Titan 2000

High-power hi-fi and public-address amplifier

It could be argued that most of the output amplifiers published in this magazine lack power. Although this is a debatable point, it was felt that a true heavyweight output amplifier would make a welcome change for many constructors. The Titan 2000 can produce 300 watts into 8 Ω, 500 watts into 4 Ω, and 800 watts into 2 Ω. For those who believe that music power is a reputable quantity, the amplifier can deliver 2000 watts of this magical power into 4 Ω.

Brief parameters

Sine-wave power output	*300 W into 8 Ω; 500 W into 4 Ω; 800 W into 2 Ω*
*Music power**	*2000 W into 4 Ω*
Harmonic distortion	*<0.005%*
Slew limiting	*85 V μs^{-1}*
Open-loop bandwidth	*55 kHz*
Power bandwidth	*1.5 Hz – 220 kHz*

**See text about the validity of this meaningless quantity.*

Design by T. Giesberts

INTRODUCTION

Amplifier output has been a cause of argument for as long as there have been audio power amplifiers. For domestic use, a power rating of 2×50 W is more than sufficient. With the volume control at maximum and the use of correctly matched good-quality loudspeakers, this will provide a sound pressure level (SPL) equivalent to that of a grand piano being played forte in the same room.

However, not all amplifiers are intended for domestic use: many are destined for discos, small music halls and other large rooms. But even here, what power is really required? Since doubling the amplifier output increases the SPL by a barely audible 3 dB, it was felt that 300 watts sine wave power into 8 Ω would appeal to many.

'PROGRAMMABLE' POWER OUTPUT

The amplifier has been designed in such a manner that its output is 'programmable' as it were. With a sine wave input, it delivers an average power of 300 W into an 8 Ω load, which should meet the requirements of all but the power drunk. Compared with the output of 50 W from a domestic audio amplifier, this gives an increase in SPL of 7.5 dB. If even higher outputs are needed, the load impedance may be lowered to 4 Ω, which will give an increase in SPL of 10 dB compared with a 50 W output.

Although music power is a deprecatory term, since it does not really give the true power rating of an amplifier, readers may note that the Titan 2000 can deliver 2 kW of this magical power into 4 Ω. (*True power is average power, that is, the product of the r.m.s. voltage across the loudspeaker and the r.m.s. current flowing into the speaker. The term music power is generally meaningless, because to some manufacturers it means the product of the peak voltage and peak current; to others it means merely double the true power; and to yet others, even more disreputable, it means quadrupling the true power*).

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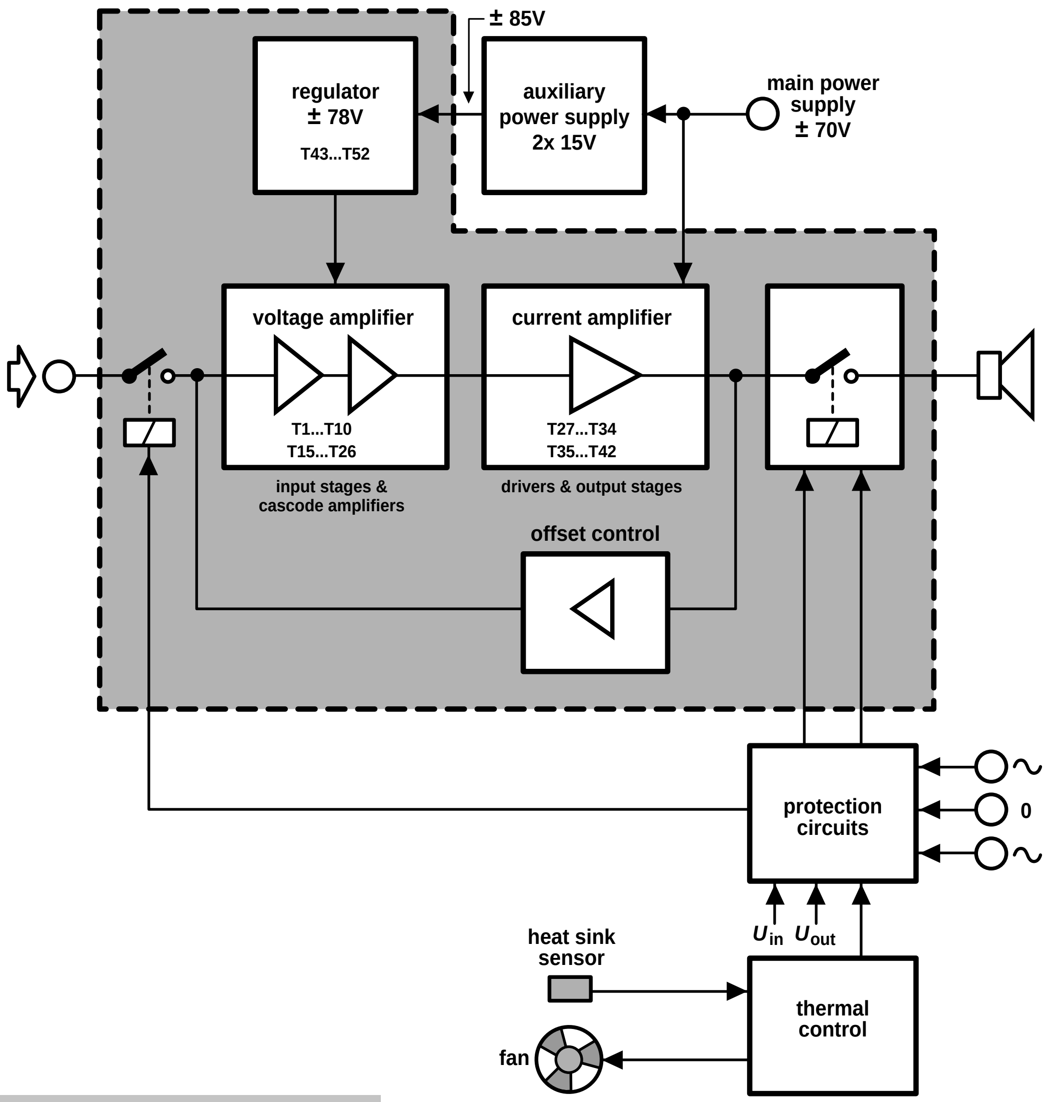

Figure 1. Simplified block diagram of the Titan 2000. The auxiliary power supply, protection networks and thermal control are discrete circuits built on discrete PCBs.

However, power is not the only criterion of an amplifier. Low distortion, good slew limiting, and an extended power bandwidth, as possessed by the Titan 2000, are also hallmarks of a good amplifier.

Power bandwidth denotes the frequency range over which the power falls to not less than half its maximum value. This is much more telling than the frequency response, which is usually measured at a much lower output level.

Slew limiting is the maximum input voltage change that can occur in one

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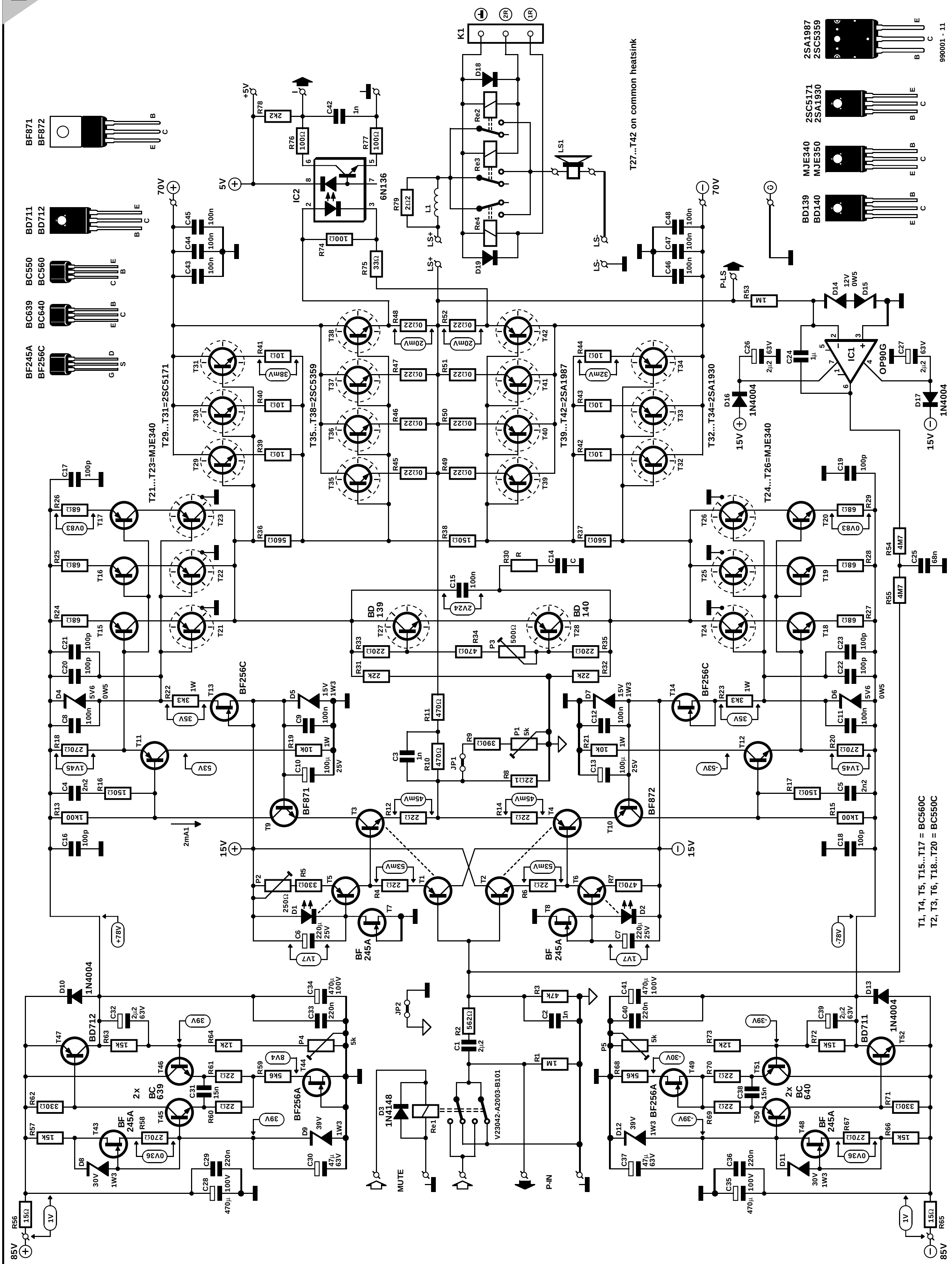
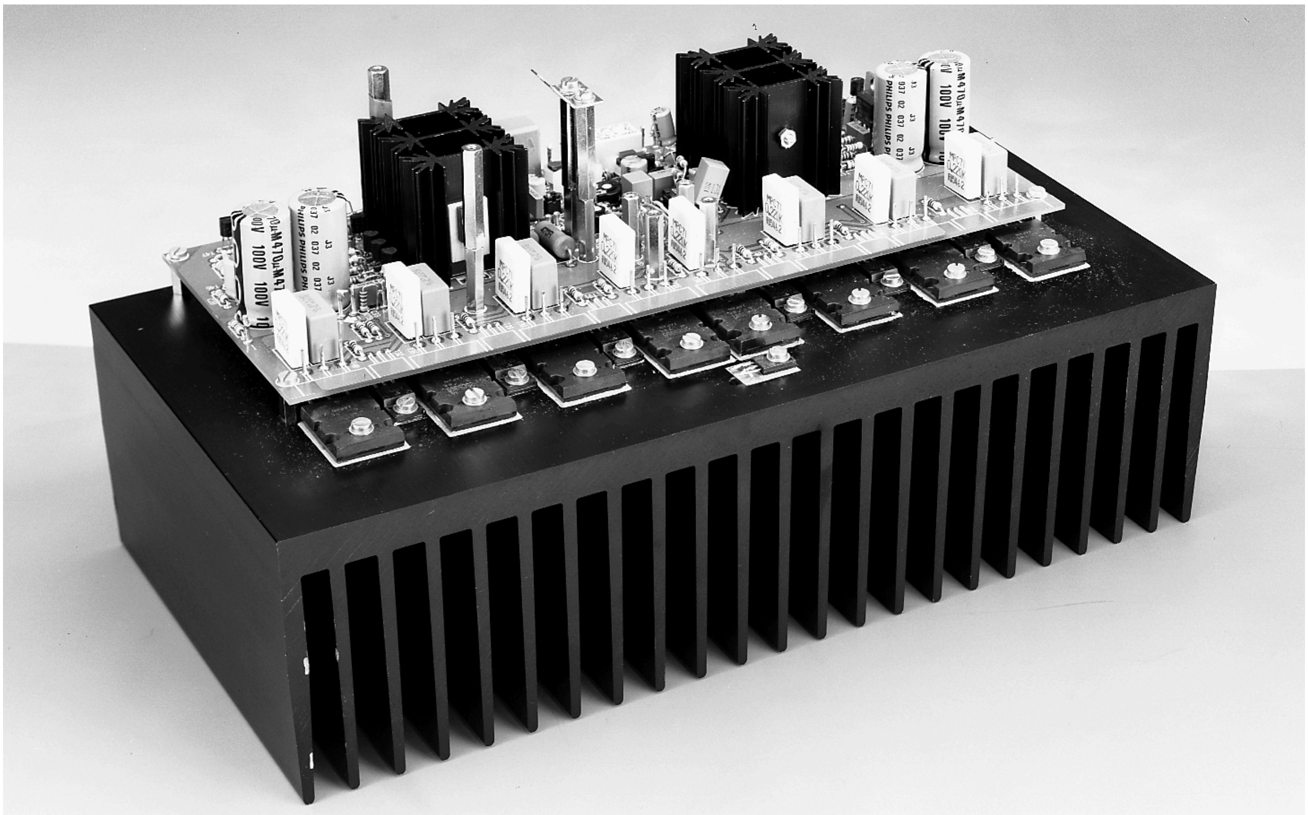


Figure 2. Although the circuit diagram gives the impression of a highly complex design, the amplifier is, in essence, fairly straightforward.



microsecond, and to which the amplifier can respond.

DESIGN CONSIDERATIONS

The Titan 2000 is based on the 'compact power amplifier' published in the May 1997 issue of this magazine. That was a typical domestic amplifier with a power output of 50 W into 8 Ω or 85 W into 4 Ω. The special property of this fully balanced design was the use of current feedback instead of voltage feedback, which resulted in a fast-responding amplifier with a large open-loop bandwidth. The amplifier performed well both as regards instrument test and measurements and listening tests. However, to serve as a basis for the Titan 2000, its output current and drive voltage range had to be increased substantially.

For a start, the supply voltage has to be more than doubled, which means that transistors with a higher power rating have to be used in the power supply. The higher supply voltage also results in larger potential drops across a number of components, and this means that dissipation problems may arise.

The large output current required for the Titan 2000 makes a complete redesign of the current amplifier used in the 'compact power amplifier' unavoidable, since that uses insulated-gate bipolar transistors (IGBTs). Although these are excellent devices, the large spread of their gate-emitter voltage makes their use in parallel networks next to impossible. To obtain the requisite output power, the use of parallel networks of symmetrical pairs of transistors is inevitable.

In view of the foregoing, bipolar transistors are used in the current amplifier of the Titan 2000. However, these cannot be driven as readily as IGBTs, which means that current drive instead of voltage drive is used. This entails a substantial upgrading of the driver stages and the preceding cascode amplifiers (which also consist of a couple of parallel-connected transistors). The good news is that the power transistors in the Titan 2000 are considerably less expensive than IGBTs: an important factor when eight of these devices are used.

Finally, the protection circuits have been enhanced in view of the higher voltages and currents. The circuits protecting against direct voltages and short-circuits are supplemented by networks protecting against overload and (too) high temperatures. The latter is coupled to a proportional fan control.

In short, a large part of the Titan 2000 is a virtually new design rather than a modified one.

BRIEF DESCRIPTION

The block diagram of the Titan 2000 is shown in **Figure 1.** The voltage amplifier consists of input stages T_1–T_{10}, and cascode amplifiers/pre-drivers T_{15}–T_{26}. The current amplifier is formed by driver transistors T_{27}–T_{34}, and output transistors T_{35}–T_{42}.

The offset control stage prevents any direct voltage appearing at the output of the amplifier.

The loudspeaker is linked to the amplifier by three heavy-duty relays.

The current amplifier operates from a ±70 V supply, which is provided by two 50 V mains transformers. To enable the voltage amplifier to drive the current amplifier to its full extent, it needs a slightly higher supply voltage to compensate for the inevitable losses caused by inevitable voltage drops. This is accomplished by superimposing a ±15 V potential from an external auxiliary supply on to the main ±70 V supply and dropping the resulting voltage to ±78 V with the aid of regulator T_{43}–T_{52}.

The combined protection circuits constantly compare the input and output voltage of the amplifier: any deviation from the nominal values leads to the output relays disconnecting the loudspeaker and the input relay decoupling the input signal.

The thermal protection circuit monitors the temperature of the heat sink and, if necessary, switches on a fan. If, with the fan operating, the temperature approaches the maximum permissible limit, the output relays are deenergized and disconnect the loudspeaker.

