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HEXFET AMPLIFIER UPGRADE

Design by T. Giesberts

The Medium Power HEXFET amplifier published in this magazine in December 1993 has one small drawback: it delivers ‘only’ 60 W into 8 Ω (or 120 W into 4 Ω). Otherwise, it is a first class amplifier that provides excellent music reproduction, which is evidenced not so much by measurement as by audition. To some listeners, it has a quality not unlike that of a valve amplifier. Because of its popularity and the many requests for a version with higher output power, it has been upgraded to provide around 90 W into 8 Ω (about 160 W into 4 Ω).

By a stroke of good fortune, a pair of IGBTs (Insulated Gate Bipolar Transistors – see our June 1995 issue) proved ideal replacements for the HEXFETs used in the original design. Apart from the figures for power output, the technical specification remains virtually the same (see box).

Modification

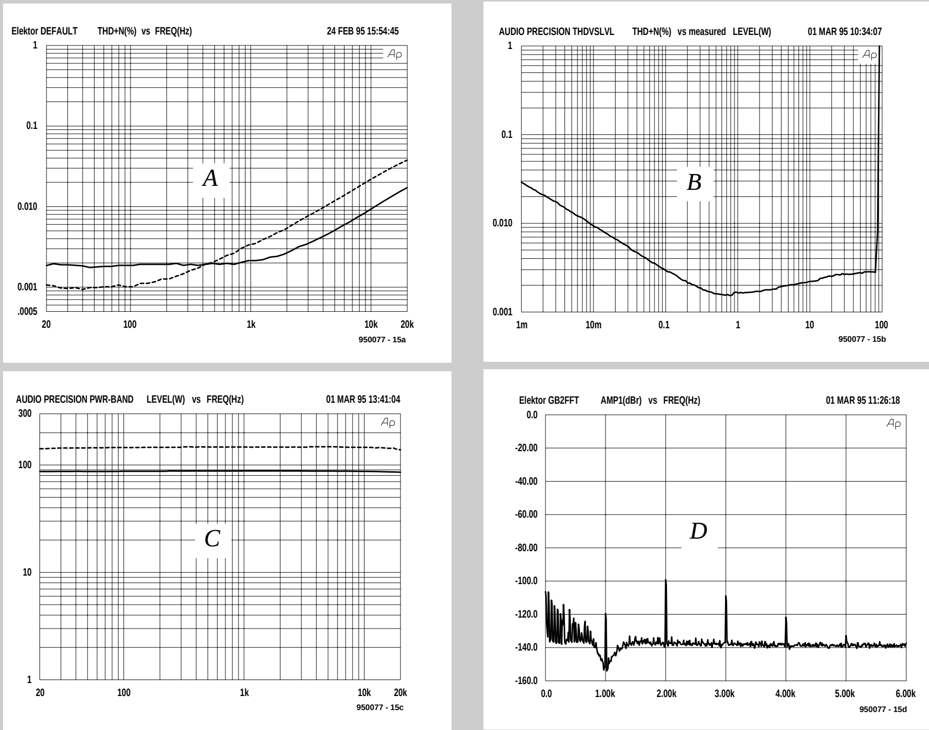
The original design already allowed for a higher-output version, whence the duplicated holes for the output transistors on the printed-circuit board. At that time, advance information on the IGBTs was already available, but samples were not.

Although IGBTs are quite different from HEXFETs, the board for the original design can be used without any modification. In fact, the circuit has hardly changed. The most noticeable alteration is the replacement of the fuses in the source lines of the power FETs by emitter resistors for the IGBTs. The only other changes are in the value of two resistors in the compensating circuit of the input stage, of one in the quiescent-current circuit, and of one resistor and two capacitors in the protection circuit. This means that anyone who has built the original HEXFET amplifier can quickly modify it to the upgraded version.

One item needs to be replaced, however: the mains transformer. After all, more power can not be obtained from the same supply voltage/current. The original transformer with 2×25 V secondaries must be replaced by one that provides 2×30 V at 3.75 A. This will result in a direct voltage of ±43 V.

