Easy-to-build circuit includes group delay compensation

Headphone amplifier for CD players

CD players which have only one D-A converter inevitably have a phase difference between channels. This unit corrects that error and also provides two headphone outputs with adjustable level. It is a high performance circuit which does not degrade the CD signal quality.

by JOHN CLARKE

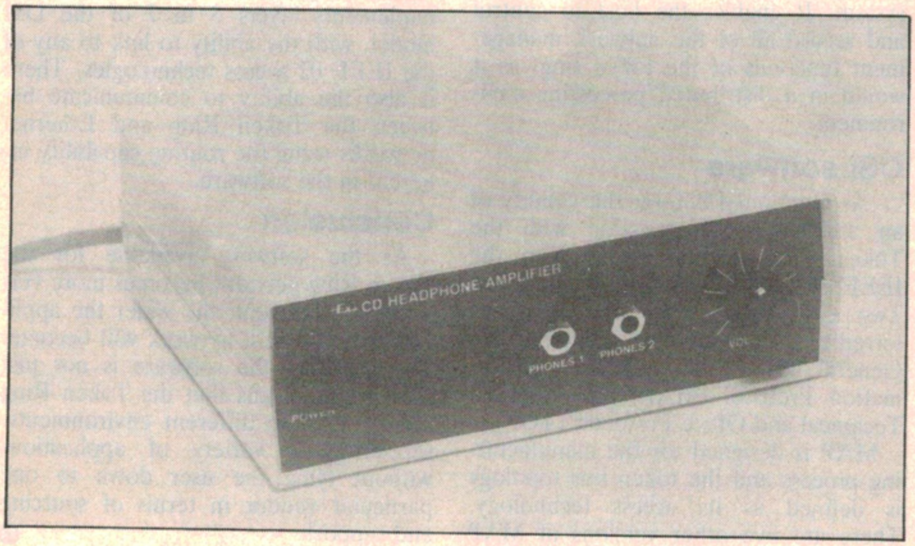
There are two possible reasons for building this project, depending on your requirements. The first reason could apply to most people who have a CD player. With the inclusion of a headphone amplifier and set of headphones, a compact disc player can become a complete and relatively inexpensive hifi system.

Let's face it. There are many times when it is not possible to listen via loudspeakers and so you are better off listening via headphones than not at all. The problem is, quite a few CD players do not have a headphone socket and if they do, the maximum output level may not be sufficient to drive all headphones to adequate sound levels.

Also, some CD players do not include a volume control for the headphone socket and this is unacceptable for anything more than the shortest of listening periods.

Of course, the chances are that your amplifier has a headphone socket with more than adequate output drive but there is something silly, isn't there, about listening to a pair of headphones via a 50 to 100 watt per channel amplifier. More often than not too, unless the amplifier's performance is exceptional, it will degrade the signal quality from your CD player.

Therefore, we have recognised that there is a need for a high quality headphone amplifier with performance equal to or better than compact disc standards. We also went one better than the typical amplifier by providing two headphone sockets.