CIRCUIT DESCRIPTION

The circuit diagram of the Titan 2000 is shown in **Figure 2**. In spite of the large number of components, the basic cir-

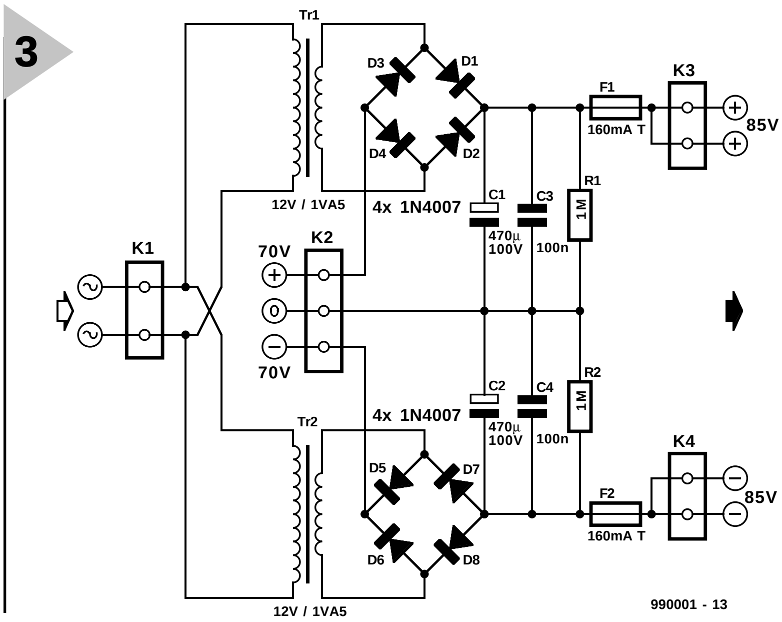


Figure 3. Circuit diagram of the requisite auxiliary power supply.

cuit is straightforward.

As already noted in the previous paragraph, transistors T_1–T_{10} form the input amplifier, T_{11} and T_{12} are buffers, T_{13} and T_{14} are current sources, T_{15}–T_{26} form the cascode amplifier/pre-driver stage, T_{27}–T_{34} are the driver transistors in the current amplifier, T_{35}–T_{42} are the output transistors, and T_{43}–T_{52} form a sophisticated supply voltage regulator.

Input amplifier

Strictly speaking, the input amplifier is formed by transistors T_3–T_4. Cascode stages T_9–T_{10} serve merely to enable the input section handling the high voltages. These voltages are limited by zener diodes D_5 and D_7, which are part of the potential divider that also sets the operating points of T_{21}–T_{26}. In view of the requisite stability, the current through the zener diodes is held constant by current sources T_{13} and T_{14}. Resistors R_{22} and R_{23} limit the potential across, and thus the dissipation in, these field-effect transistors.

Otherwise, the input section is virtually identical to that of the 'compact power amplifier'. The drop across the emitter resistors of buffers T_1 and T_2 determines the drop across the emitter resistors of T_3 and T_4, and consequently the setting of the operating point of the overall input section. To eliminate the influence of temperature variations, T_1 is thermally coupled to T_3 and T_2 to T_4.

Since the operating point of buffers T_1 and T_2 is critical, current sources T_5 and T_6 have been added. The reference for these current sources is provided by light-emitting diodes (LEDs) D_1 and D_2. The current through these diodes is determined by current sources T_7 and T_8. In view of the requisite stability, diode D_1 is thermally coupled to T_5 and D_2 to T_6.

Any imbalance of the input stages is compensated by making the current through T_5 equal to that through T_6 with potentiometer P_2.

Cascode amplifiers/pre-drivers

The large output current of the Titan 2000 necessitates a proportionally large pre-drive voltage, which is provided by three parallel-connected cascode amplifiers, T_{15}–T_{26}. The current through these amplifiers is arranged at 10–15 mA, but the current feedback used may cause this level to be appreciably higher. This is the reason that the transistors used in the T_{21}–T_{26} positions are types that can handle currents of up to 50 mA when their collector-emitter voltage is 150 V.

The input section is linked to the cascode amplifiers by buffers T_{11} and T_{12}, which results in a lowering of the input impedance. The arrangement also enables an increase in the values of R_{13} and R_{15}, which results in a 3 dB increase in amplification of the input section.

The function of resistors R_{19} and R_{21} is threefold: they limit the dissipation of the buffers; they obviate the need of an additional voltage to set the operating point of the buffers; they limit the maximum current through the buffers, and thus the cascode amplifiers, to a safe value.

The open-loop amplification of the Titan 2000 is determined solely by those of the input section and cascode amplifiers. The amplification of the input section depends on the ratios R_{13}:($R_{12}+R_8$) and R_{15}:($R_{14}+R_8$) and, with values as specified is ×10 (i.e., a gain of 20 dB).

The amplification of the cascode amplifiers is determined largely by the ratio of parallel-connected resistors R_{31} and R_{32} and the parallel network of R_{24}–R_{26}. With values as specified, the amplification is about ×850 (remember, this is a push-pull design), so that the overall amplification of input section plus cascode amplifiers is ×8500 (a gain of close to 80 dB).

Current amplifier

Since one of the design requirements is that the amplifier is to work with loads down to 1.5 Ω, the output stages consist of four parallel-connected pairs of transistors, T_{35}–T_{38} and T_{39}–T_{42}. These transistors have a highly linear transfer characteristic and provide a direct-current amplification that remains virtually constant for currents up to 7 A.

Like the output transistors, the driver stages need to remain within their safe operating area (SOA), which necessitates a threefold parallel network. The transistors used in the driver stages are fast types (f_T = 200 MHz).

Setting the bias voltage for the requisite quiescent current is accomplished by balanced transistors T_{27} and T_{28}. These transistors are mounted on the same heat sink as the output transistors and driver transistors to ensure good thermal coupling and current control. Of course, the current rises during full drive conditions, but drops again to its nominal level when the amplifier cools off. The quiescent current is set to 200 mA with potentiometer P_3.

Owing to the large output current, the connection between amplifier output and loudspeaker is not arranged via a single relay, but via three. Two of these, Re_3–Re_4, are controlled in synchrony by the protection circuits. When they are deenergized, their disabling action is delayed slightly to give the contacts of the third relay, Re_2, time to open, which is of importance in a fault situation.

Input relay Re_1 is switched off in synchrony with Re_2 to ensure that there is no input signal by the time Re_3 and Re_4 are deenergized.

Optoisolator IC_2 serves as sensor for the current protection circuits. The light-emitting diode in it monitors the voltage across R_{48}–R_{52} via potential divider R_{74}–R_{75}, so that the positive as well as the negative output currents are guarded. The use of an optoisolator prevents earth loops and obviates compensation of the ±70 V common-mode voltage. The +5 V supply for the optoisolator is derived from the protection circuits.

Feedback

The feedback loop runs from the output of the power stages to the junction of T_3 and T_4 via resistors R_{10} and R_{11}. This is current feedback because the current through T_3 and T_4 depends on the potential across R_8, which is determined largely by the current through R_{10} and R_{11}. The overall voltage amplification of the output amplifier is determined by the ratio R_8:(R_{10} + R_{11}).

Compensation

Capacitors C_3–C_5 and resistors R_{16}, R_{17} form part of the compensation network required for stable operation.

Low-pass filter R_2–C_2 at the input is essential to prevent fast, that is, high-frequency, signals causing distortion. This filter is also indispensable for stability's sake.

Coupling capacitor C_1 is needed because the available offset compensation network merely redresses the bias current of the input buffers and is not intended to block any direct voltages at the input.

Relay Re_1 at the input enables the input signal to be 'switched off'. It forms part of the overall protection and in particular safeguards the input section against overdrive. The overall protection circuit will be discussed in detail next month.

Network R_9-P_1 is intended specifically for adjusting the common-mode suppression when two amplifiers are used in a bridge arrangement. It is needed for only one of these amplifiers, and may be interconnected or disabled by jumper JP_1 as needed.

Offset compensation is provided by integrator IC_1, which ensures that if there is any direct voltage at the output of the amplifier, the operating point of T_1-T_2 is is shifted as needed to keep the output at earth potential. The operational amplifier (op amp) used draws only a tiny current (20 µA) and has a very small input offset (450 µV).

Supply voltage for IC_1 is taken from the ±15 V line for the input section via diodes D_{16} and D_{17}. This arrangement ensures that the supply to the IC is retained for a short while after the main supply is switched off so that any interference is smoothed out.

Diodes D_{14} and D_{15} safeguard the input of IC_1 against (too) high input voltages in fault conditions.

The values of resistors R_{54} and R_{55} arrange the level of the compensating current at not more than 1 µA, which is sufficient to nullify the difference between the base currents of T_1 and T_2.

Regulation

Although current feedback has many advantages, it also has a serious drawback: poor supply voltage suppression. This makes it essential for the supply voltage for the voltage amplifier to be regulated. In view of the requisite high symmetrical potential and the fact that the unregulated voltage that serves as input voltage can vary substantially under the influence of the amplifier load, two discrete low-drop regulators, T_{43}–T_{47} and T_{48}–T_{52} are used.

As mentioned before, owing to inevitable losses through potential drops, the supply voltage for the input section and cascode amplifiers needs to be higher than the main ±70 V line. Furthermore, the input voltage to the regulators must be higher than the wanted output voltage to ensure effective regulation.

Fortunately, the current drawn by the voltage amplifier is fairly low (about 70 mA) so that the input voltage to the regulators can be increased with a simple auxiliary supply as shown in **Figure 3**. This consists of two small mains transformers,two bridge rectifiers, D_1–D_4 and D_5–D_8, and the necessary reservoir and buffer capacitors.

The ±15 V output is linked in series with the ±70 V line to give an unregulated voltage of ±85 V.

The 39 V reference is provided by zener diode D_9. This means that the regulator needs to amplify the reference voltage ×2 to obtain the requisite output voltage.

The zener diode is powered by current source T_{43}, to ensure a stable reference, which is additionally buffered by C_{30}.

Differential amplifier T_{45}-T_{46}, whose operating point is set by current source T_{44}, compares the output voltage with the reference via potential divider R_{63}-R_{64}-P_4. This shows that the output voltage level can be set with P_4.

Transistor T_{47} is the output stage of the regulator. The output voltage remains stable down to 0.2 V below the input voltage.

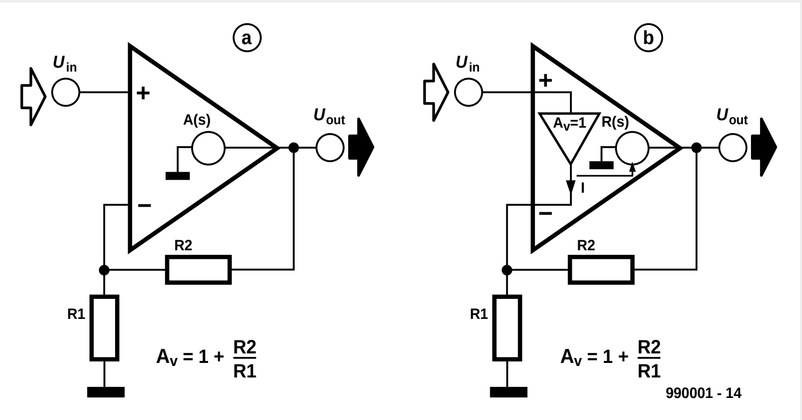
Current-feedback

In an amplifier using voltage feedback (Figure a), the differential voltage at its inputs is multiplied by the open-loop amplification. The feedback loop forces the output voltage to a level that, divided by network R_1-R_2, is equal to the input voltage.

Whereas an amplifier with voltage feedback has high-impedance inputs, an amplifier with current feedback (Figure b) has an high-impedance and a low-impedance input. Its input stage consists of a buffer with unitary gain between the inverting and non-inverting inputs. Essentially, the inverting input is the low-impedance input. The buffer is followed by an impedance matching stage that converts the output current of the buffer into a directly proportional output voltage.

The current feedback loop operates as follows. When the potential at the non-inverting input rises, the inverting input will also rise, resulting in the buffer current flowing through resistor R_1. This current, magnified by the impedance matching stage, will cause the output voltage of the amplifier to rise until the output current flowing through resistor R_2 is equal to the buffer current through R_1. The correct quiescent output voltage can be sustained by a very small buffer current. The closed-loop amplification of the circuit is determined by the ratio (1 + R_2):R_1.

A interesting property of an amplifier with current feedback is that the closed-loop bandwidth is all but independent of the closed-loop amplification, whereas that of an amplifier with voltage feedback becomes smaller in inverse proportion to the closed-loop amplification – a relation known as the gain-bandwidth product.



Resistor R_{57} and diode D_8 protect T_{43} against high voltage during switch-on, while D_{10} prevents current flowing through the regulator in the wrong direction.

Capacitors C_{31} and C_{32} enhance the rate of operation of the regulator.

Network R_{56}-C_{28}-C_{29} provides additional smoothing and r.f. decoupling of the ±85 V lines.

NEXT MONTH

Next month's second and concluding instalment of this article will describe details of the protection circuits, the fan control, and the construction of the amplifier. The instalment will also include detailed specifications and performance characteristics.

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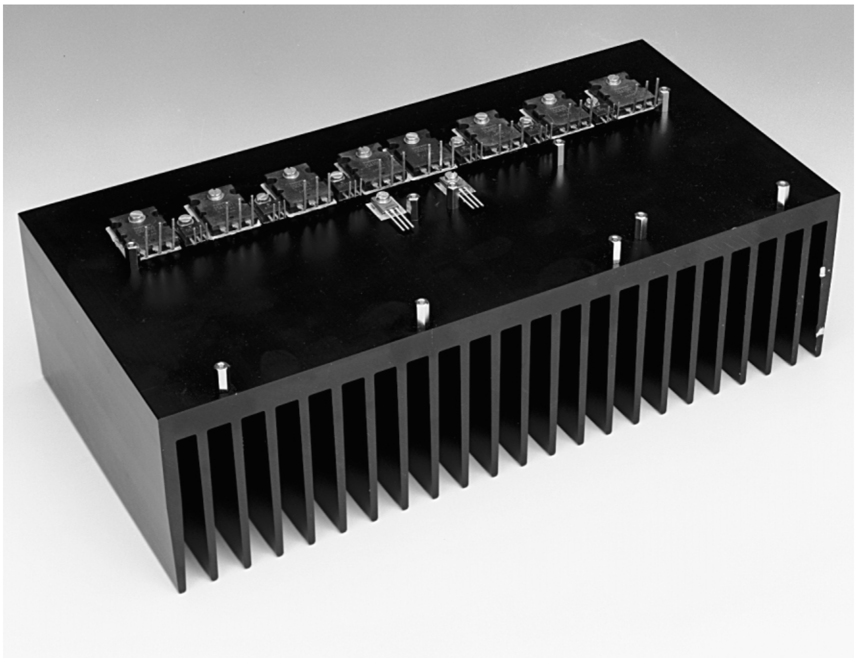

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Part 2: protection network

This second of four parts deals primarily with the protection network incorporated in the amplifier. This indispensable network safeguards the amplifier and the loudspeakers connected to it against all kinds of error that may arise. The network is an independent entity with its own power supply.

Correction. In last month's first part of this article, it was stated erroneously that the article consists of two parts, whereas in fact it will be described in four parts.

Design by T. Giesberts

INTRODUCTION

As mentioned briefly in Part 1, extensive and thorough protection is a must in an amplifier of this nature. It may well be asked why this is so: is there such a likelihood of mishaps arising? Or is the amplifier so vulnerable? On the contrary: extended tests on the prototype have shown that the Titan 2000 is a very stable and reliable piece of equipment. In fact, unusual means had to be used to actuate the protection circuits during these tests, since not any standard test prompted the amplifier into an error situation.

The extensive protection is necessary because by far the largest number of mishaps occur owing to actions by the user, not because of any shortcomings in the amplifier. For example, the most robust and reliable amplifier can not always cope with extremely high overdrive or overload conditions.

SIX FUNCTIONS

The integrated protection network consists of six sub-circuits:

- power-on delay
- transformer voltage sensor
- temperature sensor
- current sensor
- direct-current sensor
- overdrive sensor

The power-on delay ensures that the relays in the amplifier are energized 50–100 milliseconds after the supply has been switched on to prevent switch-on clicks.

The transformer voltage sensor reacts to the cessation of the secondary voltage of the mains transformers to prevent switch-off clicks and crackles.

