MANY OF OUR HIGH-POWER audio amplifier designs already provide an output for headphones. The additional circuitry required for headphone support is simple; just two resistors in series with the loudspeaker outputs to limit the drive current and protect the phones in the event of amplifier failure.

Considering its simplicity, this resistive limiting scheme works well, although it will cause distortion if the load is non-linear – a likely prospect with most headphones. Apart from eliminating this potential source of distortion, there are a number of other reasons why you might consider building a separate headphone amplifier.

For a start, not everyone owns a pair of top-rated headphones, or even a high-performance power amplifier. After all, an amplifier that equals or betters the performance of this new headphone amplifier will set you back more than a few pounds!

Another reason might be for use with the latest 'high-tech' audio electronics equipment. The headphone outputs in much of this gear cannot drive low-impedance phones – or at least not to decent listening levels. In addition, available output power in portable devices is deliberately limited to conserve battery energy. This means that lots of distortion might be present at higher listening levels, even with sensitive headphones.

One way around this is to feed the line-level outputs of this gear into your power amplifier and then plug your low-impedance headphones into that. That works, but then you're tethered to an immovable object. Besides, the power required to drive headphones is around 1/1000th of that required to drive loudspeakers, so a large power amplifier could be considered a tad oversized for the job!

Design outline

One of the challenges in designing a general-purpose, low-distortion headphone amplifier is catering for the huge variation in headphone specifications. Models with 8Ω (nominal) impedance are common, as are 32Ω, 60Ω, 120Ω and 600Ω versions – plus many in between.

At the high impedance end of the scale, a large output voltage swing will be necessary to develop full power, whereas at the low end, current limiting is needed to prevent driver

Features and Performance

Main Features

- High performance – very low noise and distortion
- Drives high and low-impedance headphones
- High output power (up to 200mW into 8Ω and 32Ω)
- Dual headphone sockets – can drive two pairs!
- Works with a preamp or any line-level audio source

Measured Performance

Frequency response.......................... flat from 10Hz to 20kHz (see graphs)

Rated output power..................200mW into 8Ω and 32Ω, 85mW into 600Ω

Max. output power (current or voltage limited)...................575mW into 8Ω, 700mW into 32Ω, 130mW into 600Ω

Harmonic distortion .... typically 0.0005% (600Ω load), 0.001% (32Ω load) and 0.005% (8Ω load)

Signal-to-noise ratio (A-weighted)............... –130dB (600Ω), –120dB (32Ω) and –111dB (8Ω) with respect to 100mW output power.

Channel crosstalk ....better than –68dB from 20Hz to 20kHz at 100mW output power (see graphs)

Input impedance...~47kΩ || 47pF

Output impedance.. ~5Ω

Note: all tests were performed with the amplifier driven from low source impedance. For crosstalk measurements, the non-driven input was back-terminated into 600Ω.

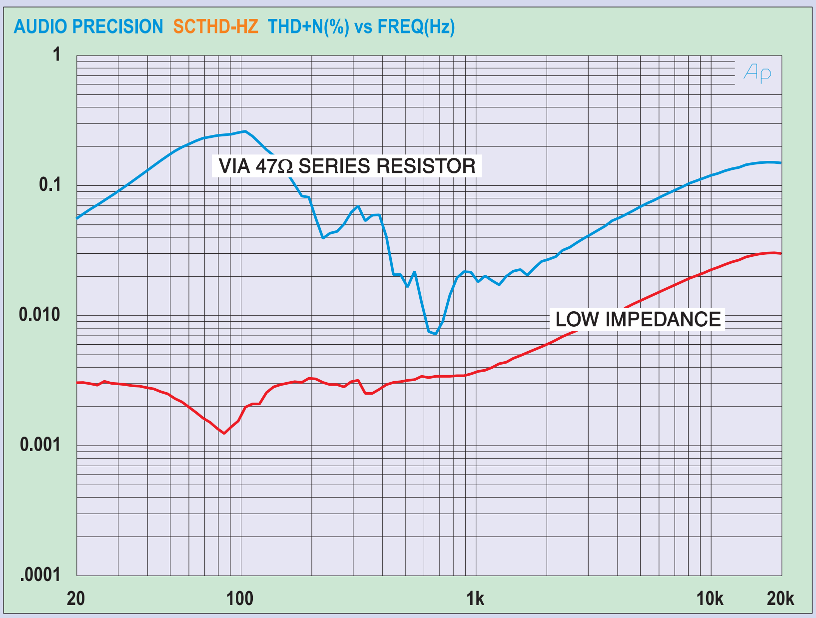

Fig.1: these plots of distortion versus frequency at 100mW highlight the impedance non-linearity of a real pair of 8Ω headphones. When driven directly from the low-impedance headphone amplifier output, performance is very good (bottom curve), as the amplifier's feedback loop can act to linearise the signal. However, when isolated with a 47Ω series resistor (top curve), the headphone's non-linearities are immediately exposed!

