PPP HiFi Valve Power Amplifier

using KT88 valves

Design by G. Haas (Experience Electronics)

Thanks to their pleasant sound, valve-type power amplifiers continue to enjoy uninterrupted popularity. With such an amplifier, you can eliminate the impression of coldness, sterility and artificiality that many people experience with CDs.

The design for a power amplifier that is presented in this article is based on the PPP principle. PPP stands for 'Parallel Push-Pull'. 'Push-pull' means that the output stage is composed of two active elements acting in phase opposition. One of the valves handles the positive half-cycles, while the other one handles the negative half-cycles. In a Parallel Push-Pull configuration, the valves in the output stage are connected in parallel with respect to the ac signal. The disadvantage is that the power efficiency per valve pair is less than with classical Class AB push-pull operation. Otherwise the PPP principle has only advantages. This output stage configuration was invented in the early 1950s, and it was the configuration of choice in studios. Reduced distortion, good sound and a wide frequency

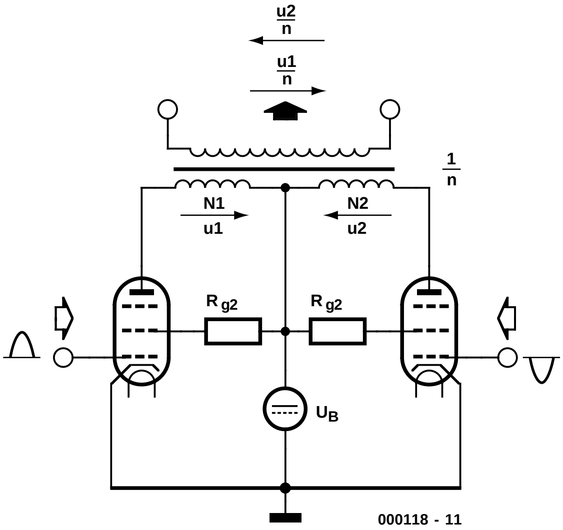
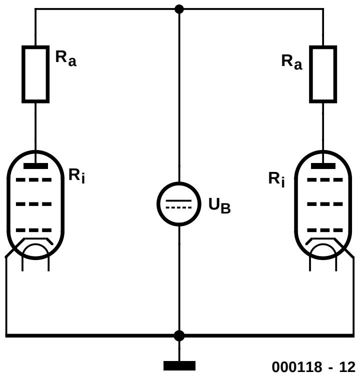
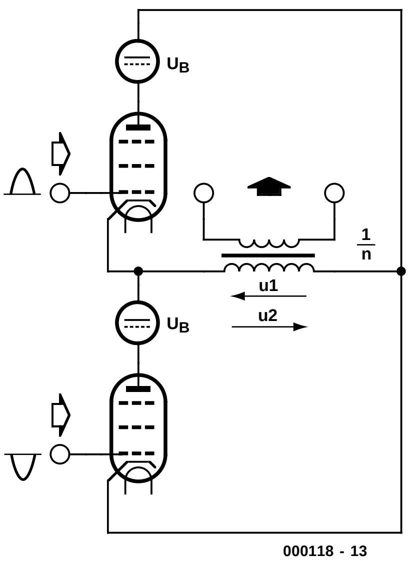


Figure 1. Basic circuit of a conventional Class AB push-pull output stage.



$$R_{l1} = 2 \cdot R_i + 2 \cdot R_a = 2 \cdot (R_i + R_a)$$

Figure 2. The ac equivalent circuit of Figure 1.



$$R_{l2} = R_i/2 + R_a/2 = 1/2 \cdot (R_i + R_a)$$
$$R_{l2} = 1/4 \cdot R_{l1} (!)$$

Figure 3. In a PPP output stage, the signal current flows through the entire primary winding of the transformer.

response were more important in this application area than high power efficiency. With the triumphal march of semiconductor technology, PPP was unable to retain any significant territory, due to its relatively low power efficiency and relatively high price. However, with the aid of modern resources it is possible to construct excellent HiFi PPP power amplifiers at an acceptable price.

AB versus PPP

In order to enable you to better understand the PPP technique, we first have to delve into a bit of theory. The schematic diagram of **Figure 1** shows the basic circuit of a classical Class AB push-pull circuit. Each of the control grids of the power valves is driven by a half-wave signal from a paraphase circuit. This is shown symbolically in the figure; in practice the two valves would naturally be driven by positive half-wave signals, since otherwise the circuit would not work. Here the left-hand valve is responsible for the positive half-cycle and the right-hand valve for the negative half-cycle. The output transformer combines the two half-cycles to form the complete sine wave. The figure shows the polarities of the voltages that appear in opposite phases across two halves of the primary transformer winding (N1 and N2). They generate a voltage on the secondary side of the transformer that is reduced by the transformer ratio *n*. From the figure, you can also see the response of the power stage to hum components in the supply voltage. If a hum voltage is superimposed on the supply voltage U_B, it will be fed into the two windings N1 and N2 in equal measure. If the circuit on the primary side of the transformer is completely symmetric, which means that the windings, output valves and quiescent currents are identical, the hum voltages cancel each other out due to the antiphase feed into the transformer. Unfortunately, perfect symmetry cannot be achieved in practice, so U_B must be adequately filtered.

Figure 2 shows the ac equivalent circuit of the basic circuit of Figure 1. The power supply U_B represents a short circuit for ac signals. The ac internal resistance is given by the series connection of the internal resistances of the two valves and the two windings N1 and N2 with their equivalent resistances Ra. Both output valves are operated with a non-zero quiescent current, in order to avoid cut-off distortion when the sine wave signal passes through zero.