The temperature sensor responds to excessive heat sink temperatures, but it should be noted that this works only in

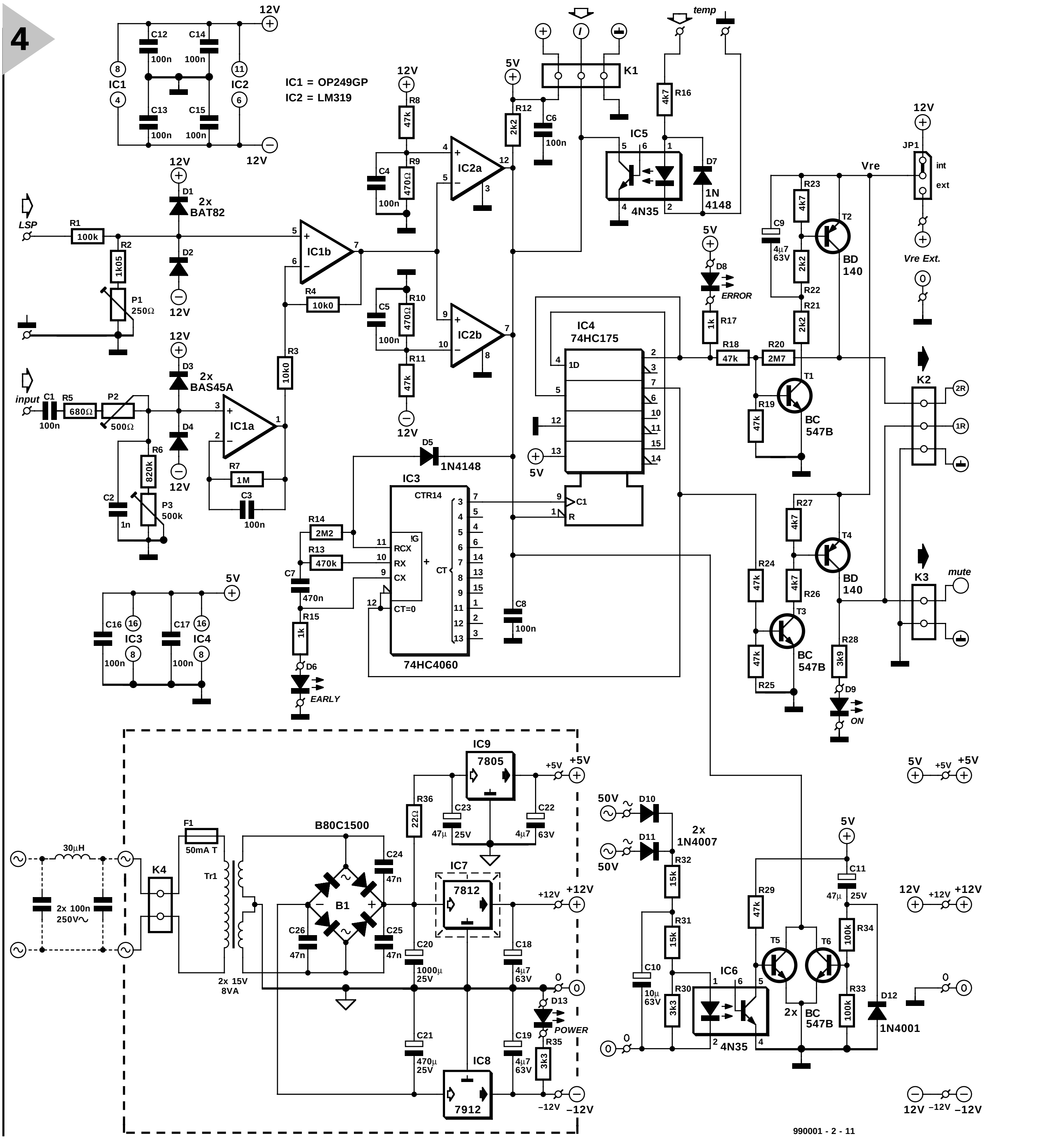

Figure 4. The protection network consists of six sensor circuits each of which causes the input and output relays of the amplifier to be deenergized when a fault occurs.

conjunction with the fan drive, which is reverted to later in this article.

The current sensor monitors the output current, while the direct-current and overdrive sensors form a combined circuit that monitors differences between the input and output signals, and reacts to excessive direct-current levels or distortion. This circuit is the most important and 'intelligent', but also the most complex of the six.

All sensors, when actuated, react in the same way: they cause the output relays and the mute relay at the input of the amplifier to be deenergized immediately. This action causes the input signal and the output load to be disconnected from the amplifier. After the fault causing the sensor action has been removed or remedied, the relevant protection circuit is disabled, whereupon the amplifier relays are reenergized after a short delay.

When the protection network is actuated, a red LED lights to indicate an error. When the fault has been removed or remedied, the red LED remains on, but a yellow LED flashes to indicate that the amplifier will be reenabled shortly. The red LED then goes out, shortly followed by the yellow, whereupon a green LED lights to indicate that all is well.

COMMON SECTION AND POWER-ON DELAY

The circuit of the integrated protection network, including the +5 V and ±12 V power supplies, is shown in **Figure 4**.

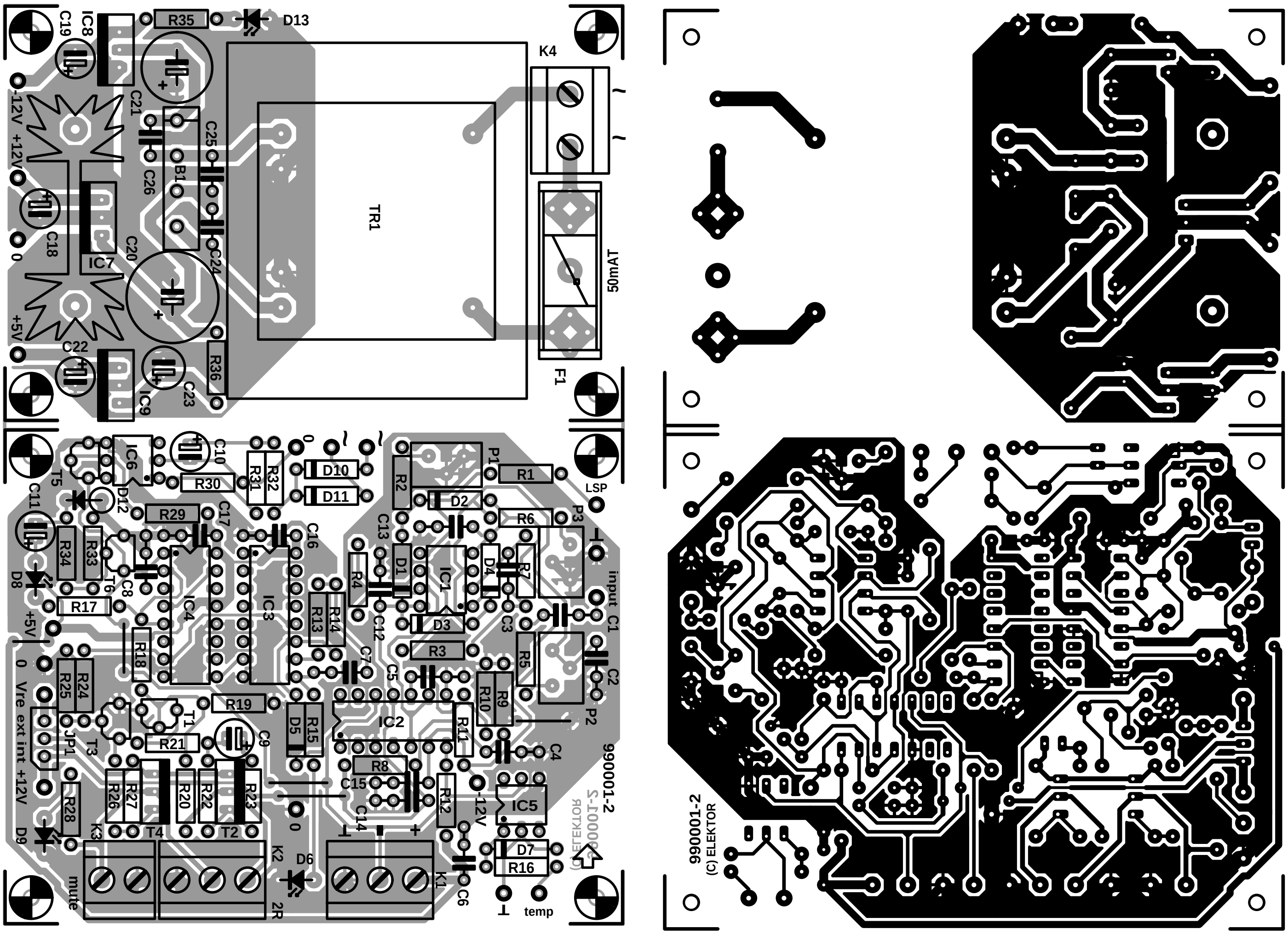

Figure 5. The printed-circuit board of the overall protection network.

Parts lists

Protection network

Resistors:
R_1, R_{33}, R_{34} = 100 kΩ
R_2 = 1.05 kΩ
R_3, R_4 = 10.0 kΩ
R_5 = 680 Ω
R_6 = 820 kΩ
R_7 = 1 MΩ
R_8, R_{11}, R_{18}, R_{19}, R_{24}, R_{25}, R_{29} = 47 kΩ
R_9, R_{10} = 470 Ω
R_{12}, R_{21}, R_{22} = 2.2 kΩ
R_{13} = 470 kΩ
R_{14} = 2.2 MΩ
R_{15}, R_{17} = 1 kΩ
R_{16}, R_{23}, R_{26}, R_{27} = 4.7 kΩ
R_{20} = 2.7 MΩ
R_{28} = 3.9 kΩ
R_{30}, R_{35} = 3.3 kΩ
R_{31}, R_{32} = 15 kΩ
R_{36} = 22 Ω
P_1 = 250 Ω, multiturn preset (upright)
P_2 = 500 Ω, multitun preset (upright)
P_3 = 500 kΩ, multiturn preset (upright)

Capacitors:
C_1, C_3 = 0.1 µF
C_2 = 0.001 µF
C_4, C_5, C_6, C_8, C_{12}–C_{17} =0.1 µF, ceramic
C_7 = 0.47 µF
C_9, C_{18}, C_{19}, C_{22} = 4.7 µF, 63 V, radial
C_{10} = 10 µF, 63 V, radial
C_{11}, C_{23} = 47 µF, 25 V, radial
C_{20} = 1000 µF, 25 V, radial
C_{21} = 470 µF, 25 V, radial
C_{24}–C_{26} = 0.047 µF, ceramic

Semiconductors:
D_1, D_2 = BAT82
D_3, D_4 = BAS45A
D_5, D_7 = 1N4148
D_6, D_8, D_9, D_{13} = 3 mm high-efficiency LED (yellow, red, green, green respectively)
D_{10}, D_{11} = 1N4007
D_{12} = 1N4001
T_1, T_3, T_5, T_6 = BC547B
T_2, T_4 = BD140

Integrated circuits:
IC_1 = OP249GP (Analog Devices)
IC_2 = LM319N
IC_3 = 74HC4060
IC_4 = 74HC175
IC_5, IC_6 = 4N35
IC_7 = 7812
IC_8 = 7912
IC_9 = 7805

Miscellaneous:
JP_1 = 2.54 mm pin strip and pin jumper
K_1, K_2 = 3-way terminal block, pitch 5 mm
K_3 = 2-way terminal block, pitch 5 mm
K_4 = 2-way terminal block, pitch 7.5 mm
B_1 = bridge rectifier, rectangular, Type B80C1500
F_1 = fuse, 50 mAT and fuse holder
Tr_1 = mains transformer, 15 VA, with 2×15 V secondary
Heat sink (for IC_7) = e.g. Fischer SK104, 50 mm
Mains interference filter

The network is linked to the input and output of the amplifier via terminals ‘input’ and ‘LSP’ respectively (to terminals ‘P-IN’ and ‘P-LS’ on the amplifier board).

Terminals ‘50 V≈’ are connected to the secondary windings of the mains transformers.

The three output relays and the mute relay in the amplifier are linked to the protection network via K_2, and K_3 respectively.

The current sensor is connected to the output of optoisolator IC_2 in the amplifier (‘I->’ on the amplifier board) via K_1.

The terminals marked ‘temp’ are intended to be linked to the output of the fan control circuit.

As mentioned earlier, the action of each sensor results in the deenergizing of the output and mute relays in the amplifiers. This implies that the outputs of the the various sensor circuits are interlinked. This is effected by combining the open-collector outputs of these circuits into a wired OR gate with R_{12} functioning as the common pull-up resistance. The combined output signal serves to reset a number of

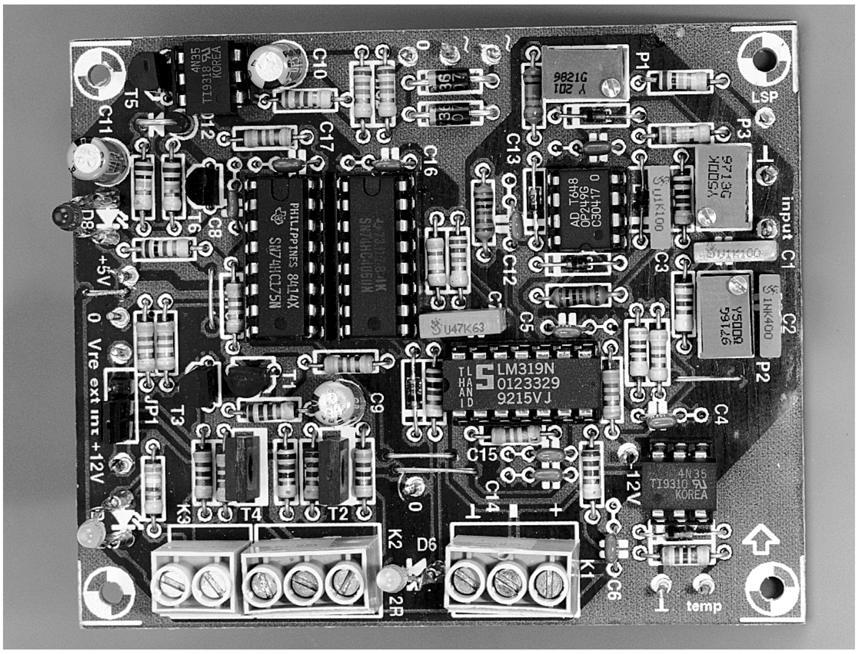

Figure 6. Completed prototype of the protection network.

D-type bistables (flip-flops), contained in IC_4, which are interconnected to form a shift register. Note that D-type bistables are essential since these can be set and reset in a defined manner.

The outputs of IC_4 are used to drive two level converters, T_1-T_2 and T_3-T_4 respectively, which bridge the difference between the 5 V level of the logic ICs and the 12 V supply for the relays. Jumper JP_1 enables a different, external supply voltage (V_{RE}) to be used if 12 V relays are not employed.

Transistors T_1 and T_2 drive Re_1 and Re_2, which are the first to be energized (synchronously). On switch-off, capacitor C_9 ensures that T_2 remains on for some milliseconds longer during which period Re_3 and Re_4 are deenergized (see Part 1).

The power-on delay, which also operates after a fault situation, is more complex than usual. To start with, after the supply voltage us switched on, input CLR of IC_4 is held low (active) for a few seconds by the circuit around T_6. When, after this period, CLR is made high by R_{12} –which happens only when there is no error situation (any longer)–the internal oscillator of IC_3 is enabled via D_5. This results after a few seconds in a clock pulse appearing at the CLK input of IC_4 , whereupon Q_4 goes high. The period between the oscillator being enabled and the appearance of the first clock pulse is not defined since, owing to the presence of T_6, a power-on reset is purposely not provided. To ensure a minimum delay in the energizing of Re_1 and Re_2 in spite of this, a high level is clocked into Q_4 after IC_3 has been enabled. The precise moment at which this happens varies, therefore, only when the supply voltage is switched on for the first time.

A period of IC_3/Q_3 later, Q_1 of IC_4 goes high, whereupon Re_1 and Re_2 are energized. After another period, Q_2 of IC_4 becomes high, whereupon Re_3 and Re_4 are energized. At the same time, IC_3 is disabled since its reset is interlinked with Q_2 of IC_4.

The red LED, D_8, in parallel with Q_1 of IC_4 lights when the relays in the amplifier are not energized, either because the amplifier is (not yet) switched on, or owing to an error.

The yellow LED, D_6, is linked to the output of the oscillator in IC_3, causing it to flash until IC_4 is clocked.

The green LED, D_9, is connected in parallel with Re_3 and Re_4, so that it lights only when the amplifier is fully switched on.

TRANSFORMER VOLTAGE SENSOR

The 50 V≈ secondary voltages of the mains transformers in the amplifier are rectified by diodes D_{10} and D_{11}, and smoothed by R_{30}-R_{31}-R_{32}-C_{10}. The values of these components ensure that the LED in optoisolator IC_6 lights sufficiently to hold the associated photo transistor on. This transistor pulls the base of T_5 to ground, causing T_5 to cut off. When the secondary voltages fail, T_5 is switched on immediately via R_{29}, whereupon the D-type bistables in IC_4 are reset.

Use is made of an optoisolator purposely to avoid any risk of earth loops between the supply return and the ground of the protection network, which is linked to the input ground of the amplifier.

TEMPERATURE SENSOR

The temperature sensor works in a manner similar to that of the transformer voltage sensor. The optoisolator in this circuit is IC_5, which, in contrast to IC_6, is normally cut off and comes on only when the heat sink becomes excessively hot.

The sensor reacts to the fan control circuit switching the fan speed to maximum (because the heat sink is getting too hot). A comparator in the fan control circuit then toggles, whereupon IC_5 is actuated via the 'temp' input and resets the D-type bistables in IC_4. This situation changes only after the heat sink has cooled down to an acceptable temperature (although the fans may still be rotating).