Parts List – Stereo Headphone Amplifier

1 PC board, code 662, size 134 × 103mm
2 PC mount switched RCA phono sockets (CON1, CON2)
2 6.35mm PC mount switched stereo sockets (CON3, CON4)
1 3-way 5mm/5.08mm terminal block (CON5)
1 8-pin gold-plated IC socket
4 TO-126/TO-220 micro-U heatsinks
4 M205 PC mount fuse clips
2 M205 500mA fast-blow fuses
4 M3 x 10mm tapped spacers
4 M3 x 6mm pan head screws
4 M3 x 10mm pan head screws
4 M3 nuts and flat washers
2 11.8mm ID plastic bobbins
1 2-metre length of 0.63mm enamelled copper wire
1 120mm length of 0.7mm tinned copper wire (for links)

Semiconductors
1 OPA2134PA dual FET-input op amp (IC1) (Farnell 791-039)
2 BC557 *PNP* transistors (Q1, Q5)
2 BC547 *NPN* transistors (Q3, Q7)
2 BD139 *NPN* transistors (Q2, Q6)
2 BD140 *PNP* transistors (Q4, Q8)
4 3mm red LEDs (LED1-LED4) – see text
12 1N4148 diodes (D1-D12)

Capacitors
2 470µF 25V PC electrolytic
4 100µF 16V PC electrolytic
2 10µF 35V/50V non-polarised PC electrolytic (max. 6.3mm diameter)
6 100nF 50V MKT polyester
2 47nF 100V polyester film (greencap)
2 1.2nF 50V MKT polyester
2 100pF 50V ceramic disc
2 47pF ceramic disc

Resistors (0.25W, 1%)

2 47kΩ	4 1kΩ
2 7.5kΩ	8 100Ω
8 4.7kΩ	2 47Ω 1W 5%
2 1.2kΩ	2 10Ω 1W 5%
2 2kΩ	4 4.7Ω 0.5W 1%

Additional items
2 RCA plugs
Shielded audio cable
1 50kΩ dual-gang log pot (for standalone use)
2 panel-mount RCA sockets (for standalone use)

For power supply upgrade
2 TO-220 micro-U heatsinks
2 M3 x 6mm pan head screws
2 M3 nuts and flat washers

or headphone burnout at abnormally high volume settings.

Another consideration is headphone impedance variation with frequency. While distortion due to this effect can be minimised with low amplifier output impedance, this requirement would seem less important than when driving loudspeakers. We're also aware that some manufacturers are producing models that have virtually flat impedance curves over the audio spectrum and so will be unaffected by an amplifier's output impedance. In fact, international standard IEC 61938 specifies that headphones should be driven by a 120Ω source, regardless of headphone impedance.

Alas, it seems unlikely that all headphones will exhibit the ideal 'flat' (purely resistive) impedance response. To test this theory, we drove a pair of reasonable quality 8Ω headphones first from a low-impedance (5Ω) source and then added a 47Ω series resistor. The results are presented in Fig.1.

Sensitive level

The maximum amplifier output power needed to produce the desired volume level depends on another widely varying parameter: headphone sensitivity. Modern dynamic headphones are very efficient, typically producing 90-100dB SPL (sound pressure level) per milliwatt of input, with many reaching full volume with just a few milliwatts. To cater for varying sensitivity levels, commercial headphone amplifiers are typically rated at between 10mW and 100mW, or more.

Unfortunately, the impedance rating of a headphone pair is not necessarily related to its sensitivity, so a general-purpose amplifier design will ultimately be a compromise. It must generate sufficient volume when driving low-sensitivity, low-impedance phones, but may well overdrive high-sensitivity and/or high-impedance models at high volume settings. It must also remain stable when driving varying impedances, and be able to develop full power into 8Ω units.

Updated and uprated

Although the heart of this design still relies on the old boosted op amp idea, it includes a number of improvements to significantly boost power handling and performance as well. In addition, we've carefully designed the PC board layout to minimise distortion and crosstalk.

The result is a unit that clearly outperforms our previous designs in all areas, yet is still relatively inexpensive and easy to build. Let's look at the circuit in more detail.

Circuit description

The amplifier consists of two identical circuits, labelled 'left' and 'right' to represent the stereo audio channels. To reduce clutter, the circuit diagram (Fig.2) shows only the left channel. Bracketed annotations refer to the right channel.

Note that some components are common to both channels, including the power supply input connector (CON5), fuses (F1, F2), filter capacitors and headphone output sockets (CON3, CON4).

An RCA phono socket (CON1) accepts the audio signal, which is AC-coupled to the circuit via a 10µF, non-polarised (NP), capacitor and terminated with a 47kΩ resistor. A 100Ω resistor and 47pF capacitor form a simple RF filter, after which the signal is fed into the non-inverting input of an op amp (IC1a).