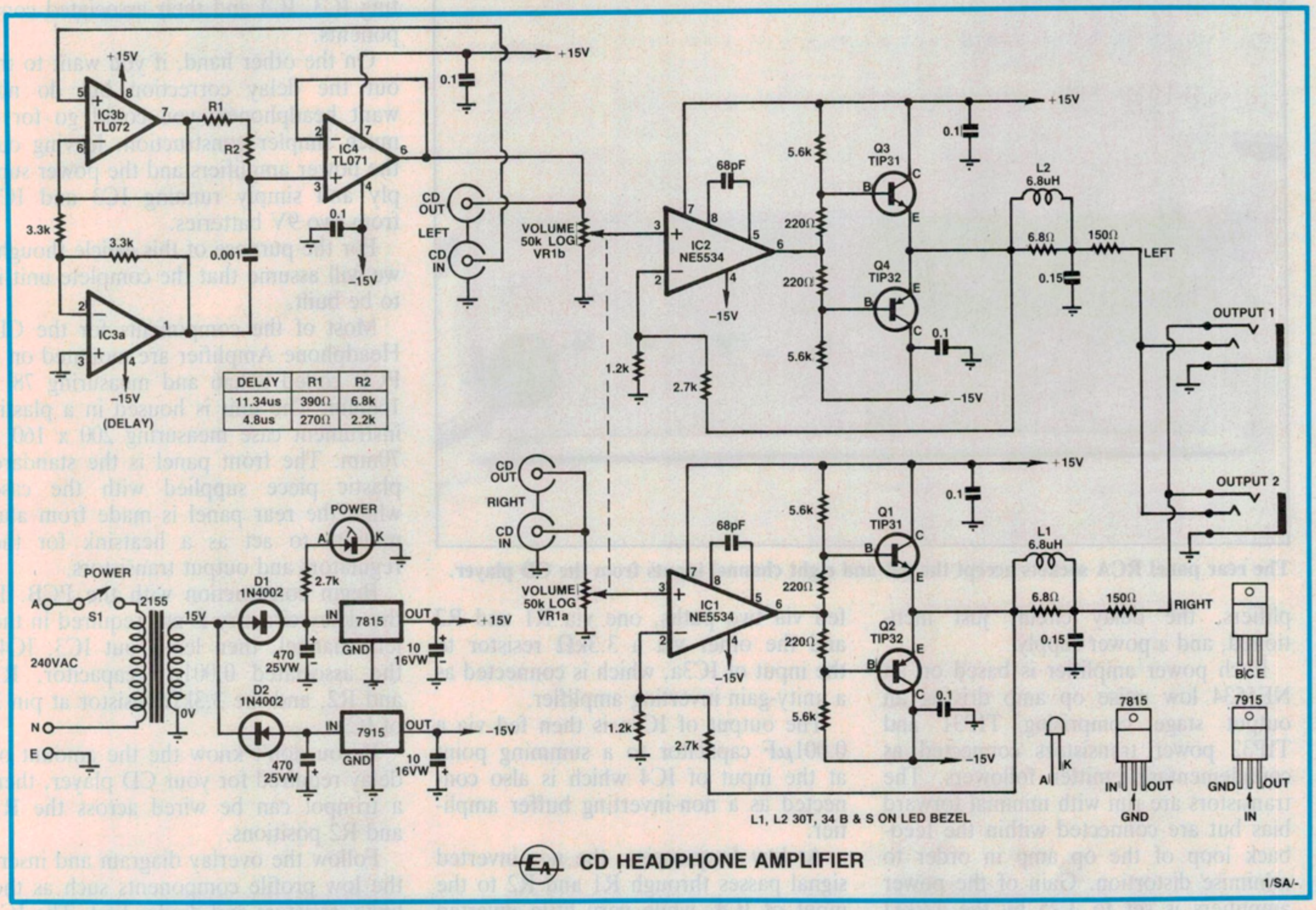
Phase error correction

The second feature of this project which is likely to be of interest to readers is the phase error correction circuit. This compensates for the inevitable phase error that occurs in CD players which use only a single digital-to-analog converter. The majority of CD players from Japan, with a number of notable exceptions, come into this category.

Strictly speaking, it is more correct to refer to group delay rather than phase delay. In a compact disc player, the digital information is read off the disc in serial form and stored in memory. Then the data is fed to the D-A decoder so that the signal for the left channel comes out slightly ahead of that for the right channel.

For some players with a single D-A decoder, the delay is 11.34μs while others have a shorter delay of 4.8μs. This delay applies to right-channel signals of all frequencies and constitutes a phase error which is directly proportional to frequency. For those decks with a delay of 11.34μs, the phase error at 20kHz is about 81 degrees while for those with 4.8μs delay, the phase error is about 35 degrees at 20kHz.

Whether or not this delay or phase error is audible probably depends on



The circuit consists of two low power amplifiers, a delay circuit (IC3 and IC4) and a power supply.

the listening situation. Significantly perhaps, most of the CD players from Europe which are highly regarded amongst audiophiles are Philips-based and have dual D-A decoders (14-bit with 4-times over-sampling) and hence no phase error. Notable CD players from Japan which feature dual D-A converters are Denon and Nakamichi and again, these players are highly regarded amongst audiophiles.

Those who discount the importance of this phase error point out that it amounts to a path difference from the speakers to the ear of less than 4mm. For headphone listening it may be more significant.

Whether or not you believe the phase error to be significant is perhaps unimportant. Those who believe that it is important now have the means to correct it. Those who believe that it is unimportant can build this circuit (or the relevant part thereof) to put their belief to the test.

Unfortunately, the right channel delay is not specified by manufacturers of players with a single D-A converter. Some typical figures for current model CD players are as follows: ADC CD100X, 4.8μs; Audio Technica AT-CD20, 11.34μs; Onkyo DX-200, 4.8μs; Pioneer PD-M6, 11μs; Sharp DX-111, 4.8μs; and Sony CDP-502ES, 4.8μs.