CURRENT SENSOR

To nullify high common-mode voltages and to prevent any risk of earth loops, the current sensor also uses an optoisolator, IC_2 (**Figure 5**). However, this is not located on the protection board, but directly at the output of the amplifier.

The values of the relevant components cause the sensor to be actuated when the output current is about 40 A. This may appear a very large current, but this is due entirely to the specified requirement that the amplifier must be capable of delivering 60 V into a load of 1.5 Ω without the protection circuit being actuated. The current level may be lowered to some extent by increasing the value of R_{74} in the amplifier.

Output resistor R_{78} is in parallel with R_{12} by linking terminals 'I', '+5 V' and ground on the amplifier board to K_1 on the protection board via three lengths of insulated, stranded circuit wire twisted together. This arrange-

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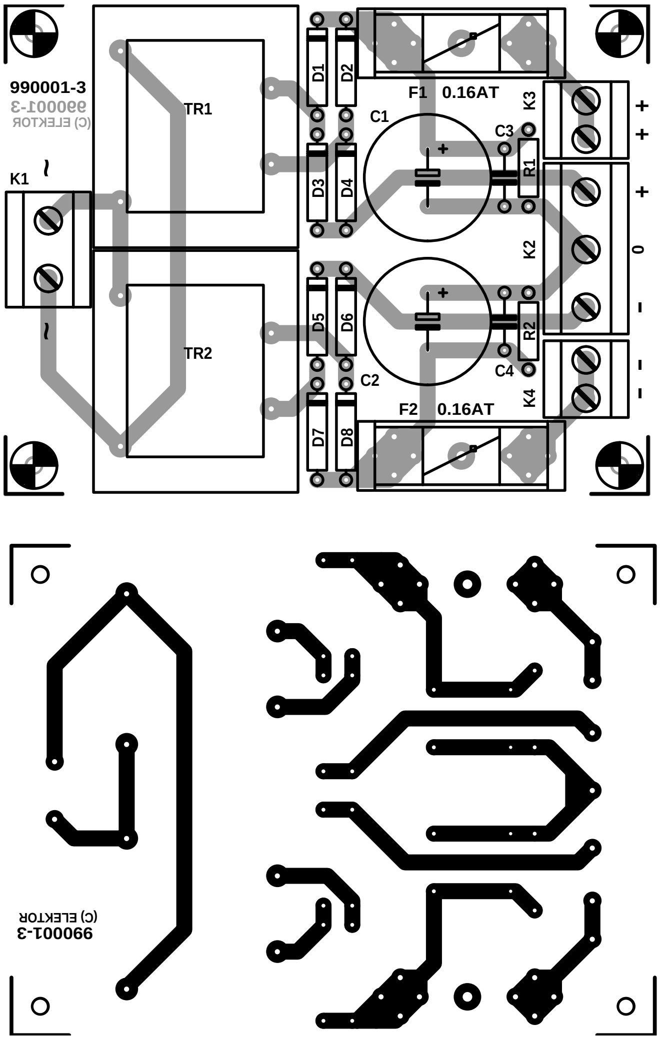

Figure 7. Printed-circuit board for the auxiliary power supply described in Part 1.

Parts lists

Auxiliary power supply

Resistors:
R_1, R_2 = 1 MΩ

Capacitors:
C_1, C_2 = 470 µF, 100 V, radial
C_3, C_4 = 0.1 µF, 100 V, pitch 7.5 mm

Semiconductors:
D_1–D_8 = 1N4007

Miscelleneous:
K_1 = 2-way terminal block, pitch 7.5 mm
K_2 = 3-way terminal block, pitch 7.5 mm
K_3, K_4 = 2-way terminal block, pitch 5 mm
Tr_1, Tr_2 = mains transformer, 1.5 VA, with 12 V secondart
F_1, F_2 = fuse, 160 mAT, and fuse holder

ment ensures a low impedance to any interference and a high reaction speed.

DIRECT-CURRENT AND OVERDRIVE SENSOR

The d.c. and overdrive sensor constantly compares the input and output signals of the amplifier and reacts when the difference between the two is too great. The comparison is effected with the aid of operational amplifier IC_1 which has a very low bias current and a very low offset. It is, of course, essential that during the comparison of the two signals by differential amplifier IC_{1b} the differences in phase and transit times do not lead to error detection. At the same time, the voltage amplification (×43) of the amplifier must be taken into account.

The amplification is compensated by potential divider R_1-R_2-P_1 at input LSP. The potentiometer is a multiturn type to ensure accurate adjustment.

The phase difference is compensated by the circuit based on IC_{1a}. The transit at high and low cut-off points is simulated by first-order networks that can also be adjusted very accurately with multiturn potentiometers P_2 and P_3.

The inputs of IC_{1a} and IC_{1b} are protected by diodes. Since any leakage current of these diodes, combined with the high input impedance (≈ 1 MΩ) of IC_{1a}, might lead to an appreciable offset, and therefore to an unwanted error detection, the diodes, D_3 and D_4, are special types with a leakage current of only 1 nA.

The output of differential amplifier IC_{1b} is monitored by a window comparator formed by IC_{2a} and IC_{2b}. The value of the components used in potential dividers R_8-R_9 and R_{10}-R_{11} ensures that the protection circuit is actuated when the direct voltage reaches a level of ±5 V or the distortion becomes 2.5 per cent. Such distortion will normally be the result of overdrive, but the circuit reacts equally well to oscillations or other spurious signals that cause too large a difference to be detected.

CONSTRUCTION AND SETTING UP

The integrated protection network is best built on the printed-circuit board shown in **Figure 5**. Populating this board should not present any undue difficulties, but it should be noted that diodes D_6, D_8, D_9 and D_{13}, are not located on the board, but are linked to it via flexible, stranded circuit wire. They are fitted to the front of the enclosure.

Jumper JP_1 will normally be in position 'intern' unless relays with a coil voltage other than 12 V are used.

A prototype of the completed protection board is shown in **Figure 6**.

All input and output terminals of the board are clearly marked with the same symbols as shown in Figure 4. Most interconnections can be made in thin, stranded hook-up wire to DEF61-12, but the input and output links ('input' and 'LSP') must be screened audio cable.

Although the power supply for the protection network can be fitted on the same board, the relevant section may be cut off and fitted elsewhere. Of course, the supply lines must then be linked to the relevant terminals on the protection board via insulated, stranded hook-up wire.

The power supply is straightforward. From the secondary output of the specified mains transformer, Tr_1, a symmetrical ±12 V supply is obtained with the aid of regulators IC_7 and IC_8. From the same secondary, a +5 V supply for the digital circuits is obtained with the aid of regulator IC_9. Since the relays are fed by the +12 V line, regulator IC_7 must be fitted on a heat sink.

To ensure that the protection network is not actuated by interference on the mains supply, it is advisable to precede the power supply by a suitable noise filter. This may be made from a 30 µH choke and two 0.1 µF, 300 V≈ capacitors as shown in dashed lines in Figure 4.

The network is set up by maximizing the common-mode suppression with the aid of an oscilloscope or a multimeter with sufficient bandwidth. Measurements need to be made at 1 kHz, 20 kHz, and 20 Hz. The open-circuit amplifier is driven as far as possible by a suitable sine-wave generator or CD player with a test CD.

With a signal of 1 kHz, set P_1 for minimum sign al at the output of IC_{1b}, follow this with a signal of 20 kHz and adjusting P_2, and finally, with a signal of 20 Hz, by adjusting P_3. Since the settings influence one another to some extent, the potentiometers should be set a couple of times, perhaps also at some different audio frequencies.

POWER SUPPLY

The auxiliary power supply described in Part 1 is best constructed on the printed-circuit board shown in **Figure 7**. The mains voltage is linked to K_1, the ±70 V to K_2 and the +85 V and –85 V lines to K_3 and K_4 respectively. Since all currents are low level, the wiring may be made in thin, insulated, stranded hook-up wire. A completed prototype board is shown in **Figure 8**.

The main supply for the amplifier is a straightforward, unregulated type, providing an output of ±70 V. Its circuit diagram is shown in **Figure 9**.

Since the specified requirements call for a 2 Ω load, the supply must be rated at 1000 VA, which necessitates two toroidal transformers. To prevent unforeseen equalizing currents, the dual secondaries are not linked in parallel, but are individually connected to a bridge rectifier. The outputs of the rectifiers can be connected in parallel without any problem. The rectifiers need to be mounted on a suitable heat sink such as a Type SK01.

It should be clear that the wiring of the power supply must allow for the large output currents of the amplifier. In the prototype, the electrolytic capacitors are linked by 3 mm thick strips of aluminium. The remainder of the wiring should be in insulated, high-current wire to BS6231 with a conductor size of 50/0.25 mm (2.5 mm^2) or better. The use of car-type connectors is recommended.

Note that the power supply as described is intended for use with a mono(phonic) amplifier that can deliver 800 W into 2 Ω and should remain stable with loads of 1.5 Ω. If you are certain that you will always use 4 Ω or 8 Ω loads, the power supply requirements may be relaxed to some extent. A reasonable relaxation is the use of 2×50 V/300 VA transformers and 10,000 µF/100 V smoothing capacitors. The rating of the primary fuses may then be reduced to 1.5 AT.

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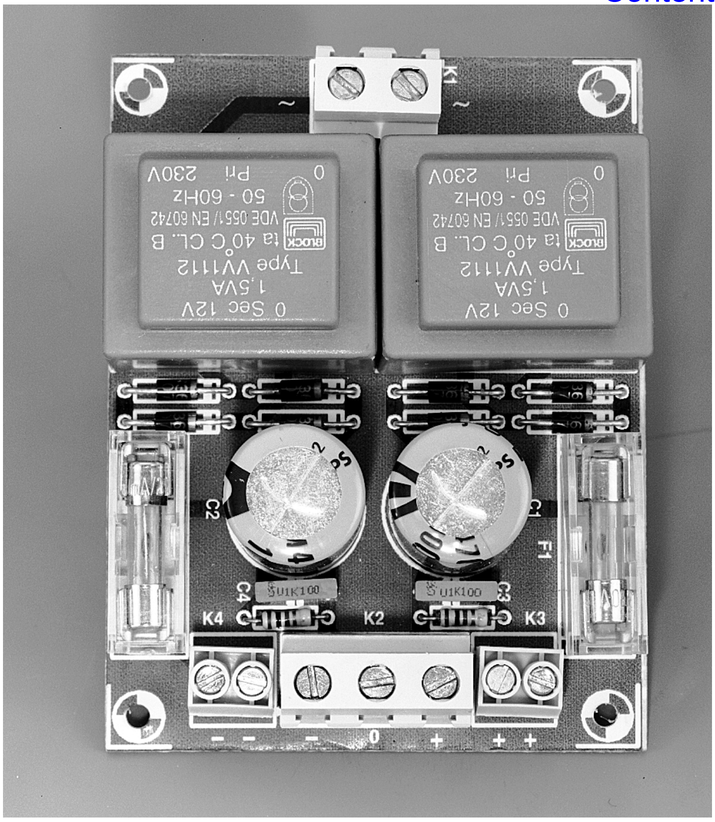

Figure 8. The auxiliary power supply is small enough to fit in most enclosures.

MAINS-ON DELAY

The use of a mains-on delay is recommended when heavy loads are to be switched on, as in the case of the present amplifier. Such a delay circuit switches on the mains to the load gradually to ensure that the switch-on current remains within certain limits and to prevent the mains fuses from blowing.

The most recently published (in this magazine) mains-on delay is found in the July/August 1997 issue (p. 74), whose circuit diagram is reproduced in **Figure 10**. Its printed-circuit board is readily connected with the primary windings of the two mains transformers. The board is not available ready-made, however, and its diagram is, therefore, reproduced in **Figure 11**.

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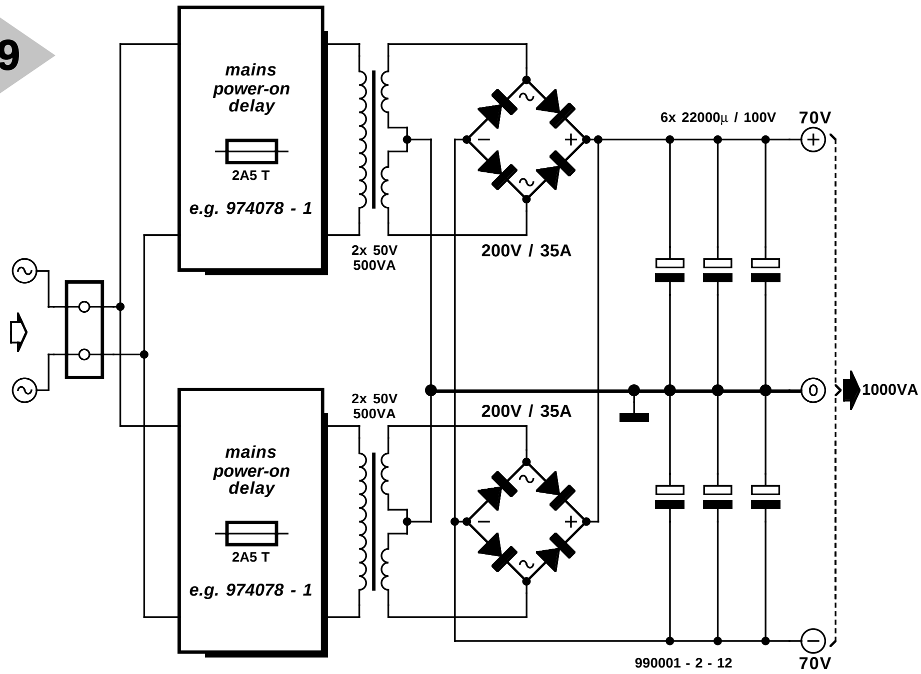

Figure 9. The main power supply for the amplifier is a heavy-duty entity in which the six capacitors are particularly impressive.

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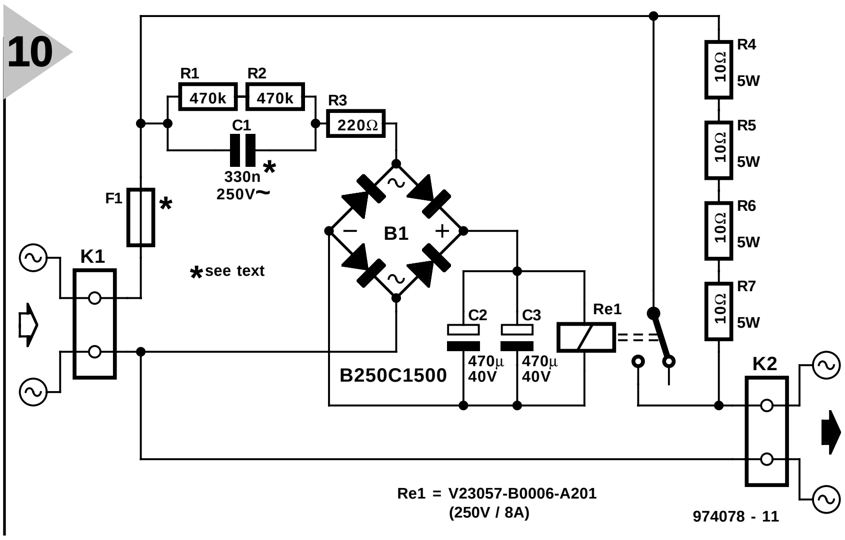

Figure 10. The mains-on delay ensures that the switch-on current remains within certain limit. Two of these delays are required for each Titan 2000.

The delay arranges for the load, that is, the Titan 2000, to be switched on in two stages. In the first of these, the switch-on current is limited by series network R_4–R_7. After the delay determined by capacitors C_2 and C_3, the series network is shorted by a relay contact, whereupon the full current flows between K_1 and K_2.

Relay Re_1 can switch up to 2000 VA. Its supply voltage is obtained from the mains with the aid of rectifier B_1, capacitor C_1 and resistor R_3.

Since the amplifier power supply uses two mains transformers, two mains-on delay circuits are needed.

Fuse F_1 functions as a primary mains fuse for the amplifier.

Capacitor C_1 is a metallized paper type intended especially for use with mains voltage applications.

Bear in mind that the circuit is linked directly to the mains supply and thus carries lethal voltages.

Next month's third instalment of this article deals with the construction of the amplifier, a few other practical matters, and some measurements.

