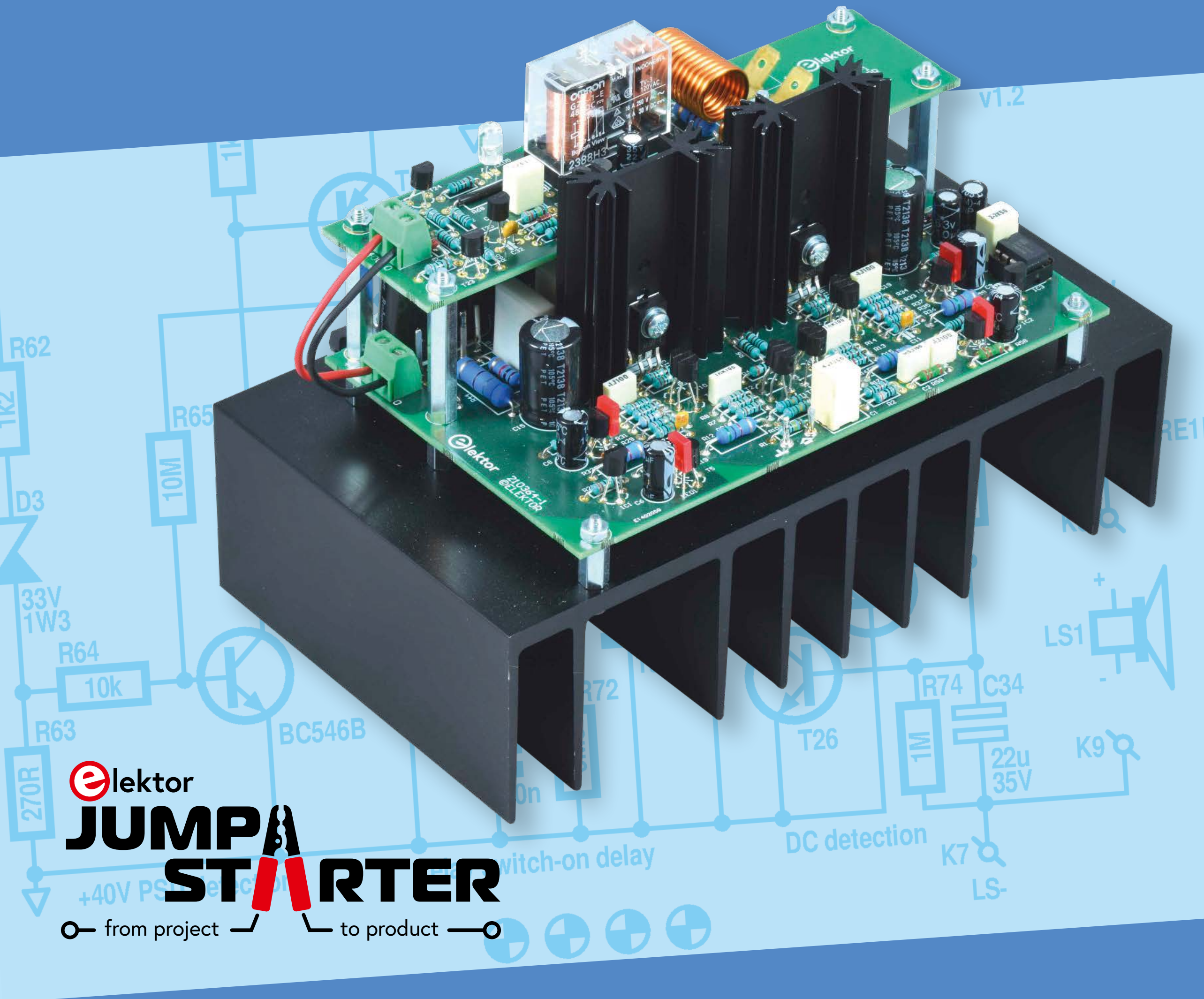
46 pages instructions

Construction Manual

Elektor Fortissimo-100

Power Amplifier Kit



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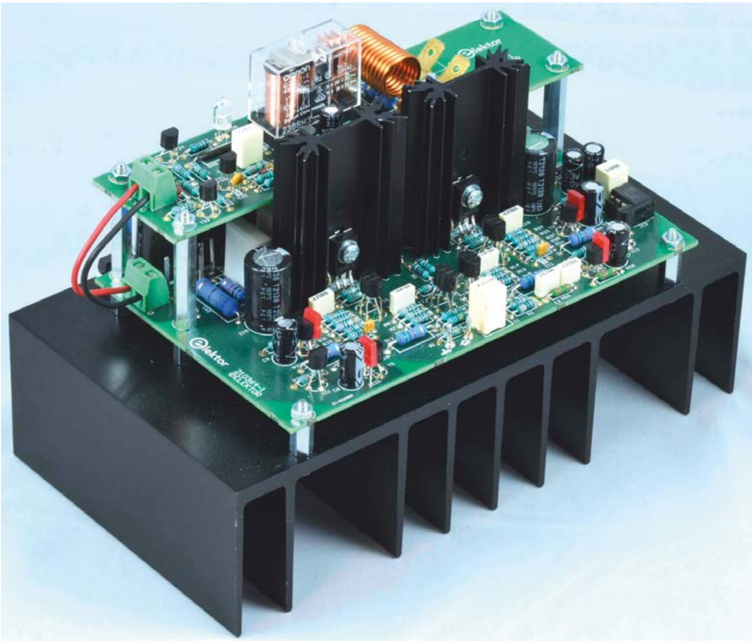
Elektor Fortissimo-100
Power Amplifier Kit

Designed by Ton Giesberts - Elektor Labs

Construction Manual

V1.0 – date: September 8, 2022,

Notice: This manual is only available as a downloadable PDF at: www.elektor.com/20273.



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Notice

This document is complementary to the information contained in:

1. the editorial article “The Elektor Fortissimo-100 Power Amplifier” published in *Elektor Magazine edition 11&12 2022;*

2. the engineering background and discussions posted on the Elektor Labs website.

Web Links to these publications may be found in Section 22.

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www.elektor.com; www.elektormagazine.com.

1 – Kit Contents

- Two PCBs: amplifier PCB and protection PCB.
- All parts listed in the Bill of Materials (BOM) found at the end of this document (Section 19).
- Construction Manual – Downloadable PDF.

Figure 1. Contents of the Fortissimo-100 Power Amplifier kit as supplied by the Elektor Store.

Before embarking on the construction of the Kit, be sure to inspect the contents using the Bill of Materials and the photos that follow. Check that all parts are supplied and in usable condition.

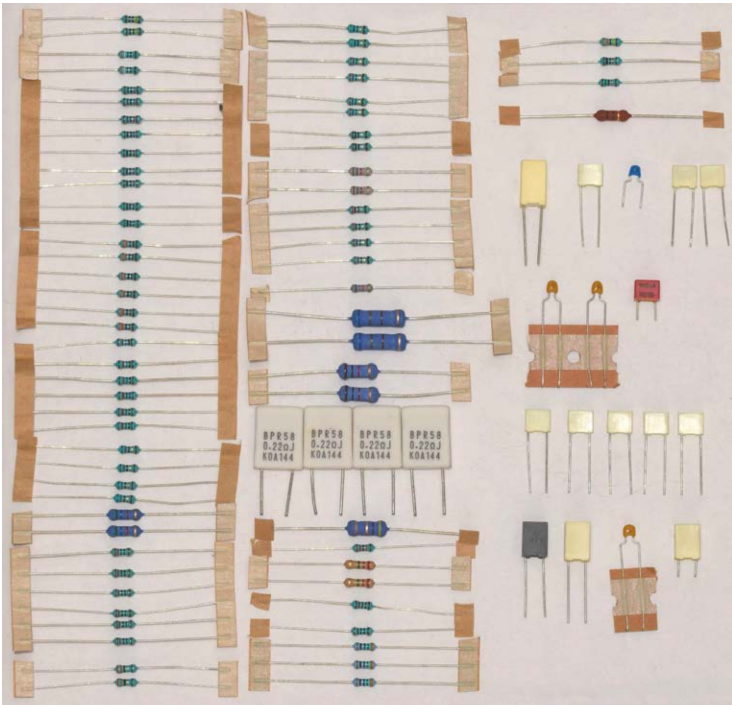

Figure 2. The resistors and small capacitors in the kit.

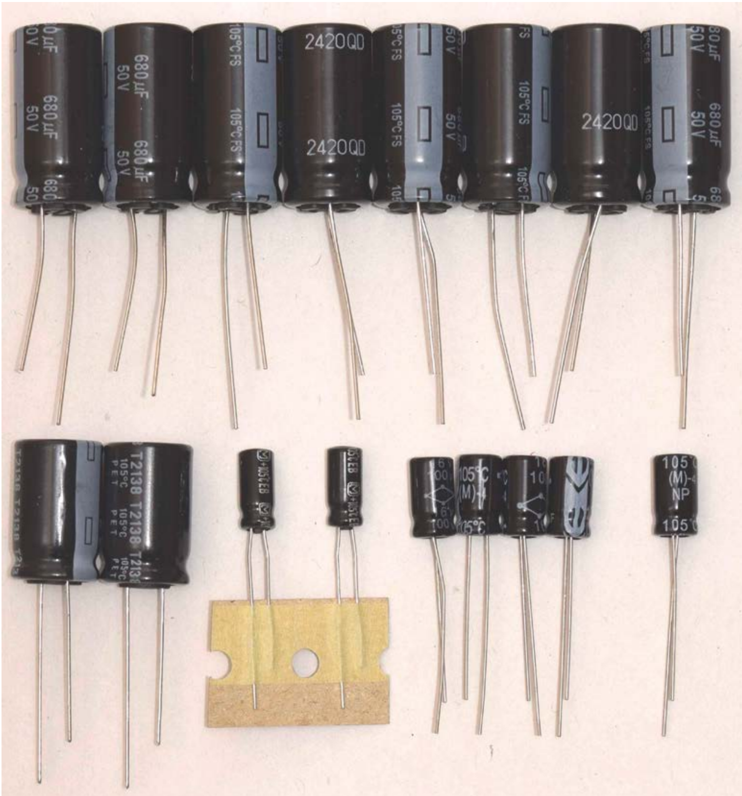

Figure 3. The electrolytic capacitors in the kit.

