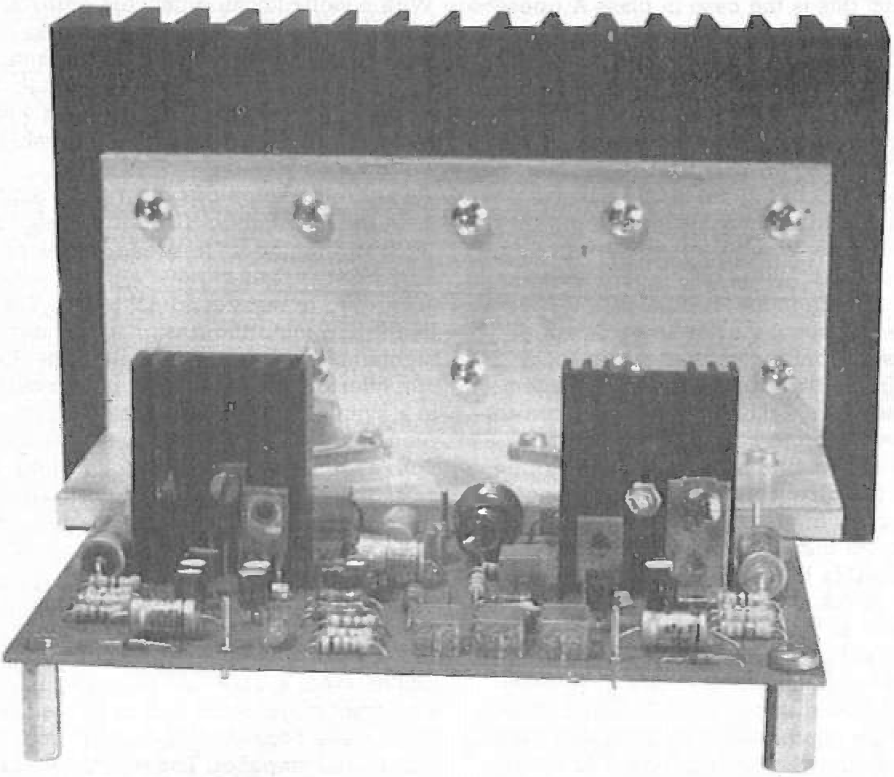


This photograph of two AXLs forming a stereo amplifier shows how the printed circuit boards, the MOSFETs, the aluminium bracket, and the heat sink are connected together.

AXL amplifier

class A, B or AB

The AXL amplifier described here is intended for operation in class A, AB, or B. Its design specification stipulated that it should be reasonably compact, reliable, robust, and relatively inexpensive to build. It is suitable for use as a power amplifier for electrostatic headphones, in an active loudspeaker system, or in a small hi-fi installation.

The classification of an amplifier depends on the portion of the input current cycle during which output current flows. In class A amplifiers, output current flows over the whole of the input current cycle. These amplifiers have low distortion and low efficiency. In class B amplifiers the output current is cut off at zero input signal, so that a half-wave rectified output is produced. Such amplifiers are very efficient but suffer from cross-over distortion. In class AB amplifiers the output current flows for more than half but less than the whole of the input cycle. At low input-signal levels class AB amplifiers tend to operate in class A, and at high input-signal levels as class B amplifiers.
Power amplifiers commonly work in push-pull, that is, they use two matched devices in such a way that they operate with a 180° phase difference. The output circuits combine the separate outputs in phase. When complementary transistors are used in the two halves, no phase shift is required in the inputs. If both halves of the stage are active simultaneously, they

