compact power amplifier

Fast high-end design

The battery-powered preamplifier published in our February 1997 issue must have made many of our readers long for a matching power amplifier. Odd as it may seem, it is almost two years ago that we last published a high-end power amplifier. This realization prompted the present compact power amplifier whose quality and layout match those of the preamplifier. It offers medium power output, is not overly complex and has a very high slew rate.

Design by T. Giesberts

The introduction gives a good idea of the power amplifier described in this article.

The term ‘compact’ refers to both the power output and the dimensions of the amplifier. Of course, compactness is a relative term, because the amplifier contains no fewer than 19 transistors. Over the years, compactness has taken on a different meaning than, say, ten years ago. Then, a compact amplifier was understood to contain not more than eight to ten transistors; today this figure is nearer to twenty-five. After all, as everybody now realizes only too well, quality always has its price.

As far as output power is concerned, the present amplifier is definitely intended for normal domestic use. It produces some 50 watts into 8 Ω or 85 watts into 4 Ω, which is more than ample for its intended use. Even at relatively high volume, a domestic power amplifier seldom provides more than 1–2 power output. To high-volume freaks it may sound odd, but most loudspeakers produce a sound pressure of about 90 dB at a distance of 1 metre for an input of only 1–2 watts—enough to make the neighbours rush for the telephone.

It is clear, therefore, that the present amplifier has more than ample reserve to reproduce even the highest peaks in a piece of music without any discernible distortion.

A further benefit of the circuit is the use of such a relatively high quiescent current that with power outputs up to 2.5 W the amplifier operates in Class A, which enhances the overall quality of the reproduced sound.

There are some other aspects which will be reverted to in detail later. Firstly, the power output is produced by two insulated gate bipolar transistors (IGBTs). These bipolar MOSFETs or, if you prefer, gate-controlled transistors have been used in power amplifiers published by us before.

Secondly, the amplifier uses current feedback instead of the more usual voltage feedback. This has a beneficial effect on the open-loop bandwidth, the power bandwidth and the slew rate.

Thirdly, as may be seen from the technical data, the figures for harmonic distortion, intermodulation distortion and the damping factor are very good, indeed. They make it clear that although the amplifier is small in size, it is large in performance.

THE DESIGN

Experts in audio amplifier technology, as well as many other knowledgeable constructors, will see from **Figure 1** that in some respects the design of the power amplifier is different from the usual arrangement.

To start with, the almost obligatory differential input amplifier is not there. In its stead there is a symmetrical input stage that has some resemblance to the buffer stage used at the input of

Figure 1. The most conspicuous aspect of the circuit diagram is the omission of the traditional differential amplifier at the input. The output stage is based on insulated gate bipolar transistors.

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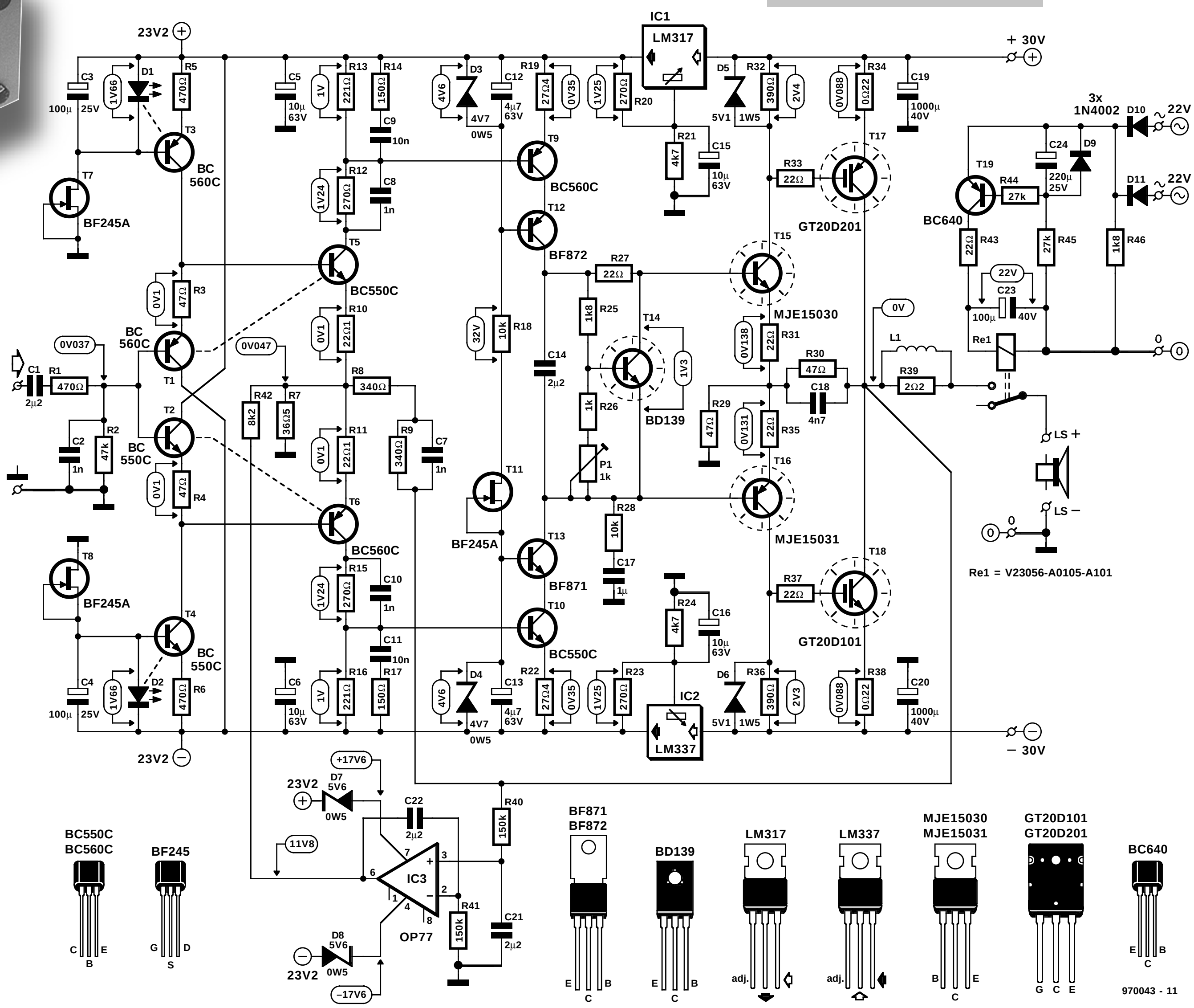