The situation with a PPP output stage is different, as can be seen in **Figure 3**. You will notice that there are two supply voltage sources and that the valves are connected to

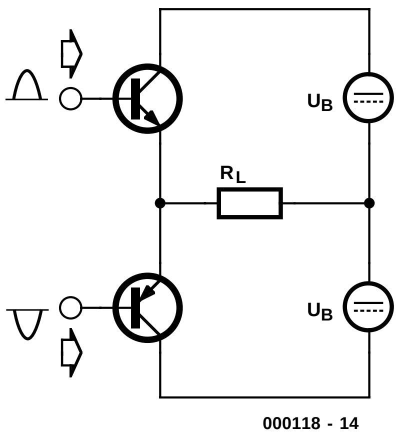


Figure 4. The ac equivalent circuit of Figure 3.

the transformer in a completely different manner. The ac signal current flows through the complete primary winding of the transformer, which is similar to the situation with a mains transformer. Here the valves are connected in parallel for ac signals, which reduces the internal resistance of the PPP circuit by a factor of four. This has various benefits. First of all, the transformer may have a smaller transformer ratio. This reduces the effects of stray inductance and winding capacitance, which yields an improved frequency response. Besides this, a genuine ac current flows through the complete primary winding, instead of one half-cycle per half winding as in the classic Class AB push-pull circuit. This avoids the much-feared 'flyback' effect that occurs with Class AB push-pull output stages, in which a half-wave voltage across one half of the primary winding generates a voltage that is twice as large on the plate of the opposite valve, due to the 2:1 ratio of the autotransformer formed by the primary winding. If the transformer core is magnetised and the stored energy is not fully consumed on the secondary side, the voltage on the primary side rises sharply, and to make matters worse it is again multiplied by the same 2:1 factor. The end result is a voltage breakdown at the weakest point — valve, socket or transformer. This may be a desirable effect in an automobile ignition coil, but in an amplifier it is devastating. In the event of a short circuit, a Class AB push-pull stage will become hot, but it will not be destroyed. Such a valve output stage is thus by nature short-circuit proof, but not open-circuit proof.

A PPP output stage, by contrast, is safe under both extreme operating conditions. Since the transformer is connected as previously described, the output stage does suffer from 'flyback'. It can be compared to a mains transformer, which also suffers no ill effects if it is connected to the mains with no secondary load. The PPP power stage can be seen as a predecessor of the standard transistor push-pull output stage. As we have seen, a whole series of indisputable benefits are associated with this design, to wit low internal resistance and tolerance of short-circuit and open-circuit loads, as well as an inherently good frequency response.

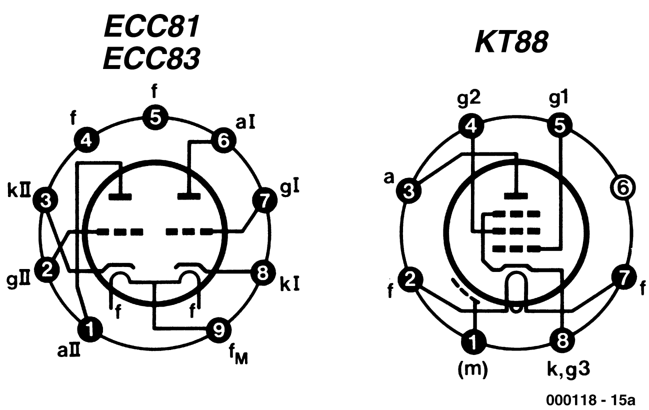
A power amplifier in three building blocks

Figure 5 shows the complete schematic diagram of a monophonic power amplifier. In consists of three blocks, and is consequently divided into three circuit boards. This allows the amplifier to be built such that the valves show to best advantage, as can be seen from the photograph. The transformers and the large electrolytic capacitors, in contrast to many other amplifier designs, are 'embedded' in the equipment.

Block 1 is the amplifier circuit, block 2 is the power supply and block 3 is the switch-on current limiter. At the input to the amplifier, provision is made for an E-1220 audio transformer. If you want to have a floating symmetric input, you can use the transformer together with an XLR socket; otherwise, a Cinch socket is adequate. Thanks to the transformer, it is possible to use floating symmetric cabling, as is common practice in studios. This avoids earth loops and quality losses due to the cabling. Furthermore, the transformer can be connected either 1:1 or 1:2. In the 1:1 configuration, the input resistance is around 34 kΩ, with an input sensitivity of 1.5 V for full output power. With the 1:2 connection, the input resistance drops to 8.5 kΩ, but the output stage can be fully driven with only 0.75 V. Suitable wire bridges are provided on the circuit board. If the amplifier is wired with a Cinch socket, the input sensitivity remains at 1.5 V.

At the input to the amplifier, the 2.2-µF bipolar electrolytic capacitor C1 ensures low-impedance coupling and at the same time blocks any dc component of the signal. Resistors R3 and R4 block coupled-in RF interference. Valve V1a provides the main amplification, with RF oscillations being suppressed by C2. Valve V1b is wired as an impedance converter, and it serves as a low-impedance source for the signal applied to paraphase circuit valve V2. The grid of valve V2a is driven directly without a coupling capacitor, since the dc potential has been brought to the proper level by suitable selection of component values. The control grid of V2b is connected to the same dc potential as the grid of V2a via R14. Capacitor C10 provides a short-circuit path to ground for any ac components that may be present at the grid of valve V2b, which is driven by the ac signal voltage via its cathode. Valve V2 must provide the full amplitude of the output voltage, since the output valves V3 and V4 only provide the signal with the current needed to achieve the desired power. The latter two valves act as cathode followers, in the same way as transistors are used as emitter followers in the output stage of a transistor amplifier.

This also gives an answer to the frequently hotly debated question, 'How do different types of valves sound?' Since the output valves of a PPP design do not contribute any-