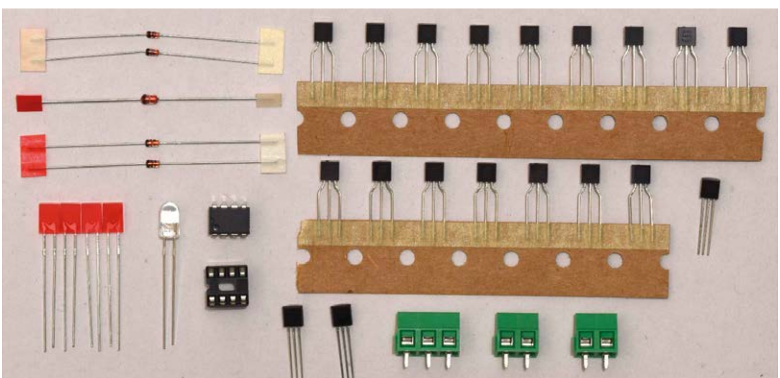

Figure 4. The small transistors, diodes, and other parts in the kit.

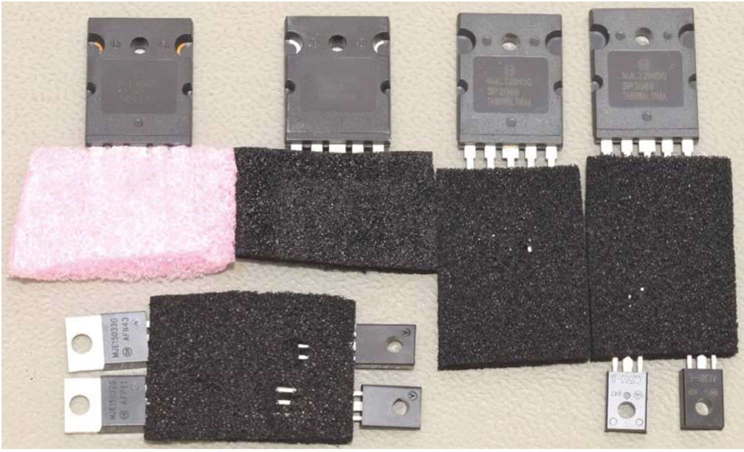

Figure 5. The larger transistors.

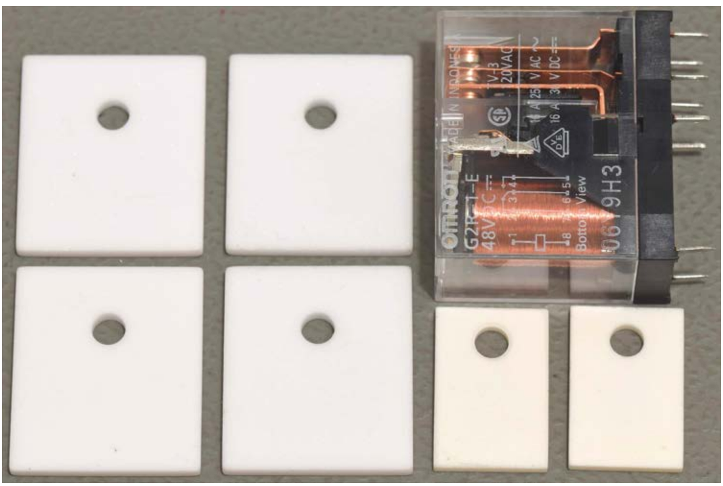

Figure 6. The ceramic pads (washers) and the relay in the kit.

Figure 7. The mechanical parts in the kit.

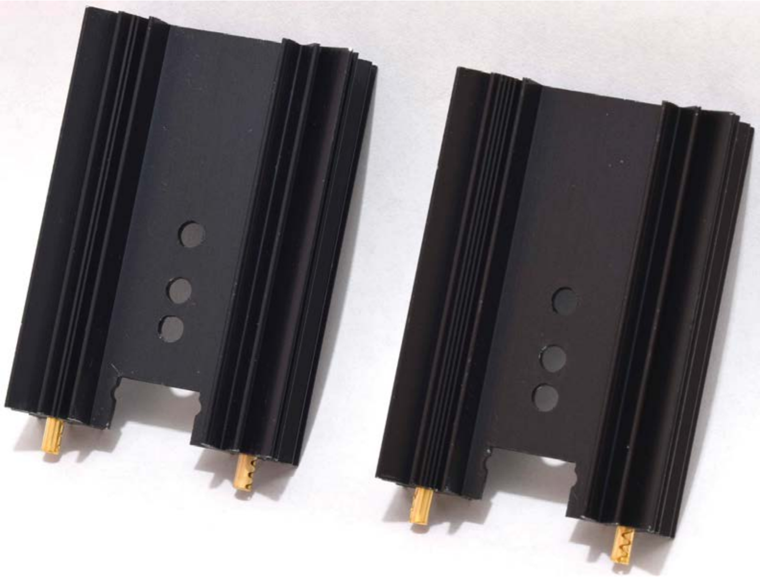

Figure 8. The SK104 heatsinks in the kit.

Figure 9. The SK53-100-SA heatsink in the kit.

2 – Introduction

Notice: It is strongly advised to closely read the entire Construction Manual before starting the construction of the amplifier.

The design, especially the placement of the power transistors T17–T22 and the PCB, is aimed at easy replication. The mechanical work needed should be possible with simple tools and basic skills like drilling 12 3-mm holes to mount the transistors and fasten the PCB in parallel with the back of the heatsink. The fin spacing of the selected heatsink (type SK53-100-SA from Fischer Elektronik) is sufficient for the heads of the black 3-mm screws while also allowing room for some error. The PCB is mounted onto the heatsink with six 10-mm long metal male-female standoffs with 3-mm thread. The 6 transistors of the output stage are electrically insulated with ceramic (Al_2O_3) pads, marked by a lower thermal resistance than comparable types. During the final stage of construction, apply some thermal grease on the back of the transistors and on the sides of the pads placed against the heatsink. Only a very thin layer is required! Take precautions not to get the thermal grease on your fingers as most types are toxic.

The DC protection and relay circuit are placed on a second, smaller PCB placed in parallel with the amplifier PCB. Six 30-mm long male-female metal standoffs ensure a solid construction. Standoffs K3 and K4 (amplifier PCB) connect the output of the amplifier to K6 (LS+) and K7 (LS–) on the protection PCB and from there via the relay and output terminals K8 and K9 to the loudspeaker. “Faston” connectors K8 and K9 (PCB versions) make sure the series resistance of this connection to the cable is extremely low.

On the finished amplifier, the screw heads should be on the back of the heatsink. Black screws won’t stand out that much when looking at the back of the heatsink. Black Allen-type screws are used for the transistors (with internal hexagonal recesses). Strangely enough, black 16-mm long screws are few and between at many electronic part distributors.

Selected parts shown in the photos may have different values or shapes in your kit. This is because the amplifier shown was a first prototype for testing.

3 – Tools Needed

- Soldering equipment for through-hole components. Soldering iron rated at 100 watts minimum. Also recommended is an extra-long tip for soldering the transistors in the output stage.
- Small pliers with flat jaws.
- Pliers with special jaws for pressing a thermal relief (bend) in the leads of the push-pull transistors. Alternatively: pliers with round jaws.
- Pozidriv screwdriver (depends on the exact type of screws in the kit).
- 2.5-mm tool for hex screws (Allen wrench; also depends on the exact type of screws in the kit).
- Drill stands or similar tool with 3-mm drill bit to drill 12 3-mm holes in the large heatsink. Consider using a 3.2-mm drill bit if accuracy of drilling is sub optimal).
- 10-mm drill bit or similar rod or tube for use as a former to wind the air inductor on.

4 – Locating and Drilling Holes in the Heatsink, for the PCB Standoffs

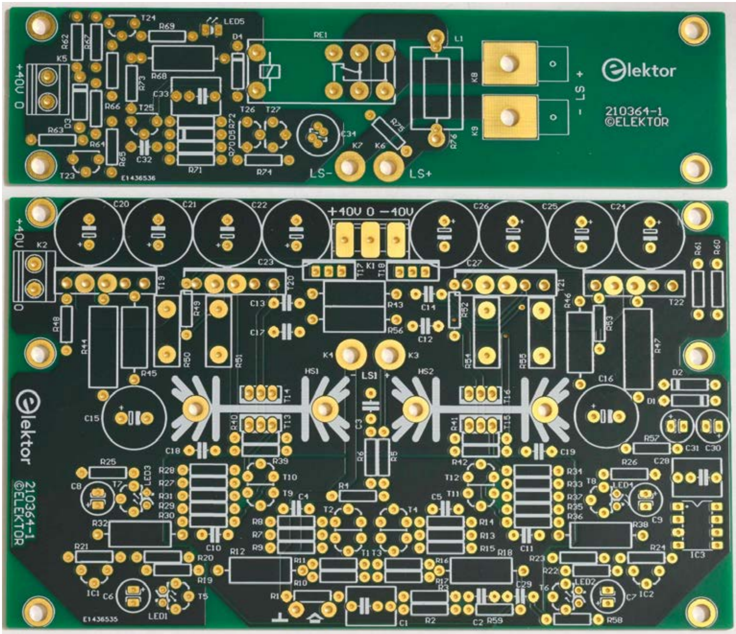

Figure 10. The bare PC boards for the amplifier and protection circuitry, as supplied in the kit.

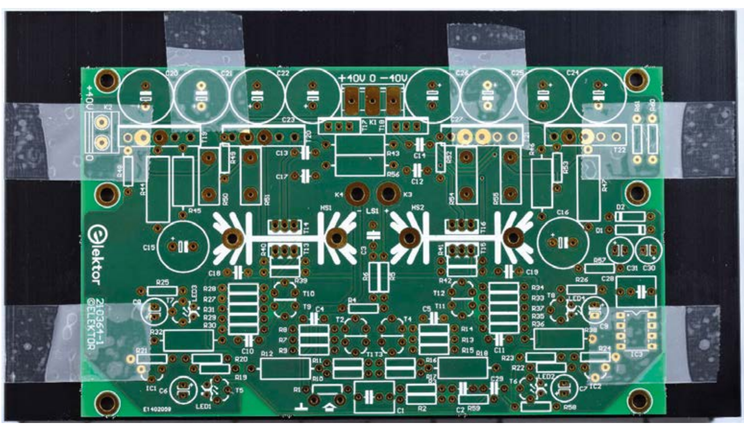

Figure 11. Amplifier PCB used as drilling template.