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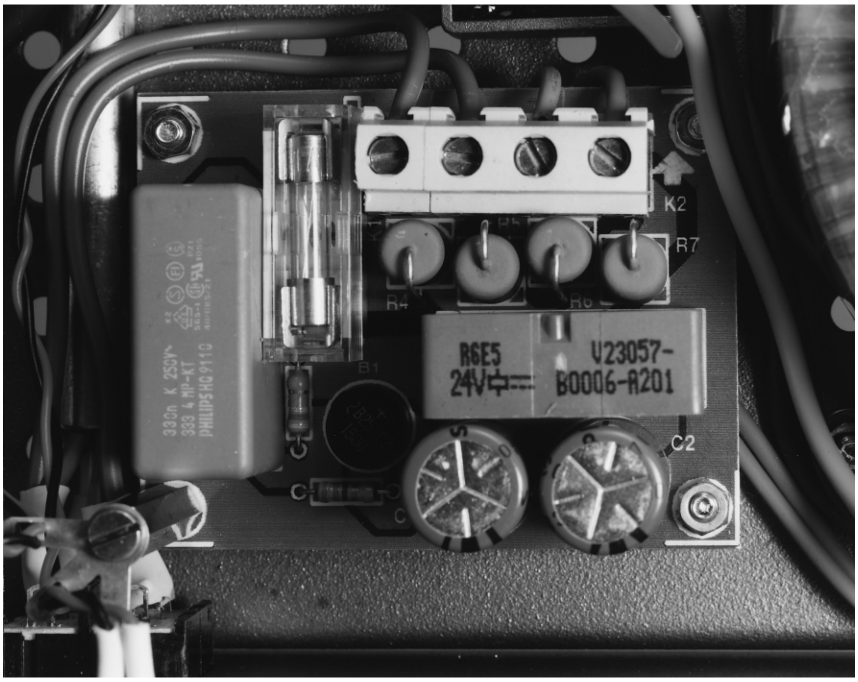

Figure 11. Printed-circuit board for the mains-on delay circuit, which is not available ready made.

Parts lists

Mains-on delay circuit

Resistors:
R_1, R_2 = 470 kΩ
R_3 = 220 Ω
R_4–R_7 = 10 Ω, 5 W

Capacitors:
C_1 = 0.33 µF, 300 V a.c.
C_2, C_3 = 470 µF, 40 V

Miscellaneous:
K_1, K_2 = 2-way terminal block, pitch 7.5 mm
B_1 = bridge rectifier, round, Type B250C1500
Re_1 = relay, coil 12 V, 1200Ω; contact rating 250 V, 8 A
F_1 = see text

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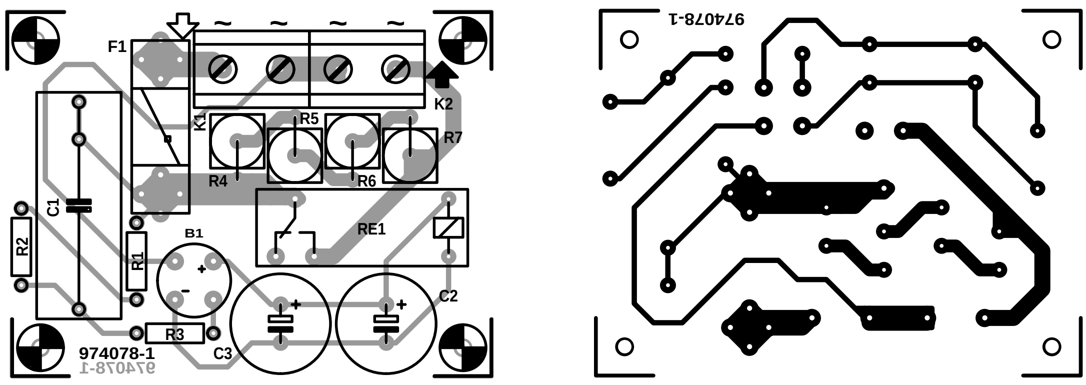
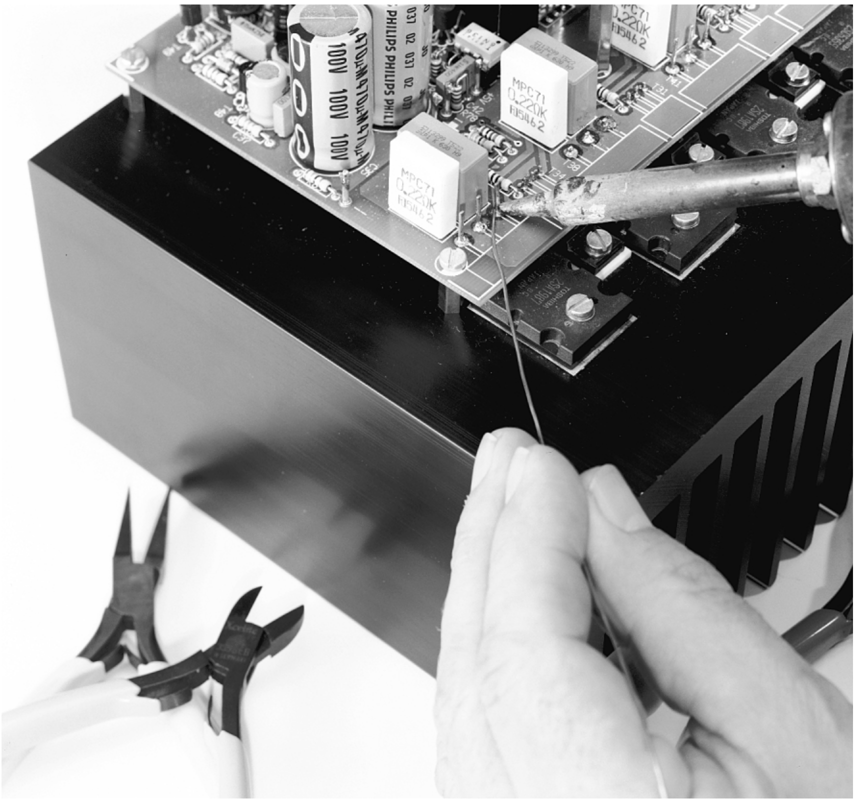


Titan 2000

Part 3: construction and setting up

This third of four parts deals primarily with the construction of the amplifier and ends with a brief resume of its performance and specifications. Let the constructor beware, however: the Titan 2000 is not an easy project and certainly not recommended for beginners in electronic construction.



Design by T. Giesberts

INTRODUCTION

It is clear from the first two parts of this article that the Titan 2000 is a complex unit that needs to be constructed and wired up with with great care to ensure the specified performance. For that reason, the construction notes will be more detailed than is usual with projects in this magazine. It is assumed that the protection network and auxiliary power supply have already been built and tested.

MOTHER BOARD

It must be borne in mind that in the case of a fast power amplifier like the Titan 2000, with a gain/bandwidth product of about 0.5 GHz, the board must be an integral part of the circuit. The mother board is therefore designed together with the remainder of the circuit. The length of the tracks, the area of the copper pads, the positions of the decoupling capacitors, and other factors, are vital for the proper and stable operation of the unit. Constructors who make their own boards are therefore advised to adhere strictly to the published layout.

Owing to the power requirements, the various stages are parallel configurations. When these are mounted on the heat sinks, a fairly large parasitic capacitances to earth ensue. This is because for reasons of stability all seven heat sinks must be strapped to earth. It

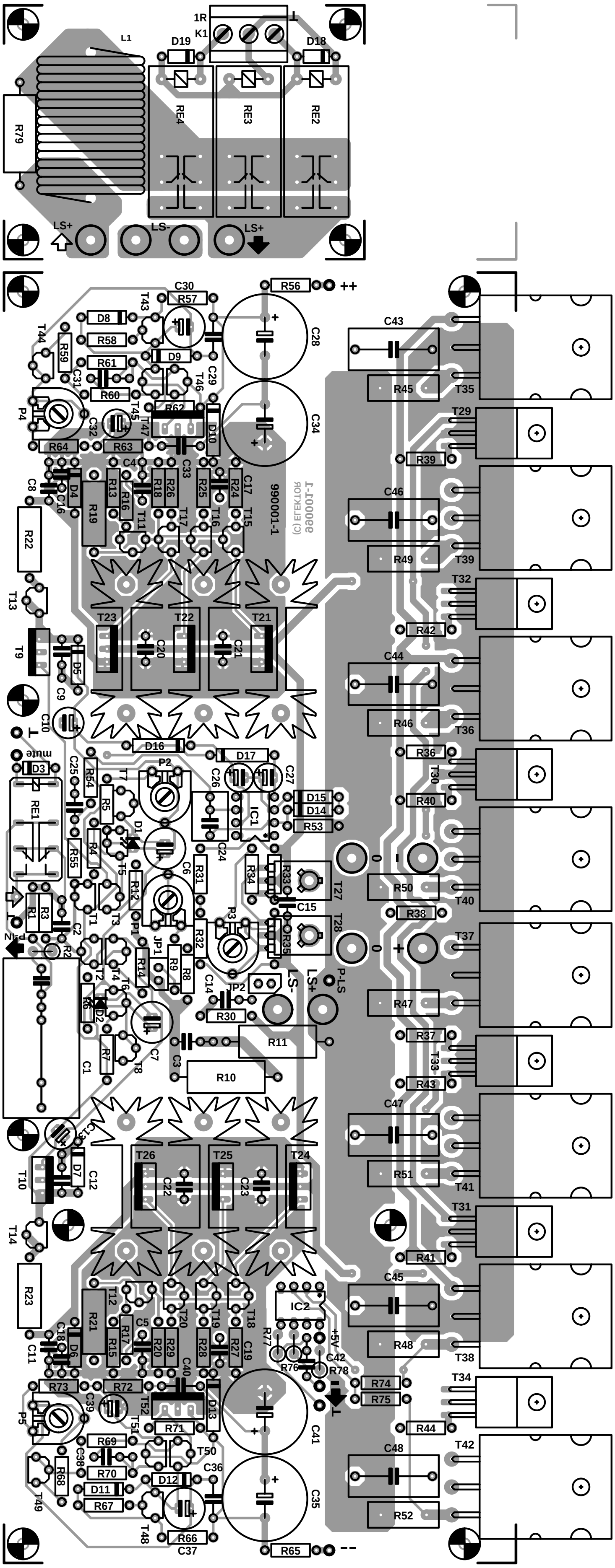


Figure 12. The double-sided printed-circuit board is intended to be combined with the heat sink into a single entity. Before that can be done, however, the section for the output relay and the inductor must be cut off the main section.

Parts lists

It is regretted that, owing to circumstances beyond our control, component codings in the various sections have been duplicated. Consequently, the mother board, protection network board, and auxiliary power supply board contain many components with the same identification (R_1-R_{36}, C_1-C_{26}, D_1-D_{12}, T_1-T_6, IC_1-IC_2, JP_1, K_1).

Amplifier

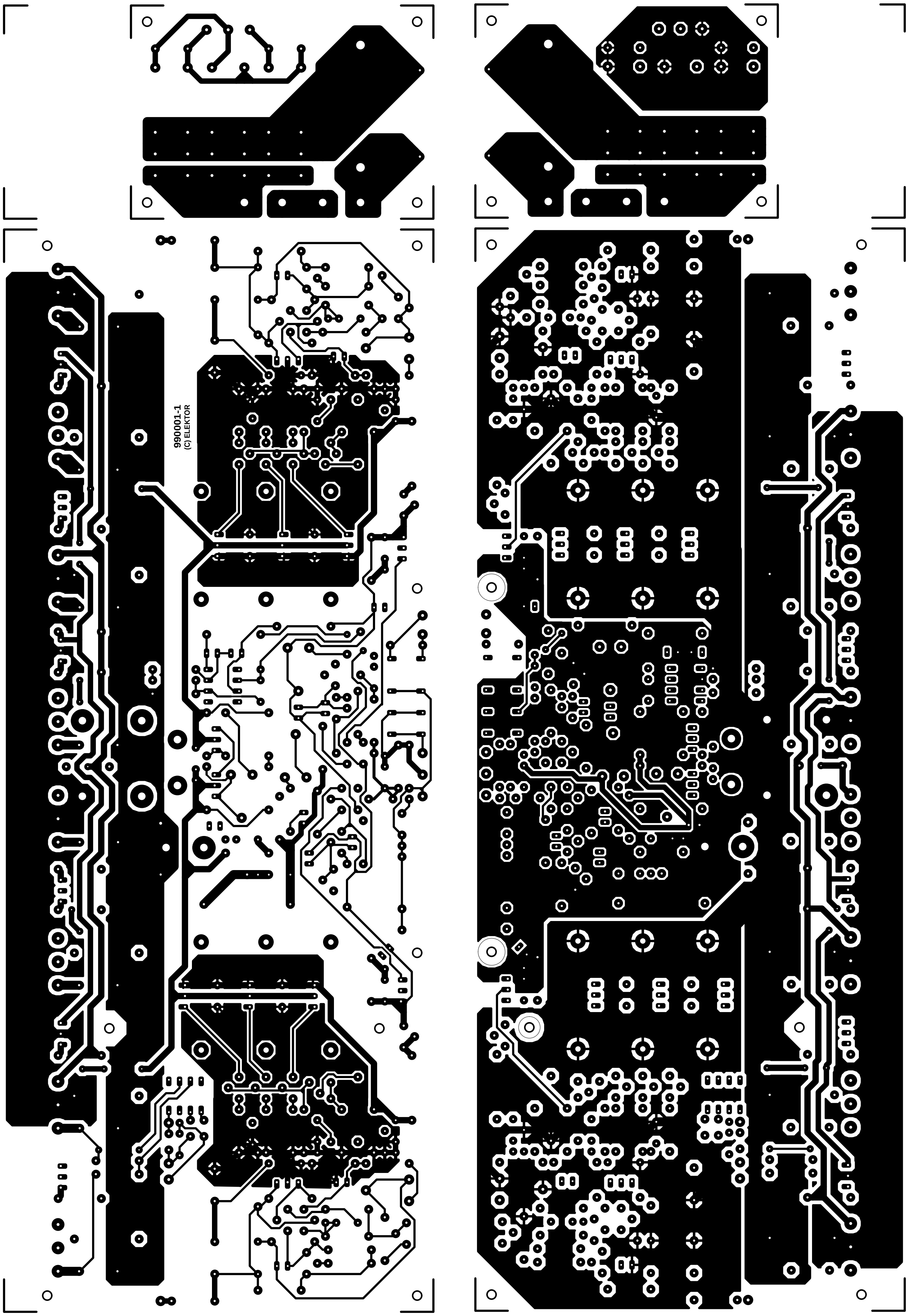
Resistors:

R_1, R_{53} = 1 MΩ

R_2 = 562 Ω
R_3 = 47 kΩ
R_4, R_6, R_{12}, R_{14}, R_{60}, R_{61}, R_{69}, R_{70} = 22 Ω
R_5, R_{62}, R_{71} = 330 Ω
R_7, R_{34} = 470 Ω
R_8 = 22.1 Ω
R_9 = 390 Ω
R_{10}, R_{11} = 470 Ω, 5 W
R_{13}, R_{15} = 1.00 kΩ
R_{16}, R_{17}, R_{38} = 150 Ω
R_{18}, R_{20}, R_{58}, R_{67} = 270 Ω
R_{19}, R_{21} = 10 kΩ, 1 W
R_{22}, R_{23} = 3.3 kΩ, 1 W
R_{24}–R_{29} = 68 Ω
R_{30} = see text
R_{31}, R_{32} = 22 kΩ
R_{33}, R_{35} = 220 Ω
R_{36}, R_{37} = 560 Ω
R_{39}–R_{44} = 10 Ω
R_{45}–R_{52} = 0.22 Ω, inductance-free
R_{54}, R_{55} = 4.7 MΩ
R_{56}, R_{65} = 15 Ω
R_{57}, R_{63}, R_{66}, R_{72} = 15 kΩ
R_{59}, R_{68} = 5.6 kΩ
R_{64}, R_{73} = 12 kΩ
R_{74}, R_{76}, R_{77} = 100 Ω
R_{75} = 33 Ω
R_{78} = 2.2 kΩ
R_{79} = 2.2 Ω, 5 W
P_1, P_4, P_5 = 4.7 kΩ (5 kΩ) preset
P_2 = 250 Ω, preset
P_3 = 500 Ω, preset

Capacitors:

C_1 = 2.2 µF, metallized polyester (MKP)
C_2, C_3, C_{42} = 0.001 µF
C_4, C_5 = 0.0022 µF
C_6, C_7 = 220 µF, 25 V, radial
C_8, C_9, C_{11}, C_{12}, C_{15} = 0.1 µF
C_{10}, C_{13} = 100 µF, 25 V, radial
C_{14} = see text
C_{16}–C_{23} = 100 pF, 100 V
C_{24} = 1 µF, metallized polypropylene (MKT)
C_{25} = 0.68 µF
C_{26}, C_{27}, C_{32}, C_{39} = 2.2 µF, 63 V, radial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(C) ELEKTOR

C_{28}, C_{34}, C_{35}, C_{41} = 470 µF, 100 V, radial
C_{29}, C_{33}, C_{36}, C_{40} = 0.22 µF, 100 V
C_{30}, C_{37} = 47 µF, 63 V, radial
C_{31}, C_{38} = 0.015 µF
C_{43}–C_{48} = 0.1 µF, 630 V

Inductors:
L_1 = see text

Semiconductors:
D_1, D_2 = LED, red, flat
D_3, D_{18}, D_{19} = 1N4148
D_4, D_6 = zener, 5.6 V, 500 mW
D_5, D_7 = zener, 15 V, 1.3 W
D_8, D_{11} = zener, 30 V, 1.3 W
D_9, D_{12} = zener, 39 V, 1.3 W
D_{10}, D_{13}, D_{16}, D_{17} = 1N4004
D_{14}, D_{15} = zener, 12 V, 500 mW
T_1, T_4, T_5, T_{15}–T_{17} = BC560C
T_2, T_3, T_6, T_{18}–T_{20} = BC550C
T_7, T_8, T_{43}, T_{48} = BF245A
T_9 = BF871
T_{10} = BF872
T_{11}, T_{50}, T_{51} = BC640
T_{12}, T_{45}, T_{46} = BC639
T_{13}, T_{14} = BF256C
T_{21}–T_{23} = MJE350
T_{24}–T_{26} = MJE340
T_{27} = BD139
T_{28} = BD140
T_{29}–T_{31} = 2SC5171 (Toshiba)
T_{32}–T_{34} = 2SA1930 (Toshiba)
T_{35}–T_{38} = 2SC5359 (Toshiba)
T_{39}–T_{42} = 2SA1987 (Toshiba)
T_{44}, T_{49} = BF256A
T_{47} = BD712
T_{52} = BD711

Integrated circuits:
IC_1 = OP90G
IC_2 = 6N136

Miscellaneous:
JP_1, JP_2 = 2.54 mm, 2-way pinstrip and pin jumper
K_1 = 3-way terminal block, pitch 5 mm
Re_1 = relay, 12 V, 600 Ω
Re_2–Re_4 = relay, 12 V, 16 A, 270 Ω
Heat sink for T_{21}–T_{26} = 38.1 mm, 11 K W^{-1} (Fischer Type SK104-STC; TO220)
Heat sink for drivers/output transistors, 150 mm, 0.25 K W^{-1}, Fischer Type SK157
Ceramic isolation washers for T_{21}–T_{34}: Fischer Type AOS220
Mica isolating washers for T_{35}–T_{42}
PCB Order no 990001-1 (see Readers Services towards end of this magazine)

is, of course, of paramount importance that these capacitances are as small as feasible. For this reason, it is vital that in the thermal coupling of T_{21}–T_{34} 1.5 mm thick ceramic—not mica—isolating washers are used. Mica washers may, however, be used with the output transistors since parasitic capacitances there are of no significance.