Technical data

Input sensitivity	790 mV_{rms} for 25 W into 8 Ω 700 mV_{rms} for 40 W into 4 Ω
Input impedance	5 kΩ
Power gain	25 dB
Output power	15 W into 8 Ω, 7 W into 4 Ω — class A — full drive, quiescent current: 1 A 2 W into 8 Ω, 1 W into 4 Ω — class A — reduced drive, quiescent current: 350 mA 25 W into 8 Ω, 40 W into 4 Ω — class AB — full drive 50 W into 8 Ω, 70 W into 4 Ω — class B, quiescent current: 100 mA
Dissipation (no signal condition)	65 W — class A with quiescent current of 1 A and supply voltage of ± 32 V 23 W — class A with quiescent current of 350 mA and supply voltage of ± 32 V 9 W — class B with quiescent current of 100 mA and supply voltage of 2 × 45...50 V
Frequency response	13 Hz...65 kHz at −3 dB class A 20 Hz...20 kHz at −3 dB class B 600 Ω source impedance
Harmonic distortion (primarily 2nd harmonic)	≤ 0.02 per cent in frequency range 20 Hz...20 kHz
Damping factor	100 (at 1 W output at 100 Hz)

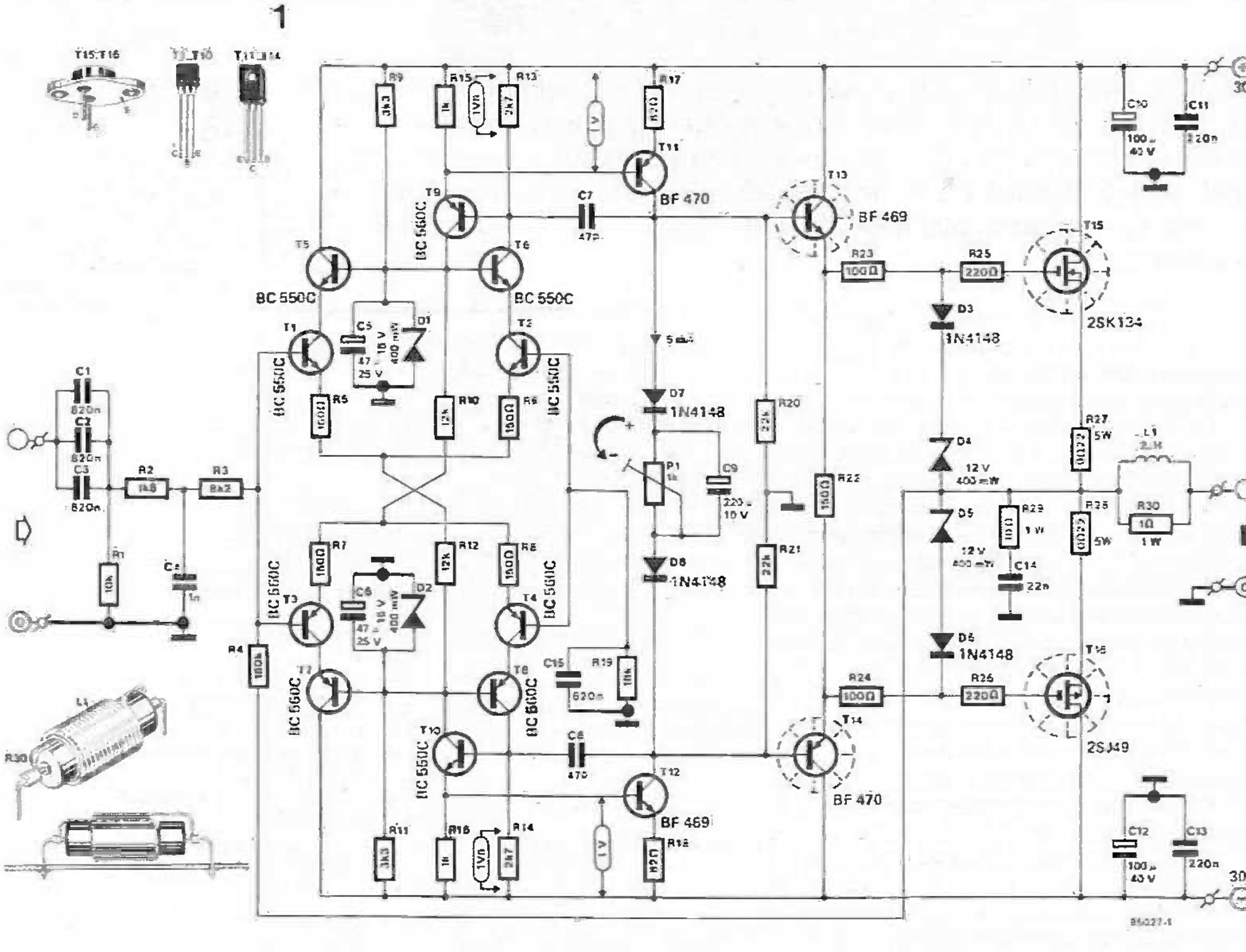
provide equal contributions to the output current; this is the case in class A operation. In class B operation only one half of the stage is active at any one time, and this depends on the polarity of the output current.
A predetermined mode of operation, A, B, or AB, is effected by suitably adjusting the quiescent current (that is, the current under no signal conditions) through the output stage. The quiescent current flows through both halves of the output stage. Each change in the current with respect to the quiescent current in each half of the stage contributes to the output current. In class A operation, the quiescent current is so high, and the output current so low, that both halves of the output stage are on all the time. In class B operation, the quiescent current is, in theory at least, zero. In class AB operation, the quiescent current is set to a level which is appreciably higher than in class B, but much lower than in class A.
Because of the heavy demands on the power supply and cooling, a class A amplifier is considerably dearer per watt output power than a class B amplifier. But, since the reproduction in class A is better than in class B, it seems logical to opt for a compromise: that is, class AB! This becomes even more attractive when you realize that during the reproduction of both music and speech full output is required during very short periods only. With a well-chosen quiescent current, the amplifier therefore sometimes works in class A (low inputs) and sometimes in class AB (high inputs). The consequent increase in distortion as compared with that in class A operation is measurable, but not audible.
As to the question of rated power output, both the Crescendo (*Elektor* December 1982) and the Mini Crescendo (*Elektor* — May 1984) appear to meet a need, at least according to many readers' letters. But bearing in mind the design specification mentioned before, we modelled the AXL amplifier on the Mini Crescendo, resulting in a symmetrical circuit with two complementary MOSFETs in the output stage. Both as regards costs and dimensions, the case, the power supply, and the heat sinks are comparable to those in the Mini Crescendo.

