a working mono amplifier. You can connect a second amplifier board to the same power supply, in a similar fashion as shown here, to build a stereo amplifier. Don't forget the speaker protector!

If this happens, switch off and wait for the power supply capacitors to discharge. Then check that all the large transistors are properly isolated from the heatsink. You should also carefully inspect all the solder joints on the underside of the board, to make sure that they all have good, shiny fillets and also check to make sure that all the correct component types and values are in the intended locations and none of the polarised components have been installed backwards.

If you still can't find the fault, you will need to power the amplifier up without fuses or safety resistors fitted. Then check the various voltages shown in the circuit diagram, Fig.1 on pages **20** and **21** of the January issue, with reference to the overlay diagrams of Fig.4 on page **26** in the February issue. If you find a voltage which is clearly wrong, this may give you a clue to where the fault lies.

Chassis assembly

If you want to build a complete stereo SC200 amplifier, it's vital to include a loudspeaker protection module. For a suitable module, see our design in the December 2016 issue.

Volume control

Once you've built the power supply, amplifier module(s) and speaker protector and wired them up, if you are not fitting a full preamplifier in the case, you will probably want to fit a volume control. This is quite simple and Fig.13 shows how to do it using a 10kΩ dual-gang logarithmic potentiometer.

Basically, you just need to connect the incoming signal wire to the clockwise end of the potentiometer with its shield ground to the anti-clockwise end. The reduced amplitude signals then appear at the wipers and these are connected to the signal wire for the cables going to the amplifier modules, with the shield grounds soldered together with the shields from the incoming wire (ie, to the anti-clockwise end of the potentiometer track).

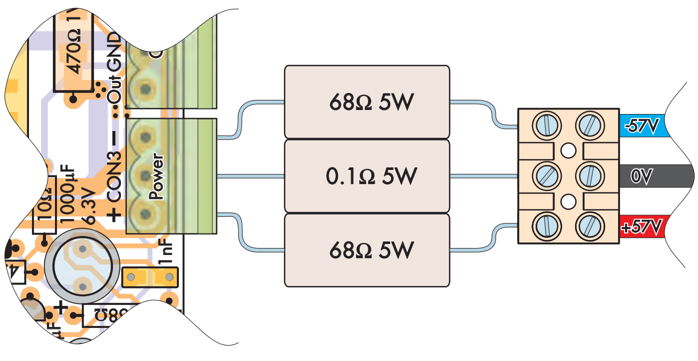


Fig.14: we recommend you connect the power supply to the amplifier board as shown here the first time you power it up. This way, if there's a fault, it's much less likely to cause any damage to the module before you have time to switch the power off.

SC200 amplifier parts sourcing

I hope you enjoyed the recent three-part series on the *SC200 amplifier*. We know quite a few of you are hoping to build it because we've had several emails about sourcing components. I've spoken to the project designer and between us we have a short list of items that we know are available.

First the transformer – the specified Altronics model is discontinued, as is the full amplifier kit. The easiest solution is to use two transformers: one 300VA 40-0-40 transformer and a 20 to 30VA 15-0-15 transformer (eg, Jaycar MT2086 or Altronics M4915B). The primaries of the two transformers should be wired in parallel. Arguably, this is superior to a single transformer since the 300VA transformer is then tasked with only supplying the power amplifier, so it will be able to supply slightly more peak current. It should also make chassis layout and wiring easier.

Second, the 'ferrite bead' choice isn't critical, but this one would work fine: http://bit.ly/2G8wEsL

Last, a couple of resistors are hard to find, but Farnell do have them:

Part 1435952: 0.1Ω, 1%, 3W 2512
Part 2476365: 6.8Ω, 5%, 3W 2512

It shouldn't matter too much if the 6.8Ω resistor is a 5% tolerance device, and not the specified 1%, since it operates with inductor L2, which will be poorly defined.