MUGEN - A Hybrid

The best of both worlds?

Wim de Haan

There are many different configurations for audio amplifiers, including types with bipolar transistors, FETs, ICs, and valves. The amplifier described here uses a mixture of transistors and valves to combine the advantages of both approaches and thus deserves the designation 'hybrid'. The result is an amplifier with audiophile performance.

Valves (or 'vacuum tubes') are experiencing a real revival in the audio world, which can readily be seen from the large number of commercial amplifiers and DIY designs that have appeared in recent years.

Unfortunately, valve amplifiers are relatively costly compared with transistor amplifiers, in part due to the need for a high voltage supply and output transformers. Output transformers in particular are a major investment.

This design attempts to remedy this situation by replacing the output valves and transformer by a solid-state circuit using modern transistors, which can drive a loudspeaker directly. Valves are used in the input stage.

Driver circuit

The amplifier (**Figure 1**) consists of a voltage stage and a current stage. The voltage stage, which is the driver portion, is built around valves V1 and V2, and it must provide adequate amplification of the input signal. Here 20 to 30 dB is a practical figure. The current stage, which is built around transistors Q4 and Q5, enables the amplifier to drive 4-ohm or 8-ohm loudspeakers. The current stage acts as buffer and does not have any gain.

The voltage stage has to supply a solid 25 V_{eff} to the current stage to drive the amplifier to its maximum output level. A key factor here is that the signal

must have sufficiently low distortion, since overall negative feedback is not used in this design. The circuit must also be able to drive a load impedance of 10 kΩ, since the driver circuit sees R11 (20 kΩ) in parallel with the combination of P3 and R16 (20 kΩ). The impedance could be increased by bootstrapping or using MOSFET drivers, but bootstrapping and MOSFET drivers do not fit with the concept of this amplifier.

In other projects implemented entirely with valves, the author has acquired experience with driver stages that must supply output signals with large amplitudes and low distortion. The 'long-tailed pair' circuit is exceptionally well suited to this task. This configuration was also chosen because it can act as a phase splitter, which allows a certain trick to be used as explained below.

The long-tailed pair can be regarded as a differential amplifier that amplifies the difference between the signals on the two control grids. The input signal is connected to the 'left' input. The 'right' input is tied to ground here, so the output signal is an amplified version of the input signal. An advantage of this arrangement is that feedback can be connected to the right input, where it will be subtracted from the original signal. This negative feedback reduces the amount of distortion.

The common cathodes of the two

halves of the ECC83 (US equivalent: 12AX7) can be regarded as a third input, which here provides 6 dB of local negative feedback.

A characteristic of the long-tailed pair is that it has two outputs with opposite phases (180 degree phase offset). The left anode is 'in phase', while the right anode is 'out of phase'.

The long-tailed pair normally has a common cathode resistor, which is what gives it its name. A current source is used instead in this design. The high internal impedance of the current source improves the characteristics of the circuit, including the distortion, and the operating current of the ECC83 can be adjusted easily using a trimpot.

Due to its high amplification factor (100) and excellent availability, the ECC83 is the right choice for this application. The need for high gain can be explained as follows. The long-tailed pair has 6 dB of local negative feedback. A normal cathode-resistor or grounded-cathode amplifier built around an ECC83 can provide a gain of more than 35 dB, and the long-tailed pair circuit used here can provide more than 29 dB. The original intention with this amplifier was to avoid using overall negative feedback. However, we have included an option for adding 6 dB of overall negative feedback. A jumper/header is provided on the PCB for this purpose. This allows every-

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Mugen Hybrid Amp – Mugen (mu-gen) is a Japanese word that means 'infinity' of 'endless'. 'Endless' is the name of a track on the live CD Changeless by the Keith Jarrett Trio. This piece was the source of the author's inspiration for this design.

Figure 1. The hybrid amplifier has a valve driver stage and a transistor output stage.

Audio Amplifier

MUGEN HYBRID AMP
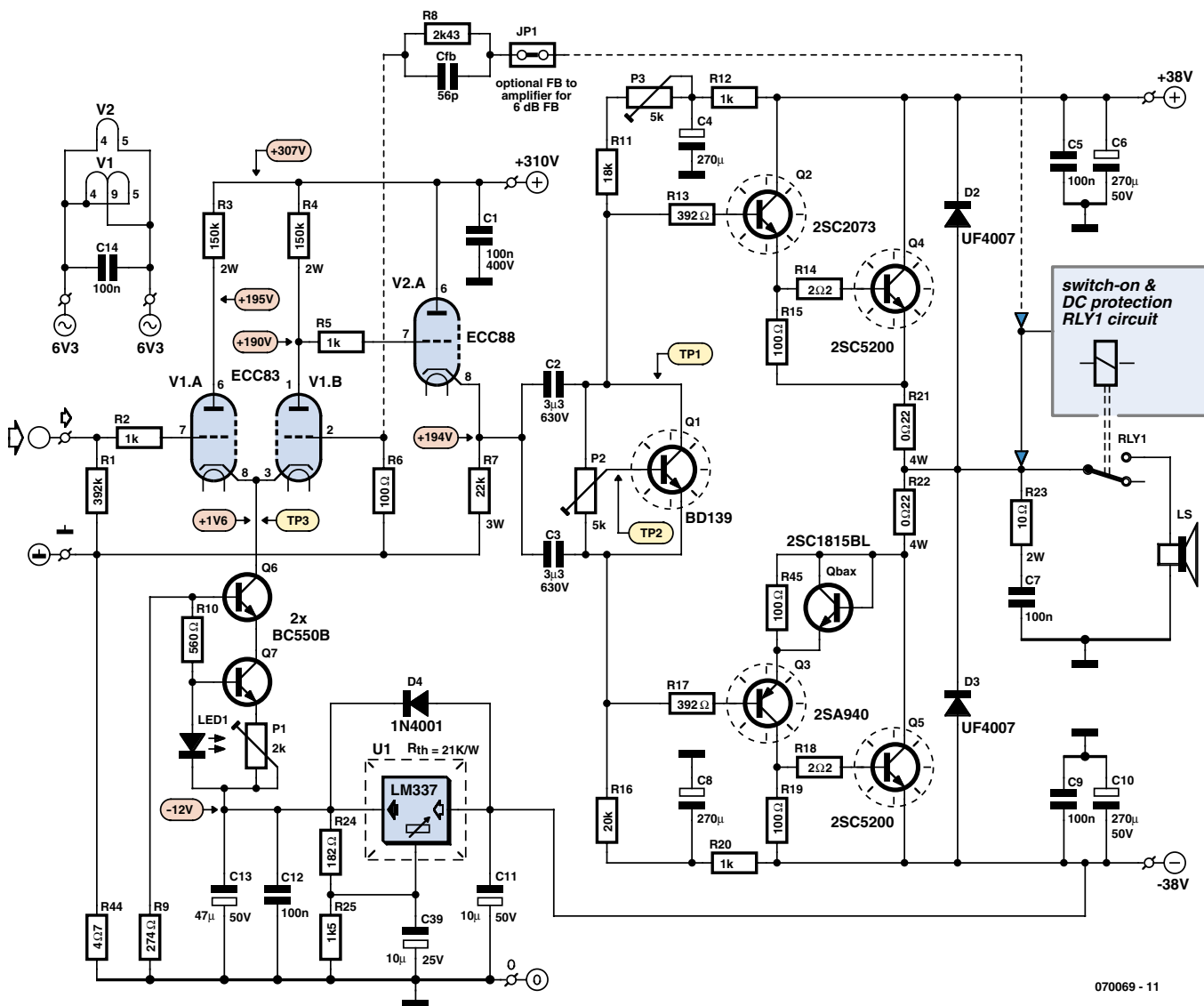
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Specifications (mesured without overall negative feedback)