Technical data

Input sensitivity	1 V r.m.s.
Output impedance	47.5 kΩ
Output power (0.1% THD)	50 W into 8 Ω; 85 W into 4 Ω
Power bandwidth (25 W into 8 Ω)	1.5 Hz–270 kHz
Slew rate	37 V μs^{-1}
Signal-to-noise ratio (1 W into 8 Ω)	107 dB (A-weighted)
	102 dB (B = 22 kHz linear)
Total harmonic distortion (B = 80 kHz)	
1 W into 8 Ω	0.0015% (1 kHz)
25 W into 8 Ω	0.0025% (1 kHz)
	0.008% (20 kHz)
Intermodulation distortion (50 Hz:7 kHz = 4:1)	
1 W into 8 Ω	0.0025%
25 W into 8 Ω	0.008%
Dynamic intermodulation distortion	
(Square wave 3.15 kHz, sine wave 15 kHz)	
1 W into 8 Ω	0.002%
25 W into 8 Ω	0.002%
Damping factor (8 Ω)	700 (1 kHz)
	450 (20 kHz)
Open-loop parameters (R_8 open)	
Amplification	×2500
Bandwidth	40 kHz
Output impedance	0.3 Ω

These data show the excellent performance of the power amplifier; exceptionally good are the power bandwidth and the slew rate. Some audio enthusiasts feel that performance data should be taken with a pinch of salt and that the important thing is a hearing test. This is not an opinion shared by this magazine. It is true that figures do not reveal everything, but it is surely admitted by all that poor data point to properties that cannot have a beneficial effect on the sound quality.

As usual, the data are accompanied by a number of curves obtained with an Audio Precision Analyser.

***Curves A** show the total harmonic distortion (THD+N) between 20 Hz and 20 kHz. The upper curve refers to 25 W into 8 Ω, and the lower to 1 W into 8 Ω. Both curves show an exemplary performance; note that the usual increase in distortion at high frequencies is small.*

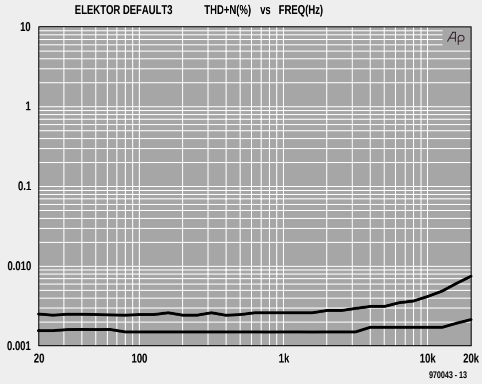
***Curve B** illustrates the distortion at 1 kHz as a function of the drive power over a bandwidth of 22 Hz to 22 kHz. The slight increase above about 2.5 W shows that from that point on the amplifier no longer operates in Class A. The clipping point is at 50 kHz.*

***Curves C** refer to the output power of the amplifier as a function of frequency with a load of 4 Ω and 8 Ω respectively.*

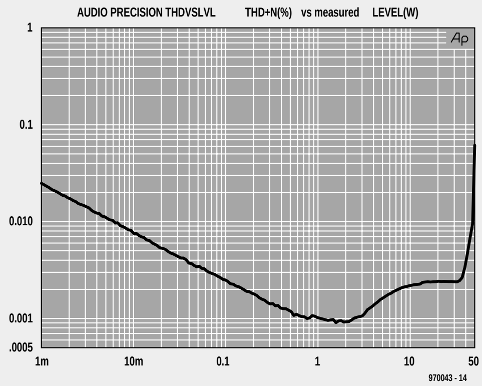
***Curve D** illustrates a Fourier analysis of a 1 kHz signal for an output of 1 W into 8 Ω. Although the 2nd and 3rd harmonics are clearly visible, their levels at –105 dB and –122 dB are well below that of the fundamental. All other harmonics remain below the noise floor.*

Listening tests showed the very good performance of the power amplifier even better than the technical data. The sound reproduction was very pleasant with good presence and transparent high-frequency performance that never became sharp. Low-frequency performance, both with classical and popular music, remained remarkably taut. The amplifier held the loudspeakers in an iron grip as it were and never relinquished control.

