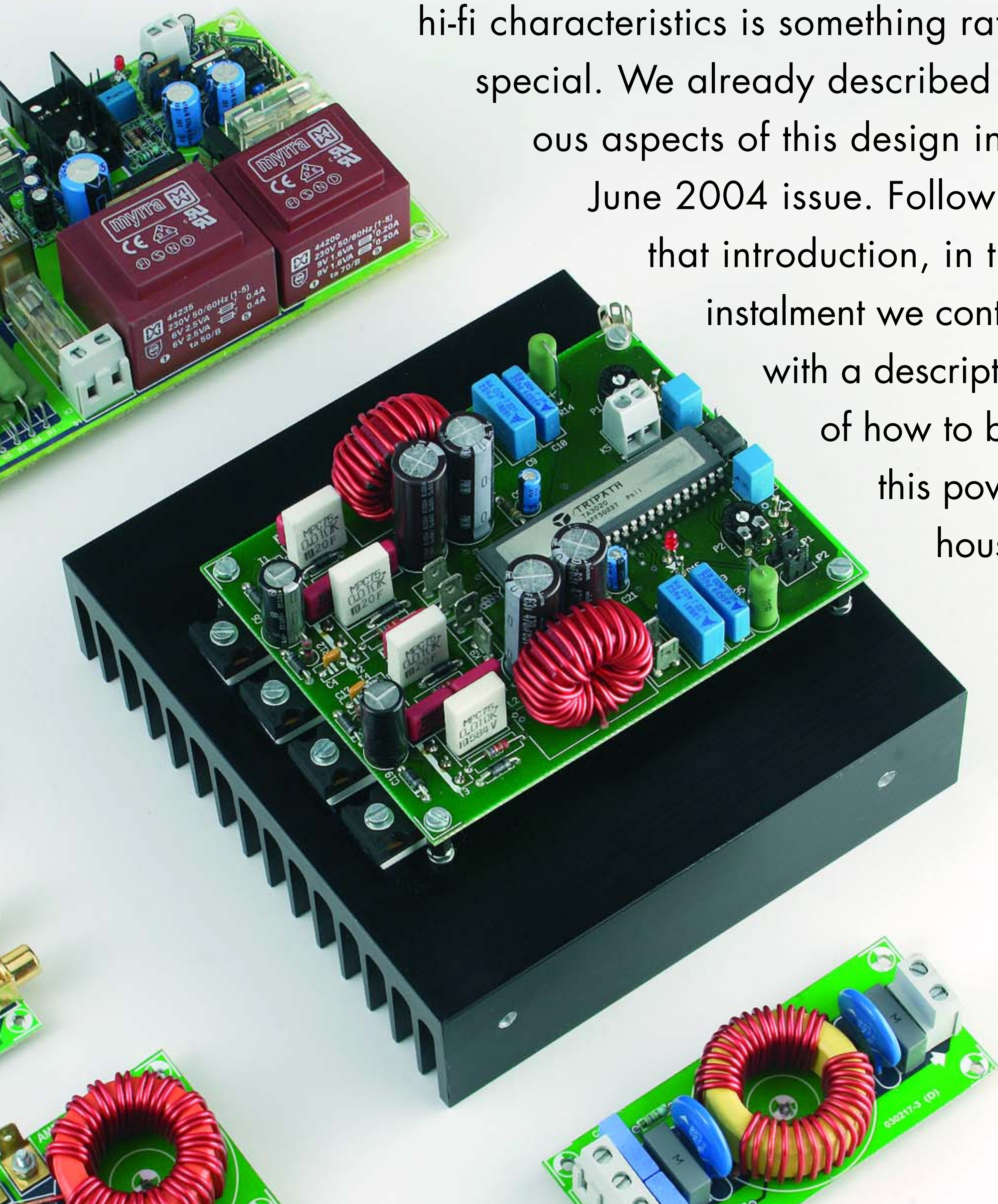
# ClariTy 2x300W Class-T

Ton Giesberts

A pulse-width-modulated output stage with hi-fi characteristics is something rather special. We already described various aspects of this design in the June 2004 issue. Following that introduction, in this instalment we continue with a description of how to build this powerhouse.



# Amplifier

# Part 2: building the amplifier board

The pulse-width modulated amplifier we're talking about here is based on the Tripath TA3020 driver IC. The term 'pulse-width modulated' may call up negative associations, but they are fully out of place here. The specifications are outstanding, and the amplifier is certainly as good as quite a few models in the upper end of the commercial range.

To make construction as easy as possible for *Elektor Electronics* readers, we can supply the printed circuit board for this project with all of the SMD components already nicely soldered in place, all at a very attractive price. And don't forget that a single circuit board houses a complete 2 × 300-W stereo amplifier.

## Special components

Before you start enthusiastically buying components, we'd like to emphasise that you can't simply conjure up a dual 300-watt amplifier from of a box of standard parts. When this amount of power is involved, even the power supply must meet special requirements. On top of that, we're dealing with a switch-mode amplifier here. That makes the circuit board layout and the quality of the components especially important. To avoid potential problems, you need to know the requirements imposed on the various components before you start building the circuit board for this final amp.

Most of the components can be obtained from Farnell as stock items, and several merchants including C-I Electronics and Geist Electronics will be offering complete parts kits for this amplifier. It's essential for some of the components to be SMD types, due to the characteristics of SMDs and the short signal paths that can be obtained with them. However, this doesn't mean that soldering has to be a problem, since all of the SMDs are already fitted to the board. The ferrite cores for the inductors are also included with the printed circuit board (two per board). Winding the inductors with 1.5-mm enamelled copper does require a pair of sturdy fingers, but we have more to say about that later on.

## Decoupling

The issue that requires the most attention with this amplifier is the interference that can be generated by quickly switching large currents. The circuit board has therefore been designed such that tracks that carry large currents have the least possible amount of coupling with the rest of the circuit. In addition, the supply voltages are always decoupled locally, in order to keep the loops in subcircuits conducting large currents as small as possible. In particular, this decoupling is provided by C5, C18, C32, C33, C36 and C37 for the output transistors. We selected 250-V MKT types for these decoupling capacitors, since they can better withstand extremely high switching currents.

Capacitors C6 and C19 also deserve special attention. For these two electrolytics, it is extremely important to have the lowest possible self-inductance and effective series resistance, as well as a good thermal rating.

The snubber networks (C4/R12 and C17/R33) help remove HF overshoots. To save space, R12 and R33 are mounted vertically. When fitting them, keep the loop as small as possible in order to keep their parasitic self-inductance as low as possible. As 1-W resistors are used here, you must allow for a somewhat larger diameter than usual (see **Figure 1**). For the capacitors (C4 and C17), we have selected 200-V ceramic types. This is because the maximum voltage across these capacitors can be nearly the full supply voltage (approximately 110 V between the positive and negative rails), or even more with any overshoots that may be present.

## Suppressing inductive spikes

Due to the physical dimensions of the components, parasitic self-inductance and overshoots will always be present. The consequences of this, particularly the inductive spikes (back-emf) from the inductors in the output filters, can be partially suppressed by using Schottky diodes and ultra-fast-recovery diodes as clamping diodes. This job is performed by D3, D4, D6, D7, D10, D11, D13 and D14. Diodes in DO-15 packages (MUR120) are fitted to the circuit board for D3, D4, D10 and D11. Diodes D6, D7, D13 and D14, which are SMD components in DO-214AA packages (MURS120T3), are fitted on the solder side underneath the IC (**Figure 2**). Both types of diodes are rated at 1 A / 200 V, with a recovery time of only 25 ns.

## MOSFET drive circuits

In the printed circuit board layout, special attention has also been given to possible loops in the paths between the driver outputs of the IC and the gates of the MOSFETs. These loops must be kept as small as possible. The loop in the drive circuit for the upper MOSFET of each channel consists of the HO driver, the gate resistor, the gate-source capacitance and the driver return connection (HO1COM or HO2COM). For the lower MOSFET, the loop consists of the LO driver, the gate resistor, the gate-source capacitance and the driver ground connection (LO1COM or LO2COM).