The component and track layouts of the mother board are shown in **Figure 12**. It will be seen that the board consists of two sections: the mother board proper and the output-relay board. The latter must be cut off before any other work is done. Later, when it is built up, it is mounted on the mother board with the aid of four 50 mm long metal spacers in such a way that the LS– and LS+ terminals on the two boards are above each other. The spacers also provide the electrical link between the boards.

The completed relay board is shown in **Figure 13**. Inductor L_1 is made from a doubled-up length of 1.5 mm enamelled copper wire wound in two layers of eight turns each around a 16 mm former (such as a piece of PVC pipe). After the coil has been wound, the PVC pipe is removed and the four windings connected in parallel. See **Figure 14**.

Ignoring the drivers and output transistors for the moment, the construction of the mother board is traditional. As always, great care must be taken during the soldering and placing of components. Do not forget the thermal coupling of T_1-T_3, T_2-T_4, D_1-T_5, D_2-T_6, T_{45}-T_{46}, and T_{50}-T_{51}, as already pointed out in Part 1. Also, T_{21}–T_{23} and T_{24}–T_{26} must be mounted on a heat sink, and isolated from it by means of a ceramic washer. When this is done, fit the composite heat sinks on the board, and link them to earth.

The input signal and the ±85 V supply lines are linked to the board via standard solder pins.

For connecting the ±70 V supply lines and the relay board, 3 mm screw holes are provided. Metal spacers are to be fixed to these and cable connectors to the top of the spacers.

MAIN HEAT SINK

When the mother board has been completed, and carefully checked, as far as described, it and the drivers and output transistors, T_{27}–T_{42}, must be mounted on the main heat sink. This is a 150 mm high Type SK157 from Fischer with a thermal resistance of 0.25 K W^{-1}. This is admittedly a very tedious job. It is vital that all requisite fixing holes are drilled accurately in the heat sink and preferably tapped with 3 mm thread. The template delivered with the ready-made board is almost indispensable for this work.

When the holes have been drilled (and, possibly, tapped) transistors T_{27} and T_{28} should be fitted first (this is important because they become inaccessible after the board has been fitted). They must be located as close as possible to the output transistors and not in the position indicated on the board. Again, the template makes all this clear. Their terminals must then be extended with the aid of short lengths of equipment wire, which are later fed through the relevant holes on the board and soldered to the board via, for instance, a three-way pin header.

The terminals of the drivers and output transistors must be bent at right angles: those of the former at the point where they become thinner and those of the latter about 5 mm from the body of the device. When this is done, screw all transistors loosely to the heat sink, not forgetting the isolating washers. If it is intended to use fan cooling, the requisite temperature sensor—that is, a Type BD140 transistor— should also be attached to the heat sink at this stage. The template does not show a location for the sensor, but it seems sensible to fit it at the centre close to T_{37} or T_{40}.

The next step is to fit all ten spacers to the heat sink: these should all be 10 mm long. In the prototype, spacers with a 3 mm screwthread at one end were used. Two of the spacers merely provide additional support for the relay board and another two form the electrical link between the negative supply line and the heat sink.

When all this work is done, the board should look more or less like that in **Figure 15**. Note that because of tests later on, there are, as yet, no ceramic isolating washers fitted on the prototype.

The next, and most tedious, step is to combine the board and heat sink. It is, of course, vital that all spacers are exactly opposite the relevant fixing holes and—even more tedious—that the terminals of all transistors are inserted into the correct mounting holes. Bear in mind that the metal

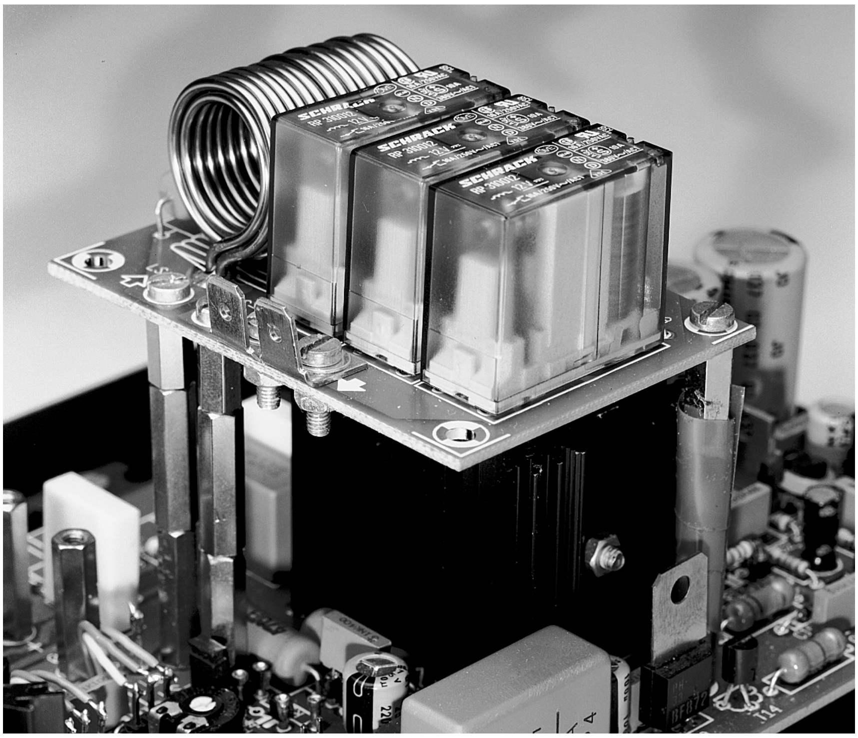


Figure 13. Illustrating how the relay board is mounted on the mother board with the aid of spacers.

spacers for linking –, +, LS+, and LS–, are already on the board. As the terminals of the output transistors are slightly longer than those of the drivers, it may be possible to do this work in two stages: output transistors first and drivers second. It may prove necessary to turn one or more of the transistors slightly, which is the reason that the fixing screws have not yet been tightened. When all terminals are correctly inserted, these screws must, of course, be tightened firmly.

The final step is to fix the relay board on the spacers that form the link for the LS– and LS+ terminals.

SETTING UP

Before the amplifier module can be taken into use, presets P_2–P_5 must be set as required. Preset P_1 is intended only for possibly adjusting the balance in case of a bridge configuration.

Start by turning P_3 (the quiescent-current control) fully anticlockwise and P_2, P_4, and P_5, to their centre position. Check the outputs of the power supply and auxiliary power supply and, if these are correct, link the +70 V line to pins '+' and '0', the –70 V line to '–' and '0', the +85 V line to '++' and the -85 V line to '--'. For absolute safety, link the ±70 V lines temporarily via a 10 Ω, 5 W resistor.

Next, set P_4 and P_5 for voltages of +78 V and –78 V respectively at the cases of transistors T_{47} and T_{52} respec-

Figure 14. Air-cored inductor L_1 is formed by laying two windings each of eight turns of doubled-up each on top of one another. The former is a length of 16 mm diameter PVC pipe as used by plumbers. The resulting four windings are simply connected in parallel.

tively (the cases of these transistors are linked to the output of the relevant regulator). It is important that the negative and positive voltages are numerically identical.

Since the parameters of the n-p-n and p-n-p transistors in the input stage are never exactly identical, there may be a slight imbalance. This may be corrected by adjusting the output of current source T_5 with the aid of preset P_2 to give a potential of exactly 0 V at the output (pin 6) of IC_1 (when 'cold').

Finally, insert an ammeter (set to 500 mA or 1 A range) in the +70 V or –70 V line, and adjust P_3 carefully for a quiescent current of 200 mA (cold condition—that is, immediately after switch-on). With a large drive signal, the quiescent current may increase to some 600 mA, but at nominal temperatures, its level will stabilize at 200–400 mA. Note that these fluctuations have no noticeable effect on the performance of the amplifier.

CHECK AND TEST

When the amplifier has been switched on for about half an hour, the voltages shown in Figure 2 (Part 1) may be verified. Note that voltage levels depending on the setting of current sources habitually show a substantial spread: 30 per cent is quite common. All measurements should be carried out with a good digital voltmeter or multimeter with a high-impedance input.

Other than the test voltages in the circuit diagram, there are some others that may be checked. For instance, the proper functioning of the output transistors may be ascertained by measuring the voltage across R_{45}–R_{52}. Hold one test probe against the loudspeaker terminal and with the other measure the potential at the emitters of all output transistors. The average value should be about 20 mV, but deviations of up to 50 per cent occur.

The voltage amplifier operation may be checked by measuring its current drain: if this is within specification, the voltage across R_{56} and R_{65} must be within 0.8–1.1 V (after the amplifier has been on for at least half an hour).

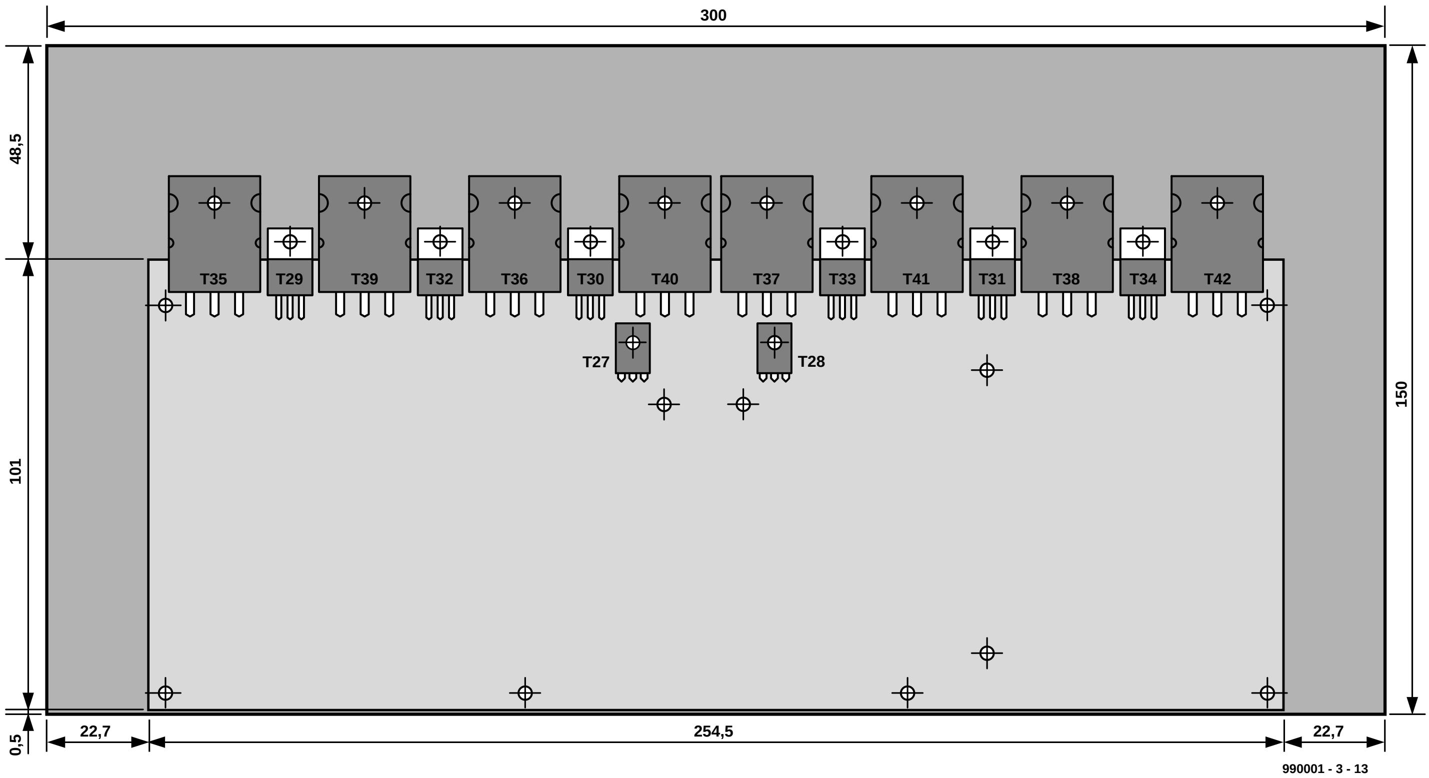
Finally, the potential drops across the emitter resistors of differential amplifiers T_{45}-T_{46} and T_{50}-T_{51} must not differ by more than a factor 2. Too large a factor is detrimental to the stable operation of the amplifiers. A too large difference may be corrected by changing the value of R_{62} or R_{71}, as the case may be. If this is unsuccessful, the relevant transistor pair will have to be replaced.

When all is well, the resistors in series with the ±70 V lines should be removed. Note that a rectified voltage of 70 V, let alone one of 140 V, is lethal. It is therefore absolutely essential to switch off the power supply and verify that the residual voltages have dropped to a safe value before doing any work on the amplifier.

Next month's instalment will deal with the wiring up of the amplifier and its performance, including specifications.

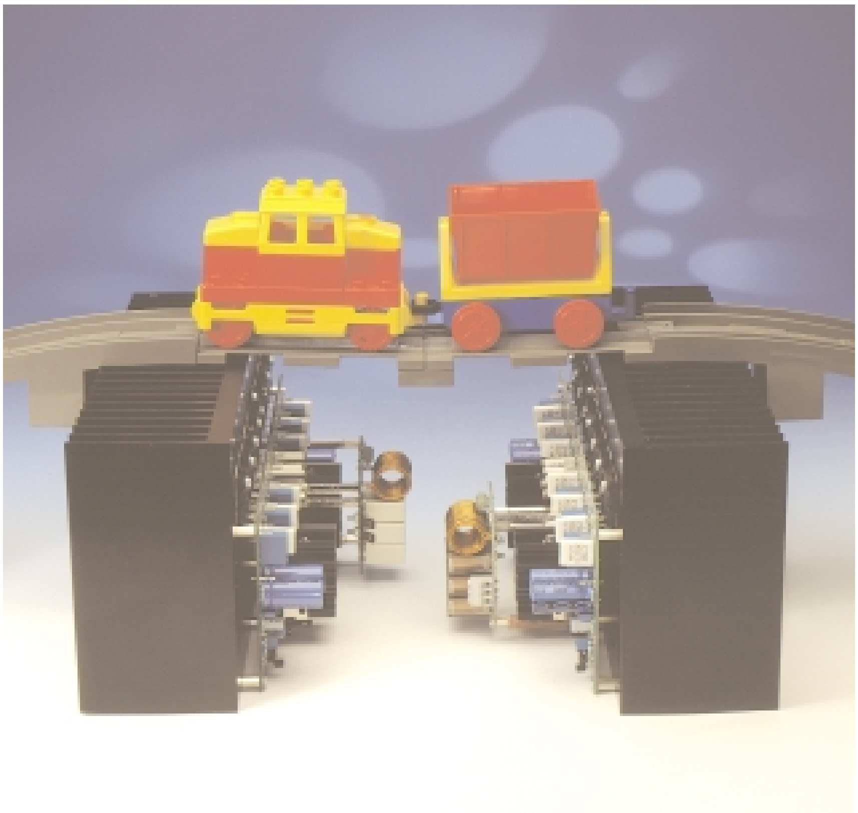
[990001-3]

Figure 15. The PCB is delivered with a template to ensure that the transistors are fitted at the correct location on the heat sink.