Input sensitivity:		**825 mV (8 Ω)**
		770 mV (4 Ω))
Input impedance:		**300 kΩ**
Gain :		**29 dB**
		(23 dB with negative feedback)
Output power (1% THD):		**70 W into 8 Ω**
		110 W into 4 Ω
THD + noise	**at 1 W/8 Ω :**	**< 0.1 %**
	at 10 W/8 Ω :	**<0.15%**
Damping factor:		**20 (with 8-Ω load)**

one who builds the amplifier to decide what he or she finds best. Even with overall negative feedback, the gain is still high enough (23 dB) to provide adequate input sensitivity.

This brings us to the previously mentioned trick. With a normal cathode-resistor circuit, it would not be possible to obtain overall negative feedback by feeding the output signal back to the cathode in the usual manner, because the output signal is in phase with the input signal and this would cause positive feedback. The V1b output signal of the long-tailed pair is out of phase, and this makes overall negative feedback possible.

Overall negative feedback forms the subject of a lot of debate. The author has learned from experience that an amplifier with strong negative feedback has a less open and 'pleasant' sound than a design without negative feedback. A value of 6 dB represents a good compromise.

A disadvantage of the ECC83 is that it has a relatively high output impedance. Consequently, a cathode follower is included after the ECC83 to provide sufficient drive for the transistor stage. The cathode follower has a low output impedance (less than 500 Ω), compared with around 50 kΩ for the long-tailed pair. After much experimenting, the best results were obtained with an ECC88 in this position. The bias is set to satisfy the maximum anode voltage rating of the ECC88 (130 V_{DC}). However, the JJ version of the ECC88 has a maximum anode voltage rating of 220 V, the same as the Philips ECC88. The high value of the cathode resistor of the ECC88 allows the ECC83 to be coupled directly to the ECC88. The ECC88 is self-biasing thanks to the large amount of negative DC feedback provided by cathode resistor R7.

A supplementary advantage of the cathode follower design used here is that the cathode voltage is 0 V when the circuit is cold and gradually rises to

its operating bias level of approximately +194 V as the ECC88 warms up. The coupling capacitors are charged gradually during this process, with the result that the transistor stage does not have to handle any spikes.

Exceptionally good results can be obtained by using a current source in place of cathode resistor R7. When an Ixys IXCP10M45 was used as the current source, a distortion of less than 0.1% (without negative feedback!) was measured at an output power of 45 W. However, this IC is difficult to obtain, so this option was not pursued any further.

For practical reasons, the amplifier described here uses JJ Electronics valves. They are readily available, nicely priced, good-quality valves, and they come from current production.

Many people regard the 6N1P as a replacement for the ECC88, but with this design the distortion was not acceptable when a 6N1P was used. A simple and interesting alternative is to use a 5751 in place of the ECC83. These are directly interchangeable types. The amplification factor is slightly lower, but this is not a problem. From an acoustic perspective, the author prefers a 5751 (from ECG/Philips or NOS) in combination with a JJ ECC88. If you have adjusted the amplifier for operation with an ECC83, the voltage at TP3 will increase automatically by about 2.2 V if you replace it with a 5751.

Coupling capacitors

The valve and transistor stages are linked by two high-quality coupling capacitors. They cannot be omitted in this design, since the DC voltage on the cathode of the ECC88 is about 194 V. Unfortunately, these capacitors affect the ultimate sound of the amplifier. The sound characteristics of capacitors are the subject of heated debate among audiophiles. Listening tests have shown clearly that these capacitors have an important effect. We finally settled on a type from the Clarity-Cap SA series, which has an extremely good price/quality ratio. Thanks to its high working voltage (600 V), the SA series is very well suited for use in designs with high voltages, such as valve circuits. The PCB layout can also accommodate types from other manufacturers, including Wima and Solen. The value of 3.3 µF was chosen to position the low-frequency roll-off well below 10 Hz. Note that the coupling capacitance combines with the input imped-

ance of the transistor stage to form an RC filter with a corner frequency of

$$1 / (2\pi \times 3.3\ \mu F \times 10\ k\Omega)$$

the coupling capacitors must have a working voltage of at least 400 V_{DC}.

Current stage

The current stage (power stage) is based on bipolar transistors. Although MOSFETS such as the BUZ900P or 2SK1058 families would also be an option, they were intentionally not chosen for this design.

The selected driver transistors are often used in audio amplifiers. They have outstanding characteristics for audio use, and besides that they are inexpensive. The output transistors (2SC5200) have excellent characteristics, and they are specifically designed for audio applications, readily available (but beware of imitations!), and very robust thanks to their large SOA (safe operating area) range. The 2SC5200 is available in two versions, with an 'O' or 'Y' suffix. This code designates the h_{FE} range. Both types work well, but all of the transistors should be the same type. The O type was used in the prototypes and the final version of the amplifier.

The current stage is a standard quasi-complementary output configuration, which means a configuration with two identical NPN output transistors. This contrasts with the currently common practice of using a complementary design with an NPN type and a PNP type. Quasi-complementary output stages were often used in the 1970s and early 1980s because complementary PNP transistors were not available, or were too expensive. This configuration has acquired a bad reputation among many people, but this is not justified. Very good results can be obtained with a quasi-complementary design. The main advantage is that the output transistors are identical. NPN and PNP transistors can never be more than approximately equivalent. This is why manufacturers such as Naim still use only the NPN/NPN configuration. The ultra-modern Denon PMA1500AE amp also uses a quasi-complimentary NPN output stage, in this case using two UHC n-type FETs.