The overshoots arising from switching the MOSFETs are limited by the resistors incorporated in the gate circuits. This unavoidably leads to a compromise between the delays for switching

# Components list

*Pre-fitted SMD parts not listed. If necessary the list of pre-fitted parts may be downloaded from our website. Suggested suppliers are mentioned with unusual components only. These suppliers are not exclusive.*

**Resistors:**
R6,R11,R27,R32 = 0Ω01, lead pitch 9mm, MPC75-E01 (H.O.D[1] , Bürklin[2])
R7,R9,R28,R30 = 5Ω6/1 W lead pitch 15mm (max.), PR01 BCComponents (Farnell # 337-584, 10+)
R12,R33 = 15Ω 1W, PR01, BCComponents (Farnell # 337-638, 10+)
R13,R34 = 240Ω
R14,R35 = 22Ω 5W (vertical))
P1,P2 = 10kΩ preset

**Capacitors:**
C1,C14 = 3µF3 50V, MKT, lead pitch 5mm or 7.5 mm
C4,C17 = 220pF 200 V, COG, lead pitch 5 mm, dipped radial multilayer ceramic, Multicomp (Farnell # 747-075, 1+)
C5,C18,C32,C33,C36,C37 = 100nF 250V, lead pitch 7.5mm or 10mm, w x l = 6 x 13 mm (max.), Wima MKS4 (Farnell # 148-888, 1+)
C6,C19 = 47µF 160V radial, lead pitch 5mm, diameter 10mm (max.), 105ºC, Panasonic EEUED2C470 (Farnell # 83-6400, 1+)
C8,C21,C38 = 47µF 25V radial
C9,C22 = 220nF 400V MKP, lead pitch 15mm, w x l = 8.5 x 18 mm (max.), Epcos B32652-A4224-J (Farnell # 400-3755, 1+)
C10,C23 = 100nF 400V MKP, lead pitch 15mm, w x l = 7 x 18 mm (max.), Epcos B32652-A4104-J (Farnell # 400-3731, 1+)
C30,C31,C34,C35 = 470µF 63V radial,

off one MOSFET and switching on the other one. For this amplifier, limiting resistors with a value of 5.6 Ω are recommended. This also allows part of the power that would otherwise be dissipated in the driver transistors to be dissipated in the resistors.

Another compromise is naturally the maximum power rating of the amplifier and the resulting MOSFET selection. Unfortunately, maximum drain current goes hand in hand with high gate-source capacitance ($C_{iss}$ = 3800 pF max.). The parasitic self-inductance of the gate is also a factor; the lower it is, the faster the gate charge can be built up or removed.

To accelerate MOSFET switch-off, diodes are placed in parallel with the gate resistors. These are also ultra-fast-recovery diodes in 'normal' packages (MUR120). Thanks to their relatively large dimensions, they can easily bridge several broad tracks on the printed circuit board. A disadvantage of using these diodes is that the power dissipation in the drivers increases.

Due to their power dissipation, the gate resistors are 1-watt types. We have selected the very compact PR-01 series from BCComponents. Due to the construction of these metallic-film resistors (helical groove), they unavoid-

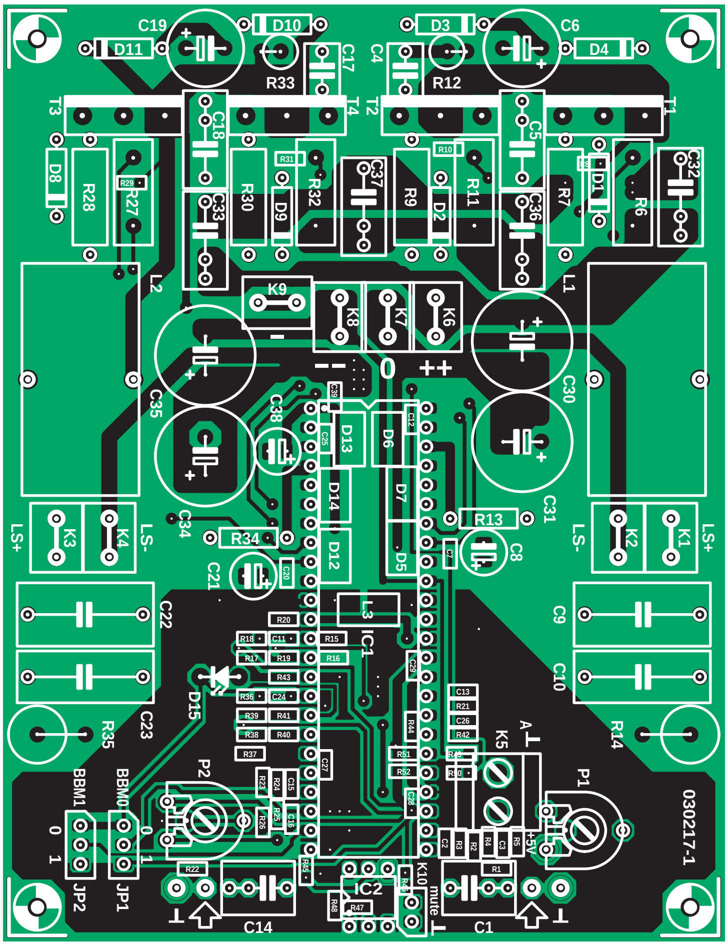
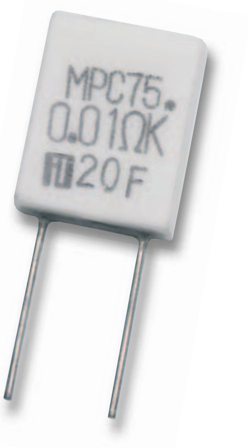



*Figure 1. Component layout (top side of the amplifier board).*




lead pitch 5mm, diameter 13 mm (max.), 105ºC, Nichicon UPM1J471MHH (Farnell # 415-3030, 5+)

**Inductors:**
L1,L2 = 11µH3, 29 turns 1.5 mm ECW (SWG 16) on T106-2 core (Micrometals) (core supplied with pre-fitted PCB)

**Semiconductors:**
D1-D4,D8-D11 = MUR120 1 A/200 V ultra fast, ON Semiconductor (Farnell # 930-994, 1+)
D15 = LED, red, high efficiency
T1-T4 = STW38NB20, TO-247 case, 200 V/38 A, ST (Farnell # 323-9408, 1+)
IC1 = TA3020, Tripath3
IC2 = CNY17-2

**Miscellaneous:**
JP1,JP2 = 3-way pinheader with jumper
K1-K4,K6-K9 = spade terminal, vertical, PCB mount
K5 = 2-way PCB terminal block, lead pitch 5 mm
K10 = 2-way pinheader
48-pin IC socket, DIP socket with turned pins 0.6" (15.24 mm) row spacing (Farnell # 416-8653, 1+)
4 ceramic washers AOS220SL, Fischer, 14 x 18 mm, 4.5 mm thick (Huijzer-Avera4)
Heatsink 0.6 K/W, 160 x 150 mm, Marston 938SP01500A200 (Farnell # 526-794, 1+)
PCB, order code **030217-91**. Comes with all SMD parts pre-fitted and cores for L1, L2 supplied.

1. www.hod-electronics.nl
2. www.buerklin.de
3. sales@profusionplc.com
4. www.huijzer.com/

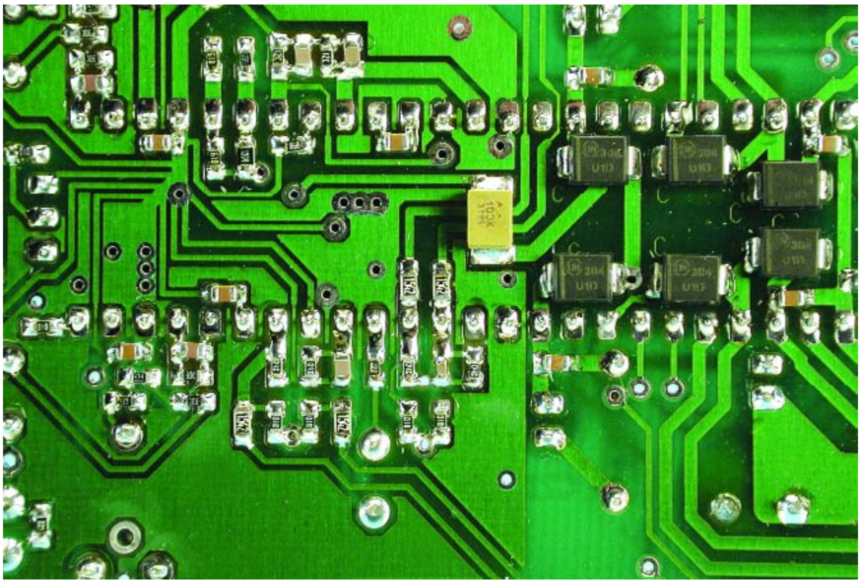


Figure 2. Bottom side of the amplifier board. The SMDs are pre-fitted.

ably have significant parasitic self-induction, but the impedance of this resistor type is still relatively constant up to 10 MHz. A good alternative would be carbon compound resistors, which have much lower self-inductance due to their construction. Sufficient room is provided on the circuit board for the latter type.