Readers with other CD players will need to determine the delay between channels before completing the headphone amplifier. This will be discussed later in the article after the construction.

Features

Our CD Headphone Amplifier is housed in a plastic instrument case and is powered from the mains. The front panel features include a power on/off switch, volume control and two headphone sockets.

At the rear is a four-way RCA socket panel which provides for the left and right CD inputs and sockets for the right and delayed left outputs. These can be applied to the input sockets of a power amplifier.

Circuitry

The CD Headphone Amplifier comprises two high-quality low-power am-

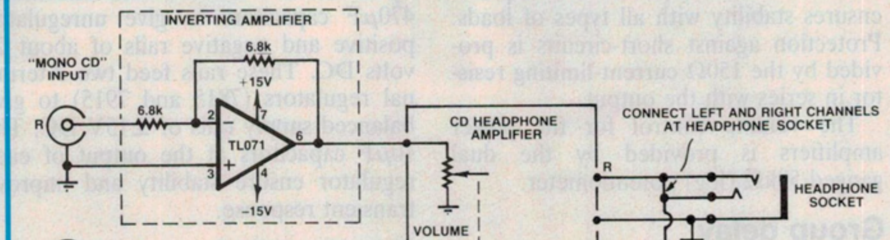
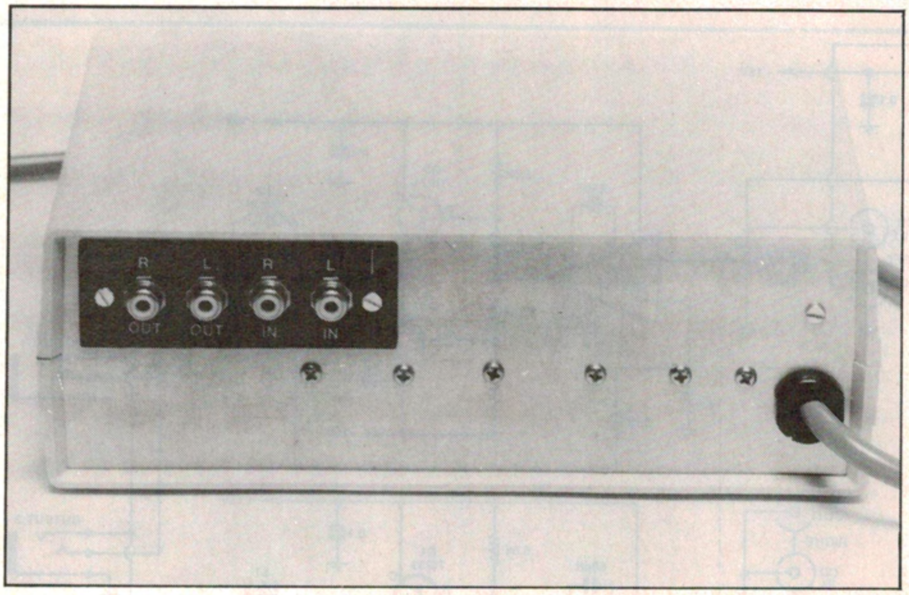


Fig.1: arrangement for adjusting the delay circuit in the headphone amplifier. A 10kΩ trimpot is substituted for R1 and R2 and adjusted for minimum sound output.



The rear panel RCA sockets accept the left and right channel inputs from the CD player.

plifiers, the delay circuit just mentioned, and a power supply.

Each power amplifier is based on an NE5534 low noise op amp driving an output stage comprising TIP31 and TIP32 power transistors connected as complementary emitter followers. The transistors are run with minimal forward bias but are connected within the feedback loop of the op amp in order to minimise distortion. Gain of the power amplifiers is set to 3.25 by the 1.2kΩ resistor at the inverting input and the 2.7kΩ feedback resistor.

The quiescent forward biasing for the driver output is supplied by the two 220Ω biasing resistors between the bases of the two transistors and the 5.6kΩ resistors from the bases to the positive and negative supply rails. The resulting bias is not enough to cause significant current to pass through the output transistors but is enough to effect a major reduction in crossover distortion.

A 68pF capacitor connected to pins 5 and 8 of the NE5534 op amp provides frequency compensation while the RLC network at the output of the amplifier ensures stability with all types of loads. Protection against short-circuits is provided by the 150Ω current-limiting resistor in series with the output.

The volume control for the power amplifiers is provided by the dual ganged 50kΩ (log) potentiometer.