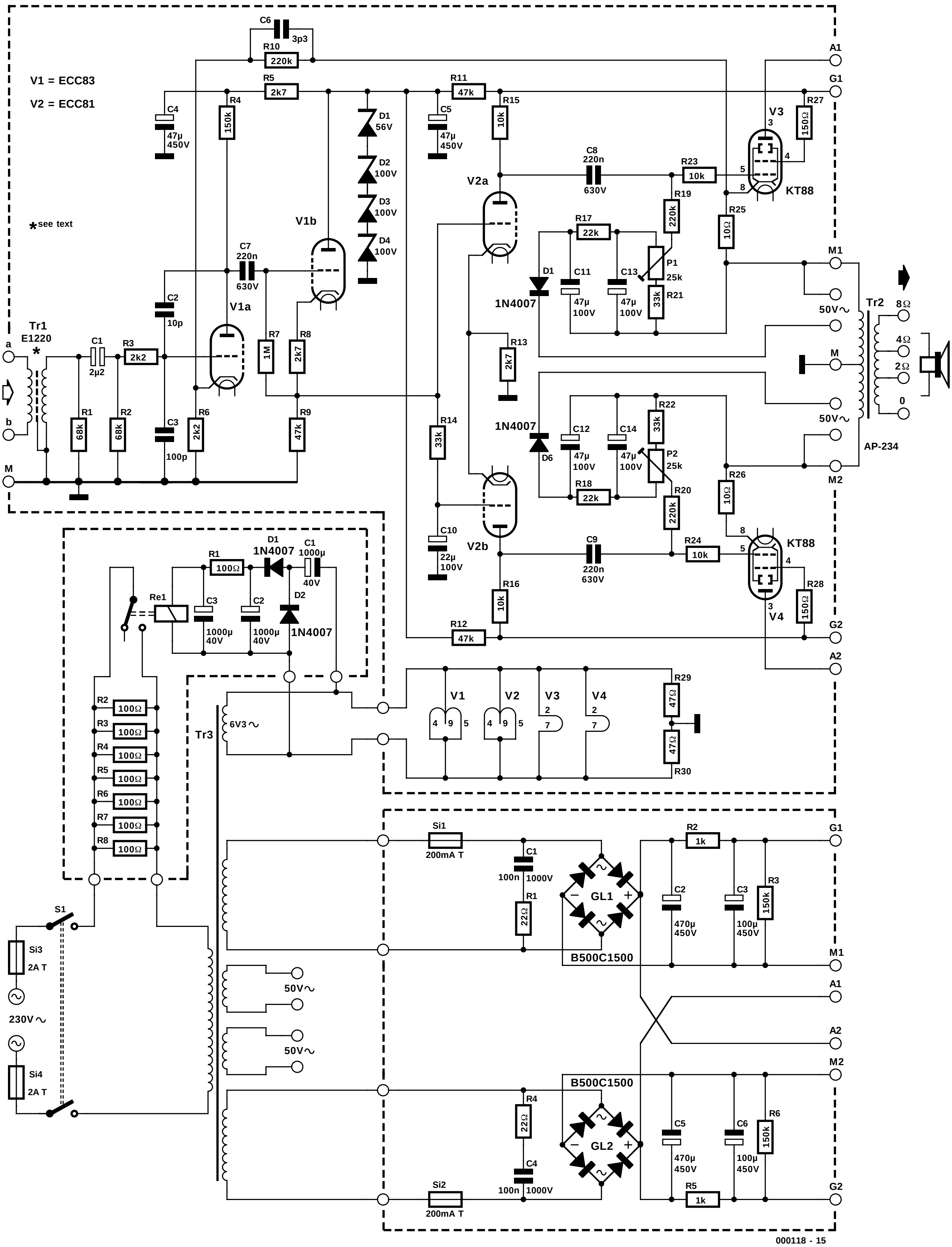
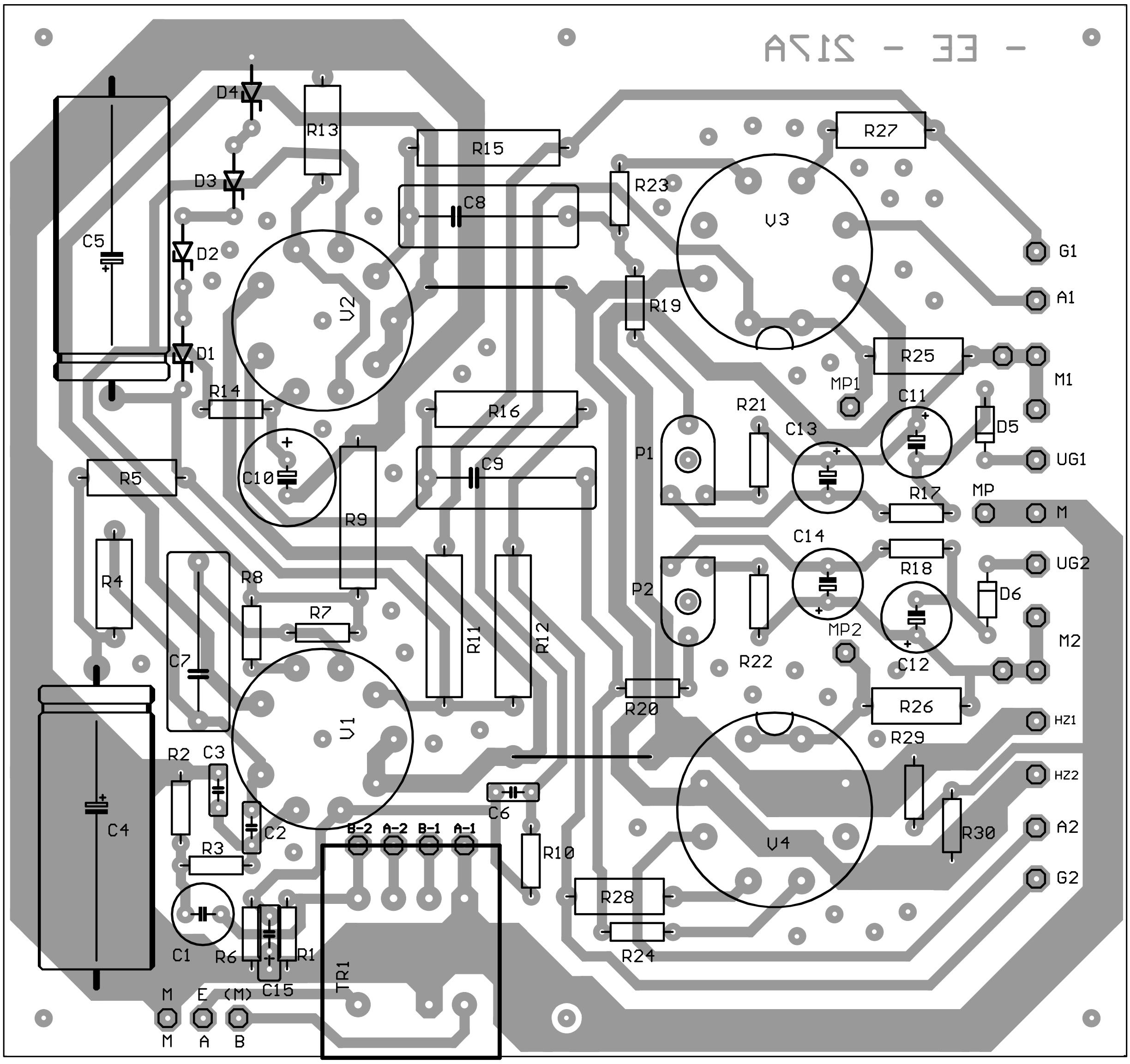


Figure 5. A circuit according to the building-block principle: the equipment can be configured as a monobloc or stereo amplifier, with different types of output valves.