Circuit

As most amplifiers, the AXL may be split into an input stage, voltage amplifiers, and an output stage. As shown in figure 1, the input stage consists of a dual symmetrical differential amplifier. The two transistors normally constituting a differential amplifier are formed by cascodes T1-T5, T2-T6, and T3-T7, T4-T8 respectively. A cascode is a super-transistor in which there is only

Figure 1. The circuit diagram of the AXL amplifier.

1



negligible feedback from collector to base. Furthermore, the collector of such a transistor is an almost ideal current source.
The output voltages of the differential amplifiers are present across resistors R13 and R14 from where they are applied to driver stages T11 and T12 via emitter followers T9 and T10. Note that the collectors of the emitter followers are conveniently connected to zener diodes D1 and D2 which are required to ensure proper balance between the two sections of the dual input circuit.
In contrast to the two Crescendos, drivers T11 and T12 are not connected in a cascode circuit, because the output stage here is voltage-controlled via complementary emitter follower T13+T14. This dual stage can draw a sufficiently high current via R22. This arrangement obviates the need of using the input capacitance of the MOSFETs for frequency compensation. This compensation is now obtained via Miller capacitors C7 and C8, which in essence are connected between base and collector of T11 and T12 respectively. There is, therefore, a deliberate feedback from output to input of the drivers, and the aim of a cascode circuit is precisely to prevent such feedback. Current amplification in this arrangement is low, and this is the reason that emitter followers T9 and T10 have been added.
The collectors of the drivers are interconnected via network P1-C9-D7-D8, which serves to adjust the quiescent current to the required level. The diodes provide temperature compensation for the current set by P1; they derive their temperature essentially from the heat sinks of T13 and T14. The stability with temperature of the quiescent current is not of paramount importance in view of the excellent thermo-electronic properties of the MOSFETs.
The parallel combination of R20 and R21 forms the load of the driver stages. The values of these resistors have been chosen such that on the one hand the voltage amplification of the drivers is reasonably high, and on the other that the contribution of these resistors (via the current amplification mechanism of T13+T14) to the gate control impedances of T15 and T16 is negligible (that is, with respect to R23+R25 and R24+R26 respectively).
As already mentioned, the output stages of the AXL amplifier are voltage controlled, because that gives an even better linearity than current drive. It also keeps the output impedance, without feedback, lower. The improved linearity and lower output impedance result in very good overall performance with a low feedback factor. And that is desirable, because feedback is and remains a necessary evil.
Diodes D3...D6 provide simple, but efficient current limiting of the MOSFETs. Network R29/C14 improves the stability under no-load conditions. Resistors R27 and R28 act as stabilizers of the direct current setting of the output stages. Network