Group delay

The group delay circuit precedes the left channel power amplifier and is an all-pass filter comprising IC3 and IC4. IC3 is a dual op amp with IC3b connected as a unity gain non-inverting buffer. The output signal from IC3b is fed via two paths, one via R1 and R2 and the other via a 3.3kΩ resistor to the input of IC3a, which is connected as a unity-gain inverting amplifier.

The output of IC3a is then fed via a 0.001μF capacitor to a summing point at the input of IC4 which is also connected as a non-inverting buffer amplifier.

At low frequencies, the non-inverted signal passes through R1 and R2 to the input of IC4, while very little inverted signal is transmitted via the 0.001μF capacitor. At higher frequencies, the capacitor allows more inverted signal from IC3a to pass through to the input of IC4. Since this summing point combines the non-inverted signal and the inverted signal, the result is a gradual phase delay which increases with frequency.

For a required delay of 11.34μs, R1 and R2 should be 390Ω and 6.8kΩ respectively. For a delay of 4.8μs, R1 and R2 should be 270Ω and 2.2kΩ respectively.

The power supply uses a 15VAC transformer which is half wave rectified by diodes D1 and D2 and filtered by 470μF capacitors to give unregulated positive and negative rails of about 20 volts DC. These rails feed two 3-terminal regulators (7815 and 7915) to give balanced supply rails of ±15V DC. The 10μF capacitors at the output of each regulator ensure stability and improve transient response.

Construction

As noted above, there are two possible reasons for building this project. If you want the double headphone facility but do not require the delay correction circuitry, it is simply a matter of omitting IC3, IC4 and their associated components.

On the other hand, if you want to try out the delay correction but do not want headphones, you could go for a much simpler construction, leaving out the power amplifiers and the power supply and simply running IC3 and IC4 from two 9V batteries.

For the purpose of this article though, we will assume that the complete unit is to be built.

Most of the components for the CD Headphone Amplifier are mounted on a PCB coded 87ha6 and measuring 78 x 168mm. The unit is housed in a plastic instrument case measuring 200 x 160 x 70mm. The front panel is the standard plastic piece supplied with the case while the rear panel is made from aluminium to act as a heatsink for the regulators and output transistors.

Begin construction with the PCB. If the delay circuitry is not required in the left channel, then leave out IC3, IC4, the associated 0.001μF capacitor, R1 and R2, and the 3.3kΩ resistor at pin 2 of IC3.

If you don't know the the amount of delay required for your CD player, then a trimpot can be wired across the R1 and R2 positions.

Follow the overlay diagram and insert the low profile components such as the links, resistors and diodes first. The ICs can then be inserted. Make sure that ther are correctly oriented before soldering them in place.

We used PC stakes for all external connections to the PCB including the driver transistors and regulators. This facilitates wiring and connection to the transistors and regulators once the PCB is installed in the case.