Circuit description

The circuit diagram of the upgraded amplifier is given in Fig. 1. Changed with respect to the earlier version are T_{12}, T_{13}, RF_1, RF_2, R_3, R_4, R_{21}, R_{35}, C_{13} and C_{14}. Also, to improve performance at high frequencies, a damping resistor has been added to, or rather in, inductor L_1. Finally, to improve the noise figure, the impedance



Brief technical data

Input sensitivity	1.1 V r.m.s.
Input impedance	47.7 kΩ
Power output (1 kHz, 0.1% THD)	88 W into 8 Ω
	146 W into 4 Ω
Music power (1 kHz burst, 5 cycles on, 5 cycles off)	94 W into 8 Ω
	167 W into 4 Ω
Power bandwidth (40 W into 8 Ω)	1.5 Hz – 115 kHz
Slew rate	>35 V μs^{-1}
Signal-to-noise ratio (1 W into 8 Ω)	105 dB (A-weighted)
	101 dB (linear 22 Hz – 22 kHz)
Harmonic distortion (1 W into 8 Ω)	0.002% (1 kHz)
(80 W into 8 Ω)	0.003% (1 kHz)
	<0.05% (20 Hz – 20 kHz)
Intermodulation distortion (50 Hz:7 kHz; 4:1)	0.002% (1 W into 8 Ω)
	0.003% (40 W into 8 Ω)
Dynamic intermodulation distortion (rectangular 3.15 kHz + sine wave 15 kHz)	0.0025% (1 W into 8 Ω)
	0.002% (80 W into 8 Ω)
Damping factor (at 8 Ω)	>600 (1 kHz)
	>400 (20 kHz)

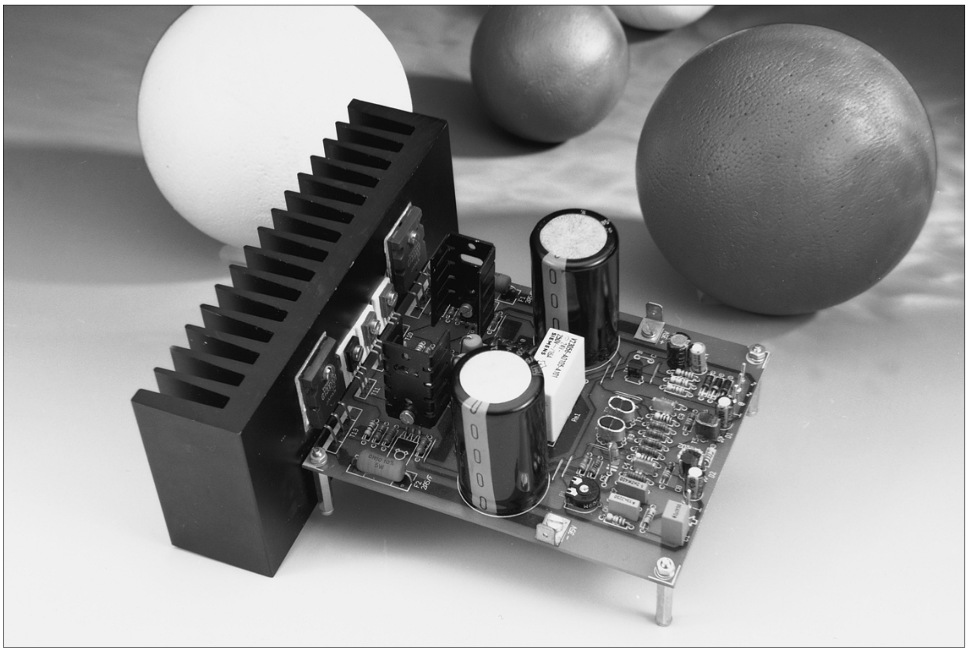
Measurements for the characteristics shown were made with an Audio Precision analyser.

A shows the total harmonic distortion (THD+N) from 20 Hz to 20 kHz. The solid curve refers to 1 W into 8 Ω and the dashed one to 75 W into 8 Ω.

B shows the distortion at 1 kHz as a function of drive (bandwidth 22 Hz – 22 kHz; load 8 Ω). The sharp bend at the end of the curve is the clipping point.

C shows the maximum power output when the distortion is 0.1%. It shows that the power is independent of frequency, whether the load is 8 Ω (solid curve) or 4 Ω (dashed curve).

D shows a Fourier analysis of a 1 kHz signal (1 W into 8 Ω) with the fundamental suppressed. The 2nd, 3rd and 4th harmonics can be seen, but they are attenuated, respectively, by 100 dB, 110 dB and 120 dB with respect to the fundamental frequency.



of input filter R_1-C_2 has been lowered.

A symmetrical design has the advantage that it minimizes problems with distortion, particularly that associated with even harmonics. Therefore, the input stages consist of two differential amplifiers, T_1-T_2 and T_3-T_4. These use discrete transistors, not expensive dual devices, to keep the cost down. Performance is excellent, particularly if the transistors are matched.