A



B



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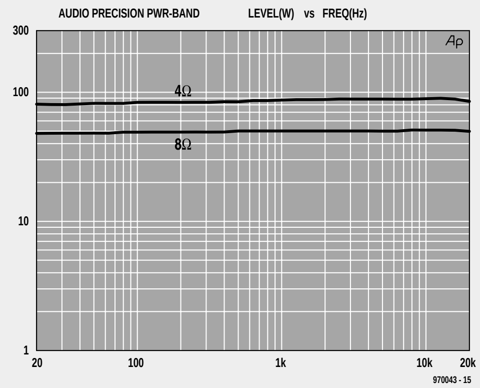
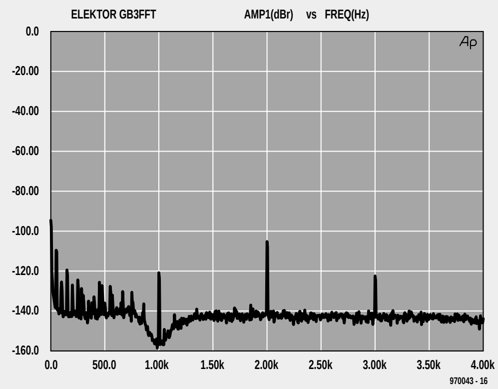


D



the battery-operated preamplifier.

In combination with current feedback this results in an amplifier that is appreciably faster than one with the traditional differential input stage.

The power amplifier has an open-loop bandwidth of some 40 kHz at the relative low amplification of ×2500. This enables the overall feedback, which many enthusiasts do not like, to be kept to a quite conservative level.

There is another side to everything and current feedback is no exception. A well-known but unavoidable drawback is the poor common-mode and supply-line suppression. In the present design, the effects of these have been countered to a large extent, however, by the use of two regulators in the power lines to all voltage amplifiers. This, in turn, has the drawback that the level of the supply voltage to these amplifiers is lower than that to the current amplifiers, although it should really be higher. This limits the maximum drive, but that is compensated by making the current amplifiers amplify ×2. Because of this, the output stage is not arranged as the usual emitter follower, but rather as a compound configuration.

Output transistors T_{17} and T_{18} are, as mentioned earlier, insulated gate bipolar types. These may be considered as transistors with a MOSFET input, which has the advantage of requiring a smaller current from the drivers, T_{15} and T_{16}. As this results in lower loading of the local feedback loop, it. means that the amplification of the drivers can be higher, which enhances the linearity of the current amplifiers.

INPUT STAGE

The input stage of the amplifier consists of emitter followers T_1 and T_2 and symmetrical voltage amplifiers T_5 and T_6 (**Figure 1**). Current feedback is obtained by coupling the output of the power amplifier to the emitters of T_5 and T_6.

The emitter followers provide impedance matching and arrange the base bias of T_5 and T_6. This arrangement relies on the fact that the drop across R_{10} and R_{11} is virtually the same as that across R_3 and R_4. The potential across the latter two resistors is held constant by current sources T_3 and T_4. Moreover, the reference voltages for these current sources are provided by D_1 and D_2, the current through which in turn is held constant by current sources T_7 and T_8.

To prevent the operating levels being upset by temperature effects in spite of these measures, T_5 and T_6 are thermally coupled to T_1 and T_2, while D_1 and D_2 are thermally coupled to current sources T_3 and T_4.

For best performance, it is advisable to select transistors T_1 and T_2 on the basis of equal base-emitter voltage and current amplification, but make sure that the (offset) potential across R_2 <50 mV. Since complete symmetry is virtually unattainable, there will always be some offset which is why the circuit based on IC_3 has been added. This stage compensates the input offset by placing an identical potential at feedback junction R_{10}-R_{11}. This will be reverted to later.

Combinations R_{14}-C_9 and R_{17}-C_{11} are compensating networks, while C_8 and C_{10} minimize the effects of the parasitic capacitances of T_5 and T_6.

VOLTAGE AMPLIFIERS AND OUTPUT STAGE

Voltage amplifiers T_5 and T_6 drive a push-pull amplifier based on T_9–T_{13}, which is arranged as a cascode stage for the following reasons. Firstly, such an arrangement limits the potential across, and the dissipation of, the actual voltage amplifier T_9-T_{10}. Secondly, a cascode configuration is ideal for obtaining high amplification coupled with a large bandwidth.

The d.c. operating point of the voltage amplifier is held stable by zener diodes D_3 and D_4, the current through which is in turn held constant by current source T_{11}.

The voltage amplifiers are loaded by the input impedance of T_{15}-T_{16}. Since this varies in accord with the output current of the power amplifier, it is linearized by resistor R_{28}. Capacitor C_{17} prevents any direct voltage from reaching the base of T_{16}.