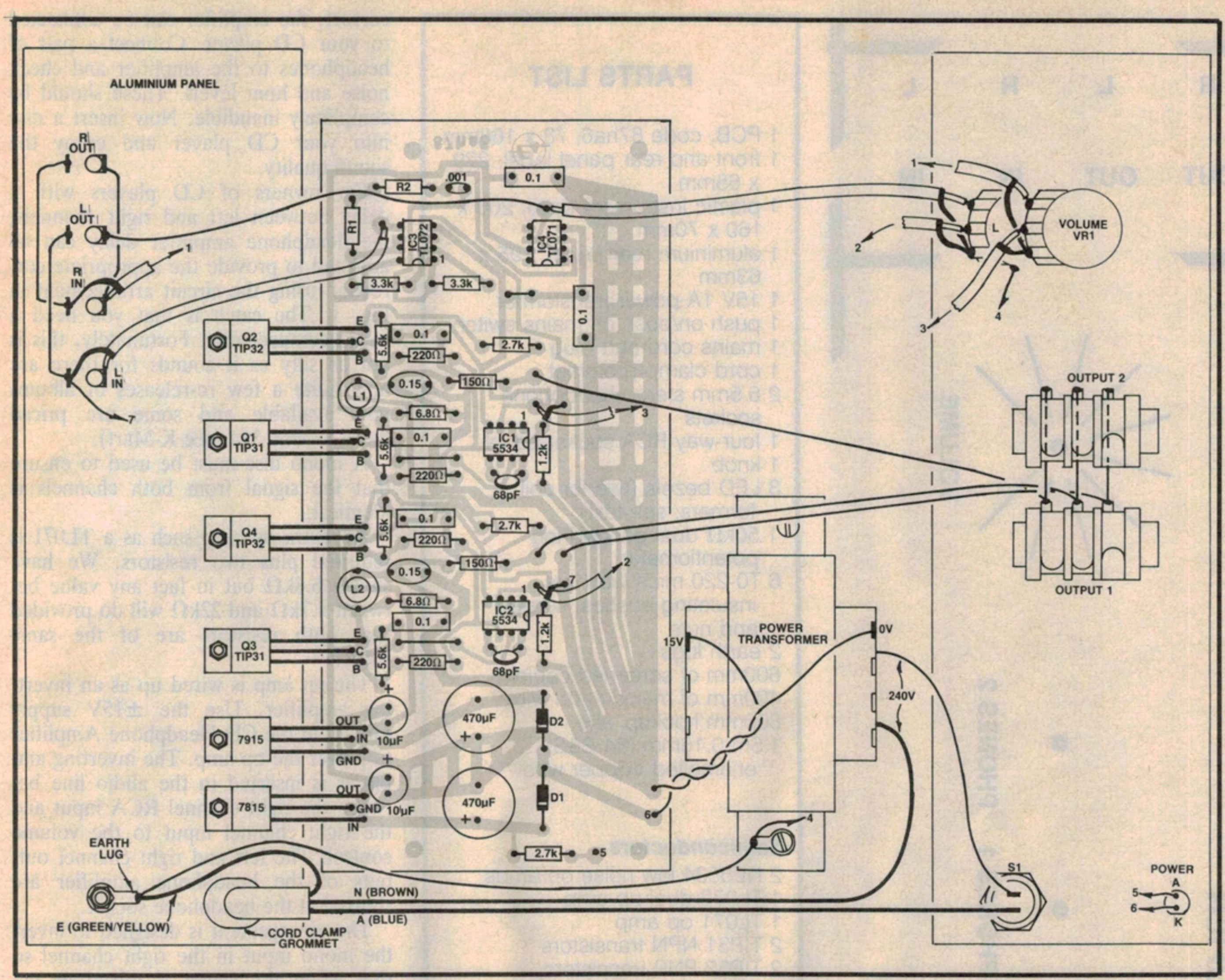
Now the capacitors can be installed. Make sure that the electrolytics are oriented as shown on the overlay diagram.

In the prototype, L1 and L2 were made by winding 30 turns of 34 B&S enamelled copper wire around 5mm LED bezels which act as formers. Strip back the insulation from the ends of the wires to allow the coils to be soldered to the PCB.

The PCB can now be secured to the base of the case using self-tapping screws into the integral spacers. Insert the aluminium rear panel into place and mark the locations for the regulators and transistors directly opposite their respective hole locations in the PCB.

Mark out the holes required to mount the cord clamp grommet, earth lug and 4-way RCA socket panel. Drill all the necessary holes in the rear panel.

The front panel should also be drilled



Q1-Q4 and the two 3-terminal regulators must be isolated from the aluminium panel using mica washers and insulating bushes.

at this stage. Use the front panel artwork as a guide for marking out the hole positions for the mains power switch, LED, headphone sockets and volume control.

Mount the RCA socket panel and the power switch, LED, headphone sockets and volume control. The transistors and regulators are mounted using mica washers and insulating bushes to isolate the metal tabs of the devices from the rear panel. Use heatsink compound between the mating surfaces to provide better heat conduction.

Once the devices are mounted, slide the rear panel into the case and solder the device leads to the PC stakes provided for connection to the PCB.

The next step is to mount the transformer on the base of the case using the integral standoffs and self-tapping screws. Remember to insert an earth lug under one of the mounting points of the transformer so that it can be earthed.

Follow the wiring diagram when making all the external connections to the printed circuit board. Clamp the three-core mains cord into the cord clamp grommet and solder the green/yellow earth lead to the earth lug on the rear panel. Continue with the earth wiring from the rear panel earth lug to the transformer earth lug. A wire then runs from this lug and is soldered to the case of the volume potentiometer.

The Active (blue) mains wire connects directly to the power switch, while the Neutral (brown) wire connects directly to one of the 240V lugs on the transformer. The second 240V transformer lug connects to the remaining switch contact.

It is important to insulate all the bare mains connections on the switch and transformer using insulating sleeving. This will avoid any possibility of accidental contact with the mains.