COMPONENTS LIST

Power Output Stage with KT 88 or 6550A

Resistors:

(unless otherwise stated, use metal film types, 0.7W, 1% tolerance;
MO = Metal oxide, 5% tolerance)

R1,R2 = 68kΩ
R3 = 2kΩ2
R4 = 150kΩ, MO, 2W
R5 = 2kΩ7, MO 2W
R6 = 2kΩ2
R7 = 1MΩ
R8 = 2kΩ7
R9 = 22kΩ, MO, 2W
R10 = 390kΩ
R11,R12 = 47kΩ, MO, 2W
R13 = 2kΩ7, MO, 2W
R14 = 33kΩ
R15,R16 = 10kΩ, MO, 2W
R17,R18 = 10kΩ
R19,R20 = 220kΩ
R21,R22 = 33kΩ
R23,R24 = 3kΩ3
R25,R26 = 10Ω, MO, 2W
R27,R28 = 270Ω, MO, 2W
R29,R30 = 47Ω
P1,P2 = preset 25kΩ

Capacitors:

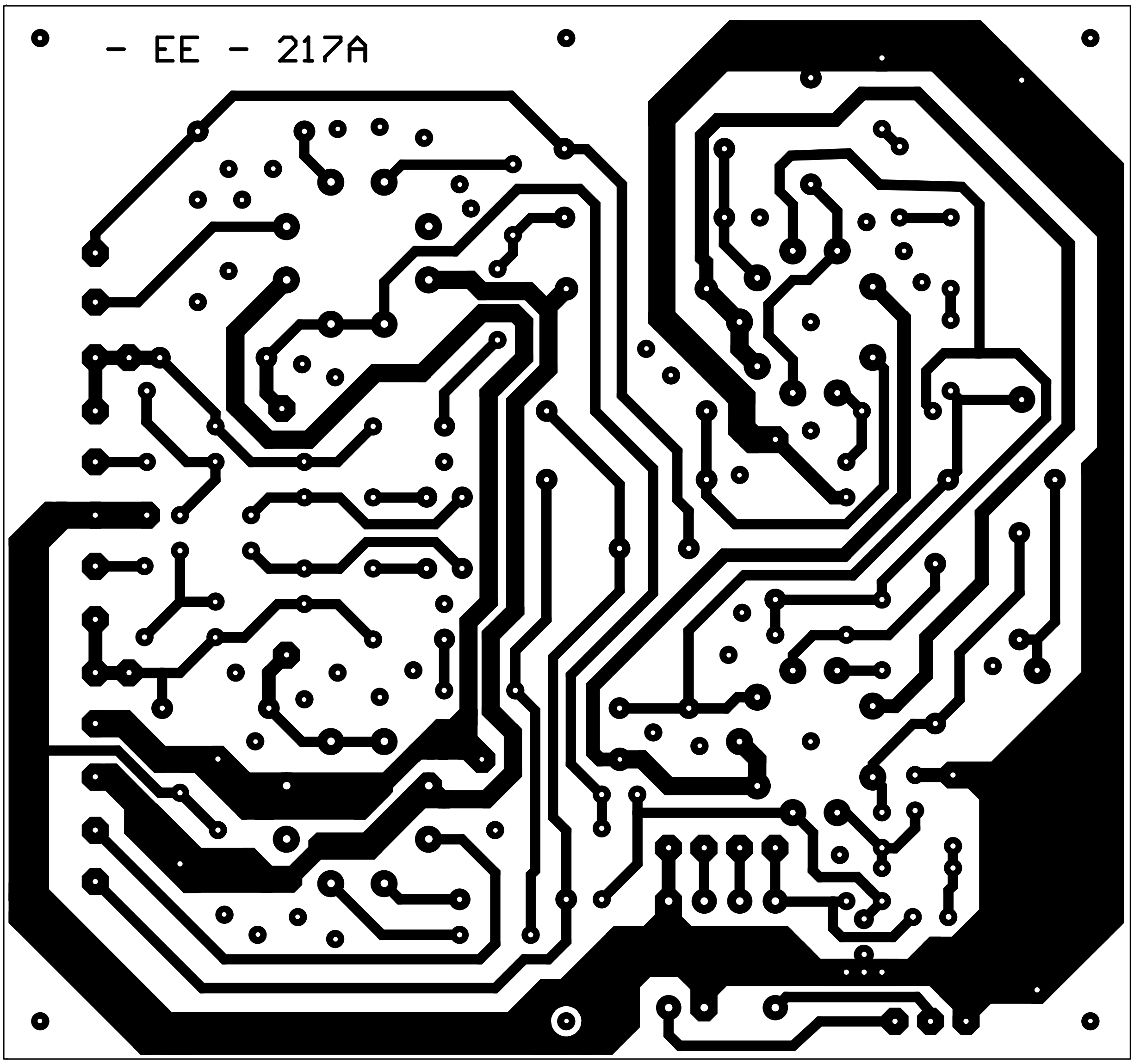
C1 = 2µF2 50V bipolar
C2 = 10pFceramic
C3 = 100pF ceramic
C4,C5 = 47µF 450V axial
C6 = 10-33pF (fit only if parasitic oscillation is noticed)
C7,C8,C9 = 0µF22 630V, MKS 4
C10 = 10µF 100V, lead pitch 5mm
C11-C14 = 47µF 100V, lead pitch 5mm
C15 = 1nF, MKH, lead pitch 7.5mm (see text)

Semiconductors:

D1 = zener diode 56V 1.3W
D2-D4 = zener diode 110V 1.3 W
D5,D6 = 1N4007

Miscellaneous:

V1 (Rö1) = ECC83
V2 (Rö2) = ECC81
V4 (Rö4),V5 (Rö5) = KT88 or 6550 A
Tr1 (Ü1) = E-1220 (if necessary)
Tr2 (Ü2) = AP-234
2 off 'Noval' (9-way) valve socket, PCB mount
2 off 'Octal' valve socket, PCB mount
Tr1 = Mains transformer NTR-P\7 (Mono) or NTR-P\5 (Stereo)