The selected supply voltage of ±38 V_{DC} is optimal for this output stage and allows a 4-ohm or 8-ohm load to be driven without any problems .
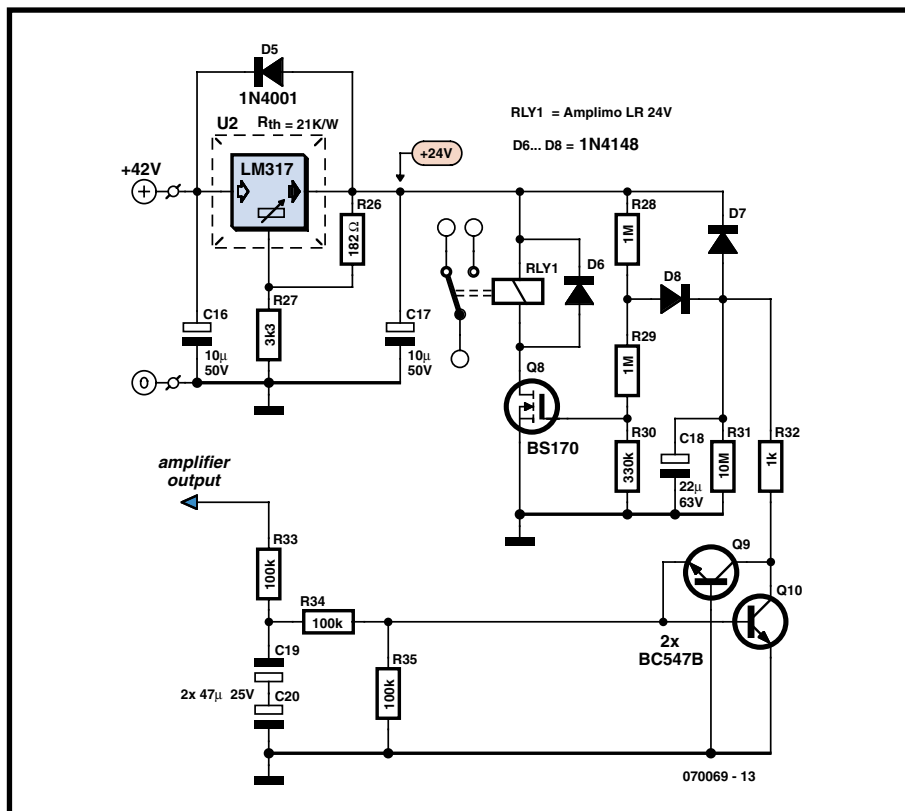

Figure 2. This circuit provides a switch-on delay and DC protection for the output.

Circuit details

Resistor R1 is a grid-leak bias resistor for V1a. Its value is not critical, but the resistor is essential because the valve would otherwise not be able to generate the negative bias that sets its DC operating point. R2 forms a low-pass filter in combination with the input capacitance of the ECC83. This prevents any tendency to oscillation. The same thing applies to R5 in combination with the ECC88. Anode resistors R3 and R4 are dimensioned to yield a voltage of slightly more than 190 V on the anodes of V1. V1 thus has the right bias with an anode current of 0.8 mA. The power dissipation is well within the permitted value.

The long-tailed pair with V1 uses a current source built around Q6 and Q7. The LED provides a reference voltage, and the current can be set easily with P1. The total current is approximately equal to 1/P1. A separate power supply using an LM377 provides a voltage of –12 V for the current source.

The overall negative feedback is applied to the control grid of V1b. As already mentioned, a value of 6 dB was chosen here. This is determined by the ratio of R8 and R6. A small capacitor

(56 pF) can be connected across the feedback resistor to increase stability. The bias of the ECC88 is chosen to generate an anode current of approximately 9 mA with an effective anode voltage of around 115 V_{DC}. The power dissipation is 1 W, which is beneficial for the service life of the valve. The total distortion would be slightly less at a higher current, but the life of the valve would be reduced significantly by the higher dissipation.

Q1 sets the quiescent current of the output transistors, and it must be fitted close to the output transistors to achieve good temperature stability. Minimum quiescent current is obtained when the wiper of P2 is turned fully toward the collector of Q1. P2 must be a ten-turn potentiometer of very good quality. The R11/P3 pair and R16 ensure the DC stability of the amplifier output, and the values of these components also determine the input impedance of the circuit, which is approximately 10 kΩ (20 kΩ || 20 kΩ). These values could be increased if MOSFETs were used, but here this is not possible due to the amount of base current required by Q2 and Q3. R12/C4 and R20/C8 are additional decoupling networks, and they are indispensable. C4
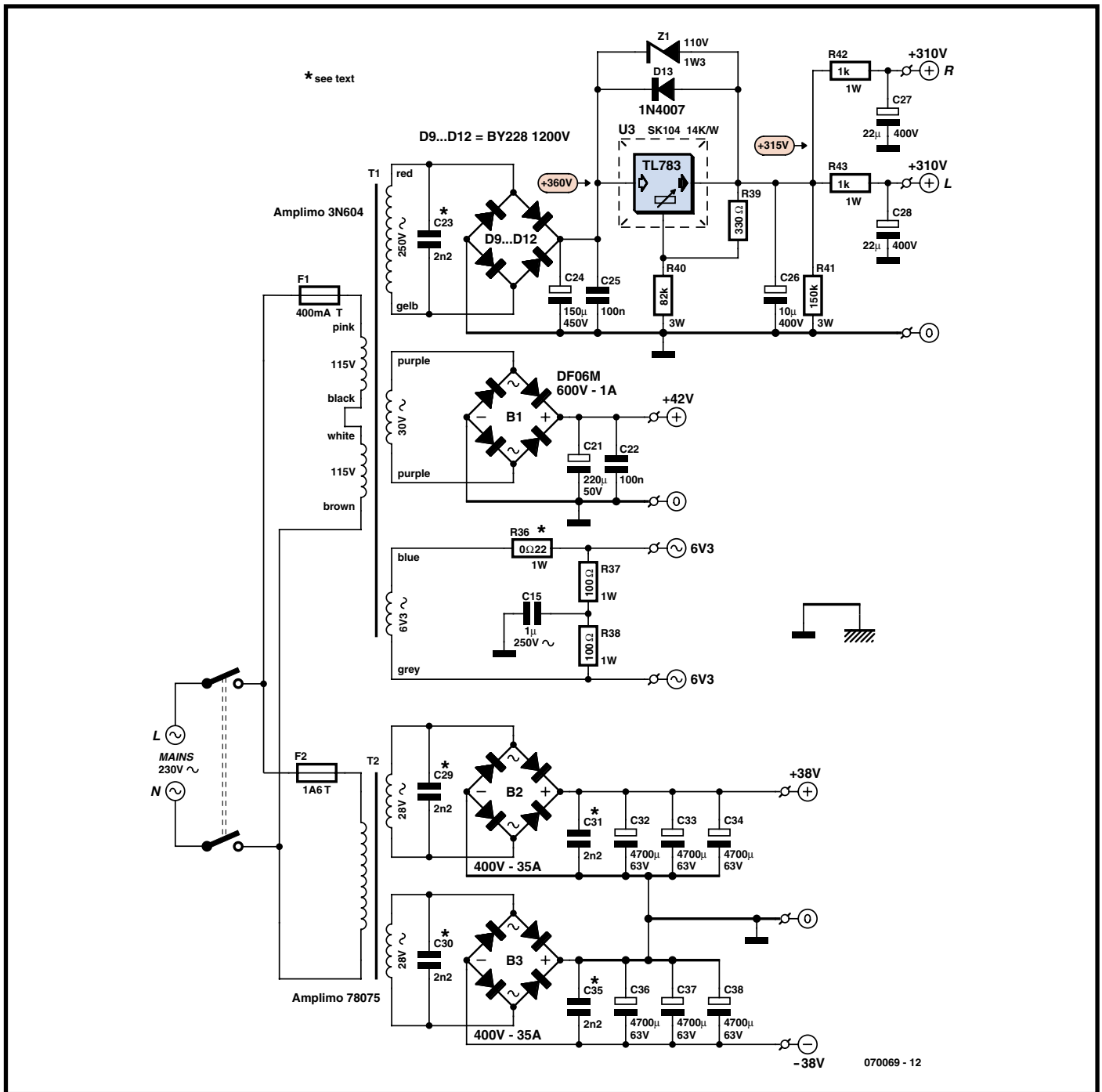
Figure 3. The power supply provides four different voltages.