Titan 2000

Part 5: half-bridging two single amplifiers



In the introduction to Part 1 it was stated that the Titan 2000 could deliver up to 2000 watts of 'music power', a term for which there is no standard definition but which is still used in emerging markets. Moreover, without elaboration, this statement is rather misleading, since the reader will by now have realized that the single amplifier cannot possibly provide this power. That can be attained only when two single Titan amplifiers are linked in a half-bridge circuit. The true power, that is, the product of the r.m.s. voltage across the loudspeaker and the r.m.s current flowing into the loudspeaker, is then 1.6 kilowatts into a 4-ohm loudspeaker.

Design by T. Giesberts

BRIDGING: PROS AND CONS

Bridging, a technique that became fashionable in the 1950s, is a way of connecting two single output amplifiers (valve, transistor, BJT, MOSFET, push-pull, complementary) so that they together control the passage of an alternating current through the loudspeaker. This article describes what is strictly a half-bridge configuration, a term not often used in audio electronics. When audio engineers speak of bridge mode, they mean the full-bridge mode in which four amplifiers are used.

In early transistor audio power amplifiers, bridging was a means of achieving what in the 1960s were called public-address power levels as high as,

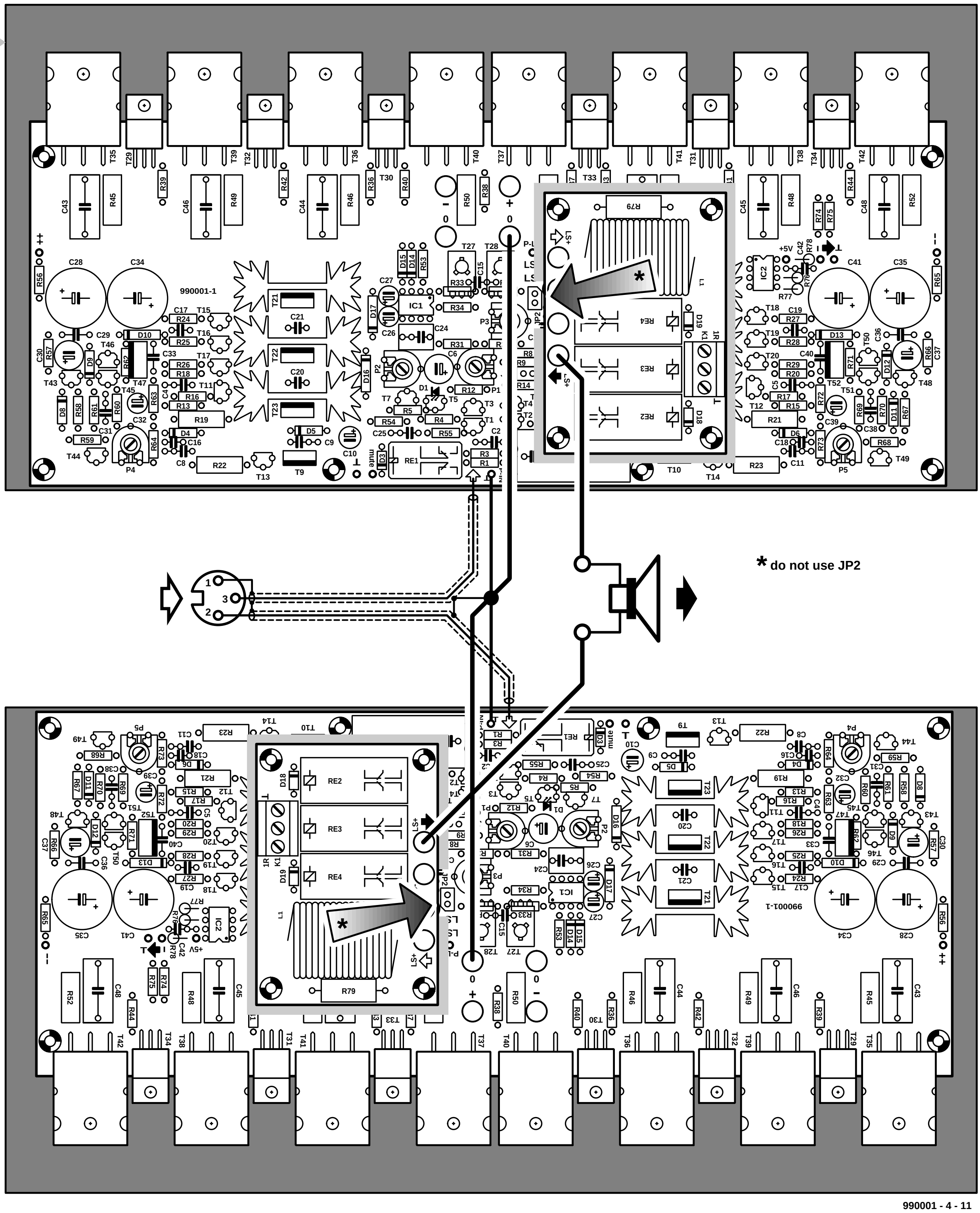


Figure 17. The interlinking required to form a half-bridge amplifier from two single Titan 2000 units. Note that the resulting balanced input may be reconverted to an unbalanced one with the Brangé design (Balanced/unbalanced converters for audio signals) published in the March 1998 issue of this magazine. The PCB for that design (Order no. 980026) is still stocked.

say 50–80 W into 8 Ω. Such power levels were then way beyond of what the voltage ratings of output transistors would permit.

Bridging is considered by many to be a good thing, since it automatically provides a balanced input (drive). However, opponents will quickly point out that it halves output damping, doubles the circuitry and virtually cancels even-order harmonics created in the amplifier.

Opponents also claim that bridging amplifiers is tedious and requires too much space. It is, however, not simple either to design a single amplifier with the same power output and the requisite power supply. A single 2 kW amplifier requires a symmetrical supply voltage of ±130 V, that is, a total of 260 V. The power supply for this would be quite a design. And where would a designer find the drivers and output transistors for this? Advocates point out that bridging amplifiers have the advantage of requiring a relatively low supply voltage for fairly high output powers.

Bridging just about doubles the rated output power of the single amplifier. Again, opponents point out that loudness does not only depend on

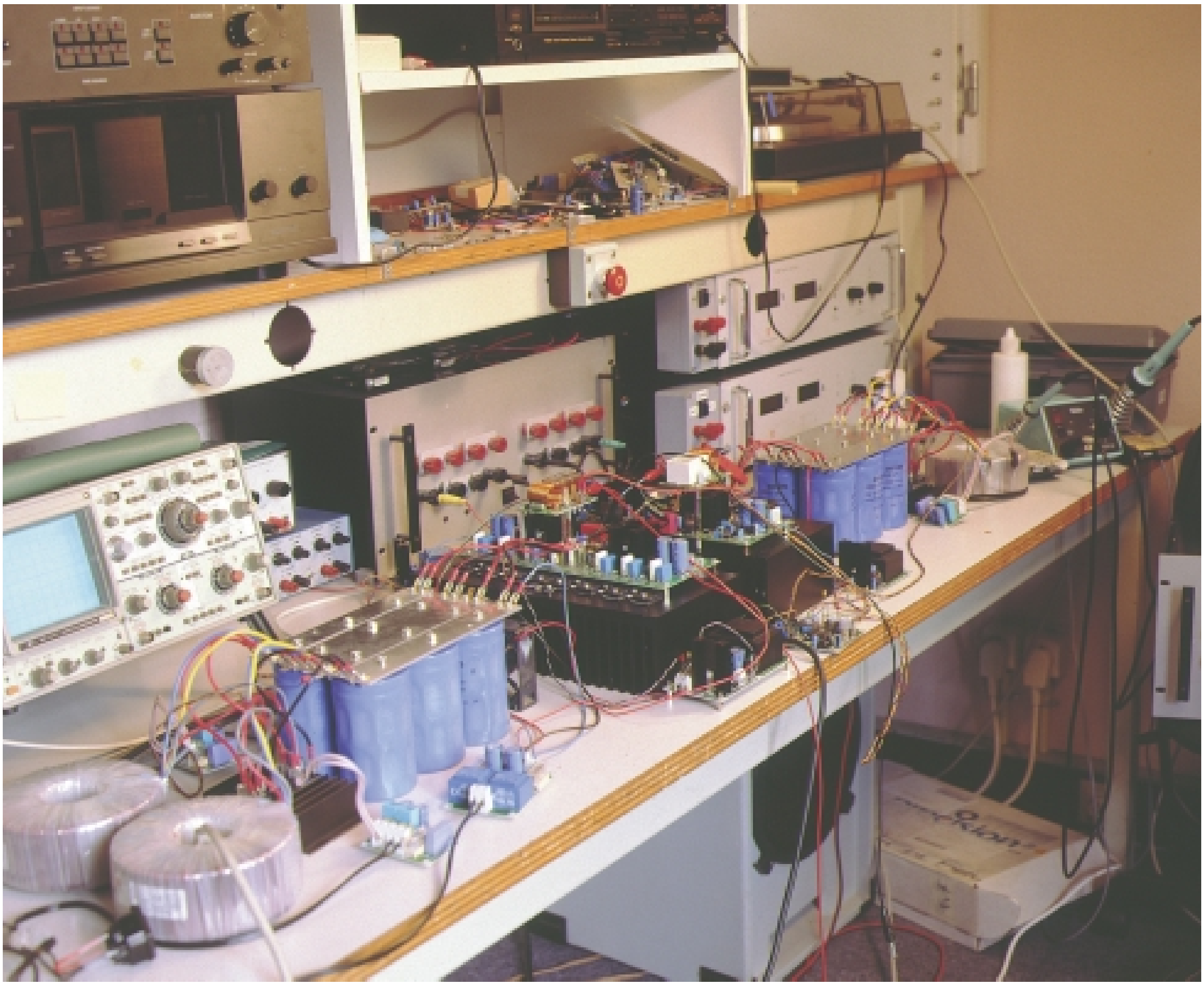


Figure 18. Test setup for the prototype half-bridge amplifier (centre). Note the large power supplies at the left and right of the amplifier.

the amplifier, but also on the loudspeaker. Bear in mind, they say, that just changing a loudspeaker with a sensitivity of, say, 90 dB_{SPL} per watt per metre to one with a sensitivity of 93 dB_{SPL} per watt per metre is equal to doubling the amplifier power rating.

Clearly, bridging two amplifiers is a mixture of good and bad audio engineering and sonics.

INTERCONNECTING

It is, of course, necessary that two completed single Titan 2000 amplifiers are available, each with its own power supply. It should then be possible to simply interlink the earths of the two units, use the inputs as a common balanced input, and connect the loudspeaker between terminals LS+ on the two amplifier. However, a few matters must be seen to first.

Owing to the requisite stability, it is imperative that the two amplifiers are juxtaposed with the space between them not exceeding 5 cm (2 in). They should, of course, be housed in a common enclosure.

The interwiring is shown in **Fig-ure 17**. Make sure that the power supplies are switched off and that the smoothing capacitors have been discharged before any work is carried out.

Start by interlinking the negative supply lines (terminals 0) with insulated 40/02 mm wire. Remove the insulation at the centre of the length of wire since this will become the central earthing point for the new (balanced) input. Link the ⊥ terminals on both boards to the new central earth with 24/02 mm insulated wire.

Connect the loudspeaker terminals to the LS+ terminals on the two boards with 40/02 mm insulated wire.

Link pins 2 and 3 of the XLR connector to the input terminals on the boards with two-core screened cable. Solder the screening braid to pin 1 of the XLR connector and to the new central earthing point.

Finally, on both boards remove jumper JP_2 from the relevant pin strip.

FINALLY

When all interconnections between the boards as outlined have been made, the single amplifiers form a half-bridge amplifier. If all work has been carried out as described, there should be no problems.

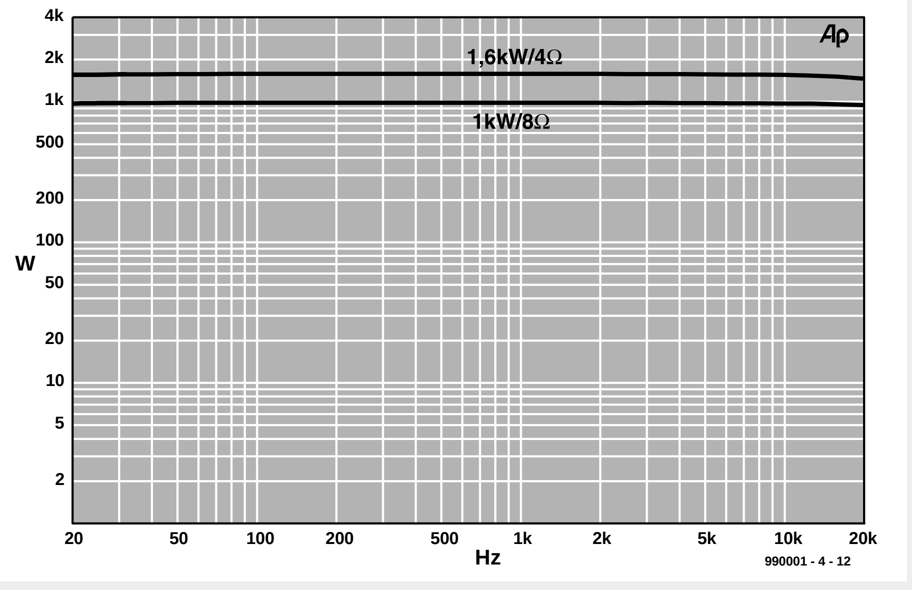
In the design stages, network R_9-P_1, inserted into the circuit with pin jumper JP_1 (see Part 1), was considered necessary for common-mode suppression. However, during the testing of the prototype, the network was found to be superfluous. It may be retained if the half-bridge amplifier is to be used with a second half-bridge amplifier for stereo purposes, when it may be used to equalize the amplifications of the two half-bridge amplifiers.

[990001]

Parameters

With a supply voltage of ±70 V (quiescent ±72 V) and a quiescent current of 200–400 mA

Input sensitivity		2.1 V r.m.s.
Input impedance		87 kΩ
True power output for 0.1% THD		950 W into 8 Ω; 1.5 kW into 4 Ω
True power output for 1% THD		1 kW into 8 Ω; 1.6 kW into 4Ω
Power bandwidth		1.5 Hz – 220 kHz
Slew limiting		170 V μs^{-1}
Signal+noise-to-noise ratio (at 1 W into 8 Ω)		97 dB (A-weighted
		93 dB (B=22 kHz)
Total harmonic distortion (B=80 kHz)		
	at 1 kHz	0.0033% (1 W into 8 Ω)
		0.002% (700 W into 8 Ω)
		0.0047% (1 W into 4 Ω)
		0.006% (700 W into 4 Ω)
	at 20 kHz	0.015% (700 W into 8 Ω)
		0.038% (1200 W into 4 Ω)
Intermodulation distortion		
	(50 Hz:7 kHz = 4:1)	0.0025% (1 W into 8 Ω)
		0.0095% (500 W into 8 Ω)
		0.004% (1 W into 4 Ω)
		0.017% (500 W into 4 Ω)
Dynamic intermodulation distortion		
	(square wave of 3.15 kHz and	0.0038% (1 W into 8 Ω)
	sine wave of 15 kHz)	0.0043% (700 W into 8 Ω)
		0.005% (1 W into 4 Ω)
		0.0076% (1200 W into 4 Ω)
Damping (with 8 Ω load)		≥ 350 (at 1 kHz)
		≥ 150 (at 20 kHz)
Open-loop amplification		×8600
Open-loop bandwidth		53 kHz
Open-loop output impedance		3.2 Ω

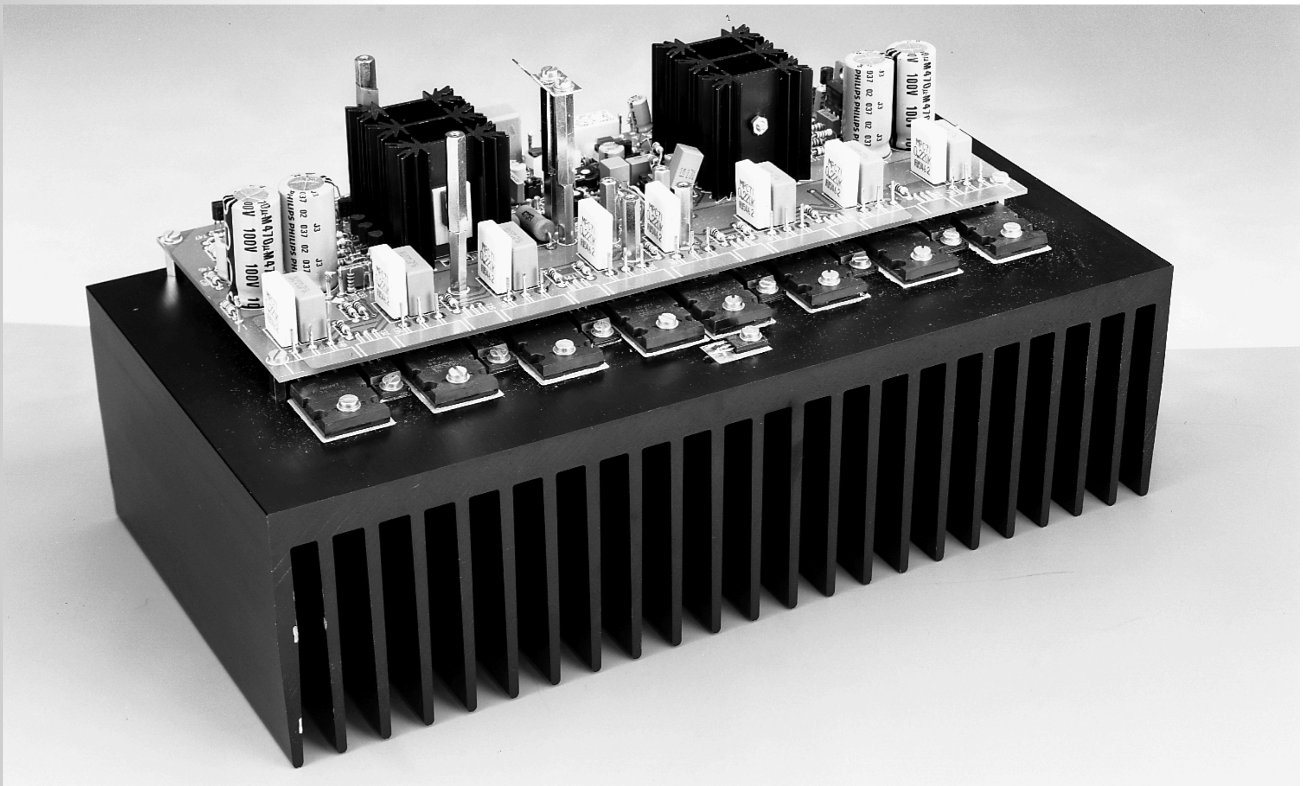


A comparison of these parameters with the specifications given in Part 4 ((May 1999 issue) show that they are generally in line. In fact, the intermodulation distortion figures are slightly better. Because of this, no new curves are given here other than power output (1 kW into 8 Ω and 1.6 kW into 4 Ω) vs frequency characteristics for 1 per cent total harmonic distortion.