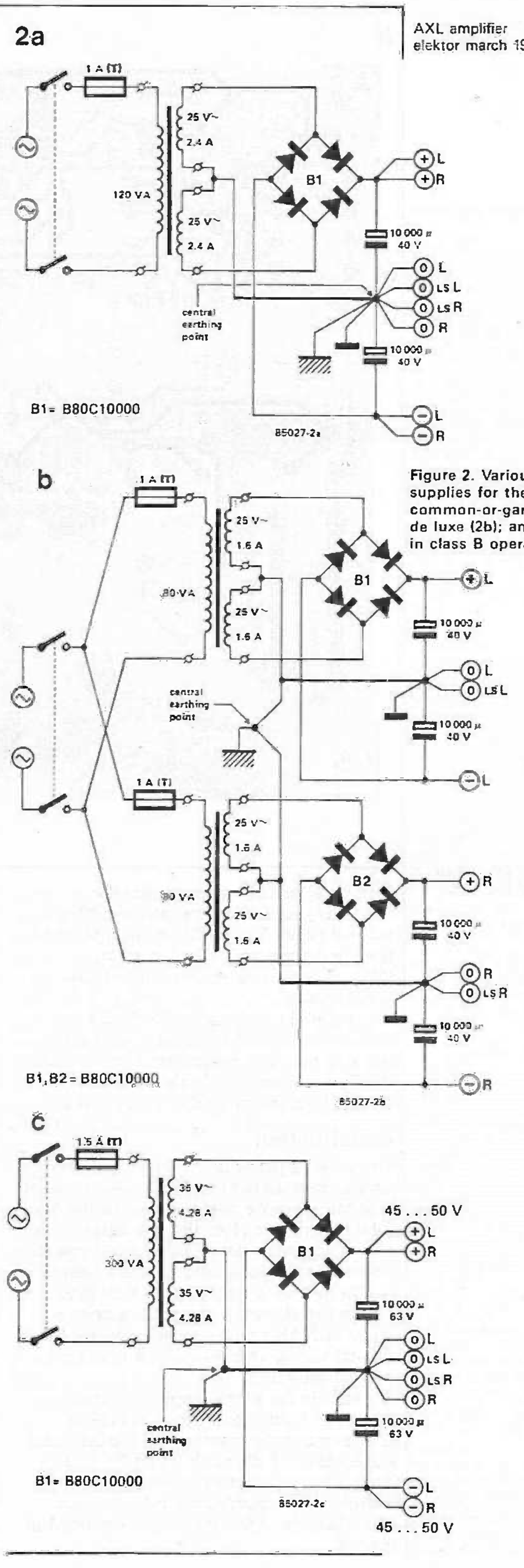


Figure 2. Various power supplies for the AXL: common-or-garden (2a); de luxe (2b); and for use in class B operation (2c).