A differential amplifier is one of the best means of combining two electrical signals: here, the input signal and the feedback signal. The amplification of the stage is determined mainly by the ratio of the collector and emitter resistances (in the case of T_1-T_2 these are R_9, R_{10}, R_{11} and R_{12}). These provide a form of local feedback: limiting the amplification reduces the distortion.

Two *RC* networks (R_3-C_3 and R_4-C_4) limit the bandwidth of the differential amplifiers and these determine, to a degree, the open-loop bandwidth of the entire amplifier.

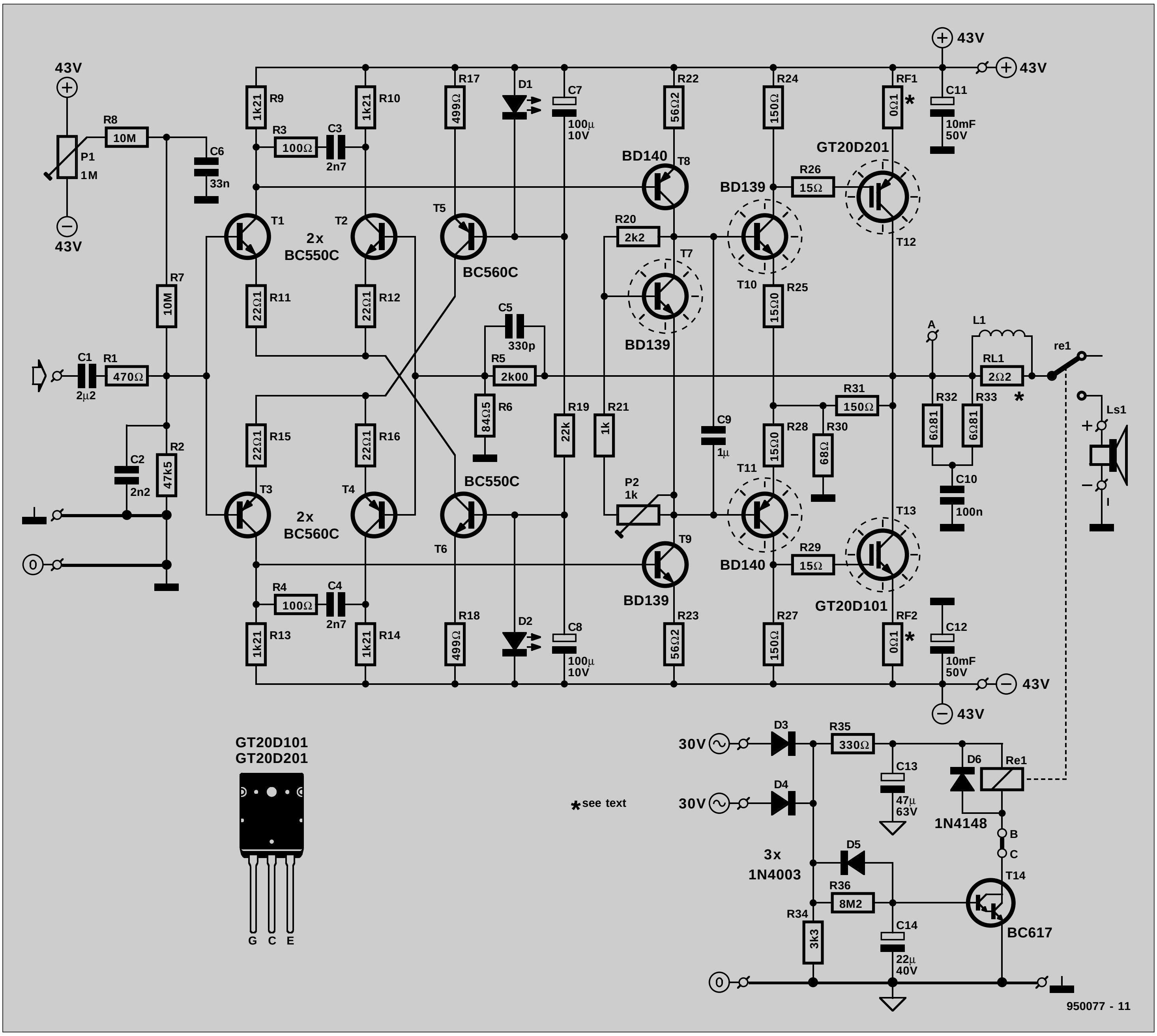


Fig. 1. Circuit diagram of the upgraded (IGBT) amplifier.