and C8 can also be 220 µF or 330 µF if desired. P3 allows the DC offset of the output stage to be set to zero. Active DC offset control in the form of an opamp integrator is intentionally not used here because the author believes that this affects the sound quality of the amplifier.

Q2 and Q4 form a Darlington pair that provides adequate current gain, as do Q3 and Q5. Q3 and Q5 form what is called a 'Sziklai pair', which is used

here to mimic a PNP transistor. Quasi-complementary circuits normally use a 'Baxandall diode' to improve symmetry and linearise the response. This approach was used in the Ekwa amplifier published in *Elektor* in 1972. In the present design, a transistor configured as a diode (Q_{bax}) is used instead of a normal diode. The measured distortion at 1 W was 0.22% with a diode in the circuit, while the value with a 2SC1815 configured as a diode was 0.08%. Note

that the BL version of the 2SC1815 should be used here. Although the -O, -Y and -GR versions can also be used, they yield results that are practically the same as with a normal diode. The difference decreases gradually at levels greater than 5 W. The PCB is designed to allow a 2SC2073 or a 1N4007 to be used instead. This is also the order of preference. Obviously, only one of these three types of components can be fitted on the board.
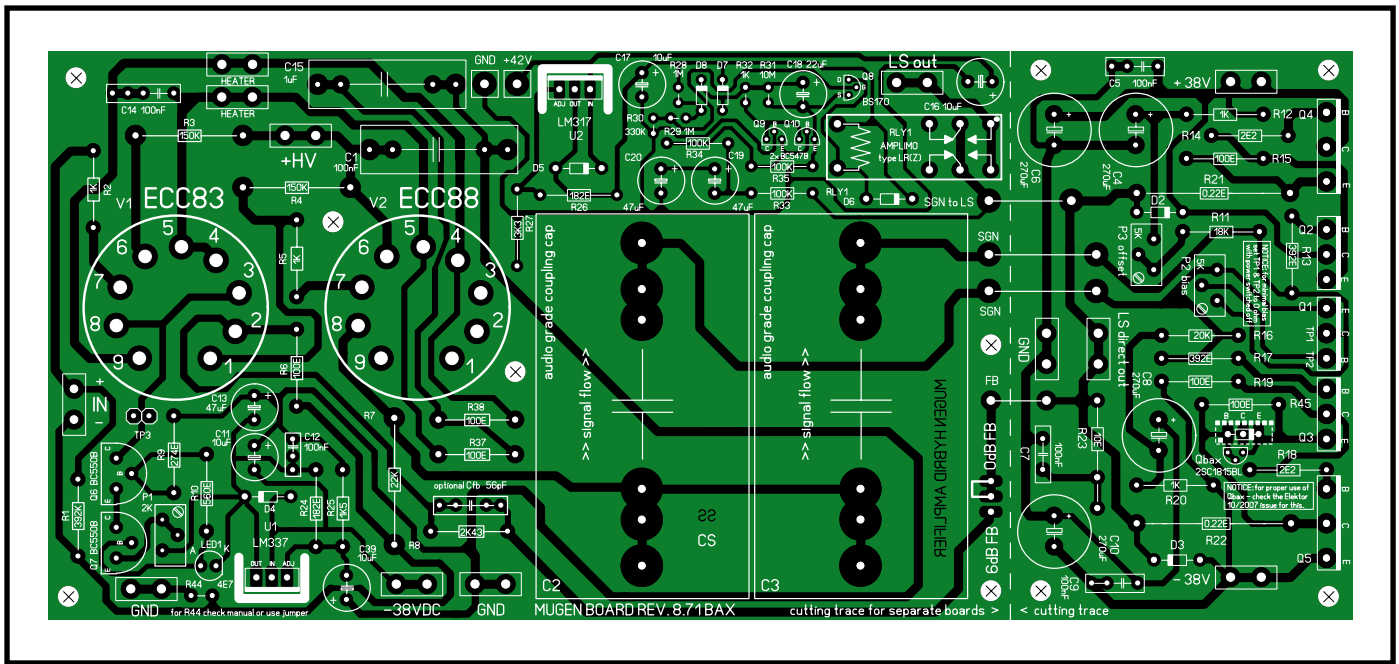
Figure 4. The amplifier board can be split in two, depending on how it is arranged in the enclosure. Component overlay reproduced at 80% of actual size.

Thanks to the inherent local negative feedback, the output stage is very stable with regard to temperature drift and quiescent current. The emitter resistors should preferably be Intertechnik MOX types. They are non-inductive and have relatively small dimensions. The amplifier output has a Zobel network built around R23 and C7, which ensures stability above 100 kHz.

Base resistors (R13, R17, R14, and R18) are used for all transistors in the output stage to prevent oscillation. The resistors for the driver transistors (R13 and R17) are essential.

The heatsink extrusion for each output stage must be rated at 0.7 K/W or less to ensure reliable operation.

The switch-on delay and DC protection circuit (**Figure 2**) is built around relay RLY1 and MOSFET Q8. This circuit was previously used in the Valve Final Amp design published in the April/May 2003 issues of *Elektor Electronics*. The switch-on delay is approximately 30 seconds. If a hazardous DC voltage is present at the output, the relay will disconnect the amplifier output from the loudspeaker. The relay used here is an Amplimo type with special contacts that make it especially suitable for use as an output relay in audio amplifiers.

A coil can optionally be fitted in series with the output to make the amplifier more general-purpose with respect to possible capacitive behaviour

of the speaker. This coil is omitted in the version of the amplifier described here. A DIY coil with an inductance of 4 µH, consisting of 16 turns of 0.75-mm enamelled copper wire wound on a 6.3-mm drill bit, can be used here if desired. A 15 Ω/2 W resistor must be fitted inside the coil and soldered across the coil.