3

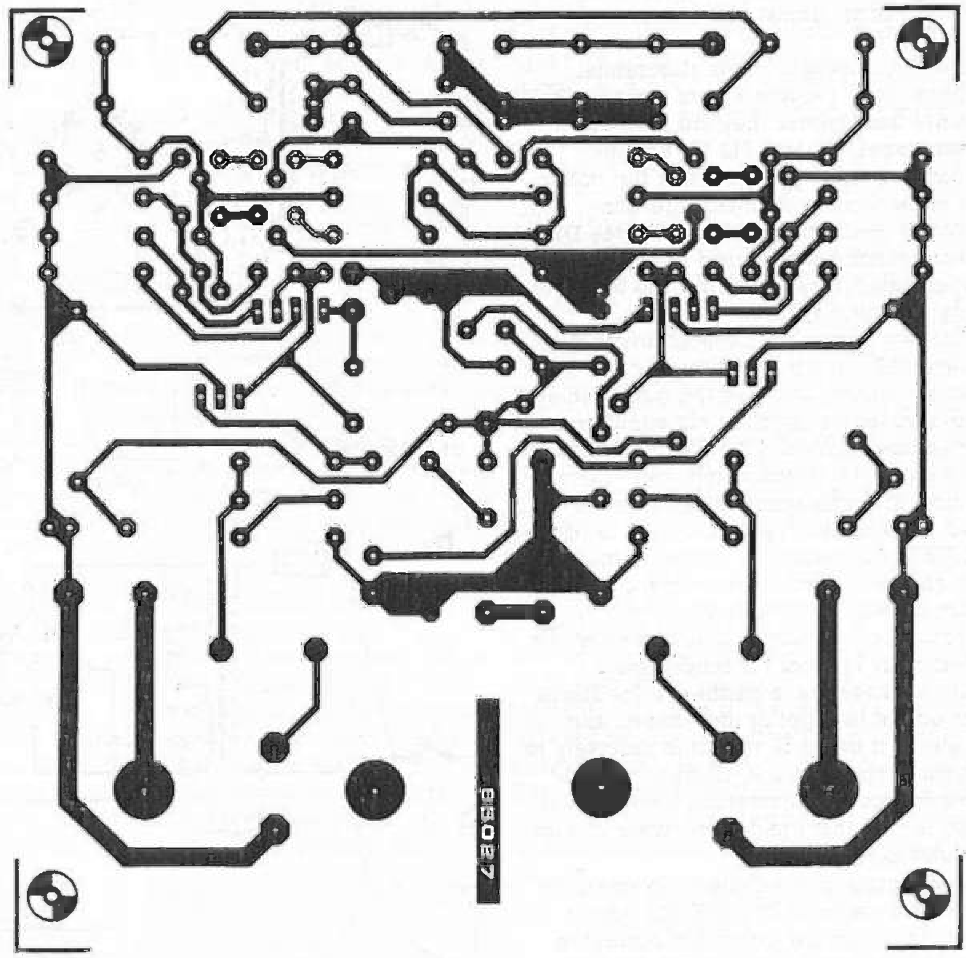
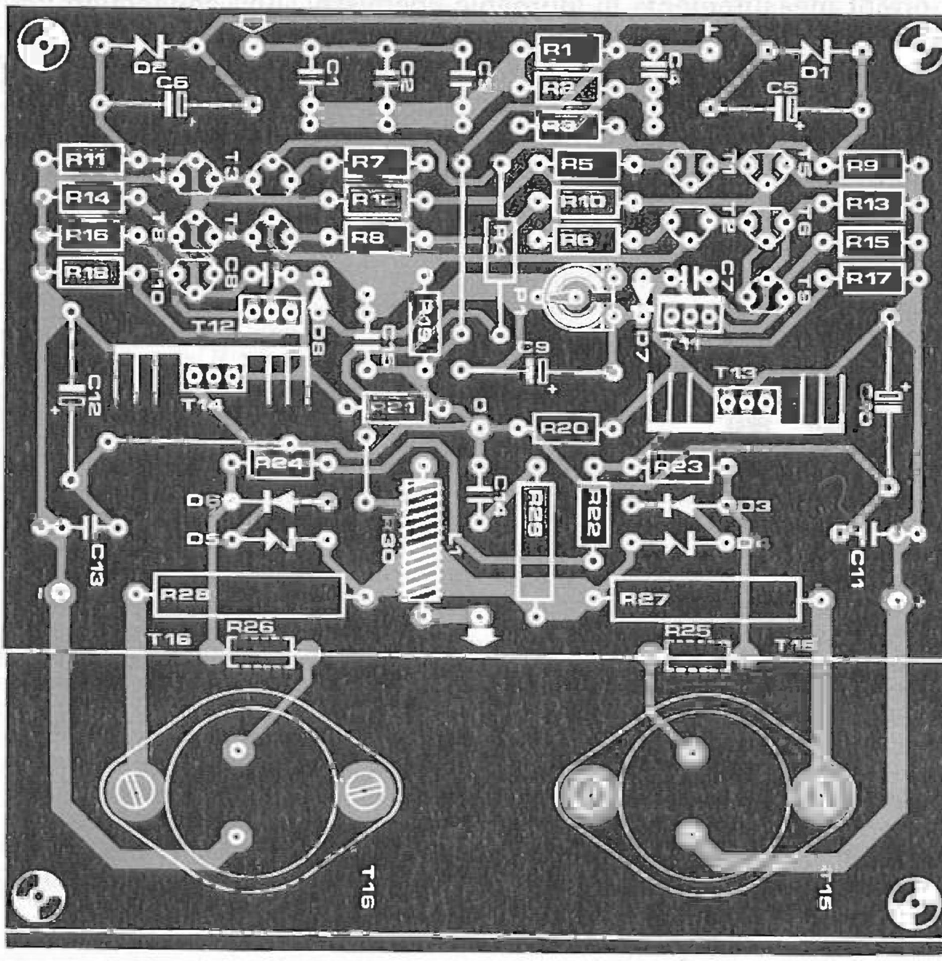