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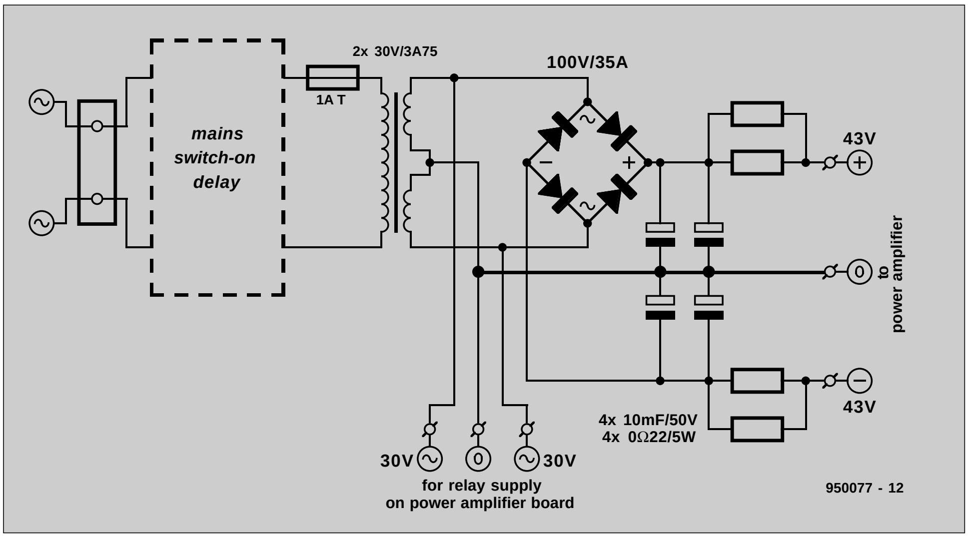


Fig. 2. Circuit diagram of the power supply for one mono IGBT amplifier.

The d.c. operating point of the differential amplifiers is provided by two current sources. Transistor T_6, in conjunction with R_{18} and D_2, provides a constant current of about 2 mA for T_1-T_2. Transistor T_5, with R_{17} and D_1, provides a similar current for T_3-T_4. The combination of a transistor and an LED creates a current source that is largely independent of temperature, since the temperature coefficients of the LED and the transistor are virtually the same. It is, however, necessary that these two components are thermally coupled (or nearly so) and they are, therefore, located side by side on the printed-circuit board.

In the input stage, C_1 is followed by a low-pass section, R_1-C_2, which limits the bandwidth of the input to a value that the amplifier can handle. Resistor R_2 is the base resistor of T_1 and T_3. So far, this is all pretty normal. Network P_1-R_7-R_8 is somewhat out of the ordinary, however. It forms an offset control to adjust the direct voltage at the output of the amplifier to zero. Such a control is normally found *after* the input stage. The advantage of putting it before that stage is that the inputs of the differential amplifiers are exactly at earth potential, which means that the noise contribution of their base resistors is negligible.

The signals at the collectors of T_1 and T_3 are fed to pre-drivers T_8 and T_9. Between these transistors is a 'variable zener' formed by T_7 which, in conjunction with P_2, serves to set the quiescent current of the output transistors.

The output of the pre-drivers is applied to T_{10} and T_{11}, which drive IGBTs T_{12} and T_{13}. This power section has local feedback (R_{30}-R_{31}).

The design of T_{10}–T_{13} is a kind of compound output stage, since the collector of the power transistors is connected to the output terminal. The voltage amplification is limited to ×3 by the local feedback resistors (R_{30}-R_{31}). Here again, this feedback serves to reduce the distortion. The overall feedback of the amplifier is provided by R_5-R-C_5.

Electrolytic capacitors C_{11} and C_{12} (10,000 µF each and part of the power supply) are located close to the IGBTs, so that the heavy currents have only a short path to follow.

At the output is a Boucherot network, R_{32}-R_{33}-C_{10}, that ensures an adequate load on the amplifier at high frequencies, since the impedance of the loudspeaker, because of its inductive character, is fairly high at high frequencies.

Inductor L_1 limits any current peaks that may arise with capacitive loads.

The signal is finally applied to the loudspeaker, LS_1, via relay contact Re_1. The relay is not energized for a few seconds after the power is switched on to obviate any plops from the loudspeaker. Such plops are caused by brief variations in the direct supply voltage arising in the short period that the amplifier needs to reach its correct operating level.