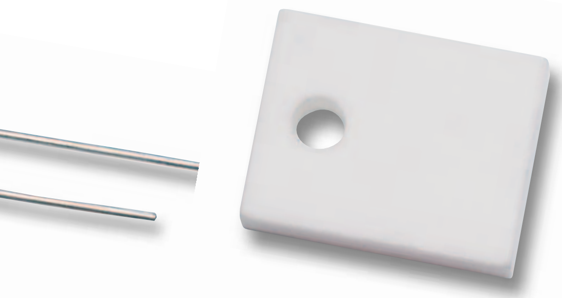
## Power supply and ground

The main supply voltage is connected to the circuit board using flat (car-type) terminals. This allows very large currents to flow and makes it easy to connect the board to the power supply. Special electrolytic capacitors are fitted across the power supply terminals to decouple the worst RF current spikes. We have done our best to implement these connections as star points, but we had to spread them out a bit to keep the distance between the IC and the MOSFET leads reasonably short.

For decoupling capacitors C30, C31, C34 and C35, we selected a Nichicon family that combines a very good capacity/size ratio with low series resistance and low self-inductance. The optimum choice from this family is the 470-µF type with a working voltage of 63 V. In our case, this determines the maximum allowable supply voltage for the final amp.

From the star point, a track runs to the inductor (L3) that isolates the analogue and digital grounds of the IC. This inductor comes in an SMD package (1812A) and is located on the solder side under the IC (**Figure 2**). It is a member of the Epcos SIMID family and has a value of 10 µH, with a series resistance of less than 1 Ω and a current rating of more than 300 mA.

The ground connections for the loudspeaker outputs are also tapped off from the star point, so the currents from the loudspeakers are conducted back to the main power supply as directly as possible. This avoids inter-




## Pre-fitted circuit board

Due to the special nature of this amplifier (particularly the high switching frequencies), the choice of components is especially important and the use of SMDs in various locations is unavoidable.

Most amplifier builders have little or no experience with soldering these miniature components, and for this reason we provide this circuit board with all of the SMDs already fitted. All you have to do is to fit the IC and the 'normal' components. In addition, two cores for the output inductors are provided with the board, since they are made from a rather special material.

The price of the circuit board and inductors is only **£34.50 / $55.70 / €49.** This is a two-channel design, so you only need one circuit board for a stereo amplifier.

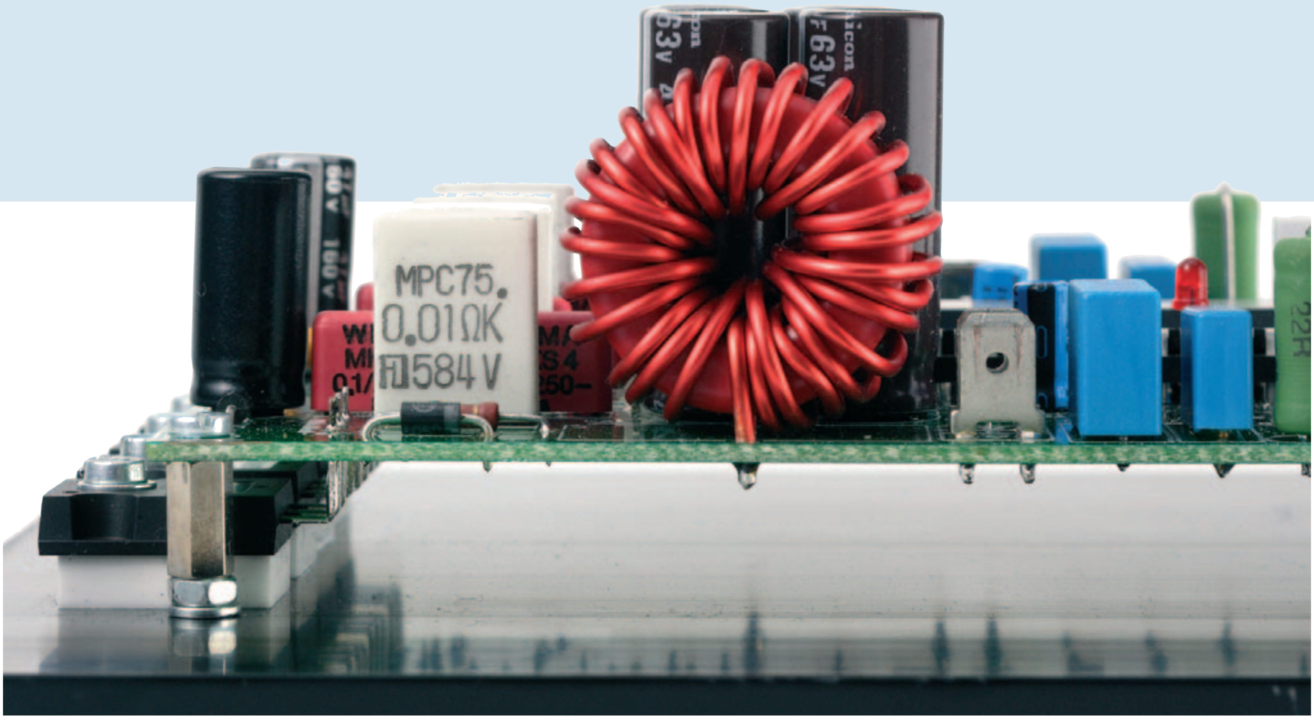



*Figure 3. For the output inductors, several turns must be placed on top of other ones. The output transistors are fitted to the heat sink below the circuit board using special insulators.*

ference to other parts of the amplifier. The ground planes on the circuit board are exclusively intended to provide protection against interference. They are only connected to the AGND pin for the analogue power supply (pin 28). This means that no other connections to the amplifier are tapped off from the ground planes.

A star point is also used for the connections between the analogue +5-V supply and the various components, including the trimpots, jumpers and resistor bridges for the modulator settings. This can be seen on the component side of the layout in **Figure 1**.

### Construction

Despite all the attention given to the layout, the level of interference generated by the output stage is rather high. This means that additional measures must be taken to minimise the negative effects on the analogue portion. This is done by keeping the surface area needed to fit the passive components as small as possible. The only way to achieve this is to implement practically everything using SMD components, and to place them as close together as possible underneath and beside the IC on the solder side of the board (see **Figure 2**).

The only components that depart from this rule are the two trimpots for DC offset adjustment and the input capacitors. Any interference picked up by the trimpots is filtered out by C3 and C16. Interference picked up by C1 and C14 is filtered out by C2 and C15. Some of the SMDs must have a voltage rating greater than 50 V, due to their location in the circuit. This applies to R15, R16, R36, R37 and R51. SMD components are also used for R8, R10, R29, R31 and several decoupling capacitors, since this gives better functional results and takes up less space.

For readers who wish to take a soldering iron to the SMDs, despite the fact that the board is provided with the SMDs already fitted (for example, to change the input sensitivity or modify the board for a lower supply voltage), the solder lands are designed to allow either 0805 or 0603 packages to be used for all SMD capacitors and resistors. They are thus somewhat larger than the standard size for reflow or wave soldering. You can thus touch a soldering iron with a very fine tip on the solder

## Kelvin connections

Kelvin connections (which are also called four-point measurements, depending on the application) are used at three locations in the amplifier to eliminate the effects of contact resistance and parasitic self-inductance.

A Kelvin connection is a connection to the terminals of a specific component for accurately measuring the voltage across the component without using extra taps. Here such connections are used for the voltages across the sense resistors for overcurrent detection, the feedback from the loudspeaker terminals and the input ground.

For current detection, it should be evident that four-point measurement is necessary, since the resistance of the sense resistor is only 10 mΩ. The overcurrent sense leads are tapped off directly from the resistor leads. The resistors are upright models in ceramic packages (MPC75 from Fukushima Futaba Electric Co. Ltd.), and they have practically zero self-inductance. If you cannot obtain these resistors, you will have to look for other low-inductance resistors with the same form. Resistors with axial leads are truly unsuitable, since fitting them vertically is by itself enough to produce too much self-inductance.