The circuit based on T_{14} forms a temperature-independent transistor zener which has become a familiar aspect in many power amplifiers. This transistor is mounted on the heat sink adjacent to output transistors T_{17} and T_{18} and stabilizes the quiescent current through these devices. The level of this current is set with P_1.

Resistor R_{27} provides the additional negative temperature coefficient needed to compensate the time delay and thermal decay in the heat sink.

The output of the voltage amplifiers is applied to current amplifier T_{15}–T_{18}. Strictly speaking, this is a compound rather than a current amplifier, since, apart from current amplification, it also provides voltage amplification. The voltage gain (×2) is determined by resistors R_{29} and R_{30}; capacitor C_{18} serves to improve the response of the stage.

Since in a compound amplifier the collectors of the driver transistors form the output of the current amplifier, the gate-emitter potential does not influence the maximum drive from the voltage amplifier. This is an important benefit, because the gate-emitter potential may be several volts. The only limiting factor in the present amplifier, is, therefore, the knee voltage of T_{17} and T_{18}.

Emitter resistors R_{34} and R_{38} are low-inductance types to prevent any tendency to oscillation or other spurious effects.

Inductance L_1 wound on R_{39} enhances the performance of the power amplifier when the load is capacitive.

Zener diodes D_5 and D_6 protect the gates of T_{17} and T_{18} against overdrive.

In operation, the temperature of drivers T_{15} and T_{16} strongly affects the setting of the quiescent current. So as to make the power amplifier as stable with temperature variations as feasible, these transistors are, therefore, also mounted on the same heat sink as T_{14}, T_{17} and T_{18}. While it is true that the quiescent current will always vary to some (small) degree with temperature, the thermal coupling of the various transistors ensures that any drift is well within acceptable limits.

MISCELLANEOUS ASPECTS

So as to keep the power amplifier as compact as possible, it does not contain elaborate protection circuits.There is, however, a power-on delay to suppress annoying clicks and plops at on and off switching. Delayed on/off switching of the power lines is effected by relay Re_1. To avoid any noise on the signal paths via the supply lines, the relay has independent power lines. For this purpose, D_{10} and D_{11} rectify the secondary voltage of the mains transformer. The resulting direct voltage is buffered by C_{23} which ensures that the energizing voltage for the relay is 22–24 V.

After the power has been switched on, T_{19} begins to conduct slowly via R_{44}-R_{45}-C_{24}. It takes a few seconds before this transistor is fully on: only then will the relay be energized. When the power is switched off, C_{24} is rapidly discharged via R_{46} so that the relay is deenergized without any discernible delay.

To aid the offset setting, IC_3 compares the output of low-pass filter R_{40}-C_{21} with the direct voltage at the output of the power amplifier. If there is a difference, the operating point of T_5-T_6 is adjusted via R_{42} in such a manner that the average output of the power amplifier remains at earth potential. This arrangement ensures that the offset voltage at the output cannot exceed that of IC_3 ($\leq$ 100 µV at 25 °C). It is a fact, however, that tiny variations caused by temperature changes cannot be eliminated entirely.

Zener diodes D_7 and D_8 reduce the supply voltage of ±23.2 V to the requisite level for IC_3.

The reasons for regulation of the supply lines to the input and voltage amplifiers has already been mentioned. The regulation is provided by IC_1 and IC_2. Type LM317 and LM337 respectively have been used for these regulators because they provide very good ripple suppression and tolerate a high peak input voltage. A further advantage of them is that their output potential can be adjusted very accurately by means of resistors R_{20}-R_{21} and R_{23}-R_{24} respectively. Capacitors C_{15} and C_{16} increase the ripple suppression to 70–80 dB.

CONSTRUCTION

The power amplifier is best built on the double-sided printed-circuit board shown in **Figure** 2. Making the board double-sided meant that it could be made very compact without the necessity of (too) long copper tracks at essential locations. The layout is unambiguous so that population of the board is straightforward.

Transistors T_{14}–T_{18} are located neatly in a row at one side of the board to facilitate their fixing on to the

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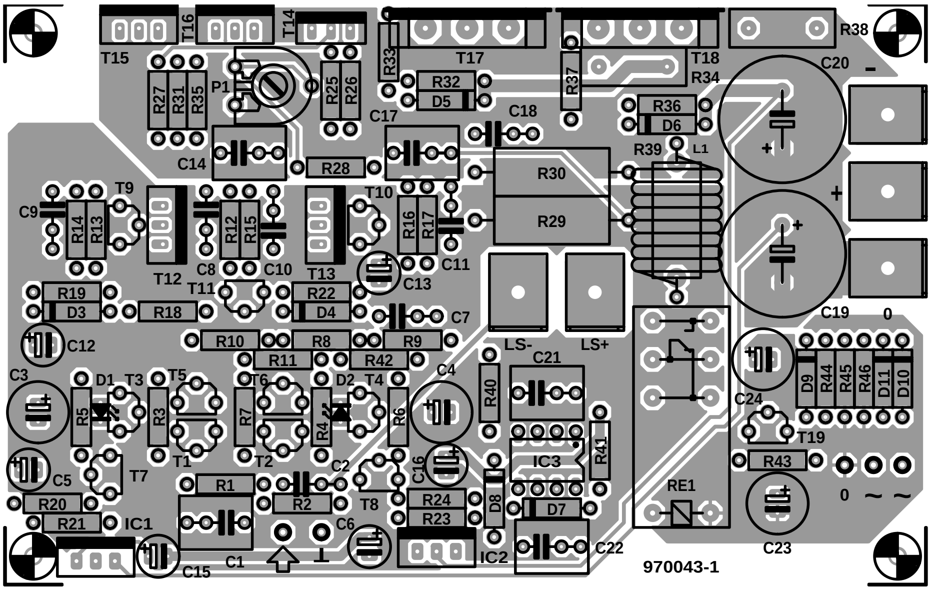
Figure 2. The double-sided printed-circuit board for the power amplifier. Large currents flow over only a few tracks.