The amplifier PCB is placed in the center on the heatsink, 1 mm from the edge where C1 is located, and fixed temporarily with sellotape so the six positions for the metal standoffs can be marked out (scored). Use a 3.5-mm drill bit and with some pressure turn it counterclockwise in the six holes located at the short sides of the PCB, taking great care to avoid damage to the PCB. **Do not score the positions K3 and K4.** Being the outputs of the amplifier, they must never be in electrical contact with the heatsink! All six holes are located at ample distances from the heatsink fins to allow room for the screw heads including a small error margin.

Figure 12. Standoffs secured in place for the PCB to be mounted.

After the six 3-mm holes are drilled, the six 10-mm standoffs are mounted on the heatsink and fastened with the black 12-mm M3 screws. Next, check if the PCB fits accurately on the six standoffs. If not, consider filing out one or more holes to slightly correct the position of the standoff(s).

5 – Bending the Output Stage Transistor Leads

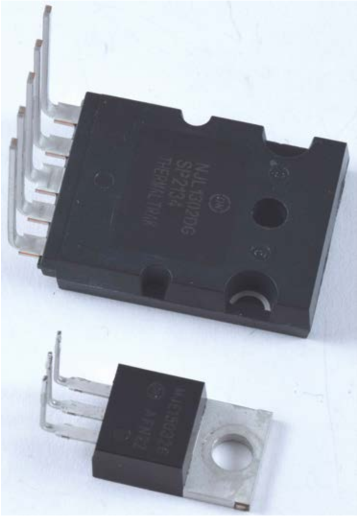

Figure 13. Bent leads of the TO-220 and TO-264 transistors in the output stage.

Bend all leads of the transistors (T17–T22) perpendicular toward the front of the transistors (Figure 13). To avoid excessive force exerted from the leads to the package of the large power transistors, use a 2-mm drill bit and a small vice. Gently clamp the pins and the drill bit between the vice jaws. Use a flat piece of material to bend all leads toward the front of the transistor. Bending the leads of the smaller TO-220 packages can be done with flat-jaw pliers. Bend them at 1 mm from the package, where the leads become smaller.

6 – Locating and Drilling Holes in the Heatsink, for the Transistors

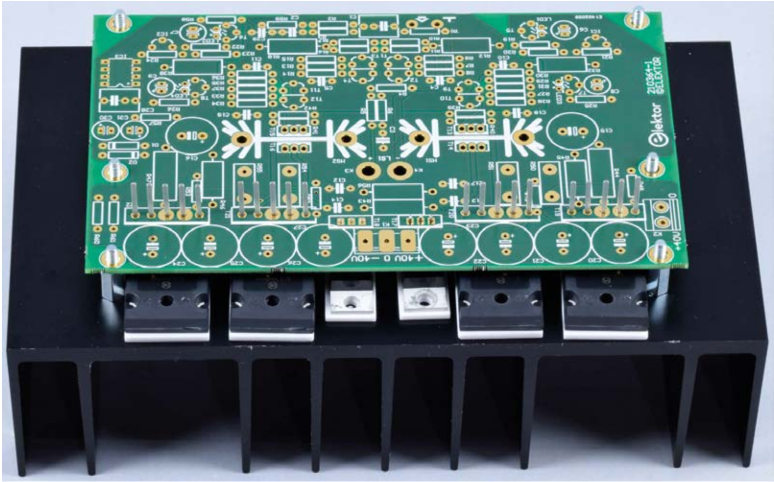

Figure 14. Preparations for marking the 3-mm holes required for the transistors.

Before mounting any parts on the PCB, locate the position of the holes for the six screws to secure the transistors to the heatsink. Figure 14 shows the PCB with the 6 power stage transistors temporarily fitted (i.e., not soldered) to permit marking out the positions of the six 3-mm holes. Also, the ceramic insulation pads must be placed between the transistors and the heatsink since this can affect the exact position of the holes. In this prototype, the four holes for the power transistors are approximately 8.8 mm from the edge of the heatsink, and the smaller transistors, at 11.5 mm. However, this can vary, and the exact location depends on the exact position of the bend in the transistor leads. It's unlikely that a drilling reference for the heatsink indicates the correct positions of the transistors. Mark (score) the six holes using a 3-mm drill bit. Using your fingers and with some force, turn the bit counter-clockwise through the aligned holes in the transistors and pads.

Figure 15. Marked-out positions for the six holes to be drilled (prototype).

Figure 16. Six 3-mm holes drilled for the transistors in the output stage.

After drilling the holes, place the transistors in position with their screws. It's not necessary to secure them with nuts. Check if the PCB is a perfect fit with all leads and the six standoffs through their holes.

Now almost all parts can be fitted on the PCBs. Start with the lowest components, small resistors and diodes (D1…D5).

7 – Small Resistors and Diodes

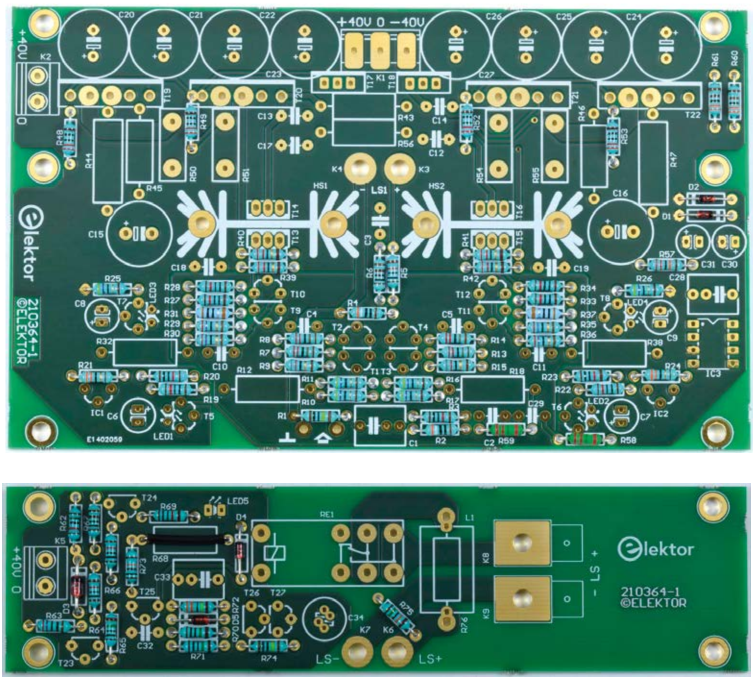

Figure 17. The small resistors and diodes soldered onto the two boards.

8 – Axial Power Resistors and IC Socket

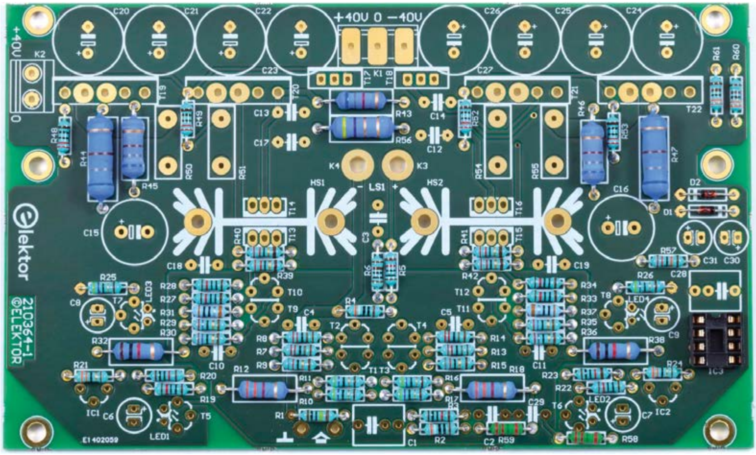

Figure 18. Axial power resistors and 8-pin IC socket (pos. IC3) soldered onto the amp board.

9 – Small Capacitors and Input Terminal Pins

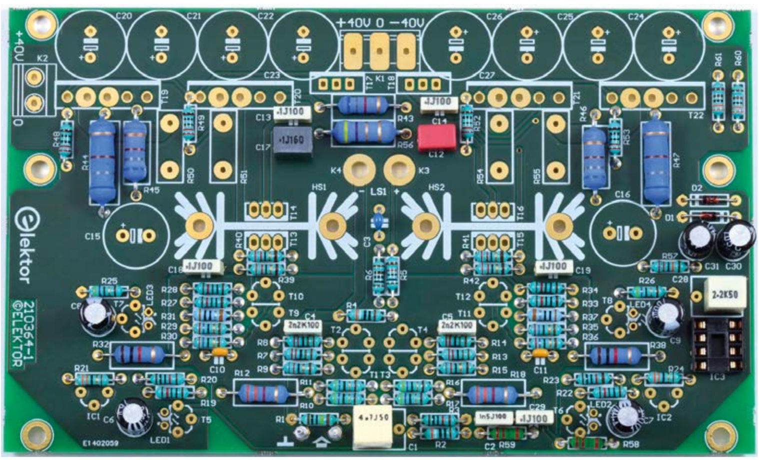

Figure 19. The small capacitors also soldered onto the amplifier board.

Place and solder the small capacitors, the smallest ones first: C3, C10, C11, C32, C4, C5, C12, C2, C13, C14, C18, C19, C29, C17, C33, C28. Next, the larger/higher-value capacitors: C6, C7, C8, C9, C30, C31, C34 , input terminal pins, C1.

10 – Finishing the Assembly of the Protection PCB

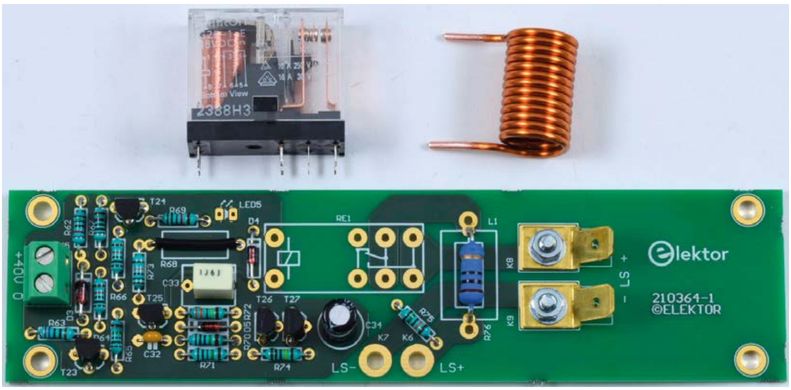

Figure 20. To finish the protection board, solder the relay and the air-cored inductor onto the board.