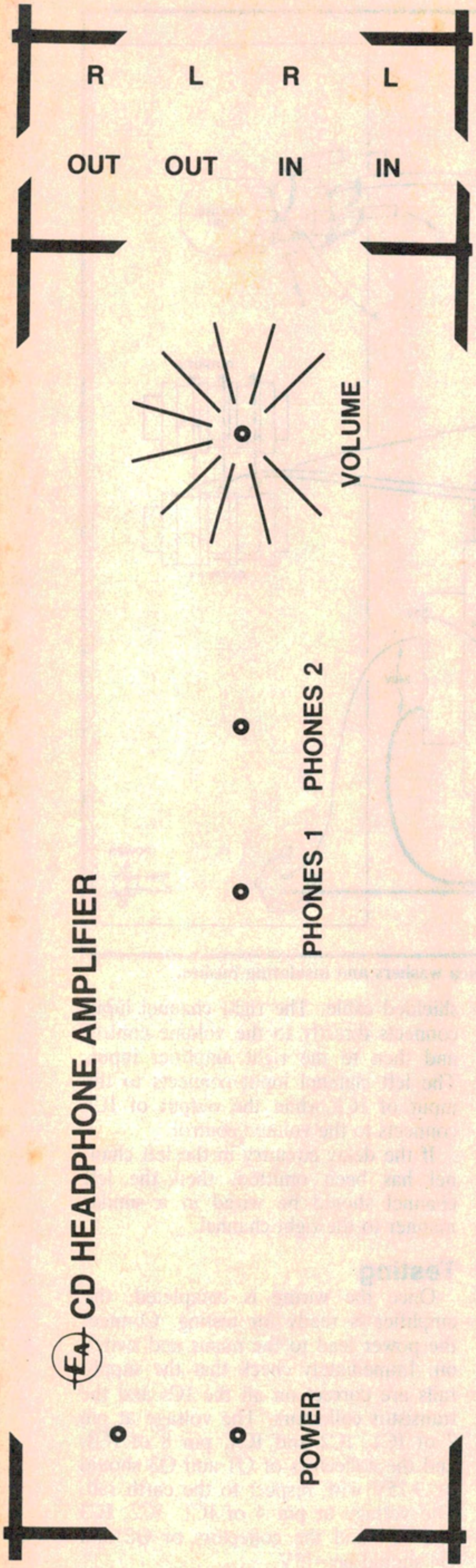
Wiring from the CD inputs to the PCB and volume control is made using shielded cable. The right channel input connects directly to the volume control and then to the right amplifier input. The left channel input connects to the input of IC3 while the output of IC4 connects to the volume control.

If the delay circuitry in the left channel has been omitted, then the left channel should be wired in a similar manner to the right channel.

Testing

Once the wiring is completed, the amplifier is ready for testing. Connect the power lead to the mains and switch on. Immediately check that the supply rails are correct on all the ICs and the transistor collectors. The voltage at pin 7 of IC1, IC2 and IC4, pin 8 of IC3, and the collectors of Q1 and Q3 should be +15V with respect to the earth rail. The voltage at pin 4 of IC1, IC2, IC3 and IC4 and the collectors of Q2 and Q4 should be –15V.

Once the voltages are found to be



PARTS LIST

1 PCB, code 87ha6, 78 x 168mm
1 front and rear panel label, 229 x 65mm
1 plastic instrument case, 200 x 160 x 70mm
1 aluminium rear panel, 195 x 63mm
1 15V 1A power transformer
1 push on/push off mains switch
1 mains cord and plug
1 cord clamp grommet
2 6.5mm stereo headphone sockets
1 four-way RCA socket panel
1 knob
3 LED bezels (two for coil formers; see text)
1 50kΩ dual ganged log potentiometer
6 T0-220 mica washers, insulating bushes, screws and nuts
2 earth lugs
600mm of screened cable
400mm of mains earth wire
800mm hookup wire
1.5m 0.16mm (34 B&S) enamelled copper wire

Semiconductors

2 NE5534 low noise op amps
1 TL072 dual op amp
1 TL071 op amp
2 TIP31 NPN transistors
2 TIP32 PNP transistors
1 7815 3-terminal regulator
1 7915 3-terminal regulator
2 1N4002 1A diodes
1 5mm LED

Capacitors

2 470μF 25VW PC electrolytic
2 10μF 16VW PC electrolytic
2 0.15μF metallised polyester
6 0.1μF metallised polyester
1 0.001μF metallised polyester
2 68pF ceramic

Resistors (0.25W, 5%)

4 x 5.6kΩ, 2 x 3.3kΩ, 2 x 2.7kΩ, 2 x 1.2kΩ, 4 x 220Ω, 2 x 150Ω, 2 x 6.8Ω, R1, R2 (see text)

Miscellaneous

PC stakes, self tapping screws, machine screws and nuts.