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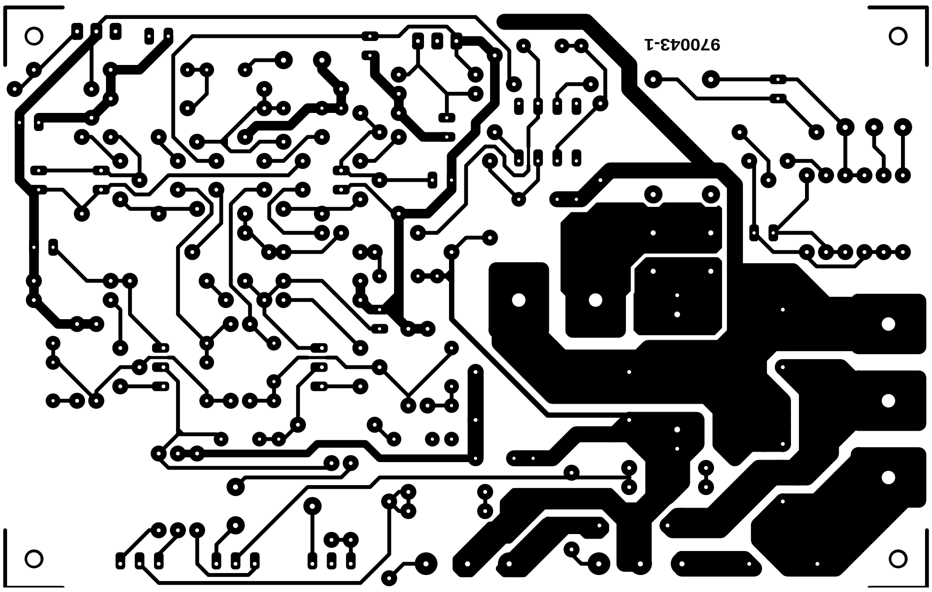

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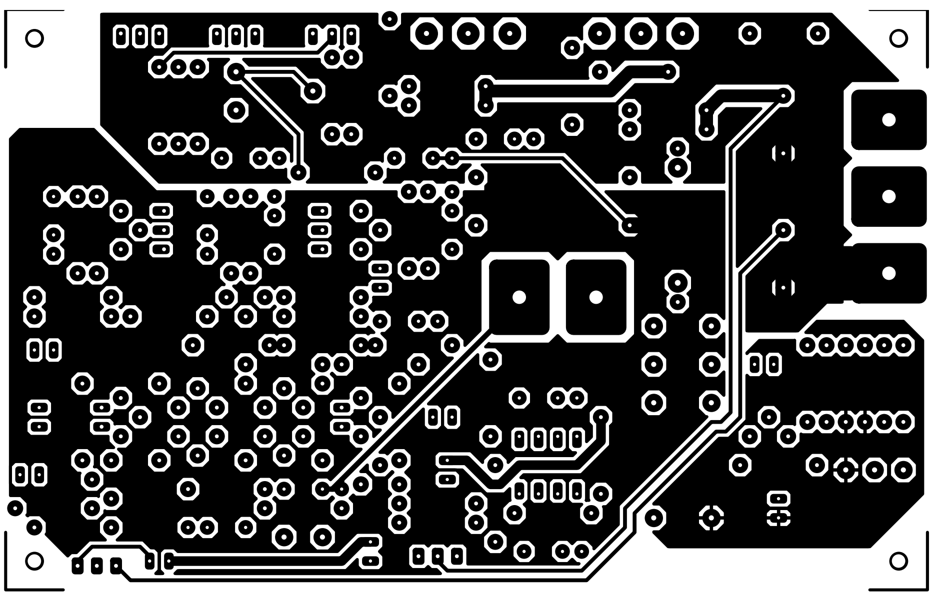