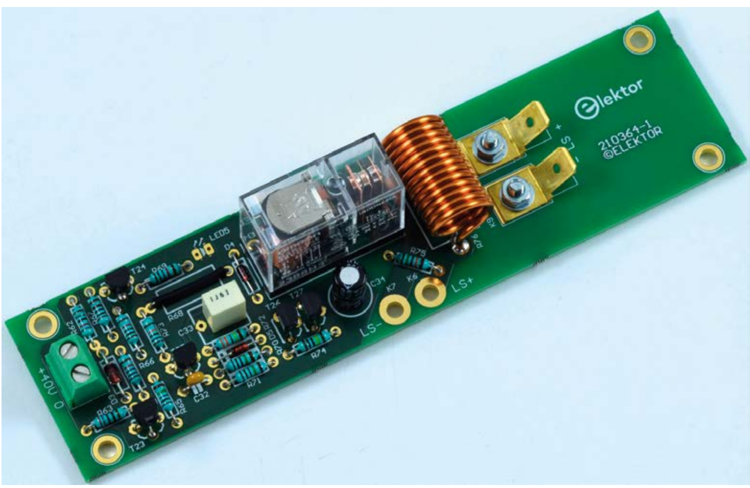

Figure 21. The completed protection board (PCB 210364-1 v1.1 shown).

At this point, finish fitting the rest of the components on the small PCB: T23, T26, T27, T24, T25, K5, Faston tabs K8 and K9 (including two 8-mm M3 screws/nuts/washers and finally, the inductor (13 turns of 1.5-mm diameter enameled copper wire), and relay RE1. The compulsory output inductor L1 is made of 13 turns in a single layer using 1.5-mm diameter enameled copper wire. The Inside diameter should be 10 mm. A 10-mm drill bit can be an aid in winding the inductor. Keep the two ends long enough to place the inductor above R76 and check if the distance of the two ends corresponds with the footprint and are in line. R76 suppresses possible ringing. Use a hobby knife to scrape the enamel insulation off the inductor wire ends, then pre-tin them lightly. LED5 is to be mounted on the front of the enclosure of the amplifier, and is connected by thin stranded wire, if so desired.

11 – Small Transistors, LEDs, Radial Power Resistors, and Large Capacitors

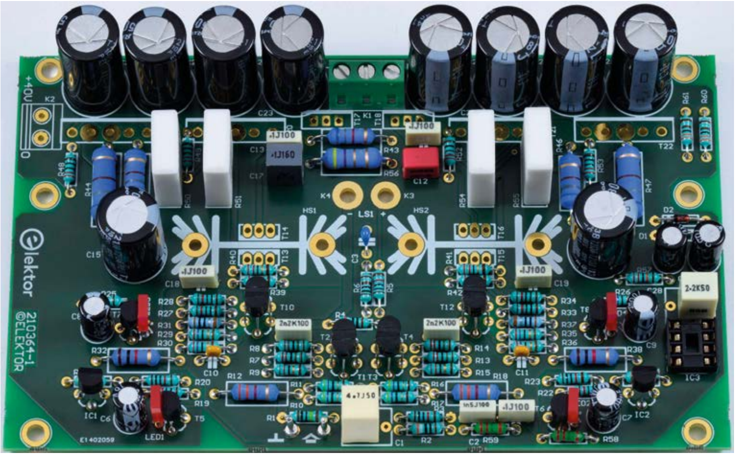

Figure 22. Small transistors, rectangular LEDs, radial power resistors and large capacitors soldered onto the amp board.

Now, T5, T6, T7, T8 and LED1, LED2, LED3, LED4 can be inserted and soldered. For best thermal coupling, Place the chip inside the LED halfway the package of the transistor that’s next to it, and flush against the transistor.

If you have enough transistors, it's favorable to select the input transistors pairs T1/T2 and T3/T4 for identical U_{BE} and h_{FE} values. The same applies to the transistors in the second differential amplifiers, T9/T10 and T11/T12. See the end of this document for details (Section 17 – Selecting BC546B/BC556B for Differential Pairs). When soldering the pairs, make sure the flat sides remain in good contact, since a maximum contact surface guarantees proper thermal coupling.

Next, the radial power resistors R50, R51, R54, R55, capacitors C15 and C16, and capacitors C20...C27 can be fitted and soldered.

12 – Placing the Loudspeaker-Signal Through-Contact Standoffs

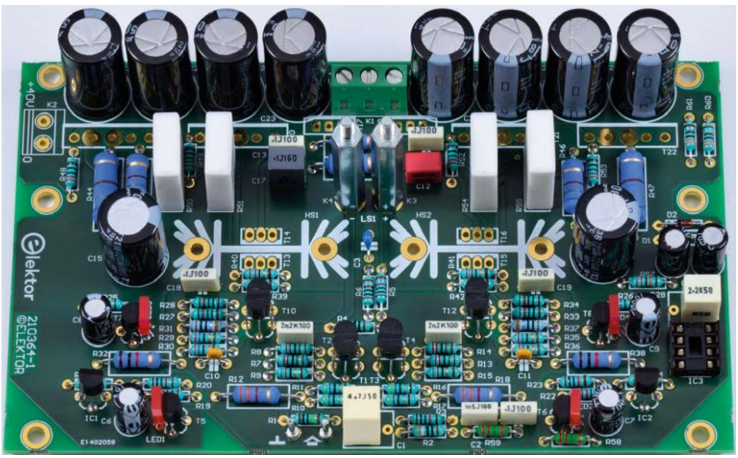

Figure 23. Two 30-mm M3 male-female standoffs are attached to the pads of K3 and K4.

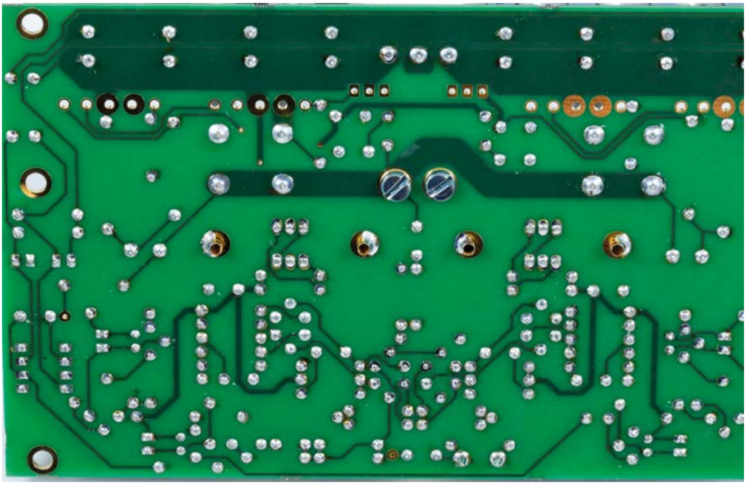

Figure 24. Each of the two 30-mm standoffs is secured with an 8-mm M3 cheese head screw.

The two metal standoffs that connect the amplifier output lines of the main PCB to the smaller PCB above it can now be fitted and secured with an 8-mm long M3 cheese head screw.

13 – Transistors T13...T16 and the Small Heatsinks

Figure 25. Special pliers and an example of the "thermal relief" bend in the leads needed for T13...T16.

Transistors T13-T14 and T15-T16 can now be mounted on the small heatsinks. A thermal relief in the leads of each transistor is recommended to reduce mechanical stress caused by temperature changes. It’s best to make a small bend in the leads, away from the heatsink. Figure 25 shows the special pliers required to do this, and a successfully “shaped” transistor. Alternatively, pliers with round jaws can be used for this job. The bend must be close enough to the package, permitting the pins of the transistors to pass through the PCB.

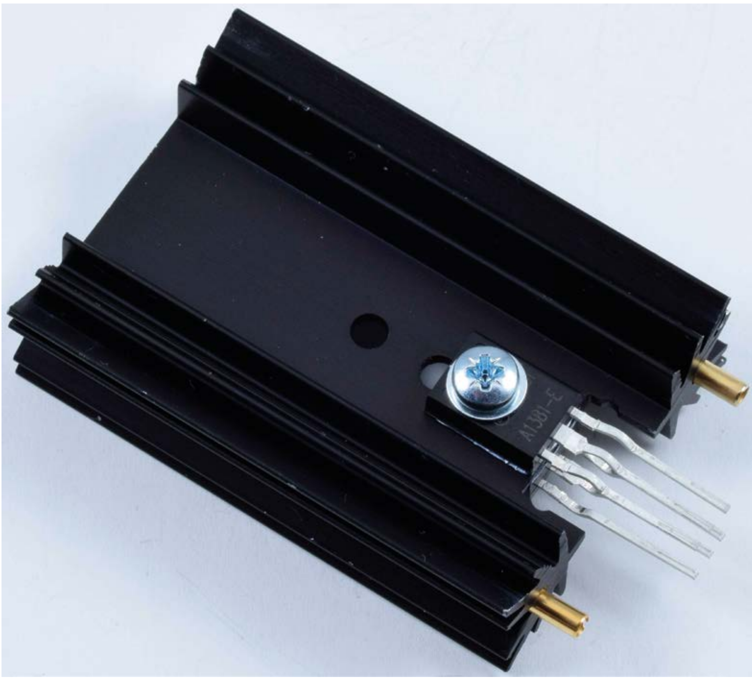

Figure 26. Two transistors mounted at each side of the small heatsink.

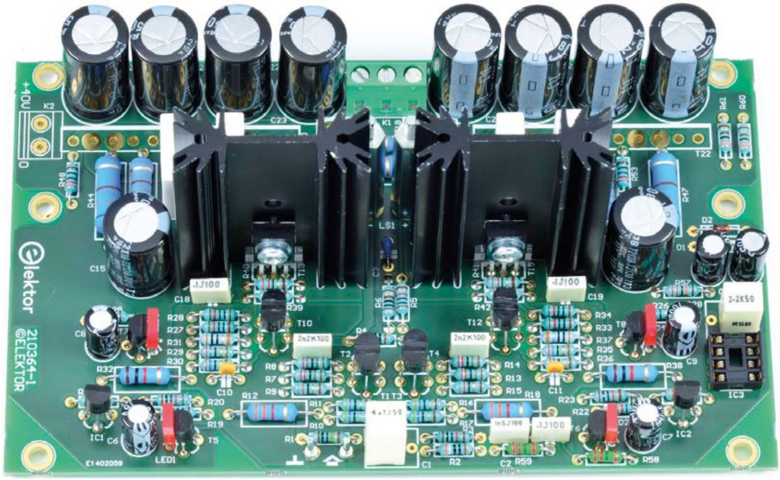

Figure 27. The two small heatsinks and transistors T13…T16 soldered in place.