Figure 3. The printed circuit board of the AXL amplifier.

L1/R30 reduces to some extent the capacitive load at the negative-feedback take-off point. The feedback is applied to the input stages via R4. Capacitors C10...C13 provide decoupling of the supply lines.
The parallel combination C1-C2-C3, in conjunction with R1, provides a filter for d.c. and very low frequency signals. Filter R2/C4 prevents signals above about 60 kHz from reaching the input stages.

Construction

The AXL amplifier is constructed along similar lines as the two Crescendos, and it may therefore be useful to reread the two relevant articles. Note that the output transistors are mounted on the printed circuit board: thermal coupling with the heat sink is effected via a right-angled aluminium bracket as shown in the photograph on page 3-27. This arrangement obviates any critical wiring and results in a very compact construction.
As regards the power supply, figure 2 gives you a choice of three. Figure 2a shows one that is common to the left-hand and right-hand channel; figure 2b gives a design for separate supply to the two channels; and figure 2c is intended for use when the AXL amplifier is operated in class B.
The circuit of figure 2a is a single-transformer design. The large-value smoothing capacitors are necessary to keep the ripple voltage on the supply lines low; with smaller capacitances this voltage might easily become unacceptably large in view of the high quiescent current. The ripple voltage does not so much affect the audio signals as reduce the dynamic range.
Note that there are two earth returns per channel: one to the pcb, and one to the loudspeaker. The central earthing point should be the only connection to the amplifier case. This means that the phono (or jack) sockets must be mounted insulated from the case. The connections between these sockets and the pcb should be made in screened cable with the screen connected as appropriate at both ends of the short cable.
The design in figure 2b provides separate supplies for the left-hand and right-hand channels, which are normally only found in very expensive amplifiers. The arrangement ensures that there is guaranteed no interaction between the two channels via the supply lines. The great advantage of using this power supply is that a stereo amplifier can be built from two absolutely symmetrical mono amplifiers which only have the mains switch in common!