In common with the Studio Series Stereo Preamplifier, we've used an OPA2134 audio op amp here for best performance. These op amps have excellent load-handling characteristics, with the ability to drive loads down to 600Ω while producing very low distortion. Of course, this falls far short of our 8Ω load requirement, so a current booster stage has been added between the op amp and the amplifier output.

As mentioned earlier, the booster stage is based on a pair of medium-power transistors (Q2, Q4) connected in a complementary emitter-follower configuration. Let's look at the positive (uppermost) half of the circuit first.

Fig.2: the circuit is based on an OPA2134 high-performance audio op amp (IC1), which drives a complementary emitter-follower output stage. This significantly boosts the amplifier's output current capability and therefore its maximum power output. Only the left channel is shown here – the right channel is identical.

Current source

Transistor Q1, a red LED and a 100Ω resistor form an active current source. With about 1.8V across LED1, close to 10mA flows in Q1's collector (C) circuit and this is used to drive the base (B) of output transistor Q2. Of note here is the choice of LED type; it must be red in colour and *must not* be a high-brightness type – just a standard 3mm type. The device we used exhibits the desired forward voltage (1.8V) at the programmed current. Similar types may also be suitable.

A current source greatly improves the amplifier's supply rail rejection when compared to the simpler resistive biasing that could have been used here. Further improvements can be seen in the base circuit of Q1, where we've split the usual single bias resistor into two 4.7kΩ halves and added a 100µF filter capacitor to the centre point, again improving ripple rejection. Note that the use of an LED instead of the more traditional diodes in this instance is really just for convenience, although it does provide a useful visual indication of operation.

In the quiescent (no input signal) state, most of the current flows into the op amp's output terminal (pin 1) via diode D5. This diode compensates for the base-emitter voltage of Q2, to minimise crossover distortion.

In practice, the forward voltages of D5 and Q2 will not be equal. Typically, the transistor will have a slightly lower forward voltage, so several milliamps (typically around 15 to 20mA) will flow in the emitter circuit of Q2 in the quiescent state. A 4.7Ω resistor adds a measure of stability to the emitter-follower configuration.

The other half of the circuit (Q3, LED2, D6 and Q4) is powered from the negative supply rail and operates in a complementary fashion, with the output transistor conducting on negative, rather than positive half-cycles.