Before securing the transistors on the heatsinks, apply a small amount of thermal grease to the back of each transistor. No insulation is needed since the package of these transistors is completely plastic. Place the head of the screw toward the input of the PCB, but don't tighten the screw yet. You can only use a screwdriver from this side to fasten the screw. Place an M3 metal washer between the head of the screw and the transistor. Figure 26 shows the transistors secured to the small heatsink. Solder the pins of the two heatsinks to the PCB first and only then tighten the screws of the transistors. Be sure to use pliers to hold the nut on the other side of the heatsink. Only then, proceed to soldering the transistor leads.

14 – The Output-Stage Transistors

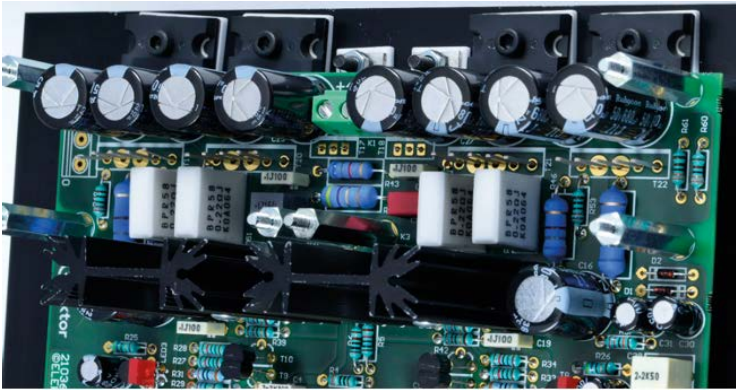

Figure 28. View of the PCB and the output stage transistors provisionally secured to the heatsink.

Figure 28 shows the six output stage transistors fastened temporarily with screws and nuts to enable them to be soldered. Also, the PCB is fixed onto the 10-mm long standoffs on the heatsink with 30-mm long standoffs (or use nuts for now). Also, place the ceramic washers for the transistors and the insulating bushes for the TO-220 transistors since all of this can influence the exact location of each transistor.

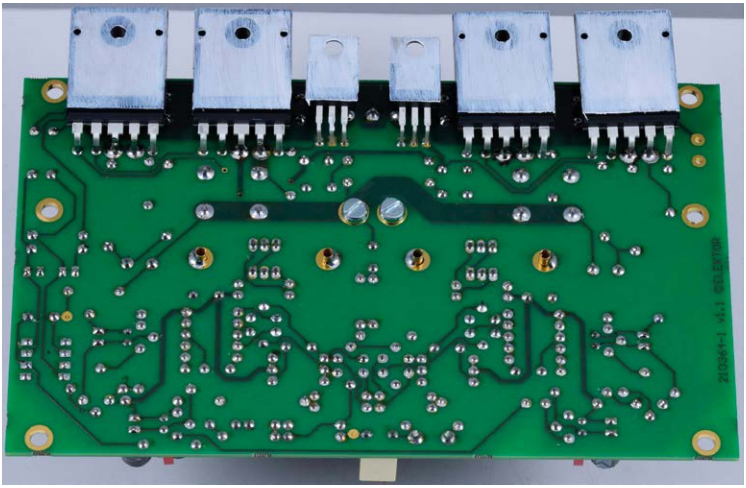

Figure 29. The output stage transistors are soldered, and thermal grease is applied to their backs.

As a minimum, solder the two leads at either side of each large power transistor without melting any plastic of various capacitors. Do more leads if possible. A longer soldering tip is recommended. All leads of T17 and T18 can be soldered from the top. When this is done, remove the screws that hold the transistors first and then the standoffs that hold the PCB. Carefully take the PCB off the heatsink and make sure not to bend the transistors. Now, the transistors are attached to the PCB at their final position. Solder the rest of the leads from the bottom side. 2-way screw terminal block K2 was not soldered yet to give better access to the leads of T19 and this should be done now. Then apply a very thin layer of thermal grease to the back of the six transistors and one side of each ceramic washer that is placed against the heatsink.

Figure 30. Slide the ceramic washers (pads) over the screw threads before positioning the PCB with the transistors.

Place the heatsink upright with the holes for the transistors at the top. Insert the six (black) screws halfway through the heatsink. The 16-mm, black screws take T19…T22, and the 12-mm, black screws take T17 and T18. Slide the ceramic washers with the greased side over the screws against the heatsink as shown in Figure 30 (in the prototype, 6 off black 16-mm screws were used).

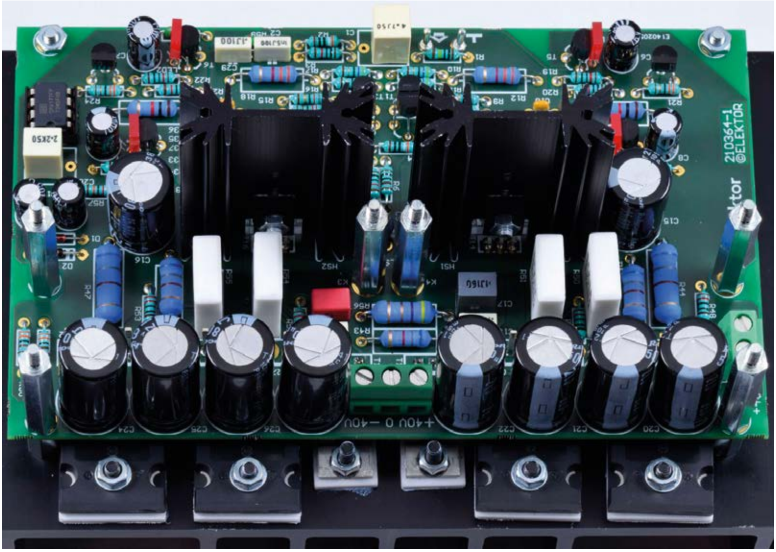

Figure 31. Top view of the finished amp PCB with the output stage transistors secured to the heatsink.

Carefully maneuver the PCB onto the standoffs on the heatsink, making sure the screws pass through the transistor holes while the ceramic washers remain in position. Place and tighten the four 30-mm standoffs and the two M3 nuts to fix the PCB securely to the heatsink. Also use M3 washers to fix the four power transistors and don't forget the insulating bushes for T17 and T18 (type IB 6 from Fischer Elektronik or similar). Tighten the six screws. Place IC3 in its socket. Figure 31 shows the practically finished power amplifier.

Figure 32. Rear view of the heatsink after 12 screws are tightened.

15 – Final Assembly

The finished protection PCB can now be placed on the six 30-mm standoffs and fastened with six M3 nuts.

The following three images show the (almost) finished module. Only the connection of the +40 V power supply between the two PCBs (K2 to K5) is missing. The photos show the construction of the first completed prototype for measurements conducted at Elektor Labs. At this stage LED5 wasn't fitted on the protection PCB.

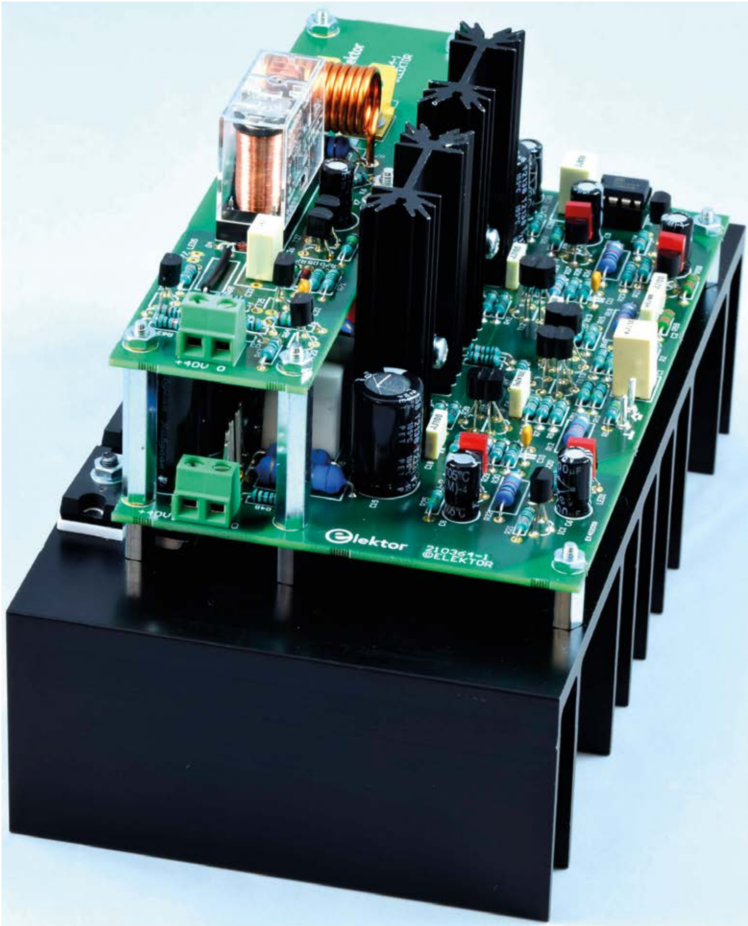

Figure 33. Left-side view of the Fortissimo-100 Power Amplifier.

Figure 34. Right-side view of the Fortissimo-100 amplifier.

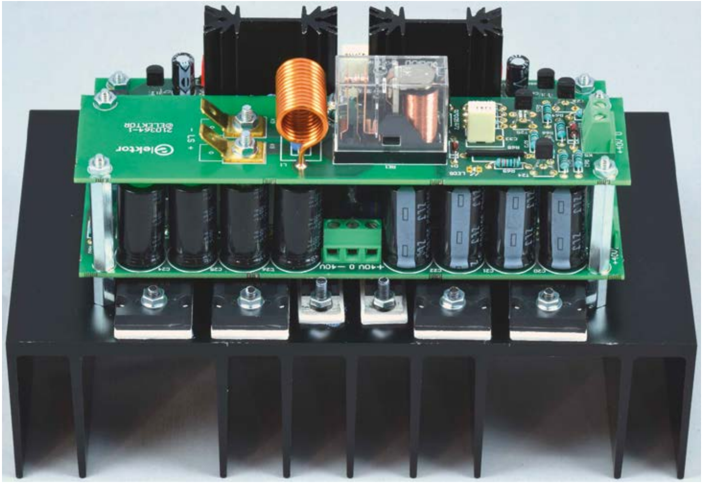

Figure 35. Broadside view of the Fortissimo-100's output stage.

Figures 33, 34, and 35 show the assembly and initial wiring of the first prototype for measurements.