Each pair of signal leads is routed close together to the pins of the IC. The same is true of the feedback from the loudspeaker terminals (to the corresponding resistors). For the input ground, using a Kelvin connection means that all ground connections are individually routed to the common ground pin of the IC (the '0V' terminal for the analogue +5-V supply). This can be clearly seen on the solder side of the amplifier circuit board. Quite a few circuit board tracks join together here, with the result that this junction is necessarily somewhat broadened.

lands while soldering, which considerably simplifies soldering SMDs.
For the capacitors in the output filters, we have chosen 400-V polypropylene types that are especially suitable for applications with extreme pulse loading. Here we also use a compact version. These capacitors have a pitch of 'only' 15 mm, which results in a low value of parasitic self-inductance here as well. There is enough room here for somewhat wider components if you wish to use a different type (such as polyester or capacitors from a different manufacturer).

## Coil winding

Winding the output inductors is not difficult, but you must pay careful attention to the winding method. With the selected wire diameter of 1.5 mm (16 SWG), the 29 turns will not fit on the selected core in a single layer. To keep the internal capacitance as small as possible, the coil is wound progressively in approximately seven sections. This means that after the first three turns are wound, the fourth turn is placed on top of the third turn, and the fifth turn is then wound directly on the core next to the third turn. It is followed by turns six and seven, with turn eight again being placed on top of turn seven, turn nine again next to turn seven, and so on (see **Figure 3**).

The relatively thick wire doesn't make the job any easier. Depending on how neatly and tightly you manage to wind the coil, you may well have to place a few more turns on top of other ones.

## IC and output transistors

Most people will probably be reluctant to solder the IC to the circuit board, so we searched for a 48-pin IC socket with very high quality. We finally decided on a type having turned contacts with 30-micron gold plating and rated at 3 A. Here we can't be satisfied with anything less.
A very important detail in fitting the output transistors is the material for the electrical insulators. As these transistors have a metal cooling surface that is electrically connected to the drain (T2 and T4), the capacitance to the heat sink (which is connected to ground) would be too large if they were fitted using standard insulators made from mica, silicone rubber, silicone foam or even fancy stuff like Kapton. We tried this, and at maximum output power there were large parasitic currents that could not be suppressed.
There is only one good solution to this problem, which is to use ceramic ($Al_2O_3$) insulators that are several millimetres thick. The insulator we use here is the Fischer type AOS220SL, which is 4.5 mm thick and is actually intended to be used with a T0-220 package, instead of the larger TO-247 package. Despite being a bit too small, the insulator fully covers the metal cooling surface of the transistor. It also keeps the parasitic capacitance extremely small.
For the heat sink, we found a type with a surface large enough to mount the circuit board parallel to the surface. The selected type (from Marston) is 160 mm wide and 150 mm deep, and it even provides a bit of clearance at the edges. Eight holes tapped for 3-mm screws can be drilled in the base, which is 10 mm thick, for fastening the circuit board and the four output transistors. We recommend that you first centre the board on the heat sink and mark the four corner holes. Next, bend the leads of the output transistors exactly where they become thinner, slide them in place and mark the positions of the four fastening holes for the transistors.

Cylindrical standoffs (metal types with a threaded end) with a length of approximately 10 mm should be used to attach the circuit board to the heat sink. The threaded end will probably be too long to be fully screwed into the heat sink. This can be solved by first fitting a nut and lock washer on the threaded end. This causes the mounting height of the circuit board to be just right, and the leads of the output transistors will pass through the matching holes in the circuit board with length to spare.

## Coming up

All that's left now is the power supply and the wiring diagram. We'll deal with them in next month's issue, when we'll also present some measured results for the fully assembled amplifier.
Items such as input and output filters and EMC problems will be handled in a separate article, which will also appear next month.

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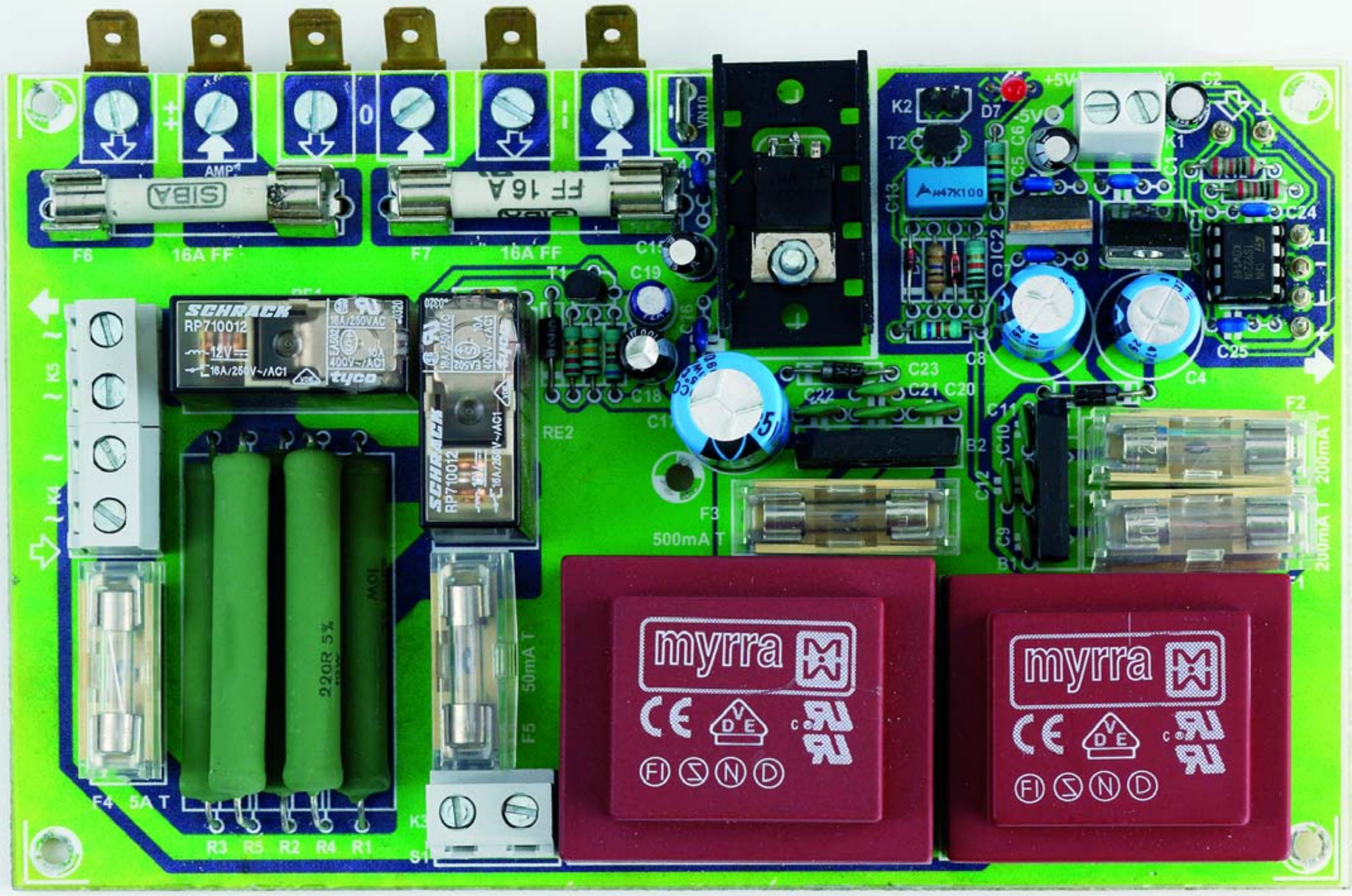
# ClariTy 2x300W Class-T



Ton Giesberts

As already mentioned in the previous parts of this article, this final amp needs more than just a heavy-duty symmetrical power supply. In this final part, we examine the main power supply, the other power supplies, final assembly and alignment.

The analogue input portion of the TA3020 operates from a stabilised 5-V supply voltage. A stabilised 10-V auxiliary voltage is also needed for driving the MOSFETs. The power supply board also has a switch-on delay for the mains voltage (current limiting). An additional feature is a buffer circuit with a phase inverter, which allows the two channels to be easily operated in a bridge configuration without requiring any modifications to the amplifier board. Naturally, the required mains power indicator and mute signal are also present.