COMPONENTS LIST

Power Output Stage with EL 34

Resistors:

(unless otherwise stated, use metal film types, 0.7W, 1% tolerance;
MO = Metal oxide, 5% tolerance)

R1,R2 = 68kΩ
R3 = 2kΩ2
R4 = 150kΩ, MO, 2W
R5 = 2kΩ7, MO, 2W
R6 = 2kΩ2
R7 = 1MΩ
R8 = 2kΩ7
R9 = 47kΩ, MO, 2W
R10 = 220kΩ
R11,R12 = 47kΩ, MO, 2W
R13 = 2kΩ7, MO, 2W
R14 = 33kΩ
R15,R16 = 10kΩ, MO, 2W
R17,R18 = 22kΩ
R19,R20 = 220kΩ
R21,R22 = 33kΩ
R23,R24 = 10kΩ
R25,R26 = 10Ω, MO, 2W
R27,R28 =150Ω, MO, 2W
R29,R30 = 47Ω
P1,P2 = preset 25 kΩ

Capacitors:

C1 = 2µF2 50V bipolar
C2 = 10pF ceramic
C3 = 100pF ceramic
C4,C5 = 47µF 450V axial
C6 = 10-33pF (fit only if parasitic oscillation is noticed)
C7,C8,C9 = 0µF22 630V, MKS 4
C10 = 10µF 100V, lead pitch 5mm
C11-C14 = 47µF 100V, lead pitch 5mm
C15 = 1nF, MKH, lead pitch 7.5mm (see text)

Semiconductors:

D1 = zener diode 56V 1.3 W
D2,D3,D4 = zener diode 100V, 1.3W
D5,D6 = 1N4007

Miscellaneous:

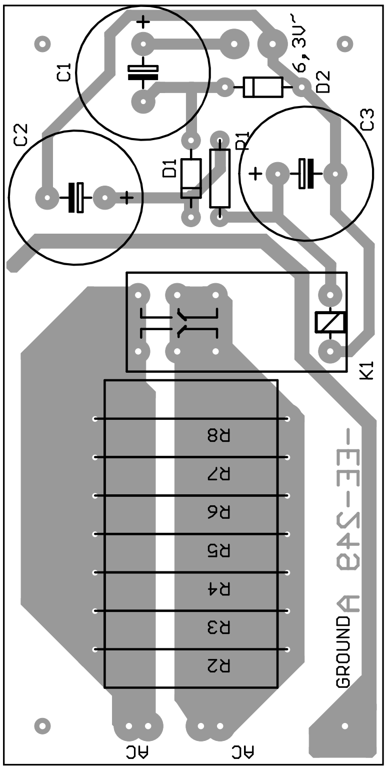
V1 (Rö1) = ECC83
V2 (Rö2) = ECC81
V4 (Rö4),V5 (Rö5) = EL34
Tr1 (Ü1) = E-1220 (if necessary)
Tr2 (Ü2) = AP-234
2 off 'Noval' (9-way) valve socket, PCB mount
Tr1 = Mains transformer NTR-P\6 (Mono) or NTR-P\3 A (Stereo)

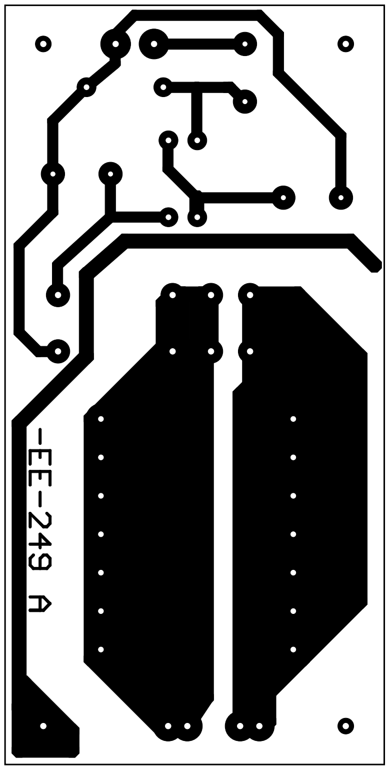
thing to the voltage gain, they have a secondary influence on the sound. With a conventional Class AB push-pull output stage, the characteristics of the output valves affects the sound much more, due to their voltage gain. The component values shown in the schematic diagram have been selected for the KT88, with which a power of 45 W per channel can be achieved. A different set of component values is also shown in the components list for use with the EL34. With this type of valve, 35 W per channel is achievable. Capacitor C15 is an important component. The frequency response drops slightly at high frequencies, due to unavoidable stray circuit capacitances. With C15, the negative feedback can be slightly reduced at the uppermost frequencies. A value of around 1 nF (guideline) should be used for C15, depending on the circuit construction. The frequency response of the completed amplifier must anyhow be checked. When C15 has the proper value, the frequency response at 20 kHz will be absolutely flat, and it may drop by around 1 dB at 100 kHz. However, it is very important to avoid making C15 too large, since otherwise the high-frequency response may become exaggerated.

High voltage and filament voltage

The wiring of the second block, the power supply, appears to be fairly complicated. Since the valves in the output stage are cross-coupled with each other, two separate secondary windings are needed in addition to the filament winding. The grid bias voltage G is generated from the two 65-V windings. The 50-V windings are intended to be used with the EL34, which can manage with a lower grid bias voltage. With 50 V, there is still a good adjustment range for the two trimpots. Each of the screen grids receives its voltage from the opposite half of the power supply. This is necessary to allow the output-stage pentodes to actually operate as such. When either one of the valves is driven fully on, the voltage between the anode and the cathode drops to a low value. If the screen voltage were to also drop by an equivalent amount, the output signal premature would be prematurely limited by the valves themselves.

Each of the screen grid voltages is filtered by 1 kΩ in combination with 100 µF. The driver valve V2 is fed from theses two voltages. The supply voltage for V1 is tapped off via R11 and R12, and additionally filtered by C5. The supply voltage for V1 is stabilised and filtered using the Zener diodes D1–D4. This is particularly important, due to the fact that V1a provides the main amplification. A stable voltage at this location contributes to the consistency of the amplification characteristic.