Left: this actual size artwork can be used as a drilling template for the front panel.

correct, the amplifier can be connected to your CD player. Connect a pair of headphones to the amplifier and check noise and hum levels. These should be completely inaudible. Now insert a disc into your CD player and enjoy the sound quality.

For owners of CD players with a delay between left and right channels, the headphone amplifier delay can be adjusted to provide the appropriate correction using the circuit arrangement in Fig. 1. The catch is that you need a mono compact disc. Fortunately, this is not as silly as it sounds for there are now quite a few re-releases of albums now available and some are priced down around $14 (see K-Mart).

A mono disc must be used to ensure that the signal from both channels is identical.

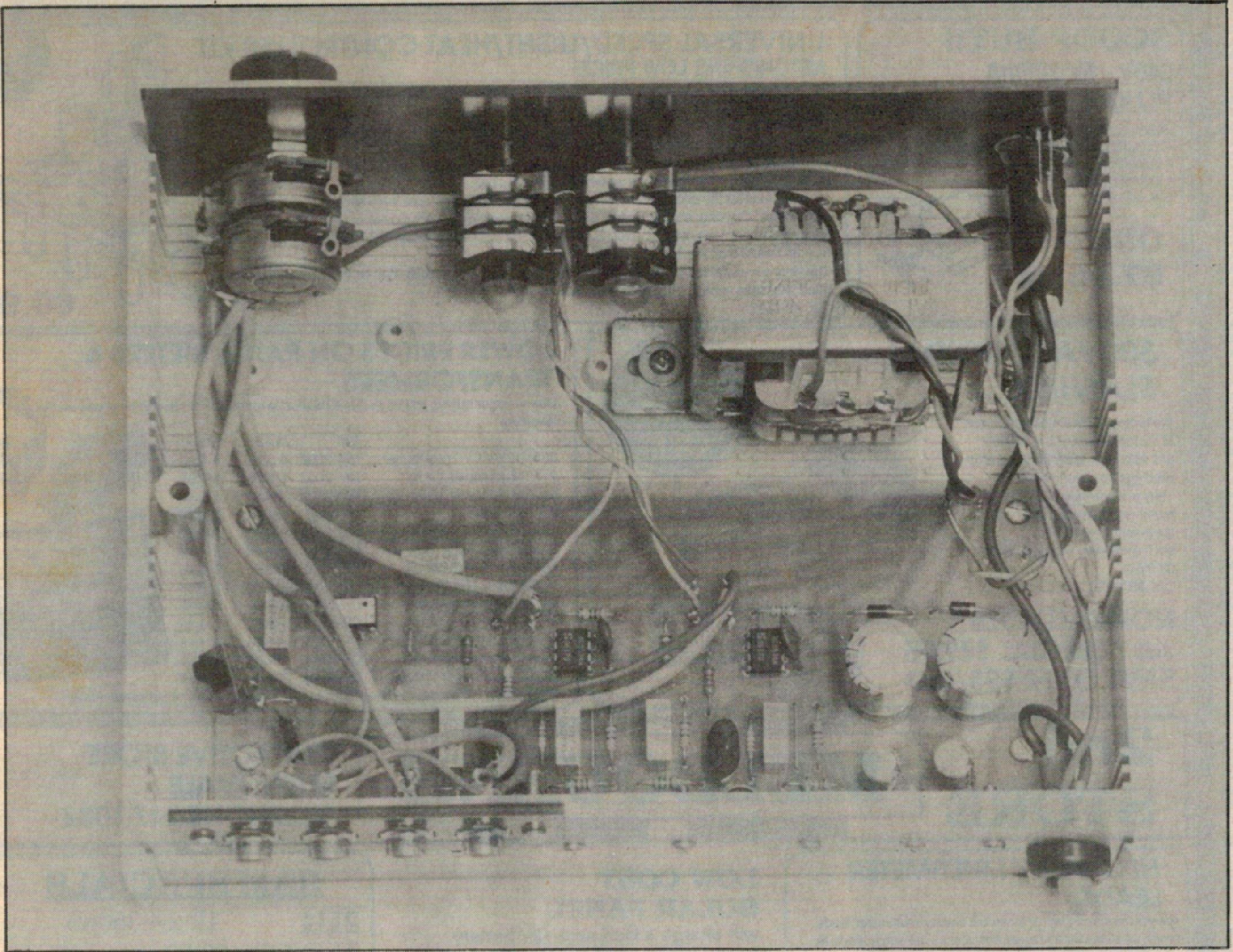
An extra op amp such as a TL071 is required plus two resistors. We have shown 6.8kΩ but in fact any value between 4.7kΩ and 22kΩ will do provided that both resistors are of the same value.