Parts list

Resistors:
R_1, R_5, R_6 = 470 Ω
R_2 = 47 kΩ
R_3, R_4 = 47 Ω
R_7 = 36.5 Ω, 1%
R_8, R_9 = 340 Ω, 1%
R_{10}, R_{11} = 22.1 Ω, 1%
R_{12}, R_{15}, R_{20}, R_{23} = 270 Ω
R_{13}, R_{16} = 221 Ω, 1%
R_{14}, R_{17} = 150 Ω
R_{18}, R_{28} = 10 kΩ
R_{19}, R_{22} = 27.4 Ω, 1%
R_{21}, R_{24} = 4.7 kΩ
R_{25}, R_{46} = 1.8 kΩ
R_{26} = 1 kΩ
R_{27}, R_{31}, R_{33}, R_{35}, R_{37}, R_{43} = 22 Ω
R_{29}, R_{30} = 47 Ω, 5 W
R_{32}, R_{36} = 390 Ω
R_{34}, R_{38} = 0.22 Ω, 5 W, low inductance
R_{39} = 2.2 Ω, 5 W
R_{40}, R_{41} = 150 kΩ
R_{42} = 8.2 kΩ
R_{44}, R_{45} = 27 kΩ
P_1 = 1 kΩ preset

Capacitors:
C_1, C_{14}, C_{21}, C_{22} = 2.2 µF metallized polyester, pitch 5 or 7.5 mm
C_2, C_7, C_8, C_{10} = 1 nF
C_3, C_4 = 100 µF, 25 V
C_5, C_6, C_{15}, C_{16} = 10 µF, 16 V, radial
C_9, C_{11} = 10 nF
C_{17} = 1 µF, metallized polyester, pitch 5 or 7.5 mm
C_{18} = 4.7 nF
C_{19}, C_{20} = 1000 µF, 40 V, radial
C_{23} = 100 µF, 40 V, radial
C_{24} = 220 µF, 25 V, radial

Semiconductors:
D_1, D_2 = LED, 5 mm, flat
D_3, D_4 = zener diode, 4.7 V, 500 mW
D_5, D_6 = zener diode, 5.1 V, 1.5 W
D_7, D_8 = zener diode, 5.6 V, 500 mW
D_9–D_{11} = 1N4002
T_1, T_3, T_6, T_9, =BC560C
T_2, T_4, T_5, T_{10} = BC550C
T_7, T_8, T_{11} = BF245A
T_{12} = BF872
T_{13} = BF871
T_{14} = BD139
T_{15} = MJE15030 (Motorola)
T_{16} = MJE15031 (Motorola)
T_{17} = GT20D201 (Toshiba)
T_{18} = GT20D101 (Toshiba)
T_{19} = BC640

Integrated circuits:
IC_1 = LM317T
IC_2 = LM337T
IC_3 = OP77 (Analog Devices)

Miscellaneous:
L_1 = see text
Re_1 = relay, 24 V, 875 Ω with single make contact 16 A, 250 V, e.g. Siemens Type V23056-A0105-A101
5 off PCB mounting flat 3-way sockets
Heat sink 1.2 K W^{-1} or smaller – see text; e.g. Fischer SK85SA/75 mm from Dau (telephone 01243 553 031)
Insulating washer and insulating bushes for T_{14}–T_{18}
PCB Order No. 970043 – see Readers Services towards the end of this issue

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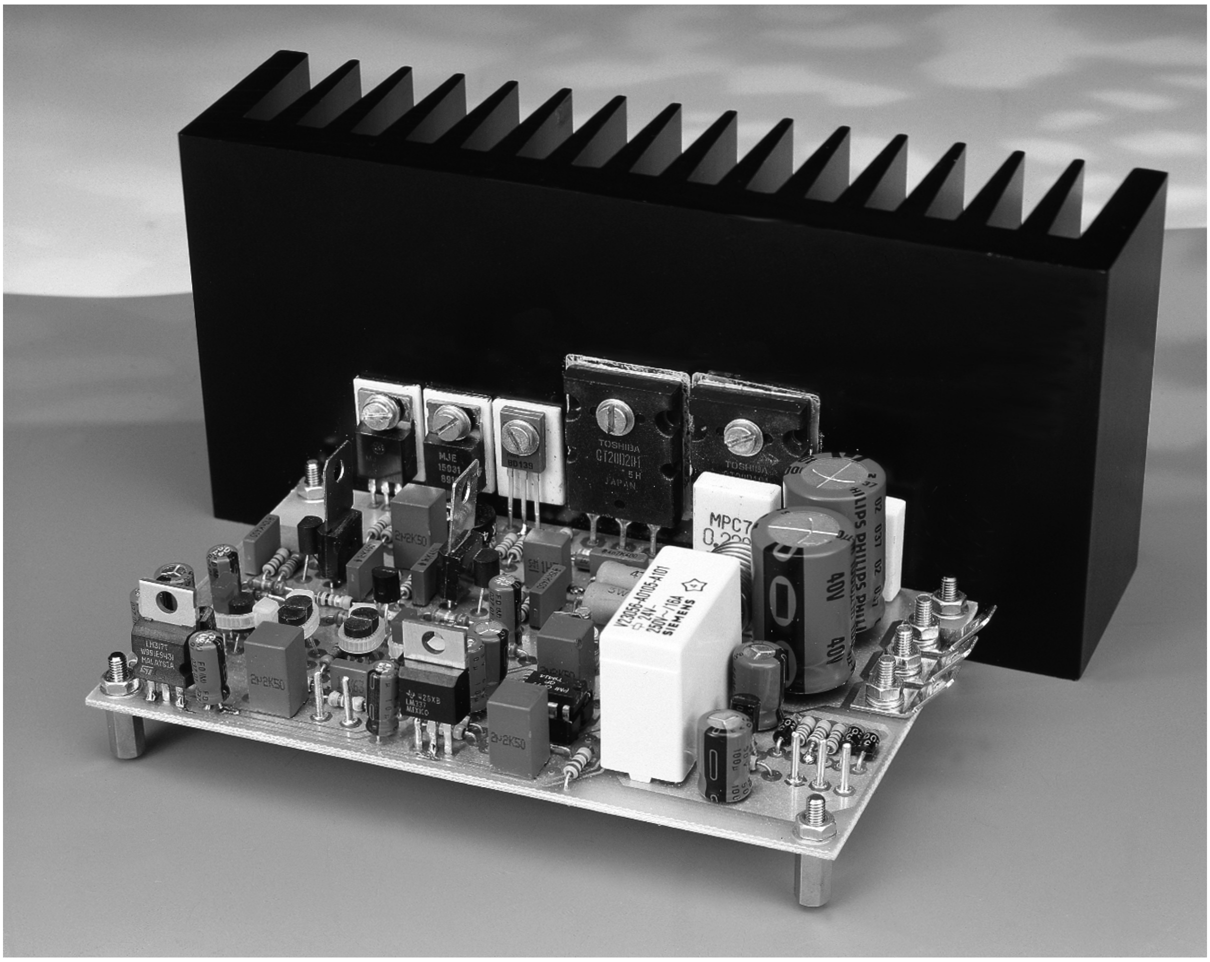