The supply voltage for the relay is derived directly from the mains transformer via D_3 and D_4. This has the advantage that the relay is deactuated, by virtue of the low value of C_{13}, immediately the supply voltage fails. The delay in energizing the relay is provided by T_{14} in conjunction with R_{36} and C_{14}. It takes a few seconds before the potential across C_{14} has risen to a value at which T_{14} switches on. This darlington transistor requires a base voltage of not less than 1.2 V before it can conduct.

The power supply—see Fig. 2—is traditional, apart from the resistors, R_5–R_8, in the power lines. These limit, to some degree, the very large peak charging currents drawn by electrolytic capacitors C_{11} and C_{12}. Moreover, together with these capacitors, they form a filter that prevents most spurious voltages from reaching the amplifier. Measure-ments on the prototype showed that this was particularly evident at frequencies below 500 Hz.

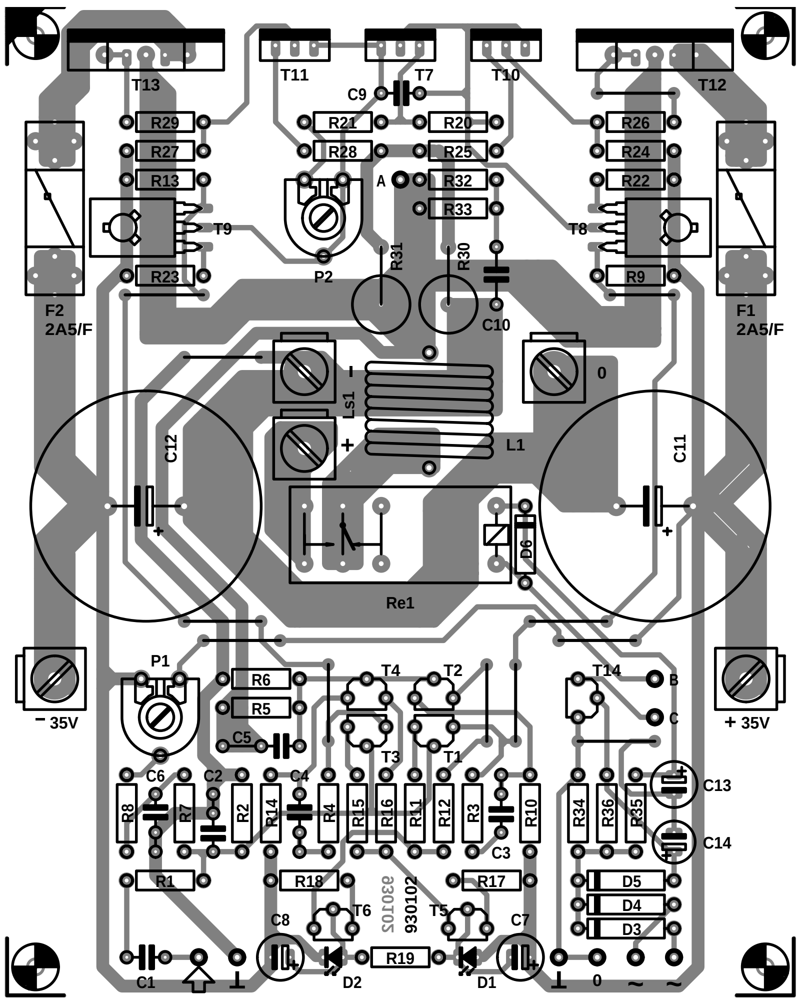


Fig. 3. Printed-circuit board

Construction

The design of the printed-circuit board for the amplifier (Fig. 3) takes good account of the large currents that flow in the amplifier. This has given rise to a couple of tracks being paralleled instead of combined, so that the effect of currents in the power section on the input stages is minimal.

Populating the board is straightforward. Although not strictly necessary, it is advisable to match the transistors used in the differential amplifiers. This may be done conveniently on an h_{fe} tester by measuring the amplification at a collector current of about 1 mA. If such a tester is not available, use a base resistor that results in a collector current of about 1 mA measured with a multimeter. With the same resistor, test a number of other transistors and note the collector currents. Mount the selected pairs on the board and pack them closely together with a 5 mm wide copper ring (made from a piece of 12 mm copper water pipe).

Inductor L_1 consists of six turns, inner diameter 16 mm ($^5/_8$ in), of insulated copper wire 1.5 mm ($^1/_{16}$ in) thick. Mount RL_1 inside the coil.

The large transistors are located on one side of the board, so that they can be fixed directly to the heat sink. They must be insulated from the heat sink with the aid of ceramic washers.

The two sizes indicated on the board for T_{12} and T_{13} were explained earlier.

Connections from the power supply and to the loudspeaker are by means of terminal blocks that can be screwed on to the board.