Power supply

The high-voltage supply (**Figure 3**) uses a type TL783 voltage regulator IC. The input voltage of the TL783 must be approximately 360 V_{DC} for proper operation. The Amplimo toroidal high-voltage transformer used here provides this voltage in a manner that is perhaps somewhat unorthodox. The 250-V winding is so generously dimensioned that it is hardly loaded by the ECC83s and ECC88s, so the secondary voltage is a good deal higher than the rated 250 V. You should bear this in mind if you use a different transformer. The TL783 is fitted with a small heat sink and must be mounted insulated.

Voltage divider R39/R40 sets the output voltage to around 315 V. Resistor R41 is included to discharge the electrolytic capacitors when the amplifier is switched off. R40 and R41 must be 3-watt types. R42/C27 and R43/C28 are additional RC filters for the left and right channel, respectively. The high voltage for V1 and V2 is approxi-

mately 310 V_{DC}.

If you cannot find a Wima FKP1 type for C23 as specified in the components list, you should omit it.

The 30-V winding of transformer T1 is used for the switch-on delay and protection circuit.

The AC filament voltage is tied to ground via a capacitor. In this case it cannot be connected directly to ground. This is because the cathode of the ECC88 is not close to ground potential here, but instead at +195 V. The capacitor arrangement allows the maximum cathode–filament voltage rating to be respected. This floating filament supply works well in practice. A value of 0.47 µF can be used instead of 1 µF with equally good results.

The value of R36 must be determined experimentally. This resistor determines the value of the filament voltage, which must be close to 6.3 V.

The power supply shown here is suitable for stereo use, but it can also be used for a mono final amplifier. If it is used for a stereo version with a single transformer and a single supply PCB, then R37, R38 and C15 only have to be fitted on one of the two amplifier boards, although fitting them on both boards will not do any harm.

The ±38-V supply is simple but effective. A toroidal transformer with a secondary voltage of 2 × 28 V_{AC} gives the best results in terms of output power. If you use a different type of transform-
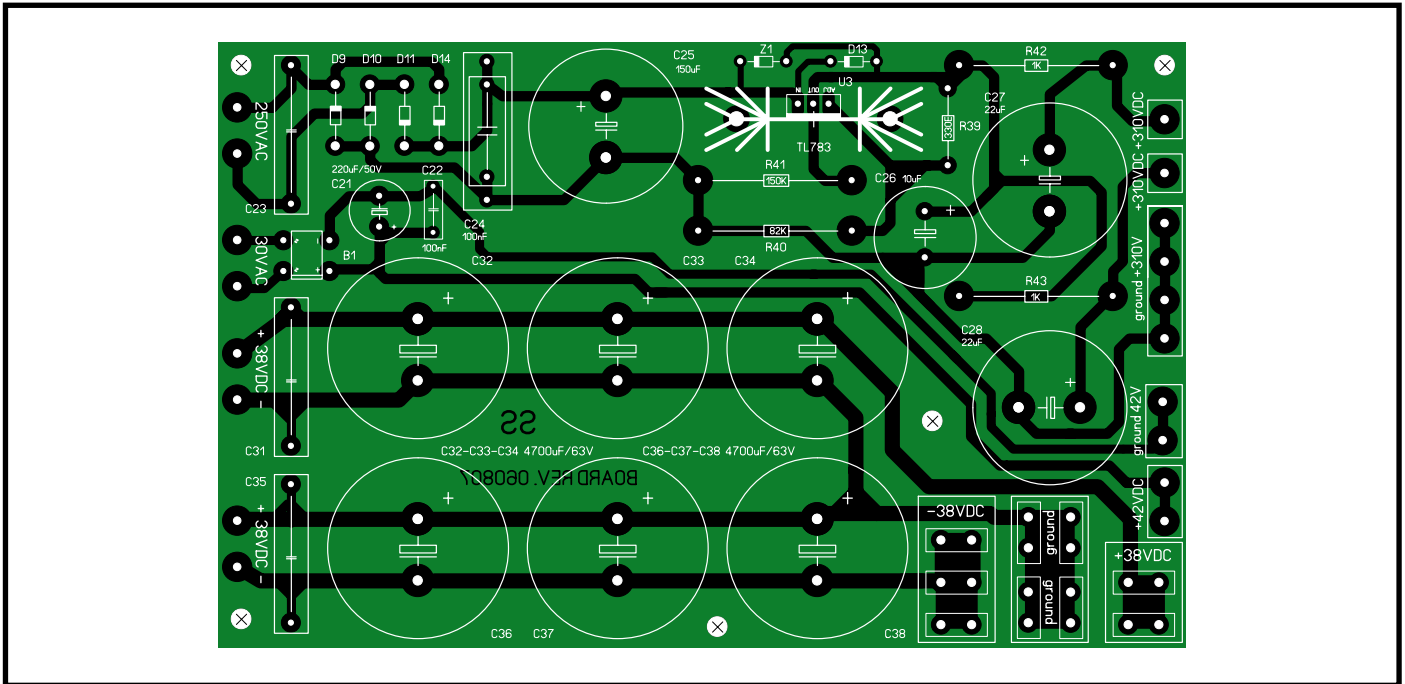
Figure 5. The power supply board is dimensioned for a complete stereo amplifier. Component overlay reproduced at 80% of actual size.

COMPONENTS LIST

amplifier & power supply
(for a stereo version, all components must be purchased double)

Resistors
(1% metal film, 600mW unless other rating indicated)
R1 = 392kΩ
R2,R5,R12,R20,R32 = 1kΩ
R3,R4 = 150kΩ 2W (BC PR02 series)
R6,R15,R19,R45 = 100Ω
R7 = 22kΩ 3W (BCPR03 series)
R8 = 2kΩ43
R9 = 274Ω
R10 = 560Ω
R11 = 18Ω
R13,R17 = 392Ω
R14,R18 = 2Ω2
R16 = 20kΩ
R21,R22 = 0Ω22 4W (Intertechnik MOX)
R23 = 10Ω 2W
R24,R26 = 182Ω
R25 = 1kΩ5
R27 = 3kΩ3
R28,R29 = 1MΩ
R30 = 330kΩ
R31 = 10MΩ
R33, R34, R35 = 100kΩ
R36 = to be determined (0.22Ω using 3N604)
R37,R38 = 100Ω 1W (see text)
R39 = 330Ω
R40 = 82kΩ 3W
R41 = 150kΩ 3W
R42,R43 = 1kΩ 1W
R44 = 4Ω7
P1 = 2kΩ,15-turn preset, T93YB (Vishay) or 3296Y (Bourns)
P2,P3 = 5kΩ,15-turn preset, T93YB (Vishay) or 3296Y (Bourns)