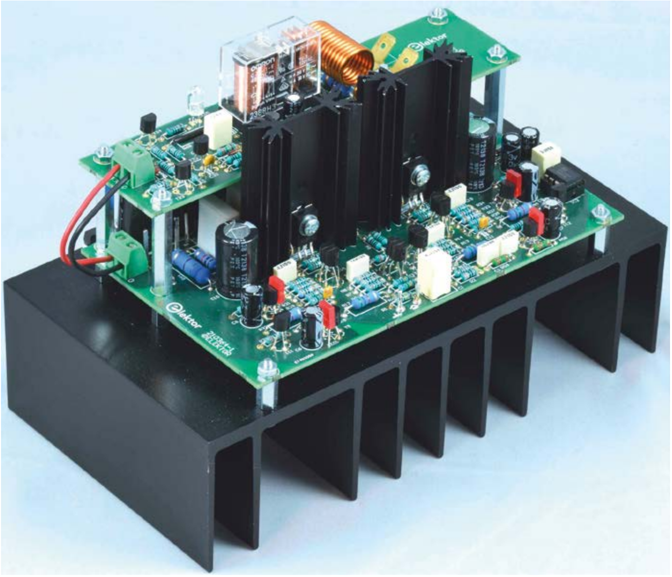

Figure 36. The finished Fortissimo-100 Audio Power Amplifier that was used for testing.

Figure 36 shows the finished amplifier with the two wires installed between K2 and K5, and with LED5 now PCB-mounted.

16 – Recommendations for the Enclosure

Before drilling holes in the heatsink, consider the enclosure you want to use for the Fortissimo-100 Audio Power Amplifier — specifically, how to secure the heatsink to the back of the enclosure. In case of a standard enclosure, the back panel is probably traded for separate aluminum plates, which is easier than making large openings in a metal panel. At both sides of the heatsink, enough room is available for M4 screws between the outer fins and going besides the PCB.

Because the amplifier PCB is close to the heatsink there must be enough holes to permit generous ventilation at the top and bottom. Even better is a wide slot going the full length of the PCB (or longer) alongside the heatsink in the top and bottom panels, thus guaranteeing a good convection of air between the PCB and the heatsink. Also, the remainder of the enclosure's top and bottom sides should have plenty of ventilation holes considering that the power supply will get hot, too.

To keep the length of the supply wires to an absolute minimum, the output of the power supply should be positioned as close as possible to screw terminal block K1 on the amplifier PCB. The type SMPS800RE switch-mode power supply (SMPS) is recommended for use. According to the SMPS800RE's datasheet, extra output capacitors are not recommended: [quote] 'if the capacitance is too high the over-current protection might trip during power ON'. [end quote] The maximum conductor cross sectional area (csa) of the wire inserted in the PCB terminal block type MKDSN 1,5/ 3-5,08 supplied in the kit is 1.5 mm^2. However, the size of the pads at the top side of K1 permit soldering much thicker wire directly onto the PCB. In the Elektor prototype version, the output of the SMPS has three "Faston" (a.k.a. spade) terminals, hence thicker wire is not a problem here.

Important Notice
The design of the PCB is explicitly intended for use as a mono amplifier! Do not use a single power supply for two amplifiers. This will cause ground loops and degrade performance of the amplifiers and can

even cause instabilities and oscillations due to the high speed of the amplifier as its gain-bandwidth product is 2.8 GHz! Star-Ground of the amplifier is in the center of the PCB, located at the loudspeaker Ground connection, K4. Only there, the Ground connections of power supply, loudspeaker and combined input and feedback come together.

17 – Selecting BC546B/BC556B Transistors for Differential Pairs

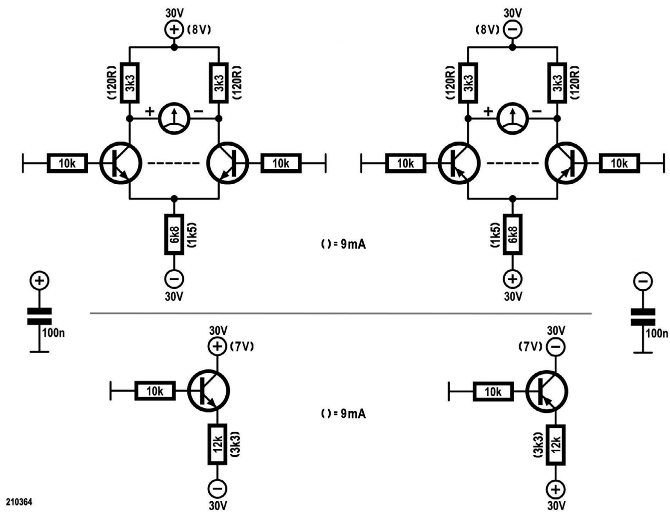

Figure 37. Test circuits for selecting matched transistors for use in the differential amplifier stages

To select the transistors for the differential input stages, simple circuits can be built on a breadboard. Use SIL or IC sockets to easily swap TUT's or use a solderless breadboard. For lowest offset, it's best to use two transistors placed or clamped against each other and then measure the potential difference between the 3.3-kΩ resistors as pictured in Figure 37. The base currents can be measured across the 10-kΩ resistors. Preferably the hFE of the NPN device is identical to that of the PNP device. Swap transistors for the lowest offset between the collector resistors. Always turn off the power supply before removing or inserting a transistor as this measurement is less temperature dependent. As a simpler way is to measure each transistor separately, tabulate UBE and hFE values and select the best matches. This is much more temperature dependent, though. You can use a 40 VDC power supply for the collector voltage if available. 6k8 should be a little lower (6k2) if you want to measure at 2.4 mA.

For the second differential stages, a few things need to be adapted. The current per transistor must be increased to approximately 9 mA (the values between parentheses). Select the common-emitter resistor and negative supply voltage to set a total current of 18 mA.

When using the differential test circuit, keep one transistor in place in the test circuit and change the other one with all the others. Again, turn off the power supply each time when removing or inserting another transistor! Measure and make a note of each offset per newly inserted transistor. Wait for the offset to settle to a stable reading. Place all available transistors in a piece of anti-static foam and use pliers to swap them on the breadboard. If not, the body heat of your fingers will seriously affect the time it takes for the reading to stabilize. Maybe a better transistor pair can be found by choosing two transistors with closer or — ideally — identical offsets. The best pair should be used for the first differential amplifier at the input, i.e., the NPN pair and the PNP pair, and the next best combination goes in the second stages.

18 – The SMPS800RE Power Supply

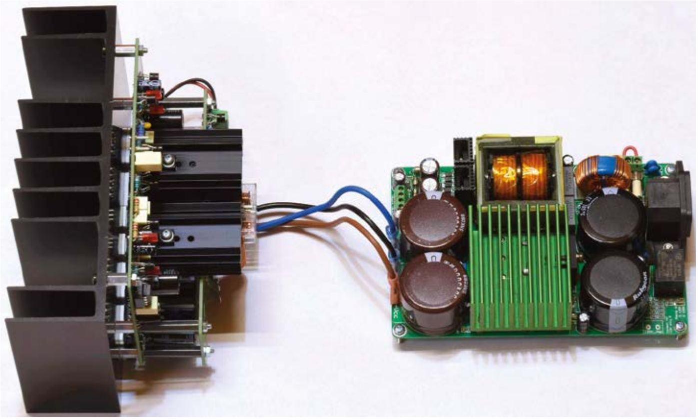

Figure 38. The Fortissimo-100 amplifier experimentally connected to the SMPS800RE power supply.

While using the SMPS880RE power supply, the distortion and noise measurements conducted on the Fortissimo-100 showed that an extra mains (AC line) filter and a common-mode filter at the output of the power supply are advantageous to the figures measured. But consider this: the levels are extremely low and we're talking about microvolts.

The following plot shows an FFT of 1 kHz at 1 W in an 8-ohm load using the SMPS800RE as a power supply for the Fortissimo-100 amplifier built with parts from a kit. The spectrum is essentially clean, right up 130 kHz. Only at higher power levels, the switching frequency is seen to shift below 130 kHz. In an enclosure, tie the three wires from the power supply to the amplifier closely together. This will minimize the risk of magnetic fields interfering with the amplifier. Recommendation: also clamp on a sufficiently large, split-ferrite core for EMI suppression, making sure it fits around all three wires to enable it to function as a common-mode filter.

At the mains side of the SMPS800RE, a small screw terminal for a power switch is available. If not connected, the power supply won't start (the red wire in the photo)! The IEC-type AC power connector is not soldered yet and can be replaced (remove the two screws) by a 3-way screw terminal block with 7.5 mm (0.3 inch approx.) lead spacing. Use a good AC line filter in the side area of the enclosure to connect the mains through this 3-way screw terminal block.
Follow all safety regulations regarding AC line voltages relevant to your country!

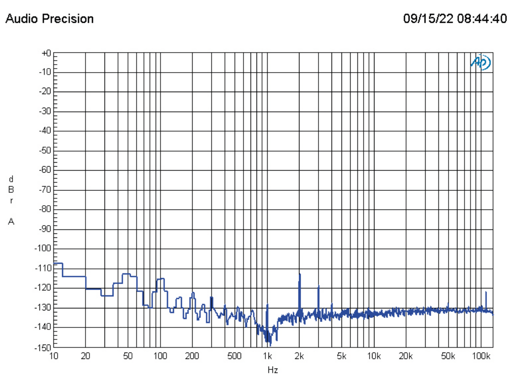

Figure 39. FFT of 1 kHz at 1 W and an 8 Ω load.

The Levels of the 2nd and 3rd harmonic are −112.6 dB and −118.5 dB down, respectively. THD amounts to a trifling 0.00026%.

19 – Bill of Materials

(PCB 210634-1 v1.1, schematic v1.2)

Resistor (small 0.6 W resistors are metal film)
R1,R74 = 1 MΩ, 1%, 0.6 W
R2,R4 = 390 Ω, 1%, 0.6 W
R3,R5,R20,R23,R64,R66,R69 = 10 kΩ, 1%, 0.6 W
R6,R67 = 1 kΩ, 1%, 0.6 W
R7,R8,R13,R14,R60,R61 = 3.3 kΩ, 1%, 0.6 W
R9,R15,R27,R28,R33,R34 = 120 Ω, 1%, 0.6 W
R10,R11,R16,R17 = 68 Ω, 1%, 0.6 W
R12,R18 = 5.6 kΩ, 5%, 1 W, metal film or metal oxide, body size 5 x 12 mm max.
R19,R22,R48,R49,R52,R53 = 220 Ω, 1%, 0.6 W
R21,R24 = 33 Ω, 1%, 0.6 W
R25,R26 = 56 Ω, 1%, 0.6 W
R29,R30,R35 R36 = 27 Ω, 1%, 0.6 W
R31,R37 = 1 Ω, 1%, 0.6W
R32,R38 = 1.5 kΩ, 5%, 1 W, metal film or metal oxide,
body size 5 x 12 mm max.