Diodes D1 to D4 add output current limiting and prevent large

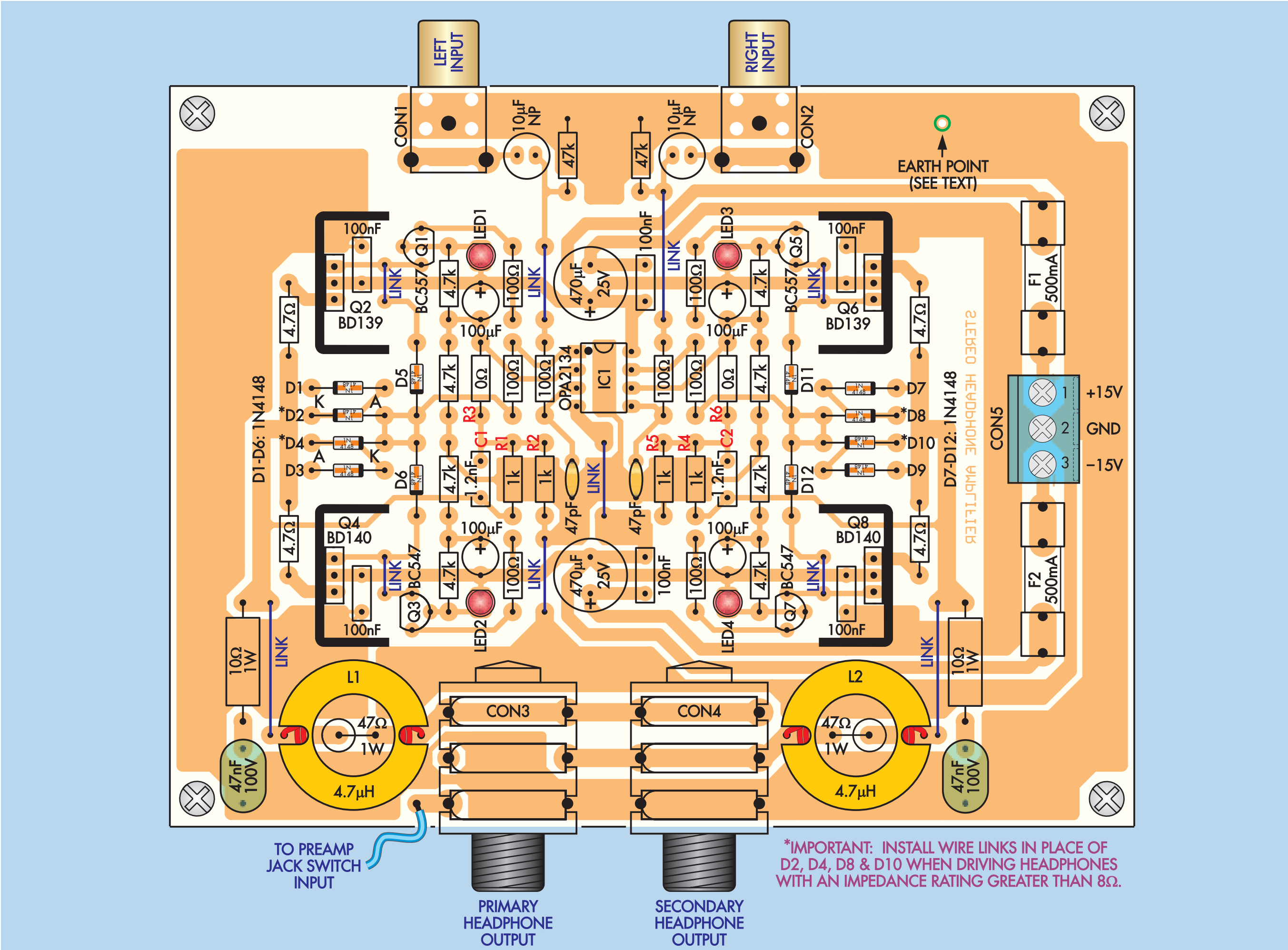

Fig.3: follow this parts layout diagram closely when assembling the headphone amplifier. Be careful not to mix up the different transistor types and double-check the orientation of the diodes, LEDs and polarised electrolytic capacitors before applying power.

reverse voltages from appearing across the circuit during a short-circuit condition. All four diodes are installed for operation into 8Ω

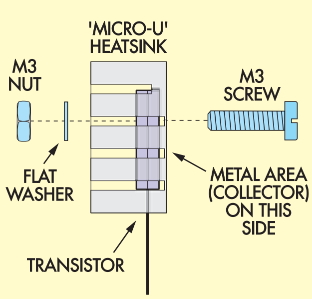

Fig.4: here's how to assemble the heatsinks to the output transistors, which must be done before fitting the transistors to the board. Make sure that the metal face of each transistor mates with the heatsink and be sure to smear both mating surfaces with heatsink compound.

headphones, giving a maximum output current of about two diodes drops (2 × 0.7V) divided by the emitter resistance (4.7Ω). For higher impedance headphones, two of the diodes in each channel must be replaced with wire links, halving the maximum current and therefore reducing the chances of accidental headphone damage.

The amplifier's output signal is picked off at the junction of the two 4.7Ω emitter resistors and fed back to the inverting input (pin 2) of op amp IC1a via resistor R1. Including the output circuit in the op amp's feedback loop has two important advantages. First, it allows the op amp to servo the output to near 0V with no input signal, accounting for mismatches in the complementary halves of the circuit. It also results in an overall improvement in linearity and reduces crossover distortion.

Resistors R1 and R2 set the amplifier gain in the usual manner, giving a gain of +2 (1+ R1/R2) with the 1kΩ values shown. This is suitable for use with a preamplifier and/or when driving 8Ω headphones (see the 'Tweaking Your Headphone Amplifier' panel for other options).

In conjunction with R1, the 1.2nF capacitor (C1) in the feedback path rolls off amplifier frequency response above the audio spectrum.

Finally, an *RLC* network at the output isolates the amplifier from headphone reactance and ensures stability under all conditions. The low impedance of the inductor (L1) at audio frequencies also allows the amplifier to drive difficult loads (down to 8Ω) with very good results. We've used air-cored inductors to avoid the signal distortion that would be introduced by ferrite and iron-cored alternatives.

Here's what a completed inductor looks like (you need two), prior to scraping off the enamel insulation and tinning the leads.

Assembly

Assembly is quite straightforward, with all parts mounting on a 134 × 103mm single-sided PC board (code 662). Fig.3 shows the details.

Begin by installing the 10 wire links, then install the 1N4148 diodes (D1 to D12). **Note that D2, D4, D8 and D10 are only installed if you intend using the amplifier with 8Ω headphones. For all higher impedance phones, install wire links in these four locations instead** (see the 'Tweaking Your Headphone Amplifier' panel).

Make sure that the cathode (banded) ends of the diodes are oriented as shown on Fig.3.

The 0.25W and 0.5W resistors and LEDs (LED1 to LED4) can be installed next. **Use wire links for R3 and R6 if you'll be feeding your amplifier from a preamp. Conversely, install 2kΩ values in these two locations if you'll be feeding it from a line-level source via a 50kΩ volume pot.** When inserting the LEDs, make sure that you have the flat (cathode) side of the body oriented as drawn on the overlay.