Capacitors
C1 = 100nF 400V$_{DC}$

C2,C3 = 3µF3 400V$_{DC}$ (ClarityCap SA 630 V audiograde capacitor)
C4,C6,C8,C10 = 270µF 50V (Panasonic FC, Farnell # 9692436)
C5,C9,C12,C14,C22 = 100nF 50V
C7 = 100nF (Vishay MKP-1834, Farnell # 1166887)
C11,C16,C17 = 10µF 50V
C13 = 47µF 50V
C15 = 1µF 250V (e.g. Wima foil capacitor, see text)
C18 = 22µF 63V
C19,C20 = 47µF 25V
C21 = 220µF 50V
C23 = 2nF2 (Wima FKP-1/700 V$_{AC}$, see text)
C29,C30,C31,C35 = 2nF2 (Wima FKP-1/ 700 V$_{AC}$)
C24 = 150µF 450V
C25 = 100nF 450 V$_{DC}$
C26 = 10µF 400V
C27,C28 = 22µF 400V
C32,C33,C34,C36,C37,C38 = 4700 µF 63V (BC056, 30x40 mm, Conrad Electronics # 446286-89)
C39 = 10µF 25V
Cfb = 56pF (optional)

Semiconductors
D1 = not used
D2,D3 = UF4007 (if necc. 1N4007)
D4,D5 = 1N4001
D6,D7,D8 = 1N4148
D9,D10,D11,D12 = BY228
D13 = 1N4007
LED1 = LED, 5mm, red
Z1 = zener diode 110V 1.3W
Q1 = BD139
Q2 = 2SC2073
Q3 = 2SA940
Q4,Q5 = 2SC5200
Q6,Q7 = BC550B
Q8 = BS170
Q9,Q10 = BC547B

Qbax = 2SC1815BL
U1 = LM337
U2 = LM317
U3 = TL783 (Conrad Electronics # 175012-62)

Valves
V1 = ECC83 (pref. JJ Electronics)
V2 = ECC88 (pref. JJ Electronics)

Miscellaneous
B1 = bridge rectifier 600 V piv @1A (DF06M)
B2,B3 = bridge rectifier 400V piv @ 35A
T1 = mains transformer, sec. 30V + 250V + 6.3V (Amplimo type 3N604)
T2 = mains transformer, sec. 2x28 V$_{AC}$, 300VA (Amplimo type 78057)
RLY1 = output relay 24V (e.g. Amplimo type LR)
Heatsink profile for U3 (Fischer SK104 25,4 STC-220 14K/W (e.g. Conrad Electronics # 186140-62)
Heatsink profile for U1 and U2, Fischer FK137 SA 220, 21K/W (e.g. Conrad Electronics # 188565-62)
Heatsink profile for Q4 and Q5, 0.7K/W or better
9-way valve socket (Noval), PCB mount, for V1 and V2
Amplifier board, no. 070069-1 (mono), www.thepcbshop.com
Supply board, no. 070069-2, www.thepcb-shop.com

Suggested suppliers
Toroidal transformers and output relay: www.amplimo.nl
ClarityCap SA capacitors: www.claritycap.co.uk
www.capsandcoils.com
http://wduk.worldomain.net
(OEM like Soniqs SAX)
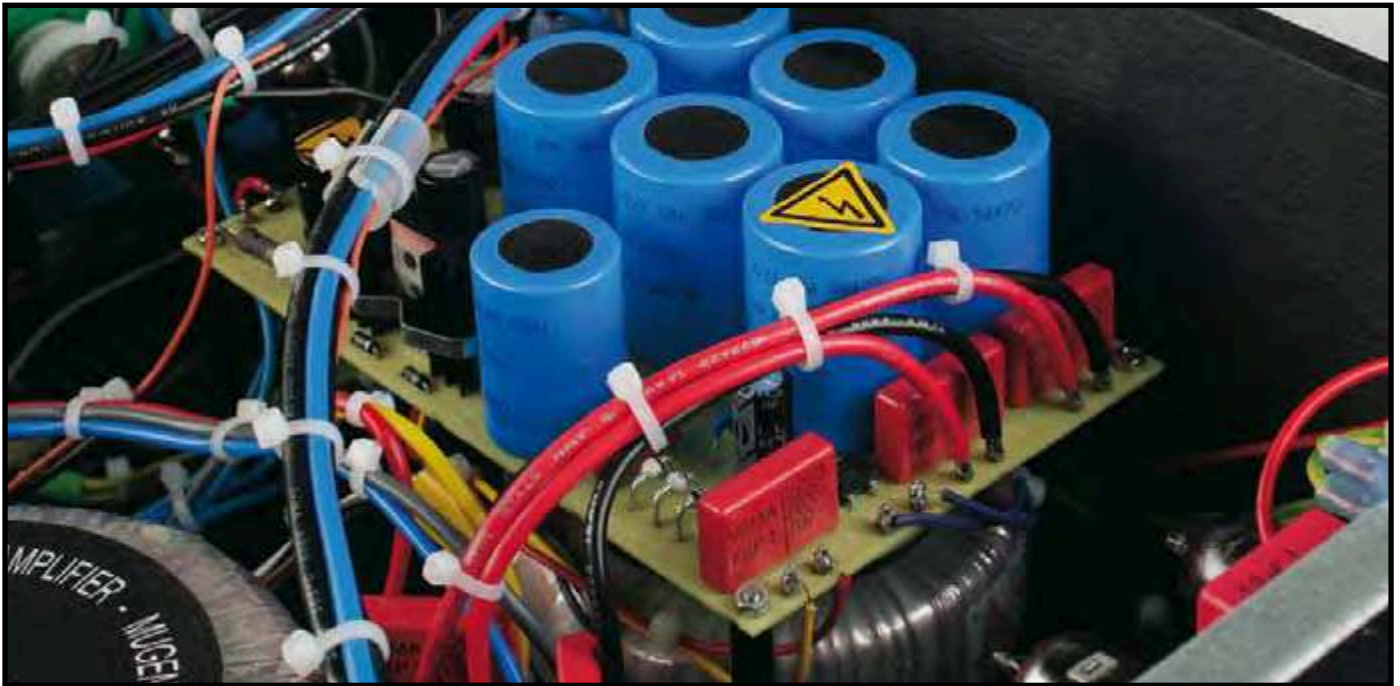
er here, a type with a more conventional value of $2 \times 25\ V_{AC}$ can be used, but the maximum output power will be somewhat less. The 2.2-nF Wima FKP-1 capacitors provide additional decoupling.

Construction

The PCBs for the amplifier and the power supply are shown in **Figures 4** and **5**. The actual size layouts can be downloaded from the *Elektor* website, or you can order ready-made boards from PCBShop. The board shown in Figure 4 is for a mono amplifier, so you need two amplifier boards and a power supply board for a stereo version.

The components list has several components with quite specific descriptions or type numbers. Based on the author's experience, you will obtain the best results from the amplifier if you use these components. However, you are naturally free to experiment with comparable components.
Assembling the power supply board is straightforward. Use good-quality blade connectors for the various supply and ground terminals. This makes wiring the amplifier much easier. After the power supply board is done, you can assemble the amplifier boards.
The amplifier board is designed so that it can be split in two in order to mount the power stage on the heat sink and the driver stage somewhere else, such as on the base of the enclosure. However, the wiring between the two parts

must be kept as short as possible. **Figure 6** shows clearly how the transistors of the power stage are fitted (all insulated!). For best results, first fit the transistors to the heat sink, bend their leads at right angles, and then secure the board to the heat sink with screws. Do not solder the transistors in place until everything is properly positioned.