Figure 3. Photograph of the completed prototype board with heat sink. Two- and three-pin flat PCB mounting connectors are used for the loudspeaker and power line connections.

heat sink. They must, of course, be electrically isolated from each other with the aid of insulating washers and bushes for the fixing screws. In view of the required temperature stability, it is advisable to keep the terminals of T_{14} as long as possible to ensure that the device, when mounted, is at about the same height as the centre of T_{17}. This makes for good thermal coupling.

The other semiconductors and integrated circuits do not need extra cooling.

As mentioned earlier, good thermal coupling of a number of components (T_1-T_5; T_2-T_6; D_1-T_3; and D_2-T_4) in the input stages is also imperative for good performance. The easiest way of ensuring this is to secure the various pairs of components together with cable ties. In the case of D_1-T_3 and D_2-T_4 this is possible only if flat diodes are used. Tie the pairs together before fitting and soldering them on to the board. Mind the orientation of the diodes. It is advisable to mark the transistors with n-p-n or p-n-p, as the case may be, so that it is clear at a later stage which pair is which.

Inductor L_1 consists of eight turns of 1.5 mm dia. enamelled copper wire wound around a 9 mm drill bit. When it is wound, withdraw the drill bit, insert R_{39} into the coil and fit and solder the assembly on to the board at a height of a few millimetres above the surface.

All connections that carry large currents are output via PCB mounting flat sockets. The power connections are at the middle of one side of the board marked LS+ and LS–. The power lines to the relay are connected via ordinary

Suggested power supply (for mono amplifier):
- Toroidal mains transformer, secondary 2×22 V, 160 VA
- Bridge rectifier 200 V, 35 A
- 4 off electrolytic capacitor 10,000 µF, 50 V
- Fuse holder and fuse 800 mA, slow

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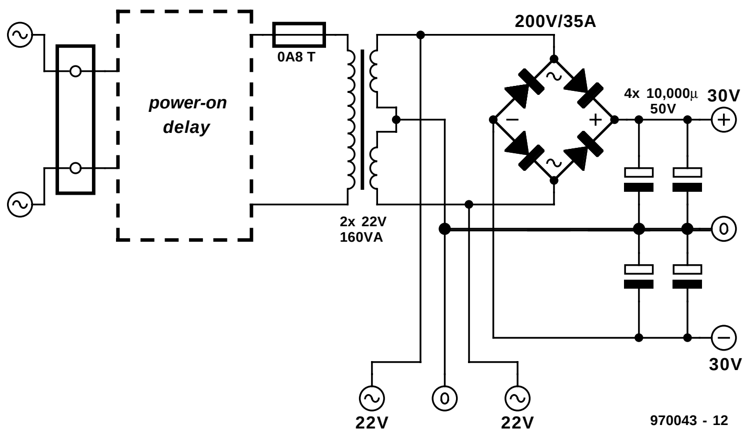

Figure 4. The power supply may be kept simple, but should have ample reserve power. Note that the diagram shows a design for a mono power amplifier.

board terminals. Note that these lines consist of three wires: this means that the earth line must NOT linked to the amplifier earth.

The completed board with heat sink is shown in **Figure 3**. The heat sink must have a thermal resistance of 1.2 K W^{-1} or smaller.