Parts list (each channel)

Resistors:

R1 = 10 k
R2 = 1k8
R3 = 8k2
R4 = 180 k
R5,R6,R7,R8,R22 = 150 Ω
R9,R11 = 3k3
R10,R12 = 12 k
R13,R14 = 2k7
R15,R16 = 1 k
R17,R18 = 82 Ω
R19 = 18 k
R20,R21 = 22 k
R23,R24 = 100 Ω
R25,R26 = 220 Ω (mount on trackside of pcb)
R27,R28 = 0Ω22 5 W
R29 = 10 Ω/1 W carbon
R30 = 1 Ω/1 W carbon
P1 = 1 k preset (turn fully anti-clockwise before mounting)

Capacitors:

C1,C2,C3,C15 = 820 n (preferably MKM = metallized plastic polycarbonate)
C4 = 1 n polystyrene
C5,C6 = 47 µ/25 V
C7,C8 = 47 p polystyrene
C9 = 220 µ/10 V
C10,C12 = 100 µ (rated voltage > single supply voltage)
C11,C13 = 220 n
C14 = 22 n

Semiconductors:

T1,T2,T5,T6,T10 = BC 550C
T3,T4,T7,T8,T9 = BC 560C
T11,T14 = BF 470
T12,T13 = BF 469
T15 = 2SK134 (Hitachi-MOSFET)
T16 = 2SJ49 (Hitachi-MOSFET)
D1,D2 = zener 15 V/400 mW
D3,D6,D7,D8 = 1N4148 (mount D7 and D8 vertically)
D4,D5 = zener 12 V/400 mW

Miscellaneous:

L1 = about 2 µH: 20 turns in 2 layers of 1 mm dia. enamelled copper wire (SWG19) on R30; see detail in figure 1
heat sink for T15 + T16; minimum height 100 mm; e.g. SK85; 0.6°C/W
aluminium bracket, right-angled, minimum dimensions: 125 mm long, 6 mm thick, each side 60 mm wide
two heat sinks for T13 and T14, 8.5°C/W, e.g. SK09
mounting and insulating hardware and silicon grease substitute for the transistors to be cooled

If it is required to operate the AXL permanently in class B, higher supply voltages are needed. A suitable power supply is shown in figure 2c. Note that the rating of capacitors C10 and C12 in the amplifier should also be increased to 64 V.
Construction of the amplifier on the printed circuit board is straightforward; note, however, that diodes D7 and D8 should be mounted vertically.
The mounting of the MOSFETs, the aluminium bracket, the heat sink, and all other practical constructional details have been described in the previous crescendo articles (*Elektor* — December 1982 and May 1984) and is further illustrated in the photograph on page 3-27.
Before the amplifier can be taken into use, it is necessary to check and, if necessary, to correct the off-set direct voltage at the amplifier output, and to set the quiescent current.
Ideally, the direct voltage at the output should be zero, but in practice a value of not more than ± 50 mV is perfectly acceptable. First, measure the direct voltage under no-load and no-drive conditions. If it is negative, T2/T6 and T3/T7 should be made to conduct harder, and T1/T5 and T4/T8 less so. This may be done by reducing R6 and R7 by a certain amount, and increasing R5 and R8 by the same amount. The total values of R5+R6 and R7+R8 therefore remain unchanged. For instance,
R6 = R7 = 120 Ω; R5 = R8 = 180 Ω.
If the direct voltage has risen to less than −50 mV, no further action is required; if not, the resistance values should be changed further, e.g.,
R6 = R7 = 100 Ω; R5 = R8 = 220 Ω.
If the direct output voltage is too high and positive, R6 and R7 should be increased, and R5 and R8 reduced, in a similar way to that described for negative values.
The quiescent current is measured by connecting a d.c. milliammeter in the positive or negative supply line, or by a d.c. millivoltmeter across R27 or R28 (about 25 mV per 100 mA). The quiescent current may be set with P1 between 100 mA and 1 A. The lower value pertains to class B operation, the higher to class A. We have found that a value of 350 mA gives the best compromise between performance and dissipation, but the final choice is, of course, yours! ◼