An enclosure with two large heat sinks on the sides was used for the prototype (see the photo of the fully assembled amplifier in **Figure 7**). It is

big enough to hold a complete amplifier board.
The two supply transformers and the bridge rectifiers for the ±38-V supply are fitted in the middle of the base of the enclosure. The supply board is located above transformer T1.

The amplifier board and supply board have several ground connections. They must all be connected separately to a single star point as indicated in **Figure 8**. In order to avoid ground loops, the grounds of the ±38-V supply, the +42-V supply and the +310-V supply
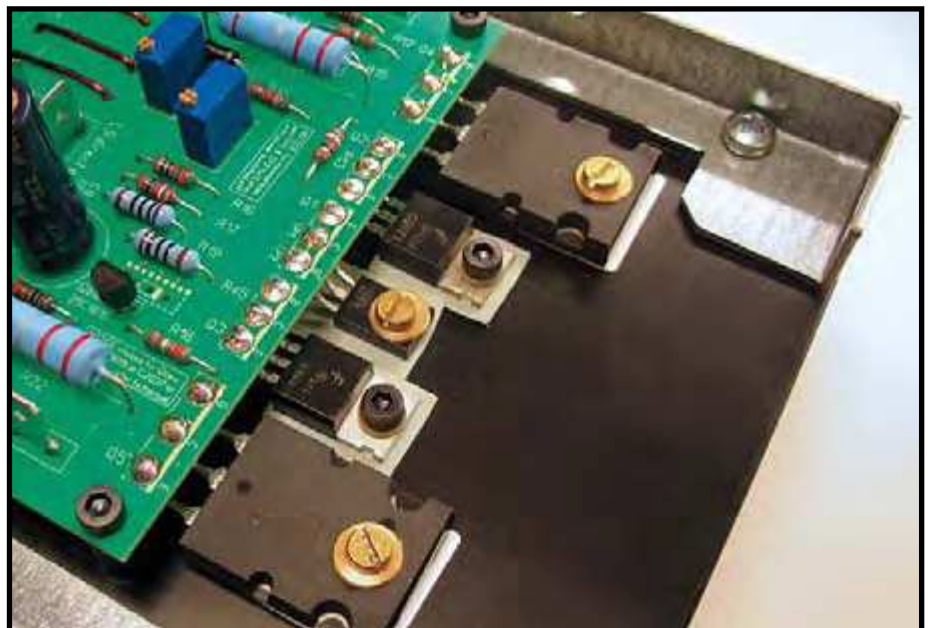

Figure 6. Fitting the power stage transistors.

are not joined on the supply board. The 4.7-Ω resistor (R44) between the input neutral terminal and circuit ground is optional and can be replaced by a wire link, but in the prototype this resistor proved to be necessary to keep the overall arrangement free of hum.

Be sure to use plastic standoffs for mounting the circuit boards. Metal types can cause shorts between PCB tracks and the heat sink or chassis.
A mains entry unit, a double-pole mains switch, a pilot light and a pair of fuse holders for the transformers can be fitted on the primary side. In this regard, consult the instructions on the *Electrical Safety* page that's published regularly in the magazine, or accessible permanently on the Elektor website.

Alignment

Inspect all components and connections before switching on the amplifier. Check that the transistors are insulated from the heat sink and from each other, check the polarity of the electrolytic capacitors, and check that the right valves are fitted in the sockets. The ECC83 and ECC88 are absolutely not electronically interchangeable.

The amplifier has three adjustment points:
- P1 sets the operating current of the ECC83.
- P2 controls the quiescent current of the output transformers.
- P3 adjusts the DC level of the output.

Before switching on the amplifier, ensure that the wiper of P2 is at the end connected to the collector of Q1.

This results in minimum quiescent current. Test points TP1 and TP2 are provided for this purpose on the PCB. Adjust potentiometer P1 to a value of approximately 800 Ω before soldering it to the board.

After switching on the amplifier, adjust P1 so the DC voltage at TP3 is +1.6 V. The exact value is not critical, but the DC voltage measured across R7 must be close to +195 V (±5%). If necessary, readjust P1 to obtain this value. The anode voltage of V1b should be about +190 V. These three voltages are interrelated.
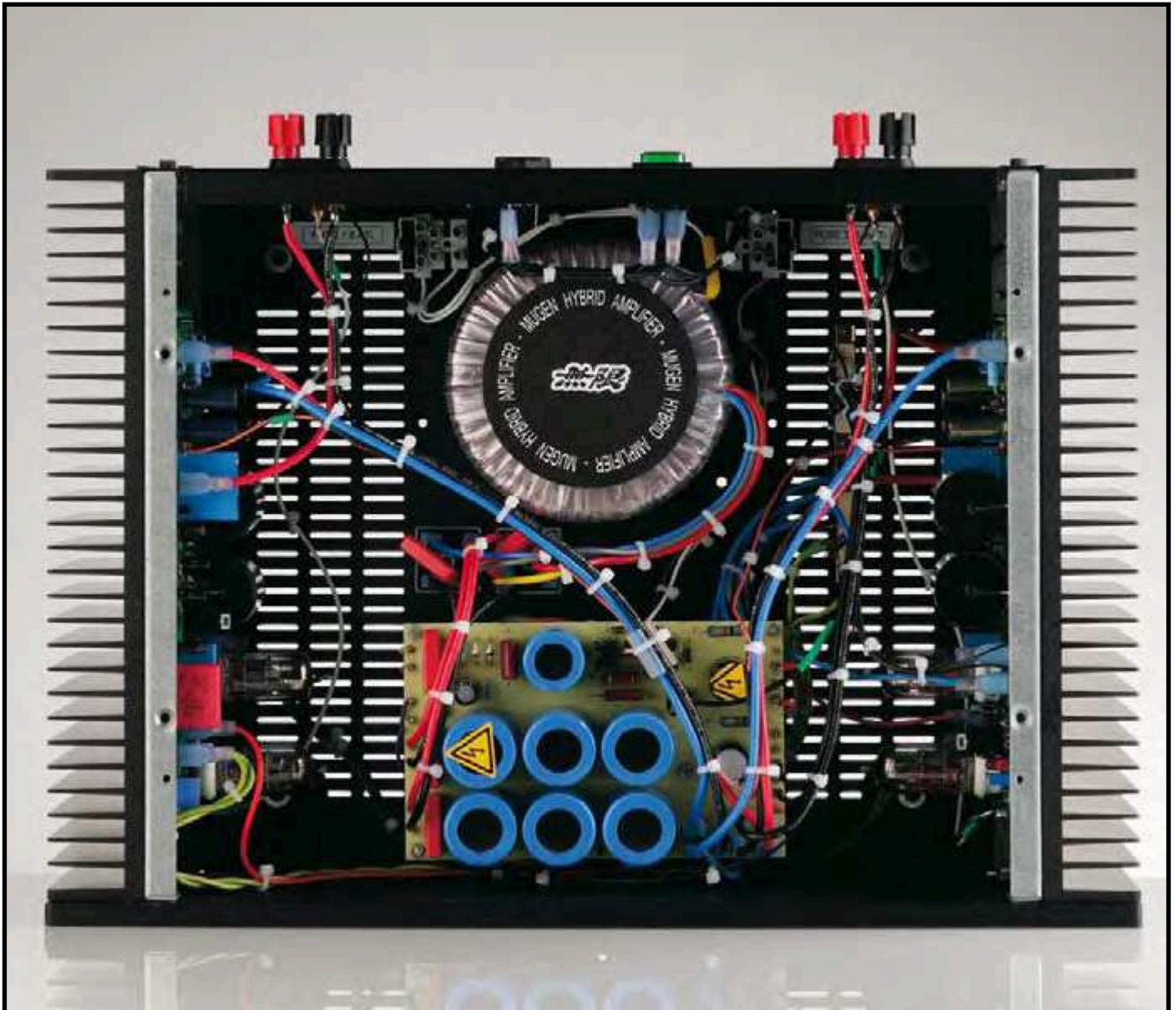