Mount the two amplifier boards, mains transformers and electrolytic capacitors in a suitable enclosure. The wiring diagram for one channel is given in Fig. 5.

It is advisable to measure the supply voltages before they are applied to the amplifiers. Also, turn P_2 to maximum (wiper towards R_{33}) before connecting the power supply to the amplifiers. Set input presets P_1 to the centre of their travel. A few seconds after the supply has been switched on, the relay should come on. Connect a multimeter (1 V direct voltage range) and adjust P_1 until the meter reads zero (both channels!).

Switch the supply off again and connect a multimeter (100 mV d.c. range) across RF_1 or RF_2. Switch on the supply and adjust P_2 for a meter reading of about 10 mV: this corresponds to a quiescent current of 100 mA through T_{12} and T_{13}. After about half an hour, the current will have stabilized at about 200 mA (meter reading of about 20 mV). Readjust P_2 slightly if required. Note that owing to the positive temperature coefficient of IGBTs, the quiescent current does not increase but drop with rising dissipation.

Finally, recheck the direct voltages at the outputs of the amplifiers and, if necessary, readjust P_1 slightly.

The loudspeakers must be 4-ohm or 8-ohm types, whose impedance must not drop below 3 Ω. It is not permissible to connect two 4-ohm units in parallel to the amplifier, because that would give problems when large drive signals are applied to the IGBTs.

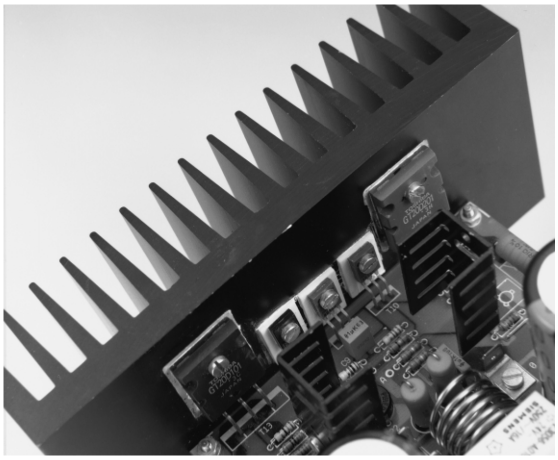
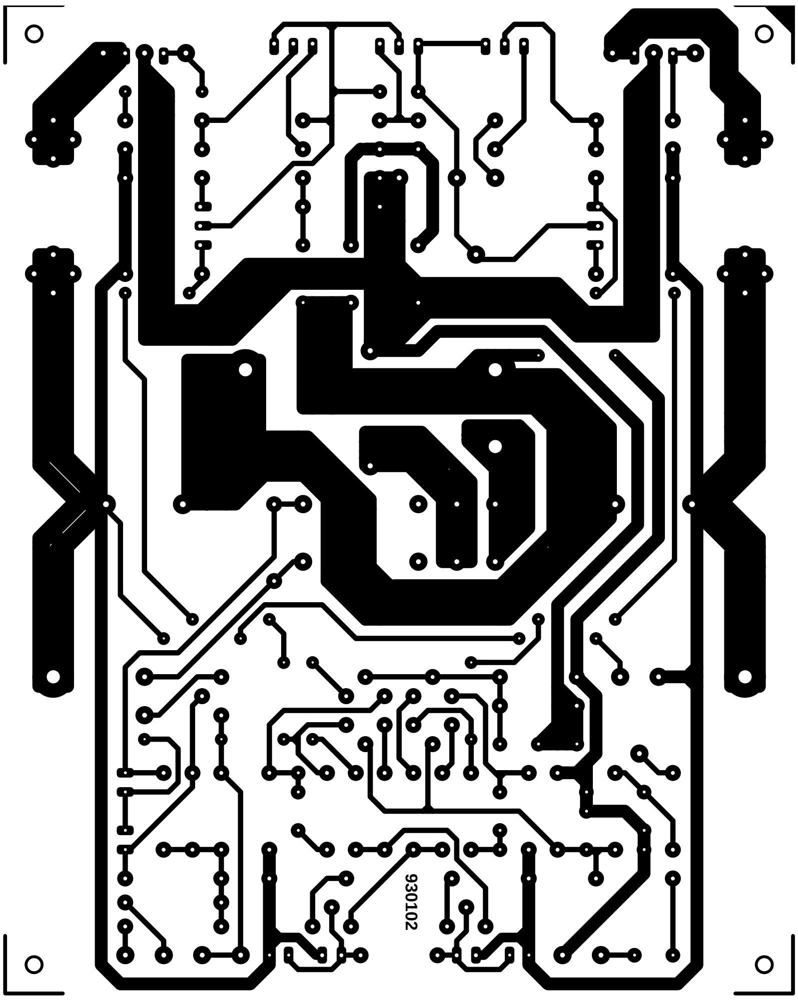


Fig. 4. Good thermal coupling between the transistors and the heat sink ensures a long life of the devices.



for the IGBT amplifier.