# Amplifier

## Part 3: power supply, assembly and alignment

### *Analogue power supply and mute circuit*

The analogue 5-V power supply has its own transformer (TR1, 2 × 9 V). A small, discrete-component circuit for generating a well-defined mute signal is added here (see **Figure 1**). The supply voltage for this circuit is taken directly from the output of the bridge rectifier (B1), filtered by a small capacitor (C14), so the amplifier can be switched to mute mode as quickly as possible when the mains voltage drops out.

The mute circuit is the height of simplicity: after C13 has been charged, T2 has enough voltage to fully drive the optocoupler on the amplifier board. C13 is slowly charged via R11 until it reaches the level defined by voltage divider R9/R10. D2 limits the voltage at the mute output, but the ultimate value is not especially critical. When the mains voltage drops out, C13 is quickly discharged by D3. The mute signal can be connected to the amplifier board via pin header K2.

The negative supply voltage is only needed for powering the phase inverter. Standard positive and negative voltage regulators are used for the +/– 5-V supplies. The +5-V supply can be connected to the amplifier board via K1. The negative voltage is also available on a solder pin, so it is also available for user-defined applications.

### *Auxiliary voltage and switch-on delay*

The 10-V supply for the output stage is also powered by a separate transformer (TR2). After rectification and filtering, the voltage is stabilised using a standard positive 10-V regulator. If a 10-V regulator is difficult or impossible to obtain, a 9-V type can also be used. Two different types of transformer are shown on the schematic diagram for this supply. The PCB is designed to accommodate a transformer with two separate windings (2 × 6 V) or one with a single winding (1 × 12 V). In either case, a 12-V ac voltage is thus made available. Just as with the analogue supply, the filter is placed after an extra diode, rather than directly following the bridge rectifier.

The voltage provided by rectifier B2 is used to power the relays of the mains switch-on delay circuit. This voltage also has minimal filtering (C19). This causes the relays to disengage as quickly as possible when the mains voltage drops out.

The switch-on delay circuit consists of two relays. The first relay (RE1) switches on power to the amplifier via a set of high-power resistors in order to limit the magnetising current of the transformer and the charging current for the electrolytic capacitors of the main power supply. These high-power resistors consist of five 10-W, 220-Ω resistors connected in parallel. Two of them are mounted above the other three, separated by a certain amount. The peak load capacity must be taken into account in dimensioning these resistors. The transient power dissipation is around 1200 W, and the absolute peak dissipation is actually more than 2 kW!

The second relay (RE2) shorts out the resistors and connects the main power supply transformer (a 1000-VA type in our prototype) directly to the main voltage. This allows the amplifier to manage with a relatively small mains switch (6-A rating). With the delay circuit, the effective value of the switch-on current does not exceed 5.2 A.

The drive circuit for the switch-on delay is a standard design. Voltage divider R6/R7/R8 ensures that the voltage at the base of T1 is not high enough for it to conduct enough current to energise RE2 until the supply voltage has reached two thirds of its nominal value. The time required for this voltage to be reached is delayed by the charging time of C20. The value of C20 can be kept to a minimum by using equal values for R6 and R7 to set the delay time. When the mains voltage drops out, D5 causes C20 to be rapidly discharged. With this arrangement, the delay time remains as nearly as possible constant if the supply is switched off and then quickly switched on again.

The required mains power indication is provided by LED D7. It must therefore be clearly visible on the front of the amplifier.

### *Main power supply*

The compactness of the amplifier is offset by the sheer mass of the power supply. Of course, we could have also developed a switch-mode power supply, but it would have to be a supply that could deliver a good 40 A at a bit less than +/– 60 V. That would be a challenge, to put it mildly. It should thus be clear why we choose to use a conventional design.

In consideration of the current levels involved here, we selected a heavy-duty rectifier that can handle a rated current of 46 A and a peak current of 90 A. For the electrolytic capacitors in the power supply, we selected types that can handle strong ripple currents. Normal power-supply electrolytics are not intended to be used in such severe applications. From the BCcomponents 2222 154 line, we selected a capacitor that can handle ripple currents of around 11 A at 10 kHz (or 20 A at 100 Hz) and has low values of self-inductance and ESR (a tall electrolytic capacitor with a small diameter). A long service live is ensured by connecting four capacitors in parallel for each half of the power supply. Here we can give you a small tip: if you order ten capacitors in a single lot from Farnell, it will cost you less than buying eight of them at the single-quantity price.

If you think the power supply is perhaps somewhat over-designed with the

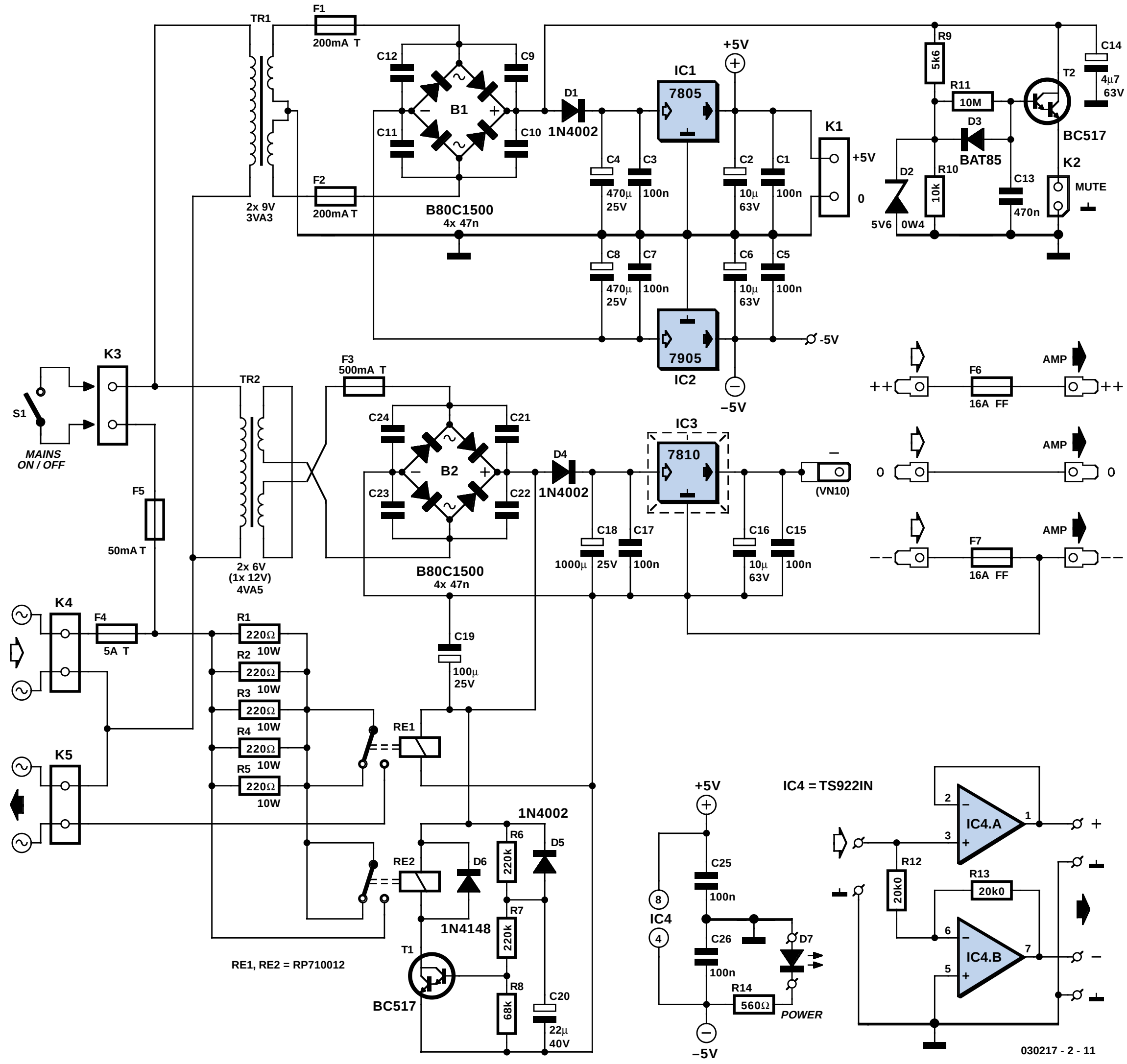



*Figure 1. Besides the auxiliary supply voltages, the power supply board provides the switch-on delay, the mute signal and a phase inverter for bridge-mode operation.*