Figure 7. The fully assembled amplifier.

After this, adjust P2 and P3 with no input signal and no load. P3 controls the output offset. The DC voltage measured at the output must lie between +50 mV and –50 mV. It varies slightly, which is normal. Then adjust P2 to set the quiescent current. The DC voltage across emitter resistor R21 or R22 must lie between 22 mV and 33 mV (for a quiescent current of 100 to 150 mA). After the amplifier has warmed up for approximately 15 minutes, check all the values again and adjust the settings as necessary.

You can repeat this procedure several times during the first hour. In between these adjustment cycles, you can test run the amplifier with an inexpensive loudspeaker (such as a PC speaker) and a bit of music.

Key points

● Be careful! High voltages are present at various places on the circuit boards. Remember that residual voltages can be present for a while after the amplifier is switched off.

● Be kind to your loudspeakers: never connect or disconnect inputs or interlinks unless the amplifier is switched off.

Results

Despite the fact that overall negative feedback is not used in this amplifier, it has relatively low distortion. The distortion is less than 0.1% at low power levels. This respectable value is the result of careful component selection and dimensioning. The damping factor is also suitable for practical use. This is often a problem with final amplifiers that do not use negative feedback.

The sound characteristics of an amplifier are often difficult to express in words, but here we'll try to give you an impression in a few sentences. The amplifier can create a splendid sound stage, the lows are controlled, and the dynamic behaviour is convincing. The listening pleasure is thus also very good. The Mugen amplifier has an honest character without any signs of an exaggerated 'valve sound' (i.e. colouration).

By combining a valve driver stage with a transistor power stage, the Mugen amplifier offers the best of both worlds at an attractive price.
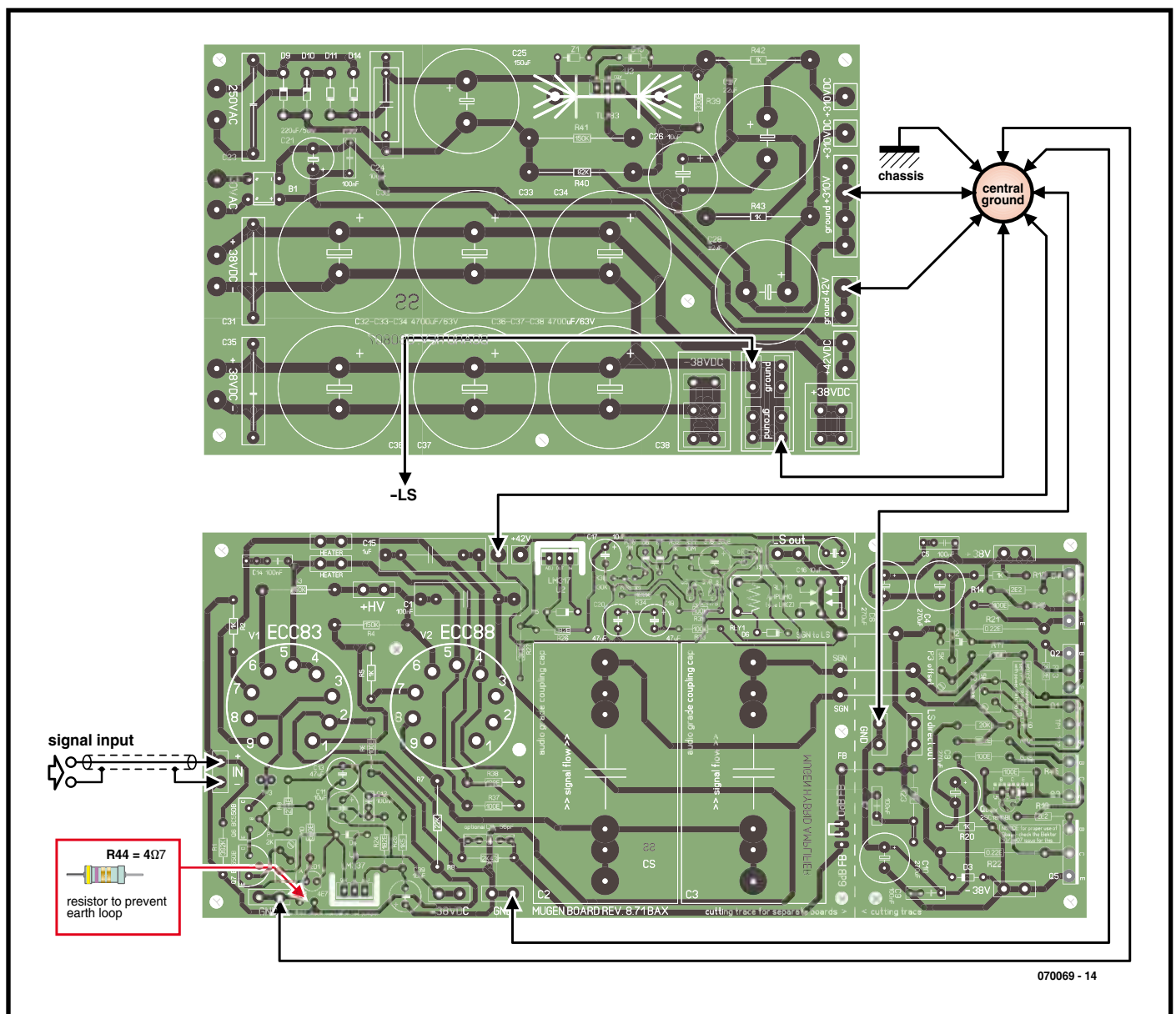
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Figure 8. The ground connections must be arranged this way in the enclosure. They are all tied to a single ground point connected to the enclosure.