Parts list (one channel)

Resistors:
R_1 = 470 Ω
R_2 = 47.5 kΩ, 1%
R_3, R_4 = 100 Ω
R_5 = 2.0 kΩ, 1%
R_6 = 84.5 Ω, 1%
R_7, R_8 = 10 MΩ
R_9, R_{10}, R_{13}, R_{14} = 1.21 kΩ, 1%
R_{11}, R_{12}, R_{15}, R_{16} = 22.1 Ω, 1%
R_{17}, R_{18} = 499 Ω, 1%
R_{19} = 22 kΩ
R_{20} = 2.2 kΩ
R_{21} = 1 kΩ
R_{22}, R_{23} = 56.2 Ω, 1%
R_{24}, R_{27} = 150 Ω, 1%
R_{25}, R_{28} = 15.0 Ω, 1%
R_{26}, R_{29} = 15 Ω
R_{30} = 68 Ω, 5 W
R_{31} = 150 Ω, 5 W
R_{32}, R_{33} = 6.81 Ω, 0.6 W, 1%
R_{34} = 3.3 kΩ
R_{35} = 330 Ω
R_{36} = 8.2 MΩ
RF_1, RF_2 = 0.1 Ω, 5 W
RL_1 = 2.2 Ω, 5 W (fit inside L_1)
P_1 = 1 MΩ preset
P_2 = 1 kΩ preset

Capacitors:
C_1 = 2.2 µF, 50 V, polypropylene
C_2 = 2.2 nF
C_3, C_4 = 2.7 nF

C_5 = 330 pF, polystyrene, axial
C_6 = 33 nF
C_7, C_8 = 100 µF, 10 V, radial
C_9 = 1 µF, polypropylene, pitch 5 mm
C_{10} = 100 nF
C_{11}, C_{12} = 10,000 µF, 50 V, radial, for PCB mounting
C_{13} = 47 µF, 63 V, radial
C_{14} = 22 µF, 40 V, radial

Inductors:
L_1 = air-core, 0.1 mH (see text)

Semiconductors:
D_1, D_2 = 3 mm LED, red (1.6 V drop at 3 mA)
D_3–D_5 = 1N4003
D_6 = 1N4148
T_1, T_2, T_6 = BC550C
T_3–T_5 = BC560C
T_7, T_9, T_{10} = BD139
T_8, T_{11} = BD140
T_{12} = GT20D201
T_{13} = GT20D101
T_{14} = BC617

Miscellaneous;
Re_1 = relay, 24 V, 1 make contact (e.g., Siemens V23056-A0105-A101*)
F_1, F_2 = fuse, 2.5 A, fast, with holder for PCB mounting
Ceramic washers (5) for T_7, T_{10}, T_{11}
Mica washers (2) for T_{12}, T_{13}
Terminal block (5) (see text)
Heat sink, 0.6 K W^{-1} (e.g., Fischer SK85**)
PCB Order No. 930102 (see p. 70)

Power supply:
Mains transformer, 2 × 30 V, 375 VA
Mains on-off switch with indicator
Fuse 1 A, slow with holder
Bridge rectifier Type B200C35000
Electrolytic capacitor (4), 10,000 µF, 50 V
Resistor (4) 0.22 Ω, 5 W
PCB (for mains-on delay) Order no. 924055 (see p. 70)