COMPONENTS LIST
Power-on Delay

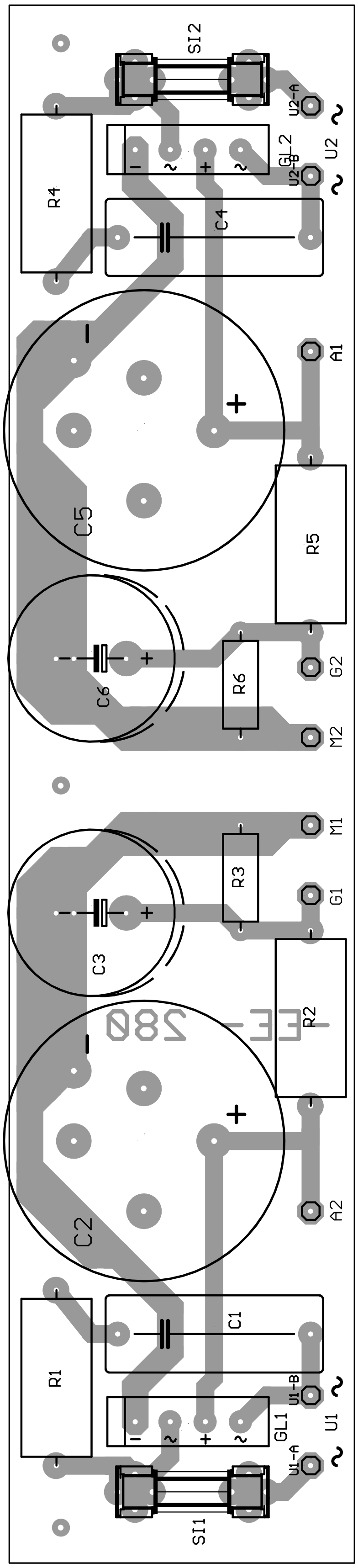
R1 = 100 Ω
R2-R8 = 100Ω, MO, 4.5 W
C1,C2,C3 = 1000µF 40V, lead pitch 7.5mm
D1,D2 = 1N4007
Rel1 = 12V coil, 2 x change-over gold-plated contact, 8A, PCB mount, (Celsea E3208)

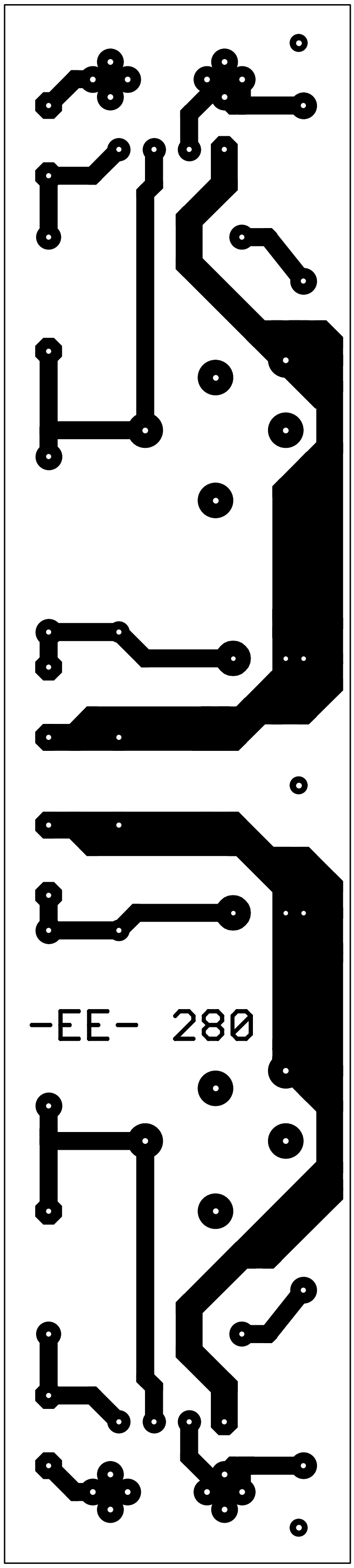
There are RC networks located in front of the high-voltage rectifiers to suppress spikes generated by the rectifiers. If they are not suppressed, these very narrow spikes, with their very broad frequency spectrum, are objectionably audible in the tweeter. If necessary, the values of these components may be modified.

The high voltages are individually and separately fused. When an output valve draws its final breath (and these valves fail the most often), it often draws a high current surge in the process. The fuse prevents any additional damage and interrupts the anode current. Fusing is also a good idea to protect against possible failure of a rectifier or electrolytic capacitor.

There are two versions of the power supply — one that can provide power to a monobloc, and another that can handle a stereo power amplifier. In order to save space and money, different values of electrolytic capacitors are used in the two versions. The compact stereo version employs a 220 µF/47 µF combination, while each half of the monoblock version (which has much more room for the power supply) is fitted with 470 µF/100 µF. If you make your own enclosure, you can always build a stereo power amplifier with two internal monaural assemblies or fit only the larger capacitors. In principle, the design shown here is a flexible set of building blocks.

The 6.3-V filament voltage is connected symmetrically to ground via a pair of 47-Ω resistors. This is essential, since the allowable potential difference between the filaments and the cathodes of the valves is limited. In addition, this drastically reduces the amount of hum noise coupled in via the filaments.





COMPONENTS LIST

Power supply, mono

Resistors:

R1 = 22Ω, MO, 4.5 W
R2 = 1kΩ, MO, 4.5 W
R3 = 150kΩ, MO, 2W
R4 = 22Ω, MO, 4.5W
R5 = 1kΩ, MO, 4.5W
R6 = 150kΩ, MO, 2W

Capacitors:

C1 = 0.1µF 1000V, MKP 10
C2 = 470µF 450V (PCB mount)
C3 = 100µF 450V, lead pitch 10mm
C4 = 0.1µF 1000V, MKP 10
C5 = 470µF 450V (PCB mount)
C6 = 100µF 450V, lead pitch 10mm

Miscellaneous:

Gl1,Gl2 = B500C1500 (500V piv, 1.5 A continuous), flat case
2 off fuse, 0.2 AT (time lag)
2 off fuse holder with cap, PCB mount

Power supply, stereo (one channel)

Resistors:

R1,R2 = 22Ω, MO, 4.5 W
R3,R4 = 1kΩ, MO, 4.5 W
R5,R6 = 150kΩ, MO, 2W

Capacitors:

C1,C2 = 0.1µF 1000V, MKP 10
C3,C4 = 220µF 450V, axial
C5,C6 = 47µF 450V, axial

Miscellaneous:

Gl1,Gl2 = B500C1500, (500V piv, 1.5 A continuous), flat case
2 off fuse, 0.2 AT (time lag)
2 off fuse holder with cap, PCB mount

Switch-on delay

The third block, the switch-on delay circuit, is driven by the filament voltage. The mains transformer is built with an MD core and has very low-impedance windings. This transformer can deliver very high peak currents, and like toroidal transformers, it draws a strong magnetisation current pulse when switched on. In addition, high-capacitance, high-voltage electrolytic capacitors are connected to the secondaries directly after the rectifiers, and when the power supply is switched on these capacitors are empty and must be charged to around 430 V. On top of this, the filaments of the valves represent very nearly a short circuit when cold. Just like incandescent lamps, they exhibit PTC resistance characteristics. Without switch-on current limiting, the branch circuit fuse (or circuit breaker) would blow (trip) when the amplifier is switched on.

Using a voltage-doubling rectifier, the necessary 12 V potential for the relay is generated from the filament voltage. At the

Technical data and measured results

Input sensitivity (for P = 43 W):		0.92 V_{rms}
Maximum output power (THD + N = 1%):		43 W
THD + N	(B = 80 kHz, 1 W, 1 kHz):	0.17 %
	(B = 80 kHz, 1 W, 20 kHz):	0.48 %
S/N (A-weighted) at 1 W:		72 dB
Damping factor (at 1 W/1 kHz):		2.67 (output impedance 3 Ω)

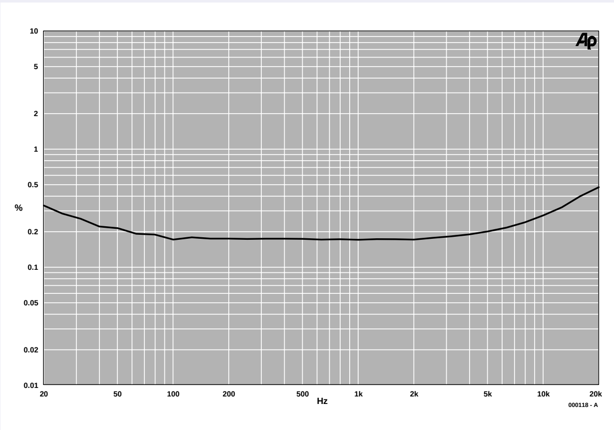


Figure A. THD + N versus frequency at 1 W

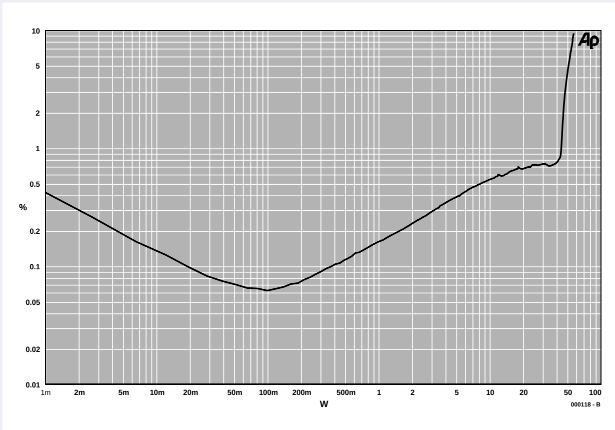


Figure B. THD + N versus output level (minimum value at 100 mW: 0.063 %)

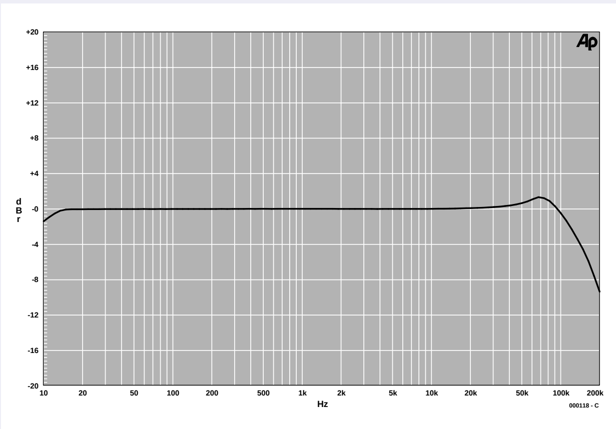


Figure C. Amplitude versus frequency (at 25 W).

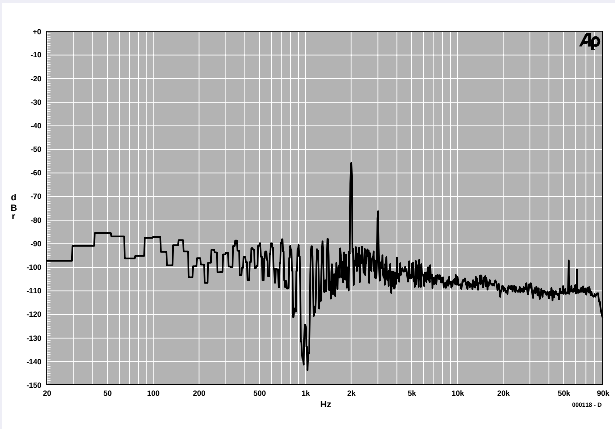


Figure D. Frequency spectrum at 1 W (amplitude of the 2nd harmonic approximately –56 dB)

moment when the unit is switched on, the relay contacts are open, so the current is limited to around 16 A by the seven power resistors connected in parallel. The relay is activated after a delay of around one second, after all the critical processes have already taken place, and it shorts out the resistors. A printed circuit board relay with two gold-plated, parallel switchover contacts has been selected here, in order to achieve high contact reliability and thus a high level of operational reliability.

Construction with flair

At the end of this article, you will find the components lists for the various equipment configurations and types of output valves. Please stick to the components specified in these lists and use only the specified components; this will help ensure that everything goes as intended.