IC1's socket, the four fuse clips, transistors Q1, Q3, Q5 and Q7, the capacitors and connectors CON1 to CON5 can all go in next. Take care not to mix up the two types of transistors (BC547, BC557), and note that the 100μF and 470μF electrolytic capacitors are polarised and must be installed with their positive leads oriented as indicated by the '+' marking in Fig.3.

All that now remains to be installed are the 1W resistors, the output transistors and their heatsinks and the two inductors. The transistors and inductors require special attention, so fit the 1W resistors first. The two 47Ω units are positioned in the inductor 'centres' and therefore must be mounted vertically, rather than horizontally.

Table 1: Capacitor Codes

Value	μF Code	EIA Code	IEC Code
100nF	0.1μF	104	100n
47nF	.047μF	473	47n
1.2nF	.0012μF	122	1n2
100pF	NA	100	100p
47pF	NA	47	47p

Transistor installation

The four output transistors (Q2, Q4, Q6 and Q8) are fitted with 'micro-U' style heatsinks *before* installation. To do this, apply a thin smear of heatsink compound to the rear (metal) face of each transistor, as well as the mating surface on each heatsink (do not use insulating washers). Affix each transistor to its heatsink using an M3 × 10mm screw, nut and flat washer (see

This is the prototype Headphone Amplifier. The final version includes a second headphone socket and has a few other minor changes.

Table 2: Resistor Colour Codes

❏	No.	Value	4-Band Code (1%)	5-Band Code (1%)
❏	2	47kΩ	yellow violet orange brown	yellow violet black red brown
❏	2	7.5kΩ	violet green red brown	violet green black brown brown
❏	8	4.7kΩ	yellow violet red brown	yellow violet black brown brown
❏	2	1.2kΩ	brown red red brown	brown red black brown brown
❏	2	2kΩ	red black red brown	red black black brown brown
❏	4	1kΩ	brown black red brown	brown black black brown brown
❏	8	100Ω	brown black brown brown	brown black black black brown
❏	2	47Ω	yellow violet black gold	not applicable
❏	2	10Ω	brown black black gold	not applicable
❏	4	4.7Ω	yellow violet gold brown	yellow violet black silver brown

Tweaking Your Headphone Amplifier

FOR THE BEST listening experience, the headphone amplifier can be fed from the Studio Series Stereo Preamplifier described last month. With this combination, a pair of top-quality 32Ω (or higher) impedance headphones will provide superb performance.

Good results can also be obtained with 8Ω headphones or even two pairs of 32Ω (or higher) units, if you want to share the experience. In addition, the headphone amplifier can be operated 'standalone', where it connects directly to a line-level signal source (no preamp required). Let's see how to get the best performance in each case.

Using 8Ω headphones

Considerable efforts were made to ensure that the amplifier drives 8Ω headphones with low distortion. To ensure you get the same results, all eight limiting diodes (D1-D4 and D7-D10) must be installed when driving 8Ω headphones! For higher impedance phones, wire links are used in place of D2, D4, D8 and D10 only.

What if you own both 8Ω and 32Ω (or higher) impedance phones and you want to use all of them with the headphone amplifier – without making changes to the board? Well, while 32Ω (or higher) headphones can be plugged into an amplifier that's configured for 8Ω use, you need to be aware of the potential risks. The amplifier is capable of delivering over 1W into 32Ω in this case, which is potentially destructive for headphones, your hearing and ultimately the amplifier as well!

By the way, we do not recommend increasing the amplifier gain (see 'Boosting volume') when driving 8Ω headphones, as this will cause an unavoidable increase in harmonic distortion. With the default signal gain of 6dB, only about 630mV RMS is required at the input to develop the full 200mW into 8Ω, hence increasing gain for typical line-level signals is pointless.

Boosting volume

Using the component values shown on the circuit and overlay (Fig.2 and Fig.3), the headphone amplifier operates with a voltage gain of two (6dB), which is more than adequate when the unit is fed from a preamplifier. It should also work fine when driving 8Ω headphones, regardless of the audio source.

However, if you want to connect the unit directly to a line-level source via a volume pot (see 'Standalone use' below) and you'll be using 32Ω or higher impedance phones, then you may find that the volume is not loud enough, even with the controls wound right up.

If after building and testing the amplifier you find that more volume is required, then the amplifier gain can be increased to 7.2 (17dB) to allow the full rated output power to be realised in all cases with a 1V RMS input signal. To increase the gain, use the following component values in place of those shown on the circuit and overlay diagrams: R1 and R4 = 7.5kΩ, R2 and R5 = 1.2kΩ and C1 and C2 = 100pF.

One negative aspect of increasing amplifier gain is an accompanying increase in harmonic distortion. Nevertheless, performance is still excellent, with 0.0004% THD when driving 600Ω and 0.004% when driving 32Ω headphones, measured at the full rated output power.