POWER SUPPLY AND QUIESCENT CURRENT

When the board has been completed and thoroughly inspected for any faulty workmanship (including a one-by-one check of the components against the part list), a few operational tests need to be carried out. Naturally, a power supply is needed and a suitable arrangement for this is shown in **Figure 4**. This is a traditional setup of power-on delay, mains transformer, with a 2×22 V, 160 VA secondary, a 35 A bridge rectifier and four 10,000 µF electrolytic reservoir capacitors. This supply provides sufficient current even when 4 Ω loudspeakers are used. Note that the diagram is for a supply for a mono amplifier: two are needed for a stereo amplifier.

The diagram also shows how the power lines for the relay are obtained.

The power-on section is advisable but not obligatory. It serves to prevent large current peaks during switch-on.

As in all power supplies, good, firm, well-soldered connections are of prime importance. They ensure that there is no unnecessary resistance in the path of large currents.

Before the power is switched on, it is vital that preset P_1 on the power amplifier is turned completely anti-clockwise. If this is not done, there is a risk that the quiescent current through the output transistors quickly reaches a very high level and the circuit is not designed to cope with this.

After the power has been switched on, check with a multimeter whether the potentials at the output of IC_1 and IC_2 are as indicated on the circuit diagram in Figure 1 (±23.2 V respectively). Then, measure the output voltage of the amplifier, which must be 0 V or very nearly so. If it is not, recheck the entire construction, particularly the input stages.

When up to this point all is well and the LEDs light, it may be assumed that the entire power amplifier is in good working order. It is then time to check all the potentials at the test points indicated in Figure 1.

Next, set the quiescent current with P_1. This is fairly high in this power amplifier: about 400 mA when a heat sink as specified is used; if a heat sink of ≤ 0.6 K W^{-1} is used, the current may even be as high as 500 mA. Connect a millivoltmeter set to its 200 or 250 mV range across R_{34} or R_{38} and turn P_1 slowly clockwise until the meter reads 88 mV (current = 400 mA) or 110 mV (current = 500 mA).

Leave the amplifier to warm up thoroughly and then readjust P_1 as required.

ASSEMBLY

The design of the printed-circuit board is intended for its use as a mono amplifier. From a quality point of view, this is the best way of building an amplifier. Use a compact enclosure, perhaps with integral heat sink, and assemble board and power supply in this to make a stand-alone mono amplifier. A stereo amplifier is obtained by building two of these mono units and simply stacking them.

Wiring up the assembly is straightforward. Use heavy-duty wire for the +ve, –ve and earth supply lines and link them to the appropriate terminals on the board. Use heavy-duty wire also for linking the loudspeaker terminals with the LS+ and LS– PCB mounting 4 mm sockets on the board.

Link the phono input socket at the rear of the enclosure to the two input terminals on the board via a short length of screened audio cable.

Next, link the two 22 V~ and 0 lines to the relay – remember that the 0 line must not be connected to the amplifier earth – see below.

The mains inlet should be of good quality, preferably with an integral fuse holder. The fuse rating is shown on the serial number label that should be affixed to the rear of the cabinet.

It is imperative that earth loops are avoided. This is best done by ensuring that there is link between the mains earth, the 0 supply line and the cabinet earth at only one point. Normally, and most conveniently this is at the signal input socket. If a non-insulated phono socket is used, this is automatically connected to the cabinet earth, so that no further action is needed.

It is, of course, possible to assemble two mono amplifiers using a single power supply in one cabinet, but this is not advisable. Even if it is desired to use only one cabinet, each of the mono amplifiers should have its own discrete power supply. The introductory photograph shows that this is how the prototype was constructed. The cabinet used for the prototype was provided with an integral heat sink and measured 445×75×305 mm (W×H×D).

[974003]

ELEKTOR		
240V~	50Hz	
No. 970043		
F = 0A8 T (2x)		

In passing ...

Most readers of this magazine know that it is published in identical form (at least as far as the articles are concerned) in Dutch, French and German, as well as in Greek, Polish, Portuguese, Spanish and Swedish in non-identical form. The Dutch, English, French and German issues are produced in the Netherlands, but published in the relevant country. These issues are the responsibility of an international team of writers/translators and technical editors.

On the face of it, there should be no problem in producing a supranational electronics magazine, since electronics is more international than any other branch of engineering. The electronics market is a world market: there is not one semiconductor or IC manufacturer who does not operate internationally. Also, norms and specifications tend to be internationally agreed.

Working in a multi-language team presents no real difficulties: most of the editorial staff have worked together for almost twenty years. Of course, technical translating is quite different from literary translating: for one, the technical translator has to know and understand the subject!

Most difficulties arise from the differences in standards laid down many years ago. For instance, an article on television will have to take into account that France (and eastern Germany) uses Secam, England PAL-I (but many other English-speaking countries NTSC), and Germany and the Netherlands PAL-B/G. The same applies to the different mains voltage outlets in the four countries. Astra transmissions are popular in Britain and in Germany, but not much in the Netherlands. Similarly, GSM mobile telephones for the E-band (1800 MHz) are in use in Britain and in Germany, but not in France and Holland.

Surprises still occur as well: chipboard or PVC tubing of the density specified in a German design are not available in the Netherlands. And Siemens products are not not easily available from retail outlets even in Germany. Strangest of all: try to find a bicycle rear light that is standard in all four countries!

[975043]