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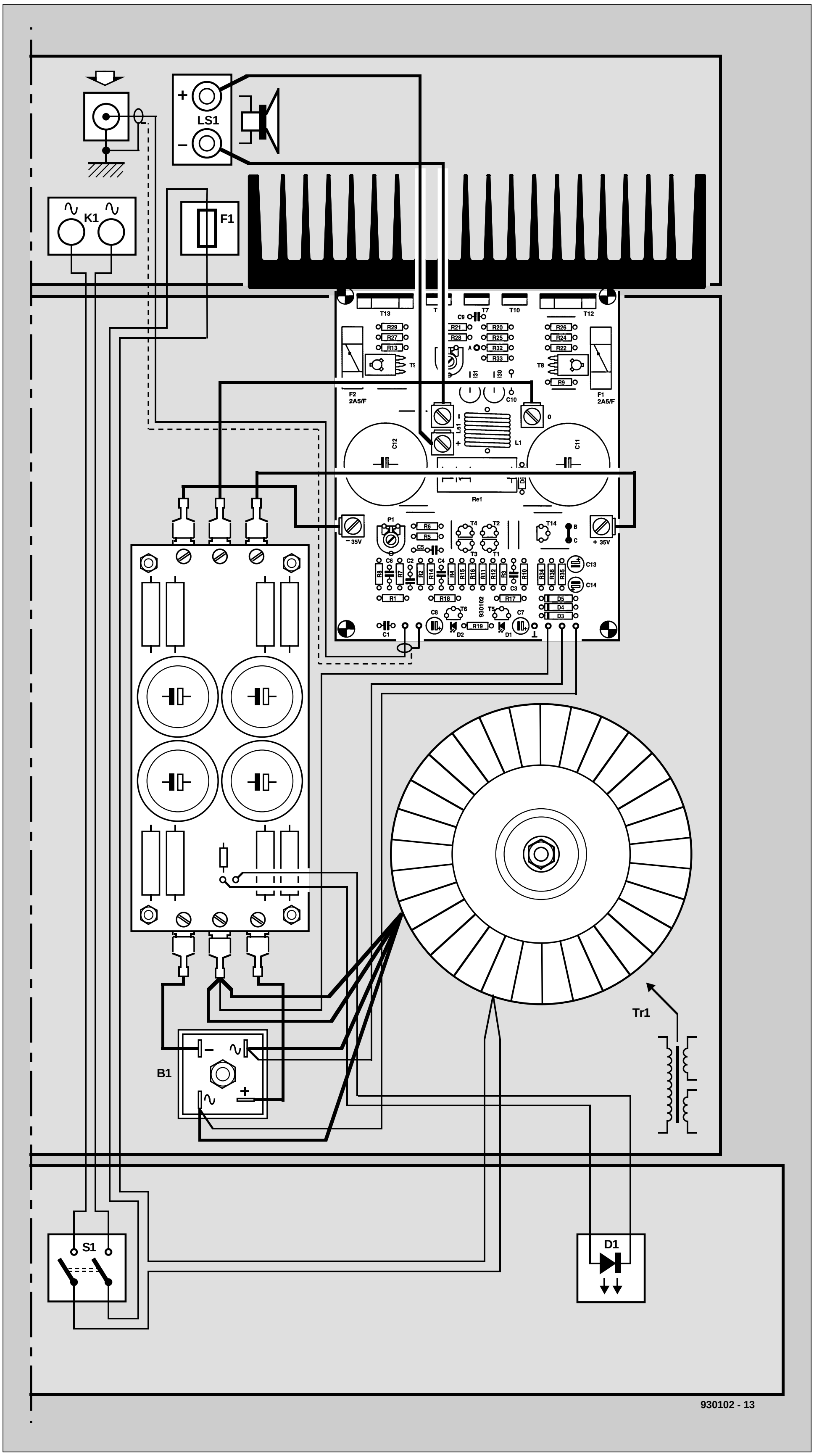

Fig. 5. Wiring diagram of the IGBT amplifier.

Mains switch-on delay

The circuitry of the 'black box' (in dashed lines) in Fig. 2 is shown above. It may be asked what the function of it is, since there is already a power-on delay in the amplifier itself. That delay serves to obviate plops and clicks caused by switching; it connects the loudspeakers to the amplifier only after this has had a short period of 'settling down'.

The mains switch-on delay is intended to switch on the mains gradually with heavy loads, so that the fuses do not blow

In the circuit, a number of power resistors, R_3–R_6, are connected in series with the mains supply lines to limit the current at switch-on to 5 A. When the mains is switched on with S_1, only relay Re_1 is energized in the first instance, so that the current must flow through the power resistors. When after a few seconds capacitors C_4 and C_5 have been charged, relay Re_2 is also energized, whereupon the power resistors are short-circuited by the relay contacts. These few seconds allow the buffer capacitors in the power supply to be charged at a reasonable rate, so that high currents are prevented.

The relay coils are connected in series and are energized directly by the mains via bridge rectifier B_1, impedances Z_{C1} and Z_{C2}, and R_1. The value of C_1 and C_2 depends on the current required by the relay coils and the level of the mains voltage. The relays specified are rated at 30 mA. If the mains voltage is 240 V, C_2 can be omitted and C_1 should have a value of 470 nF and a rating of 630 V d.c.