In KIT: MFP1-1K5 JI (TT Electronics/Welwyn),
small size 6.2 x 2.5 mm
R39,R40,R41,R42 = 22 Ω, 1%, 0.6 W
R43 = 6.8 kΩ, 5%, 1 W, metal film or metal oxide,
body size 5 x 12 mm max.
R44,R47 = 680 Ω, 5%, 3 W, metal film or metal oxide,
body size 5.5 x 16 mm max.
R45,R46 = 1 kΩ, 5%, 2 W , metal film or metal oxide,
body size 5 x 12 mm max.
R50,R51,R54,R55 = 0.22 Ω, 5%, 5 W, metal plate, radial,
lead spacing 9 mm, body size 5 x 14 mm, BPR58CR22J Koa
R56 = 4.7 Ω, 5%, 2 W, metal film or metal oxide,
body size 5 x 12 mm max.
R57 = 220 kΩ, 1%, 0.6 W
R58,R59 = 2.2 MΩ, 1%, 0.6 W

R62 = 1.2 kΩ, 1%, 0.6 W
R63 = 270 Ω, 1%, 0.6 W
R65,R70,R71 = 10 MΩ, 1%, 0.6 W
R68 = 0 Ω, jumper wire
R72 = 3.3 MΩ, 1%, 0.6 W
R73 = 100 kΩ, 1%, 0.6 W
R75 = 150 kΩ, 1%, 0.6 W
R76 = 10R, 5%, 2 W, metal film or metal oxide,
body size 5 x 12 mm max.

Capacitors
C1 = 4.7 µF, 5%, 50 VDC, pitch 5/7.5 mm, PET,
body size 7.6 x 9.7 mm max.
C2 = 1.5 nF, 5%, 100 VDC, pitch 5 mm,
body size 2.5 x 7.2 mm max.
C3 = 10 pF, ±0.5 pF, 100 V, pitch 5 mm,
C0G/NP0 (FG28C0G2A100DNT00 TDK)
C4,C5 = 1 nF, 5%, 63 VDC, pitch 5 mm, PET,
body size 2.5 x 7.2 mm max.
C6,C7,C8,C9 = 100 µF, 20%, 16 V, D 6.3 mm, preferably 105°C
C10,C11 = 220 pF, 5%, 100 VDC, pitch 5 mm, C0G/NP0,
body size 2.5 x 7.2 mm max.
C12 = 100 pF, 5%, 100 V, pitch 5 mm, PP,
body size 4.5 x 7.2 mm max.
(FKP2D001001D00JSSD Wima)
C13,C14,C18,C19,C29 = 100 nF, 5%, 100 VDC, pitch 5 mm, PET,
body size 2.5 x 7.2 mm max.
C15,C16 = 680 µF, 20%, 35 VDC, D 12.5 mm, pitch 5 mm,
5000h@105°C
(35ZL680MEFC12.5X20 Rubycon)
C17 = 100 nF, 5%, 160 VDC, pitch 5 mm, PP, body size, 5 x 7.2 mm
max. (R79GC3100Z340J Kemet)
C20,C21,C22,C23,C24,C25,C26,C27 = 680 µF, 20%, 50 VDC,
D 13.5 mm max., pitch 5 mm, 10000h@105°C
(50ZLJ680M12.5X25 Rubycon or EEUFS1H681 Panasonic)
C28 = 2.2 µF, 10%, 50 VDC, pitch 5/7.5 mm, PET,
body size 7.6 x 9.7 mm max.
C30,C31 = 10 µF, 20%, 63 VDC, D 6.3 mm, pitch 2.5 mm,
preferably 105°C
(EEUEB1J100SH Panasonic)

C32 = 10 nF, 10%, 50 VDC, pitch 5 mm, X7R,
body size 2.5 x 7.2 mm max.
C33 = 1 µF, 5%, 63 VDC, pitch 5/7.5 mm, PET,
body size 7.6 x 9.7 mm max.
C34 = 22 µF, 20%, 35 VDC, bi-polar, D 8 mm max.,
pitch 2.5/3.5 mm

Inductor
L1 = 1.5 mm diam. enameled copper wire, < 0.6 m, 13 turns,
ID 10 mm

Semiconductors
D1,D2 = Zener diode 20 V, 5%, 0.4 W, DO-35
(BZX79-C20,113 Nexperia)
D3 = Zener diode 33 V, 5%, 1.3 W, DO-41
(BZV85-C33,113 Nexperia)
D4,D5 = 1N4148, DO-35
LED1,LED2,LED3,LED4 = LED, red, 2 x 5 mm rectangular
(MCL453MD Multicomp Pro)
LED5 = LED, green, 5 mm, T-1 3/4 (5 mm)
T1,T2,T6,T7,T9,T10,T23,T26,T27 = BC546B, TO-92
T3,T4,T5,T8,T11,T12,T24 = BC556B, TO-92
T13,T14 = KSA1381, TO-126
T15,T16 = KSC3503, TO-126
T17 = MJE15032G, TO-220
T18 = MJE15033,G TO-220
T19,T20 = NJL3281DG, TO−264, 5 LEAD
T21,T22 = NJL1302DG, TO−264, 5 LEAD
T25 = BS170, TO-92
IC1, IC2 = LM334Z, TO-92
IC3 = OPA177FP, DIP-8

Miscellaneous
K1 = 3way terminal block, pitch 5 mm (1729131, MKDSN 1,5/
3-5,08 Phoenix Contact)
K2,K5 = 2way terminal block, pitch 5 mm (1729128 or MKDSN 1,5/
2-5,08 Phoenix Contact)
INPUT = 2 x Press Mount Terminal Pin, 1.3 mm,
PCB hole size 1.4 mm (13.14.419 Ettinger)

K3,K4 (=K6,K7) + 4 for 2nd PCB = metal standoff, 30 mm, M3, male-female (so 6 in total)
K8,K9 = Faston PCB, hole 3.3 mm, tab 6.35mm x 0.81mm (42822-2 Amp/TE Connectivity or similar)
RE1 = Relay 16 A /250 VAC/30 VDC, G2R-1-E 48DC Omron
4 x M3 screw, 16 mm, black (T19/T20/T21/T22 to heatsink, 839672 Toolcraft)
8 x M3 screw, 12 mm, black (standoff PCB/T17/T18 to heatsink, M312 PRSTMCB100- TR Fastenings)
4 x M3 screw, 8 mm (fasten 2 LSP standoffs and 2 Faston tabs)
18 x M3 nut
8 x M3 washer, plain, steel
6 x metal standoff, 10 mm, M3, male-female (PCB to heatsink)
HS1,HS2 = Heatsink, 9 °C/W, H 50.8 mm, SK 104 50,8 ST Fischer Elektronik
T17-T22 = Heatsink, 0.6 °C/W, 100x180x48mm, SK53-100-SA Fischer Elektronik
T19,T20,T21,T22 = Ceramic thermal pad, 23 x 20 mm x 2 mm (SL-012-AL20 Silfox)
T17,T18 = Ceramic thermal pad, 18 x 12 x 1.5 mm (SL-019-AL15, Silfox)
T17,T18 = Insulating bushing, TO-220 (IB 6, Fischer Elektronik)
IC3 = DIP-8 IC socket

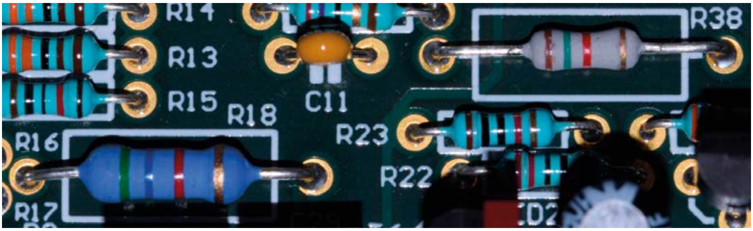

Figure 40. Detail: 1-watt resistors R18 and R38 — notice the size of R38.

The photo shows two different 1-watt resistors. Because of current component shortages, some resistors and capacitors in the kit may come from different series and manufacturers than mentioned in the BOM and shown in the photos.

20 – Specifications

Power source used: laboratory power supply rated 2 x 40 V DC, regulated + 2 x 10000 µF/50 V close to K1.

Input sensitivity	1.076 V (94 W/8 Ω, THD = 0.1%, B = 22 kHz)
Input impedance	10 kΩ
Sinewave power (1 kHz, B = 22kHz)	94 W (8 Ω, THD = 0.1%) 98 W (8 Ω, THD = 1%) 181 W (4 Ω, THD = 0.1%) 188 W (4 Ω, THD = 1%)
Bandwidth (Generator 20 Ω)	3.3 Hz – 237 kHz (-3 dB, 1 W/8 Ω) 10.8 Hz – 78 kHz (-0.5 dB, 50 W/8 Ω)
Open-loop bandwidth	≈ 20 kHz
Open-loop gain	≈ 140,000 (8 Ω load)
Slew rate	45 V/µs
Rise time	1.5 µs
Signal to noise ratio (Referred to 1 W/8 Ω)	103 dB (B = 22 Hz – 22 kHz linear) 106 dBA
Harmonic distortion plus noise	0.0008% (1 kHz, 1 W, 8 Ω, B = 22 kHz) 0.0016% (1 kHz, 1 W, 8 Ω, B = 80 kHz) 0.0016% (20 kHz, 1 W, 8 Ω, B = 80 kHz) 0.0008% (1 kHz, 50 W, 8 Ω, B = 22 kHz) 0.0008% (1 kHz, 50 W, 8 Ω, B = 80 kHz) 0.002% (20 kHz, 50 W, 8 Ω, B = 80 kHz) 0.0012% (1 kHz, 1 W, 4 Ω, B = 22 kHz) 0.002% (1 kHz, 1 W, 4 Ω, B = 80 kHz) 0.0025% (20 kHz, 1 W, 4 Ω, B = 80 kHz) 0.0023% (1 kHz, 100 W, 4 Ω, B = 22 kHz) 0.0023% (1 kHz, 100 W, 4 Ω, B = 80 kHz) 0.0042% (20 kHz, 100 W, 4 Ω, B = 80 kHz)