# COMPONENTS LIST

## power supply board

**Resistors:**

R1-R5 = 220Ω 10W (e.g. AC10 BCcomponents)
R6,R7 = 220kΩ
R8 = 68kΩ
R9 = 5kΩ6
R10 = 10kΩ
R11 = 10MΩ
R12,R13 = 20kΩ0 1%
R14 = 560Ω

**Capacitors:**

C1,C3,C5,C7,C15,C17,C25,C26 = 100nF ceramic
C2,C6,C16 = 10µF 63V radial
C4,C8 = 470µF 25V radial
C9-C12,C21-C24 = 47nF ceramic
C13 = 470nF
C14 = 4µF7 63V radial
C18 = 1000µF 25V radial
C19 = 100µF 25V radial
C20 = 22µF 40V radial

**Semiconductors:**

D1,D4,D5 = 1N4002
D2 = zener diode 5.6V 0.4W
D3 = BAT85
D6 = 1N4148
D7 = LED, red, low-current
T1,T2 = BC517
IC1 = 7805
IC2 = 7905
IC3 = 7810
IC4 = TS922IN ST (Farnell # 332-6275)

**Miscellaneous:**

B1,B2 = B80C1500, straight case (– ~ + ~) (80V piv, 1.5A)
K1 = 2-way PCB terminal block, lead pitch 5mm
K2 = 2-way pinheader
K3,K4,K5 = 2-way PCB terminal block, lead pitch 7.5 mm
F1,F2 = fuse, 200mA/T (time lag) with PCB mount holder
F3 = fuse, 500mA/T (time lag) with PCB mount holder
F4 = fuse, 5A/T (time lag) with PCB mount holder
F5 = fuse, 50mA/T (time lag) with PCB mount holder
F6,F7 = fuse, 16A/FF (very fast), 6.35x32 mm (Farnell # 534-699 with fuse clips # 230-480)
RE1,RE2 = RP710012 16A/12V/270Ω (Schrack, Farnell # 388-312)
TR1 = mains transformer, 2 x 9V/3.3VA (e.g., Myrra 44200, 2 x 1VA6)
TR2 = mains transformer, 2 x 6V (or 1 x 12V)/4VA5 (e.g., Myrra 44235, 2 x 2VA5)
1 x spade terminal, PCB mount, 2-way, straight
6 x spade terminal, PCB mount, 3mm screw/bolt mounting
Heat-sink 15 K/W for IC3 (ICK35SA Fischer)
S1 = mains on/off switch rated for 6 A

## main supply

Mains transformer 1000VA, 2 x 42V/11.9 A (e.g., Amplimo/Jaytee Z8022)
Bridge rectifier 140V/50A (e.g. Diotec Semiconductor KBPC 5002FP, Farnell # 393-5292)
8 electrolytic capacitors, 63V/15,000µF (e.g, BCcomponents # 2222 154 18153, Farnell # 248-022)
4 mounting clamps for 35-mm diameter electrolytics (Farnell # 306-526)
IEC mains appliance socket, chassis mount
PCB, order code 030217-2

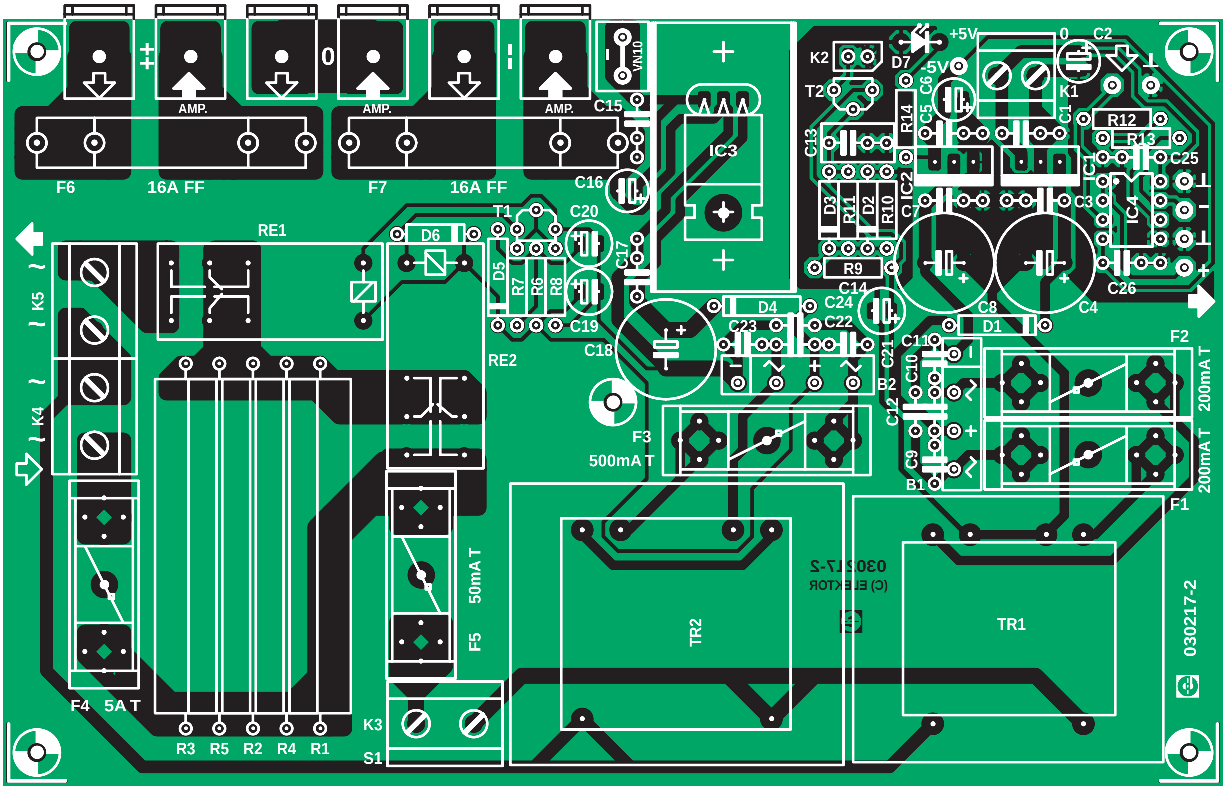



*Figure 2. The power supply board also has room for several fuses, which provide good protection for the amplifier.*

specified component values, we wouldn't immediately disagree. However, you should bear in mind that at 2 × 200 W sine-wave power, the output voltage of this supply already drops by 5 V!

## Protection

The mains voltage is routed to the power supply board via K4. The primary fuse for the main transformer (F4) is also fitted here, so it isn't necessary to use a mains connector with a built-in fuse. The mains voltage for the auxiliary voltages is tapped off after the fuse for the main transformer. If the primary fuse blows, power will also be removed from the rest of the amplifier. In the opposite case, a similar situation exists. If the fuse for TR1 and TR2 blows, the supply voltage for the mains switch-on delay circuit will drop out, and power will be removed from the entire amplifier. A situation in which only part of the amplifier is without power can occur of F1 and/or F2 blows. In this case, at most the +5 V supply voltage will be lost, and there will no longer be any signal. That will not have any further detrimental effects; the most that can happen is that a small 'pop' will be heard from the speakers.

For additional safety, the main supply voltage for the final amp is protected using two 16-A FF fuses in 32-mm cases. This ensures that the voltage decays as quickly as possible in case of a short circuit, rather than requiring the power supply capacitors to first be discharged. These fuses are also fitted on the power supply board, and they are connected between the large power supply capacitors and the amplifier board using screw-mounted flat connectors (car connectors). The advantage of using separate fuse holders is that the PCB-mount fuse clips used here can handle a continuous current of no less than 15 A (with adequate copper area on the circuit board). Most PCB fuse holders are only rated at 5 A continuous current.

## Assembly

For our prototype, we chose the 'not so quick-and-dirty' method and fabricated our own enclosure from a sheet of aluminium. This results in an unconventional design, whose shape and proportions are determined by the dimensions of the heat sink, toroidal transformer, power-supply capacitors and power supply board (**Figure 2**). The heat sink forms the front of the unit. The mains entry, input sockets and speaker connectors are fitted at the rear. Of course, you are free to package everything into another type of (standard) enclosure.

In our design, we tried to keep the power supply connections as short as possible, and we fitted the power supply board above the large toroidal transformer. The four fastening holes for this board are far enough apart to allow it to be secured to the base with ample clearance from the transformer. The two rows of four electrolytic capacitors each are placed next to each other in a single group. Their terminals are connected together using small 2-mm aluminium plates. Be sure to provide adequate separation between the plates for the +, 0 and – polarities. We recommend fitting screw-mounted flat connectors to the plates, to simplify wiring and maintenance.