Standalone use (no preamp)

When feeding the amplifier directly from a line-level source, some method of volume control will usually be required. This is easily provided with a 50kΩ dual-gang log potentiometer, inserted in series with the inputs to the amplifier (see Fig.5).

One disadvantage of this scheme is that op amp source impedance varies with changes in volume, resulting in higher signal distortion. To offset this effect somewhat, 2kΩ values can be used for resistors R3 and R6.

Accounting for feedback resistance, the inverting input will then see about 2.5kΩ (R1||R2 + R3), assuming the default 1kΩ values were used for the feedback resistors. The result is improved matching at the non-inverting input at nominal volume settings.

Note that the same 2kΩ values can be used for R3 and R6 when the amplifier is configured for the higher 17db gain option (see 'Boosting volume'). In this case, the inverting input will see about 3kΩ.

We acknowledge that the 2.5kΩ to 3kΩ values are only a rough estimation, as the real source impedance can vary anywhere from about 100Ω to 10kΩ. Considering headphone sensitivity variation, it would appear to be impossible to establish a 'typical' volume setting.

Important: when feeding your headphone amplifier from a preamplifier or other low-impedance source, resistors R3 and R6 must be 0Ω in value – use wire links!

Dual outputs

The headphone amplifier includes dual 6.35mm output sockets, allowing simultaneous connection of two pairs of headphones. Two important rules must be followed when using both sockets at once: (1) the headphones must be of the same nominal impedance rating; and (2) the impedance ratings must be 32Ω or higher.

Many listeners will prefer to set their own volume levels and this can be catered for by using headphones with in-line volume controls. Separate volume control boxes are also available from specialist audio outlets.

Note that although the sockets are connected in parallel, the jack switch output connects to the first (primary) socket only, so this socket will control the headphone/power amplifier signal routing relay on the Studio Series Preamplifier.

Fig.4), allowing just enough slack so that the transistor and mounting screw can move up and down in the heatsink slot.

Insert a transistor into its holes in the PC board (don't mix up the two types), pushing it all the way home, so that the mounting screw is all the way down in the heatsink slot and the edge of the heatsink is in full contact with the board surface. If you can't achieve this, then you've fitted the heatsink upside down!

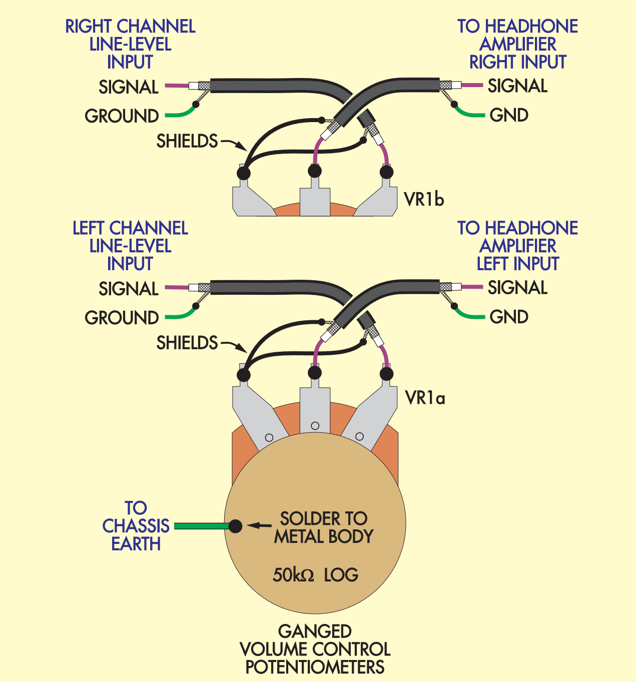

Fig.5: a potentiometer can be inserted in series with the input signals to function as a simple volume control. The metal body of the pot must be connected to chassis earth, otherwise mains hum will be introduced into the amplifier inputs.

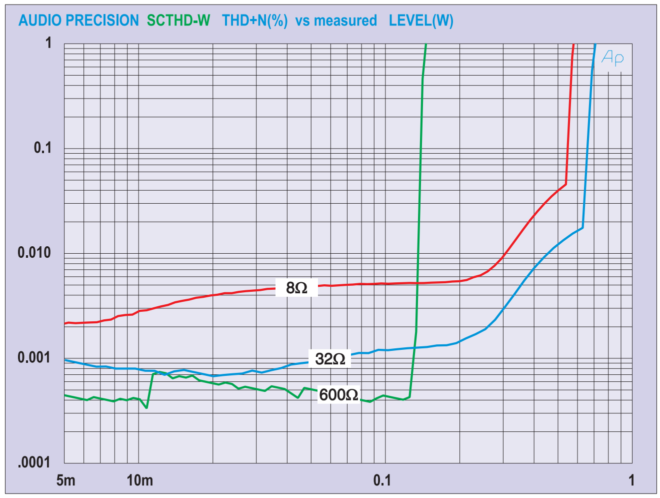

Fig.6: amplifier total harmonic distortion and noise versus output power into 8Ω, 32Ω and 600Ω resistive loads. When driving 8Ω and 32Ω loads, the current-limiting diodes begin to conduct around the 200mW mark, causing a gradual increase in distortion. Once the diodes are fully forward-biased, the output current is aggressively clamped, resulting in an almost vertical rise in distortion. For the 600Ω case, the amplifier abruptly runs out of voltage headroom at about 130mW and hard clipping is the result.