A seamless-welded, polished and bright-nickel-plated chassis has been selected for the enclosure. This gives the finished amplifier an attractive appearance. An aluminium chassis avoids magnetic distortions, which for example can result from transformer excitation. The polishing and bright nickel plating (not chrome plating) give the

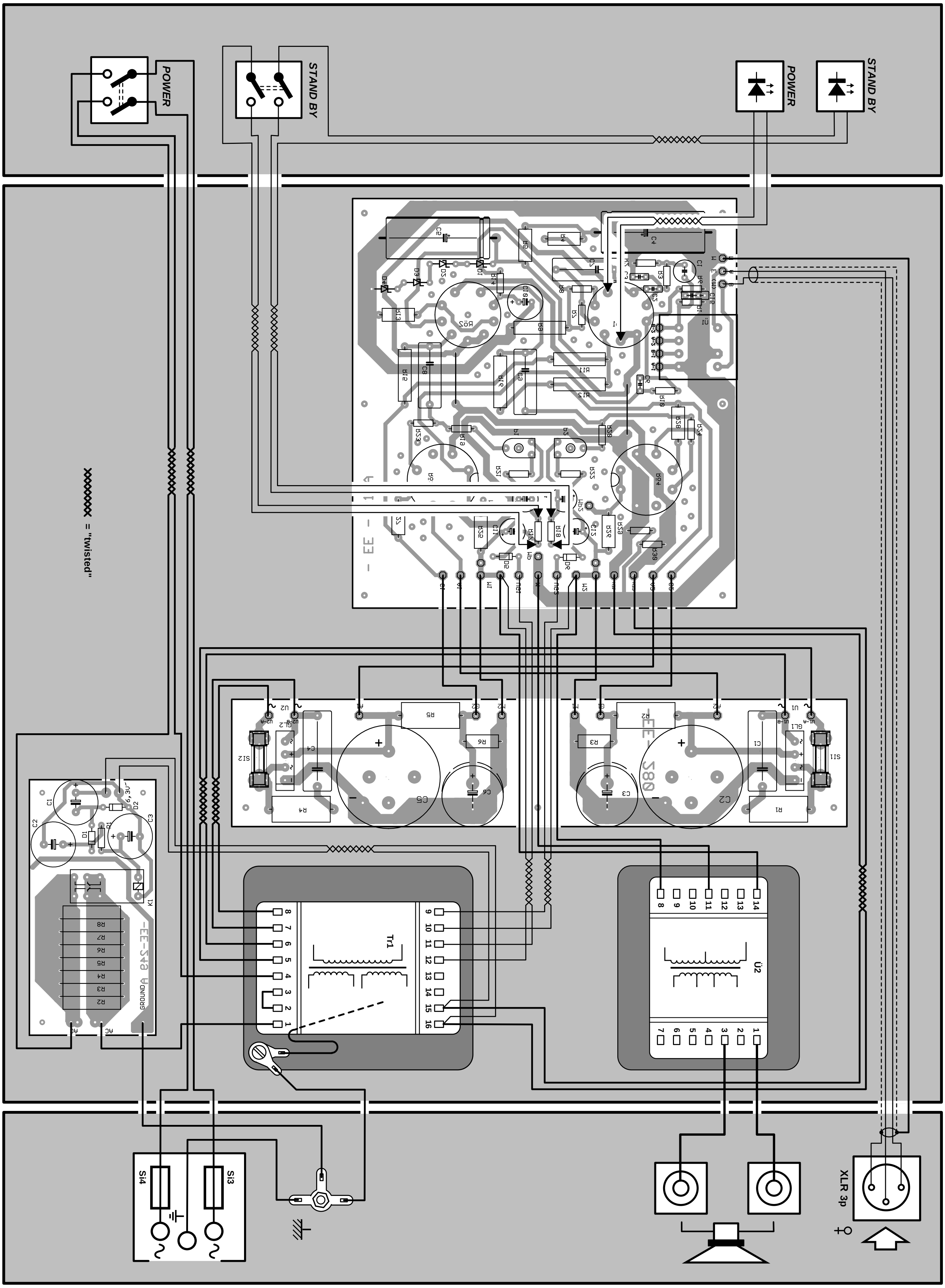


Figure 6. This wiring diagram is a nearly indispensable construction aid.

chassis an elegant appearance. Nickel optically emphasises the warm tone and appearance of the valves, in contrast to the coldness of chromium with its blue cast.

A metallic enclosure that is bonded to the safety earth (E) lead is necessary for reasons of screening and electrical safety. All sockets must be electrically insulated from the enclosure, and all circuit boards must be fitted such that they are electrically insulated from the enclosure. The safety earth lead is connected directly to the enclosure. The mains transformer has a static screen between the primary and secondary windings; this must also be connected to the safety earth lead. The signal ground is connected the enclosure at only one point, at the amplifier input, for potential equalisation. You should wire the amplifier with pairwise twisted stranded wires, using the cross sectional areas specified in the wiring diagram shown in **Figure 6**. Make a copy of this drawing before you start, and mark the connections using a coloured pen as make them. This will help you to avoid forgetting a connection or making a false connection!

Once you have finished the wiring and checked everything, you can carry out the electrical test. Start by removing the fuses for the anode voltages. The filaments should glow visibly after approximately two minutes. After this you should check whether the negative grid bias voltages are actually present at the valve sockets and can be adjusted using the trimpots. Use a voltmeter to measure the potential between M1 and the grid of V3 and between M2 and the grid of V4. Then adjust the trimpots so that the maximum negative voltage is applied to each of the two grids.

Now you can switch off the amplifier and install the fuses for the anode voltages. After switching on the amplifier, use the voltmeter to measure the voltage drops across the cathode resistors R25 and R26. The voltages across these resistors are a measure of the quiescent currents. Working back and forth, adjust the quiescent current each valve to the specified value. This must be repeated several times, since the changed load on the power supply causes the quiescent current of the already adjusted valve to change slightly. Once the quiescent currents have been set, you can use a sinewave generator, dummy load resistor and oscilloscope to check the frequency response and power output. At the very end, you will have to once again adjust the quiescent currents to the specified values. The quiescent currents must always be adjusted with no signal applied. Following this, the equipment is ready for use.

The sample amplifier was built as a set of monoblocks and as a stereo power amplifier (cover picture). With the monoblocks, there is no channel crosstalk, which yields very good localisation, spaciousness and brilliance. The stereo version is more economical, since the cost of the enclosure has to be paid only once and the power supply is less expensive.

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PCB Service

As with the Valve Preamplifier published last year, ready-made printed circuit board for the PPP Valve Power Amplifier are not available through the Publisher's Readers Services. Ready-made boards, with or without components, are available from the author:

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