The op amp is wired up as an inverting amplifier. Use the ±15V supply rails from the CD Headphone Amplifier to power the op amp. The inverting amplifier is inserted in the audio line between the right channel RCA input and the right channel input to the volume control. The left and right channel outputs of the headphone amplifier are shorted at the headphone socket.

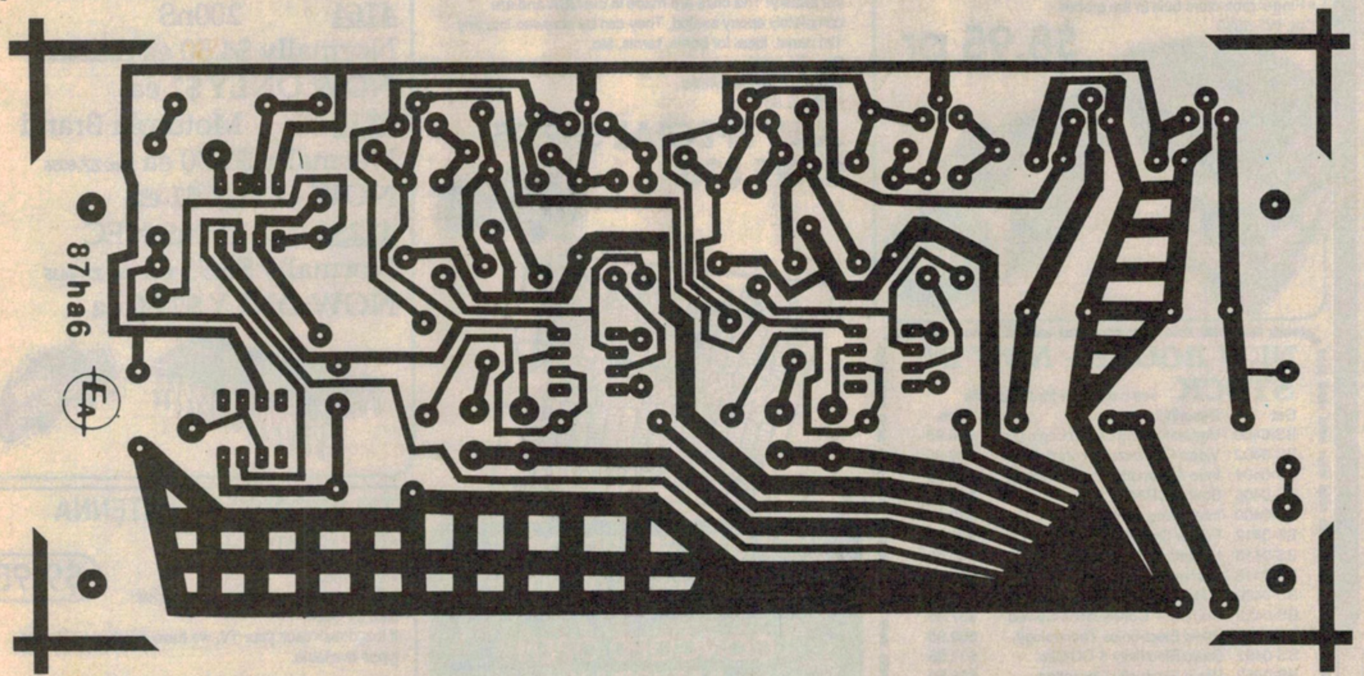
The arrangement is designed to invert the mono input in the right channel so that when the signal is mixed at the headphone socket there should be no signal due to total cancellation. If the signal is delayed in one channel, then cancellation will not be complete and a signal will be audible. In practice, the cancellation is not total, due to slight differences in level between the two channels.

Adjust the value of the R1 and R2 resistors using a trimpot for minimum sound from the headphones. This sets the phase delay within the headphone amplifier to completely compensate for the delay in one channel of the CD player. Once this has been done, measure the resistance value set for the trimpot and replace it with two series resistors which add up to give the same value.

Finally, remove the external inverting amplifier from the right channel input and remove the short between the left and right channels at the headphone socket and place the lid on the case. The headphone amplifier is now complete.



Above: view inside the prototype. Make sure that the mains cord is securely clamped and sleeve the switch contact with plastic tubing to prevent accidental shock.



Here is the full size artwork for the PCB.