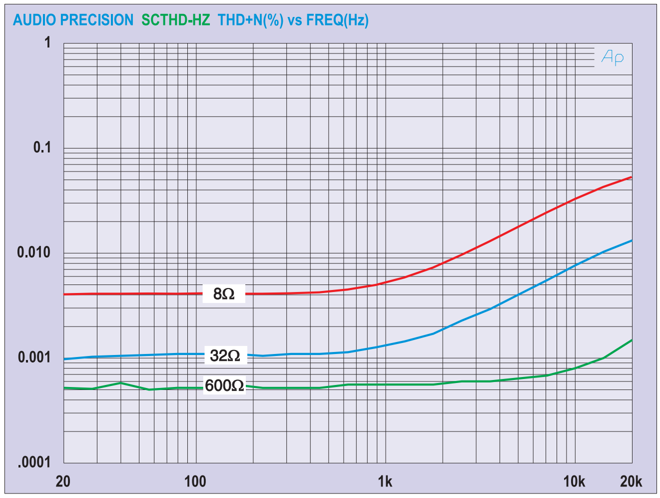

Fig.7: amplifier total harmonic distortion (THD) and noise versus frequency, measured with an output power level of 100mW. As is clear from these curves, the amplifier performs much better when driving 32Ω and higher impedance headphones. Most headphones will reach full output well below 100mW, so you can expect even better performance than these already excellent curves reveal!

Without disturbing the transistor/heatsink assembly, turn the board over and solder the transistor leads. The mounting screw can now be carefully tightened. Don't overdo it; applying too much torque will disturb the package/heatsink position!

Winding the inductors

The two inductors (L1, L2) are hand-wound. Each requires a plastic bobbin, about 1m of 0.63mm enamelled copper wire and electrical insulation tape. Some kit suppliers might provide these items preassembled, in which case you can skip the following instructions.

The insulation tape is needed to hold the windings in place while the assembly is fitted to the PC board. General-purpose tape will be wider than the bobbin, but can easily be made to fit by slicing off the unneeded width with a razor blade. Stick the tape down on a smooth, clean surface first to make the job easier.

Play out the wire before beginning and remove any kinks. Starting at one of the slots, wind on one complete layer, keeping the wire taut as you go. With one complete layer in place, start winding back over the first layer. In all, 21 turns are required, but you'll need an extra half-turn so that the wire exits at the opposite slot to the starting end (see photo).

Wind on two or three turns of insulation tape to hold the windings in place. Finally, scrape the enamel insulation off the ends of the two leads and tin them before mounting the inductor on the PC board.

Hook-up

For best results, the amplifier should be powered from the low-noise power supply described last month as part of the Studio Series Preamplifier. Even if you decide to use a different supply, the guidelines in that article regarding mains wiring, housing and general layout also apply here.

An additional step when using the low-noise supply with this amplifier is to fit small heatsinks to the ±15V regulators (see parts list). Apply a thin smear of heatsink compound to the mating surfaces during assembly, to aid heat transfer.

We'll assume that you've already assembled and tested the power supply. All that remains is to hook up the amplifier's power and signal inputs.

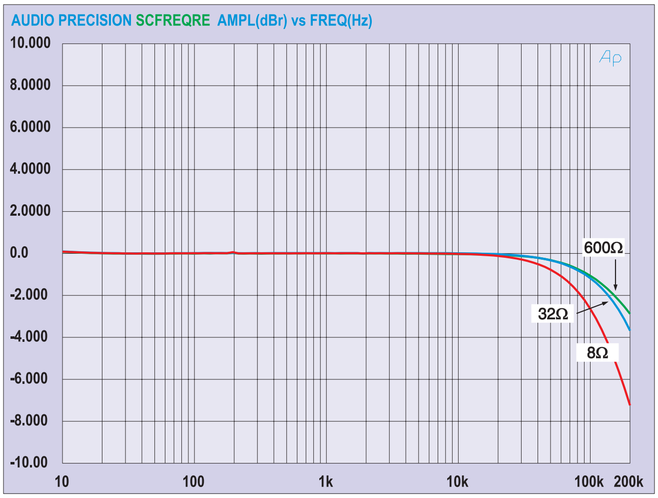

Fig.8: this graph plots the amplifier output voltage versus frequency when driven at 200mW into 8Ω, 32Ω and 600Ω loads and with 6dB of gain. As can be seen, the response is ruler flat over the audio spectrum, gently rolling off at the top end at a rate dependent on the feedback network and output loading.