The capacitors can be adequately secured using four mounting clamps. Where necessary, one mounting tab must be broken off of each clamp.

The wiring diagram is shown in **Figure 3**, which also shows the filter boards. These still have to be described.

The two centre taps of the transformer (neutral/ground) are connected to one

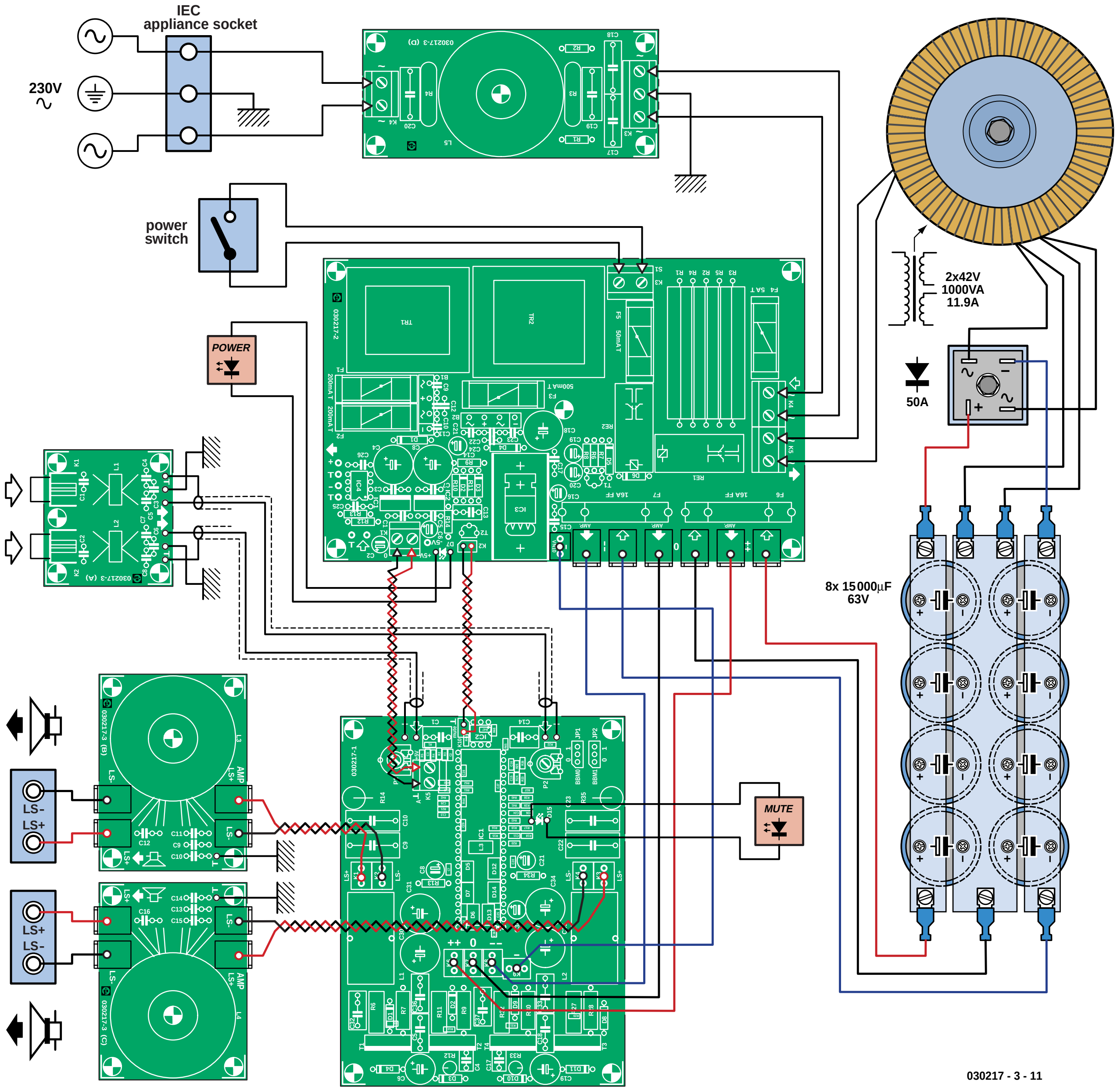



*Figure 3. The wiring diagram also shows the filters. Be sure to keep the connections as short as possible!*

side of the common ground plate for the electrolytic capacitors, between the plus and minus leads from the bridge rectifier. In our design, the bridge rectifier is fitted to the side panel, which provides it with an adequate cooling surface.

On the opposite side of the electrolytic capacitors, the three power supply terminals (including neutral) are connected to the terminals on the power supply board marked with 'input' arrows. The four terminals for the supply voltages are thus available on the power supply board. The path to the amplifier board must be as short as possible. This also applies to the 10-V auxiliary voltage!

For the main supply voltage, stranded wire with a cross section of at least 4 mm$^2$ must be used. The mute signal for the amplifier is generated on the power supply board. It is connected to the amplifier board using a twisted pair of small-diameter stranded wires. The analogue supply voltage is connected to the amplifier board using a twisted pair of stranded wires (1.5 mm$^2$).

The mains voltage output from the power supply board is connected directly to the large toroidal transformer.

There is room to fit a small fan on the rear panel for internal cooling, if so desired. Try to route the cables for the input signals as far away from the transformers as possible. The loudspeaker leads must be wired as a twisted pair for each channel to counter the effects of interference fields.

## Alignment

The only alignment that is required is to adjust the dc offsets of the outputs, which can be done after the amplifier is assembled but should preferably be done during testing before final assembly. Naturally, the dc offset voltages must be set to zero. The offsets must be adjusted (using P1 and P2 on the amplifier board) with the amplifier

## Two channels in bridge mode

If a stereo amplifier is to be used in bridge mode, the two channels must be supplied with signals having the same amplitude and opposite phases. To avoid having to change any connections or components on the amplifier board, a simple buffer circuit is provided on the power supply board. IC4a is wired as a voltage follower, and IC4b is configured as an inverting amplifier. This means that besides two decoupling capacitors for the supply voltages, only two opamps and two resistors are necessary. Since balanced supply voltages are used, no decoupling capacitors are required for any dc offsets that may be present at the inputs or outputs. Due to the simple design, small offset voltages may be present at the outputs, but the final amplifier is ac coupled and thus totally immune to such offsets.

For proper operation and low distortion, careful attention must be given to the polarity of the loudspeaker filter connections when the final amplifier board is operated in bridge mode. In this case, the amplifier is wired exactly the same as for stereo operation. Naturally, it's only necessary to build the input filter for a single channel. The output from the input filter goes to the buffer circuit on the power supply board (IC4). Two signals go from the buffer to the inputs on the final amplifier board. It goes without saying that these connections must be made using good-quality, screened audio cable. The two LS+ outputs from the loudspeaker filters form the speaker terminals of the bridge amplifier. As the return currents from the filters would have nowhere to go if the LS– outputs were left open, the two LS– outputs must be connected together. If the amplifier is used in bridge mode, it is essential to ensure that the amplifier outputs are not accidentally shorted together (due to incorrect wiring, for example).

switched on and operating in normal mode (not muted), with its rated load but without any drive signal.
In the mute mode without any load, the amplifier has an output impedance of approximately 10 kΩ. In this situation, there will be a small voltage on the output, but this does not have to be adjusted.
Besides adjusting the offset, the only other alignment is the dead-time setting for the MOSFET drive circuitry. This is determined by the positions of jumpers JP1 and JP2 (or BBM0 and BBM1). Set the dead time to 80 ns by setting JP1 to '1' and JP2 to '0'. There's no point in experimenting with other values. Using a larger value causes increased distortion, and using a smaller value causes short-circuit currents to flow through the MOSFETs, which can be fatal for them.
All possible settings are listed in **Table 1**. The component overlay on the amplifier board also clearly indicates the proper positions of the jumpers.

**Table 1.
Dead-time jumper settings**

| JP2 BBM1 | JP BBM0 | t ns |
|---|---|---|
| 0 | 0 | 120 |
| 0 | 1 | 80 |
| 1 | 0 | 40 |
| 1 | 1 | 0 |

### *Final remarks*

There are a couple of things we still have to tell you. The first is that the amplifier can be used bridge configuration, as explained in the 'Two channels in bridge mode' text box. Another essential aspect is the measured performance, which is also described in a separate box. The measurements were made using the complete amplifier, which means including the filters. Unfortunately, there is not enough room to describe the filter circuits in this article. For the time being, you can also use the amplifier without the filters, but we strongly recommend including them in the overall system.