Intermodulation Distortion	
(50 Hz : 7 kHz = 4 : 1)	0.0012% (1 W, 8 Ω)
	0.0015% (50 W, 8 Ω)
	0.0024% (1 W, 4 Ω)
	0.0041% (100 W, 4 Ω)
Dynamic IM Distortion	0.0016% (1 W, 8 Ω)
(3.15 kHz square wave +	0.001% (50 W, 8 Ω)
15 kHz sine wave)	0.0019% (1 W, 4 Ω)
	0.0021% (100W, 4 Ω)
Damping factor	570 (1 kHz, 8 Ω)
(Measured on K8/K9)	315 (20 kHz, 8 Ω)
Power supply detection	36.5 V = Off
(Positive supply only)	(slightly temperature dependent)
	36.7 = On
	(slightly temperature dependent)
DC protection	+0.54 V / –0.89 V
Output relay turn-on delay	3.5 s

21 – DC Voltages

DC voltages across various resistors and LEDs:

Resistor	**Prototype**	**Kit**	**Condition**
R7	7.90 V	7.89 V	
R8	7.85 V	7.91 V	
R13	7.90 V	8.06 V	
R14	7.96 V	8.09 V	
R19	1.06 V	1.072 V	
R22	1.05 V	1.039 V	
R27	1.2 V	1.12 V	
R28	0.9 V	0.97 V	
R33	1.2 V	1.14 V	
R34	0.95 V	0.98 V	
R25	1.006 V	0.993 V	
R26	1.007 V	1.005 V	

R39	0.28 V	0.34 V	
R40	0.28 V	0.34 V	
R41	0.28 V	0.34 V	
R42	0.28 V	0.34 V	
R55	18.7 mV	19 mV	amp cold
	28.3 mV	28 mV	amp warmed up; zero output power

LEDs (average) = 1.675 V

22 – Web Links

Fortissimo-100 Power Amplifier project page on the Elektor Labs website:
www.elektormagazine.com/labs/fortissimo-100

Fortissimo-100 Power Amplifier Kit on the Elektor Store website:
www.elektor.com/20273

Fortissimo-100 Power Amplifier article published in *Elektor Magazine:*
www.elektormagazine.com/magazine/NUMBER

QR code

23 – Schematics and PCB Layouts

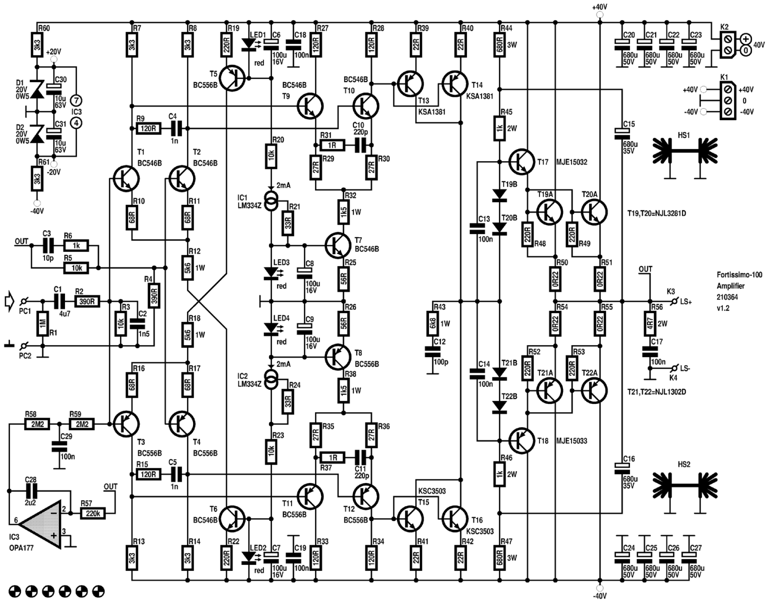

Figure 41. Schematic of the amplifier (210364-1 v1.2).

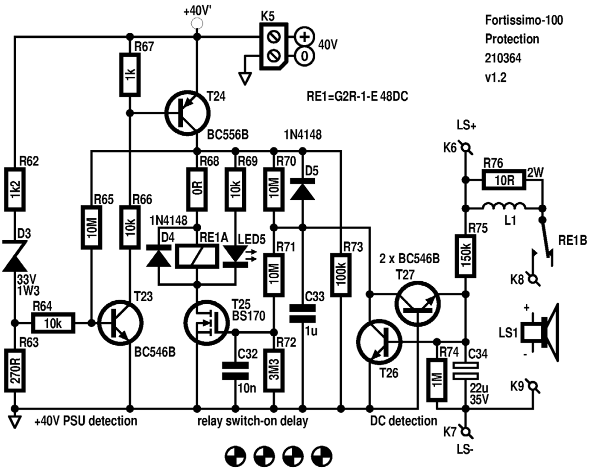

Figure 42. Schematic of the protection circuitry (210364-1 v1.2).

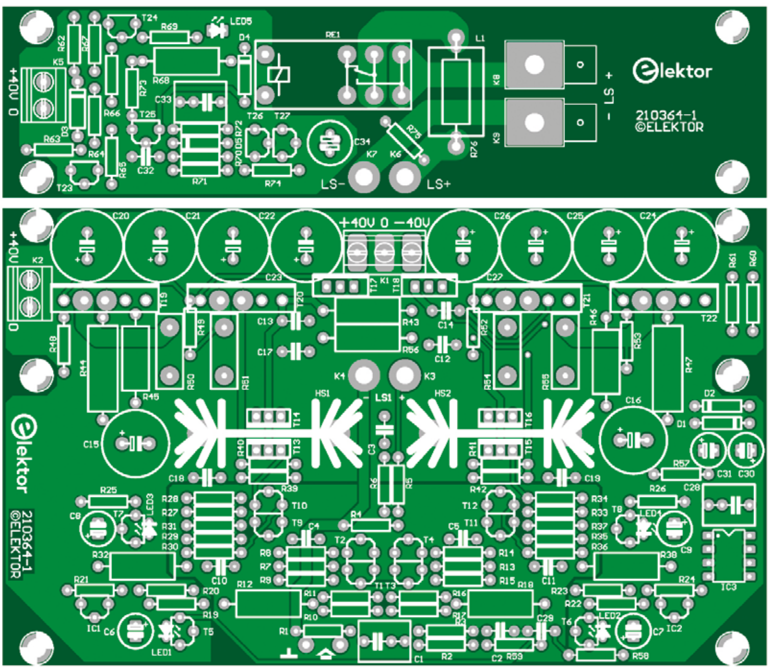

Figure 43. Top overlays of both PCBs (210364-1 v1.1).

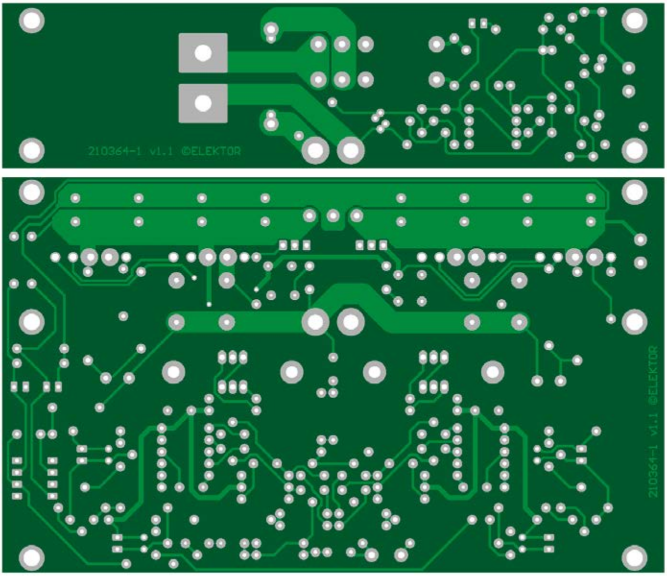

Figure 44. Bottom views of both PCBs (210364-1 v1.1)

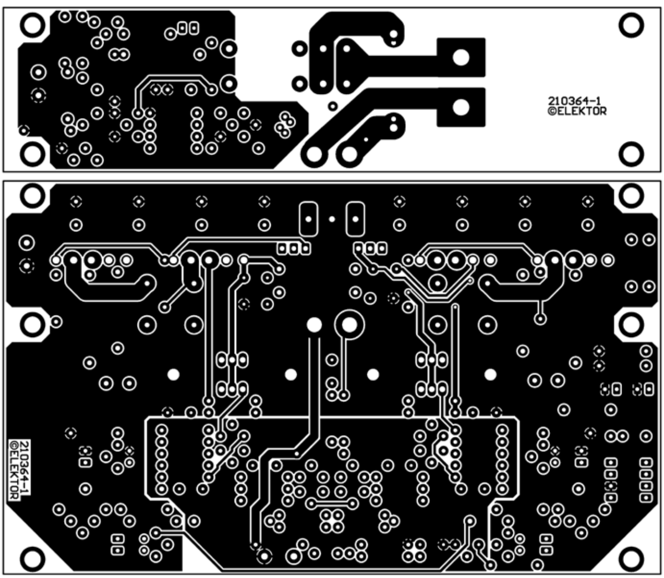

Figure 45. Top-side copper layout for both PCBs (210364-1 v1.1).

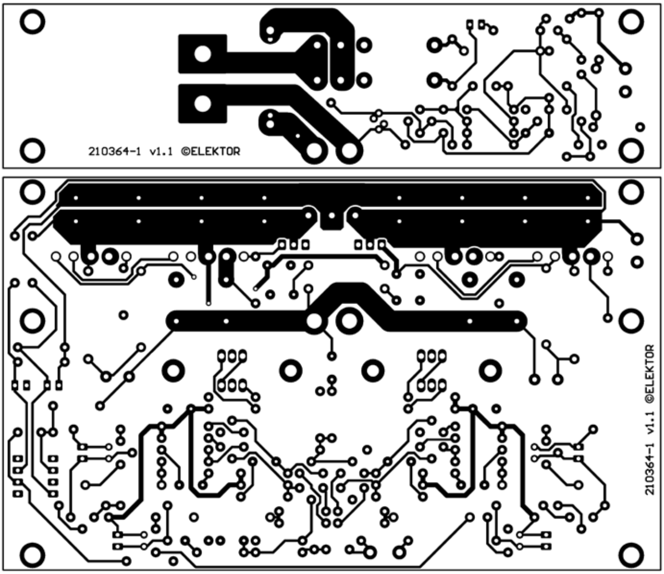

Figure 46. Bottom-side copper layout for both PCBs (210364-1 v1.1).