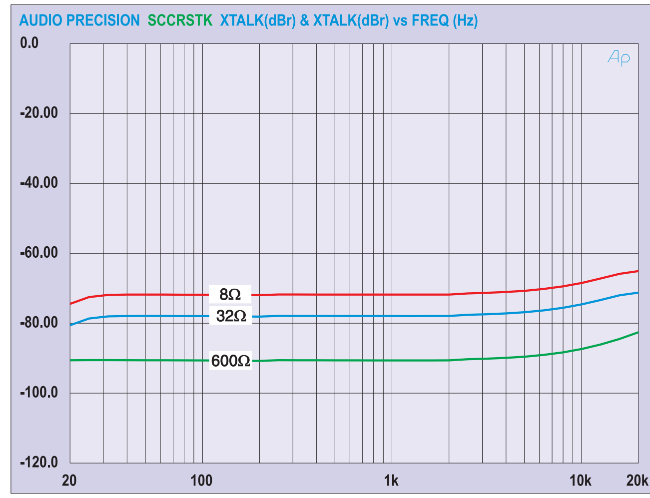

Fig.9: this is the crosstalk, again measured for 8Ω, 32Ω and 600Ω loads. Some of the coupling is due to the commoning of the headphone left and right return (ground) leads at the jack plug. The results (although good) would be better if the headphones used 4-contact jacks, thus allowing separate grounds for the left and right channels.

Connect the +15V, –15V and GND outputs of the supply to the headphone amplifier's power inputs at CON5, using medium-duty, multi-strand hook-up wire. Twist the wires tightly together to reduce noise and improve appearance. Take great care to ensure that you have all of the connections correct – a mistake here will destroy many components on the amplifier board!

Boxing-up

When installing the unit in a case with a preamp module, the headphone amplifier must not be separately earthed – only the preamp board should be earthed. However, if you're building a standalone unit (no preamp), then the headphone amplifier's common (GND) rail should be connected to chassis earth.

This is achieved by running a wire from the pad marked 'EARTH' on the amplifier board to the main chassis earth point. Do not connect any other part of the circuit or power supply to chassis earth (except the volume pot, see below).

For a standalone unit, the volume pot can be wired up next. Use a dual-gang, 50kΩ logarithmic type, connected with audio-quality shielded cable (see Fig.5). The cable may be terminated with panel-mounted RCA phono sockets on the signal input side and RCA phono plugs on the output side, which are then plugged into the RCA inputs on the amplifier board.

Caution!

Continual exposure to very high noise levels (including loud music) will cause hearing loss and can cause tinnitus. Hearing loss is cumulative, gradual and almost symptomless!

The metal body of the pot must be connected to chassis earth to reduce noise pickup. Do *not* connect the body to either of the shielded cables! Normally, the front panel will provide the necessary earth connection. If it doesn't, then connect the pot to a convenient chassis earth point using hook-up wire. Note that solder won't adhere to the nickel plating on the pot, so remove a small area of the plating with an ink rubber or scouring pad prior to tinning.

When used with a preamp, the additional volume pot is not needed. Instead, you simply wire the switched headphone outputs on the preamp to phono plugs using audio-quality shielded cable. These then plug into the phono sockets on the headphone amplifier.

In addition, the 'JACKSW' output of the headphone amplifier must be wired to the 'SWITCH' input on the preamp board. This connection will allow the preamp to reroute the audio signal from the power amplifier output to the internal headphone output when a headphone jack is inserted in its socket. Leave the 'GND' terminal on CON7 of the preamp disconnected.

Testing

To check your completed amplifier, install the fuses and power up. The four LEDs should immediately light up – if not, switch off quickly and check for serious cabling or board assembly problems. If only one LED doesn't light, then the problem is at least restricted to the associated current source/sink part of the circuit.

If all LEDs light as expected, then use your multimeter to measure the voltage between each output and ground. These points are conveniently accessible at one end of the 10Ω 1W resistors. If all is well, your meter should read within ±2mV of 0V.

Next, measure the voltage drop across each of the 4.7Ω emitter resistors (situated adjacent to the heatsinks). All should measure between about 0V and 100mV, representing a maximum emitter current of about 21mA. Note that this measurement assumes the transistors are idling at room temperature. The reading may be higher if the amplifier has been in recent use and the output transistors have warmed up.

OK, we're done. Now for the best part – the listening test – Enjoy! **EPE**

PLEASE NOTE

Stereo Preamplifier (*Feb '08*)

Page 27, Parts List. The last entry under 'Additional items': The value of the X2 type suppression capacitor should be **1nF** 250V AC. The power supply circuit (Fig.4) is correct.