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## Measured performance

The results described here were measured using a 1000-VA power supply transformer with two windings rated at 42 V / 11.9 A, together with two sets of four 15,000-μF / 63-V electrolytic capacitors. The measurements were made using the fully assembled prototype. An additional 40-kHz passive second-order Butterworth filter with an air-core inductor was used for measuring intermodulation distortion and dynamic IM distortion.

| | | |
|---|---|---|
| Input sensitivity (2 × 300 W / 4 Ω) | | 1.13 V (THD+N = 1.5 %) |
| Input impedance | | 18.9 kΩ |
| Sine-wave power (1 kHz / THD+N = 0.1 % / B = 22 Hz – 22 kHz) | | 2 × 266 W / 4 Ω<br>2 × 156 W / 8 Ω |
| Sine-wave power (1 kHz / THD+N = 1 % / B = 22 Hz – 22 kHz) | | 2 × 291 W / 4 Ω<br>2 × 167 W / 8 Ω |
| Sine-wave power in bridge mode<br>(1 kHz / THD+N = 1 % / B = 22 Hz – 22 kHz) | | 600 W / 8 Ω<br>735 W / 6 Ω |
| Bandwidth (via $9^{th}$-order elliptic filter with B = 180 kHz) | | 2.4 Hz – 98 kHz (4 Ω / 1 W)<br>2.4 Hz – 122 kHz (8 Ω / 1 W) |
| SNR (B = 22 Hz – 22 kHz) | | > 68 dB (referred to 1 W / 4 Ω)<br>> 71 dB (referred to 1 W / 8 Ω) |
| Harmonic distortion (1 kHz)<br>(B = 22 Hz – 22 kHz) | 2 × 1 W / 4 Ω | < 0.04 % |
| | 2 × 1 W / 8 Ω | < 0.03 % |
| | 2 × 200 W / 4 Ω | < 0.02 % |

| | | |
|---|---|---|
| | 2 × 100 W / 8 Ω | < 0.02 % |
| 2nd harmonic alone | 2 × 1 W / 4 Ω | < 0.01 % (THD+N = 0.037 %) |
| | 2 × 10 W / 4 Ω | < 0.02 % (THD+N = 0.023 %) |
| | 2 × 25 W / 4 Ω | < 0.025 % (THD+N = 0.026 %) |
| | 2 × 100 W / 4 Ω | < 0.013 % (THD+N = 0.017 %) |
| 2nd and 3rd harmonics | 2 × 200 W / 4 Ω | < 0.015 % (THD+N = 0.018 %) |
| Intermodulation distortion | 1 W / 4 Ω | < 0.1 % |
| (50 Hz : 7 kHz = 4 : 1) | 1 W / 8 Ω | < 0.1 % |
| | 300 W / 4 Ω | < 0.06 % |
| | 150 W / 8 Ω | < 0.0 % |
| Dynamic IM distortion | 1 W / 4 Ω | < 0.035 % |
| (3.15-kHz square wave with 15-kHz sine wave) | 1 W / 8 Ω | < 0.03 % |
| | 300 W / 4 Ω | < 0.025 % |
| | 150 W / 8 Ω | < 0.01 % |
| Damping (8 Ω / 1 kHz) | > 140 | |
| Channel separation | 200 W / 4 Ω / 1 kHz | > 94 dB |
| | 100 W / 8 Ω / 1 kHz | > 100 dB |
| | 200 W / 4 Ω / 20 kHz | > 77 dB |
| | 100 W / 8 Ω / 20 kHz | > 77 dB |

Besides these 'clinical' measurement figures, we have also recorded several curves. They probably give a better picture of the character of the amplifier, although ultimately only a listening test can provide a reliable conclusion.

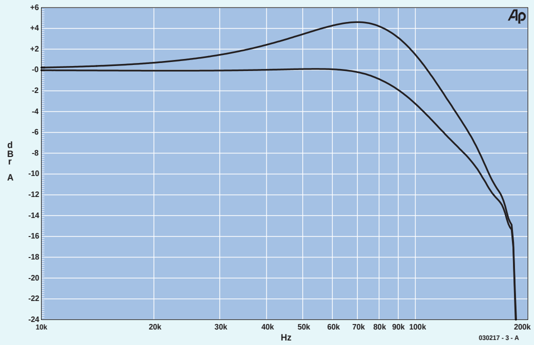
**Figure A** shows the effect of the output filter (on the final amplifier board) on the amplitude response. The upper curve is measured with an 8-Ω load and shows a rise of +0.7 dB at 20 kHz and +4.6 dB at 70 kHz. Comparison with the measurement for 4 Ω clearly shows that the filer is optimised for 4 Ω, for which it exhibits an exemplary straight-line characteristic. The sudden sharp drop-off in the curve at the end of the measured range is due to the ninth-order elliptic filter used for this measurement.

**Figure B** shows THD+N versus output level for a bandwidth of 22 Hz to 22 kHz with a 4-Ω load. The rise in the middle of the curve (around 20 W) is partly due to the influence of the other channel (additional noise). All in all, the distortion over the entire output power range up to 200 W can be considered to be nicely constant. At levels above 200 W, distortion increases due to the additional modulation applied to the amplifier output. Here the amplifier exhibits behaviour that resembles soft clipping, but true limiting only occurs at around 300 W into 4 Ω. This is also strongly dependent on the strength of the power supply. An additional second-order filter was used for this measurement to slightly smooth the curve. Without this filter, the distortion is somewhat lower (e.g. 1 % at 291 W).

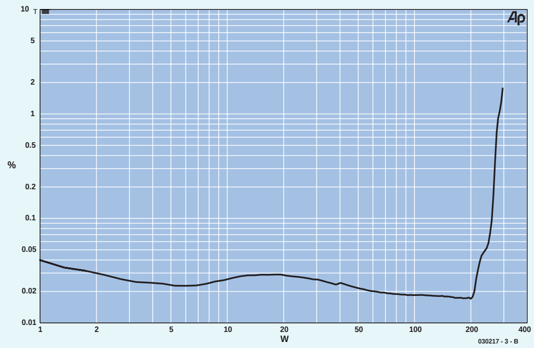
**Figure C** shows the maximum output power for loads of 2 × 4 Ω and 2 × 8 Ω. For 4 Ω, the distortion was held constant at 1 %, and for 8 Ω it was held constant at 0.5 %. Both measurements were made over a bandwidth of 22 Hz to 22 kHz. The power appears to increase starting at around 6–8 kHz, but this is naturally due to the fact that the filter suppresses harmonics above these frequencies. The curves should be drawn with a slightly dropping line starting at 5 kHz. The maximum power is slightly greater at low frequencies than at high frequencies. At 50 Hz it is approximately 163 W into 8 Ω or 306 W into 4 Ω, while at 1 kHz it is approximately 160 W into 8 Ω or 291 W into 4 Ω. The effect is thus slightly greater at lower impedance, but this is not perceptible in actual practice.

Finally, **Figure D** shows the frequency spectrum of a 1-kHz signal for 1 W into 4 Ω.. This was measured using an additional 40-kHz second-order Butterworth filter in order to prevent HF noise in the A/D converter from affecting the FFT analysis. The second harmonic thus actually lies slightly below 80 dB (< 0.01 % distortion). No power-supply ripple or other irregularities are visible here. Despite the fact that a portion of the pulse-width modulation can be seen with 1 W at the output of the amplifier, the spectrum within the audio band can be considered to be quite clean. The small bump at 50 kHz does not require any comment.

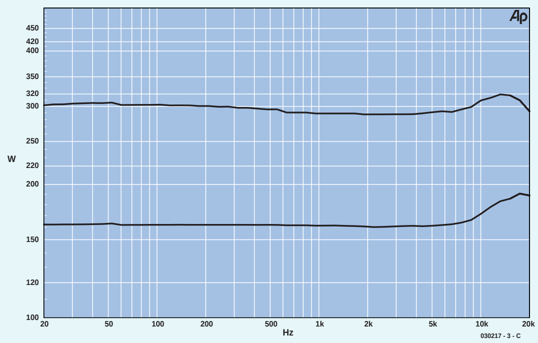
A




B




C




D