During listening tests, it was not possible to judge the half-bridge amplifier at full volume, simply because there were no loudspeakers available that can handle this power output. However, up to 200 W true power output, the half-bridge amplifier sounds exactly the same as the single amplifier. Instrument test figures show no reason to think that the performance at higher output powers will be degraded.

Titan 2000

Part 4: wiring and performance



This fourth of five parts deals primarily with the wiring up of the amplifier and ends with a brief resume of its performance and specifications. The fifth and final part of the article in a forthcoming issue will deal with the temperature control, bridge configuration and some other practical hints.

Design by T. Giesberts

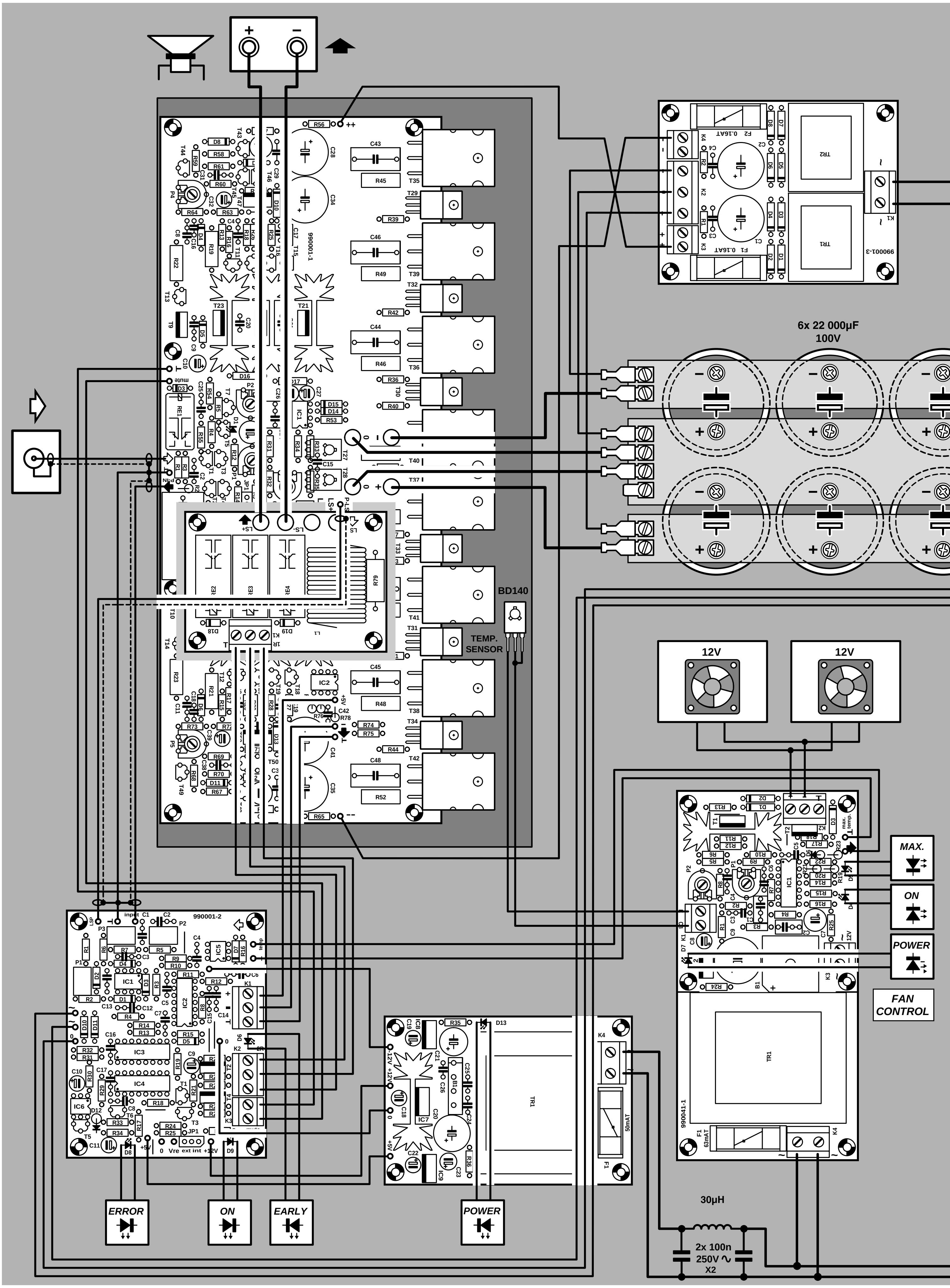
WIRING UP

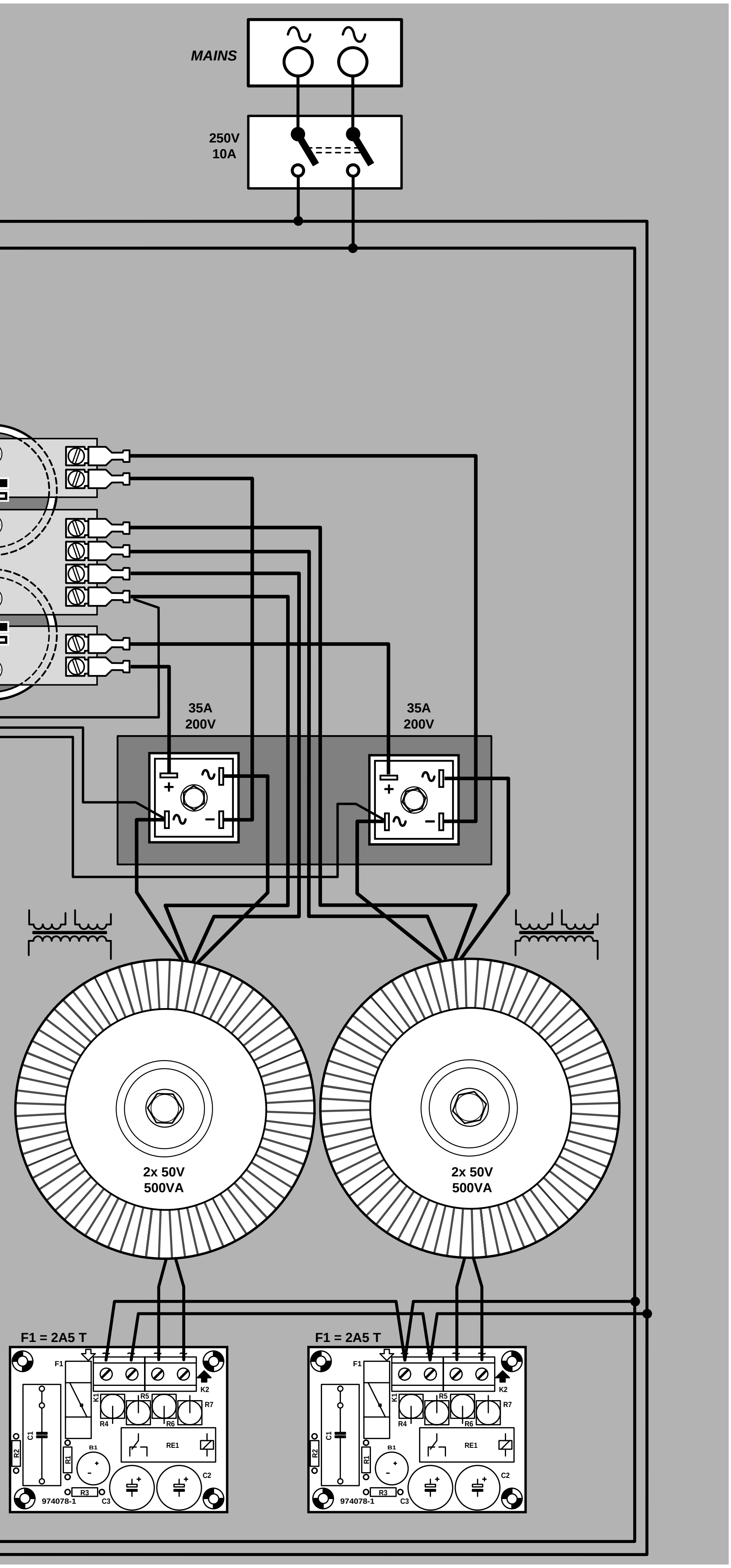
How the various board, power supplies, controls and terminals are combined into an effective and interference-free unit is shown in **Figure 16**.

As already mentioned in Part 2, all wiring carrying the main supply voltage (±70 V) must be insulated, high-current wire to BS6321 with a conductor size of 50/0.25 (2.5 mm^2). This wire should also be used to link the output terminals of the power transistors and the loudspeaker terminals. Any wiring between smoothing capacitors and the board should not exceed 15 cm and be preferably much shorter. This kind of wire is best terminated into car-type connectors.

Other wiring may be made in light-duty, stranded, insulated hook-up wire. It is advisable (and may prove to be very helpful in case of problems) to use wire with different colour insulation for dissimilar functions.

The connections between the input socket and board must, of course, be in screened audio cable. To avoid earth loops, the socket should be isolated from a metal enclosure. Bear in mind that the supply earth and the enclosure are linked by metal spacers between the two '0' terminals and the heat sink. It is, therefore, essential that the heat sink is firmly strapped to the metal enclosure.


6x 22 000µF
100V
BD140
TEMP.
SENSOR
12V
12V
MAX.
ON
POWER
FAN
CONTROL
ERROR
ON
EARLY
POWER
30µH
2x 100n
250V ~
X2
990001-1
990001-2
990001-3
990041-1



The on/off indicator, the functional indicators, and the mains on/off switch should, of course, be fitted on the front panel of the enclosure. The mains on/off switch must be a 10 A or 15 A type.

If the output power of the amplifier is limited to no more than 500 W, in which case the enclosure does not need fan cooling, the heat sink may be mounted at the outside of the enclosure or even form the sidewall or back of a home-made enclosure.

For greater output powers, cooling fans with relevant apertures at the front and back of the enclosure are a must. The heat sink must then be located in the enclosure in such a position that it is directly between the two fans, ensuring a continuous supply of cooling air.

PERFORMANCE

The specification and associated comments in the box cannot, of course, give a full impression of the performance of the amplifier. It is a well-known fact that amplifiers with an almost identical specification, and using identical loudspeakers, can sound quite different.

Particularly at low frequencies, the amplifier maintains good control over the loudspeaker, which results in a clean fast (i.e., taut over the whole audio range) sound, totally lacking in reverberation. High and medium frequencies were also reproduced with excellent definition and without any trace of tizziness.

The overall impression is that the amplifier has plenty of reserve and is not strained in any circumstances.

In next month's final instalment, the temperature control and possible bridge configuration will be discussed.

[990001-3]

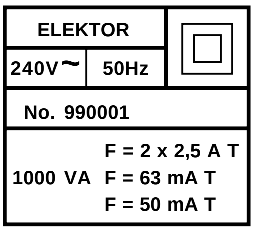


Figure 16. The wiring diagram clearly illustrates how the various parts of the amplifier are combined into a single unit.

Contents

Technical specifications

(Supply voltage = ±70 V; quiescent current = 200–400 mA)

Input sensitivity	1.1 V r.m.s.		
Input impedance	47.5 kΩ		
Sine-wave power output (0.1% THD)	280 W into 8 Ω; 500 W into 4 Ω; 800 W into 2 Ω		
Music power* (1% THD)	300 W into 8 Ω; 550 W into 4 Ω; 1000 W into 2 Ω		
Slew limiting	85 V µs^{-1}		
Open-loop bandwidth	53 kHz		
Open-loop amplification	×8600		
Power bandwidth	1.5 Hz – 220 kHz		
Signal-to-noise ratio (1 W into 8 Ω)	101 dB (A-weighted); 97 dB (B = 22 kHz)		
Damping factor (at 8 Ω)	>700 (1 kHz); >300 (20 kHz)		
Output impedance	1.6 Ω		
Harmonic distortion (THD) (B = 80 kHz)	8 Ω	4 Ω	2 Ω
at 1 kHz	0.003% (1 W)	0.0046% (1 W)	0.01% (1 W)
	0.005% (200 W)	0.0084% (400 W)	0.02% (700 W)
at 20 kHz	0.009% (200 W)	0.018% (400 W)	0.07% (700 W)
Intermodulation distortion (IM)			
(50 Hz:7 kHz = 4:1)	0.004% (1 W)	0.01% (1 W)	0.034% (1 W
	0.016% (150 W)	0.025% (300W)	0.07% (500 W)
Dynamic IM			
(square wave 3.15 kHz with sine wave 15 kHz)	0.003% (1 W)	0.0036% (1W)	0.0055% (1 W)
	0.003% (200 W)	0.005% (400 W)	0.0085% (700 W)

*See Part 1 about the validity of this meaningless quantity.

The specified figures were measured after the amplifier had been switched on for two hours. The figure show that the Titan 2000 compares favourably with most amplifiers. The slew limiting is a measure of the speed of the amplifier, which is exceptionally good in the Titan 2000.

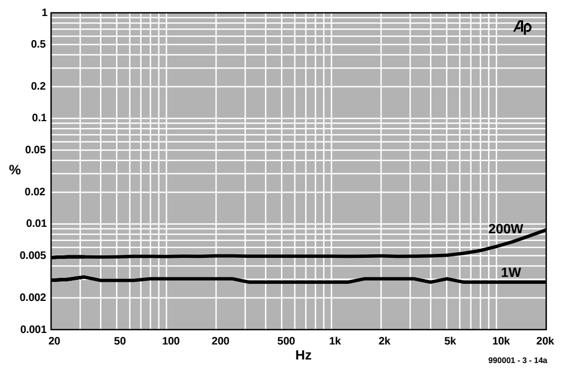
Figure A shows the total harmonic distortion plus noise (THD+N) for an output of 1 W into 8 Ω (lower curve) and for 200 W into 8 Ω. The latter figure corresponds with 70% of the peak sine wave power and the curve shows that the distortion increases clearly only above 10 kHz.

Figure B shows the THD+N at 1 kHz as a function of the drive with an output impedance of 8 Ω. The curve is purposely drawn for a bandwidth of 22 kHz so that the noise above 20 kHz does not degrade the performance of the amplifier. From about 2 W, the distortion increases slightly with increasing drive, which is normal in most amplifiers.

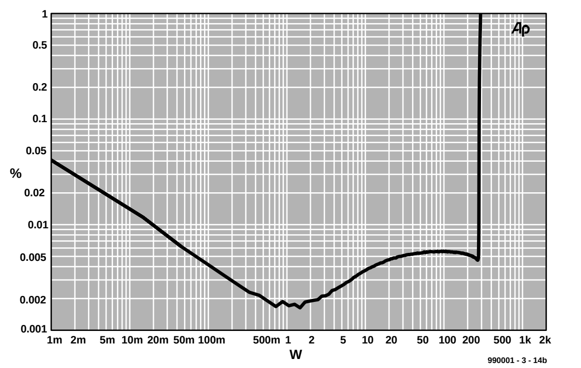
Figure C shows the peak output of the amplifier at a constant distortion of 0.1% and a load of 4 Ω (upper curve) and 8 Ω. The bandwidth was 80 kHz.

Figure D shows a Fourier analysis of a reproduced 1 kHz signal at a level of 1 W into 8 Ω. It will be seen that the 2nd harmonics are down just about 100 dB, while the 3rd harmonics are down to –114 dB. Higher harmonics lie below the noise floor of –130 dB.

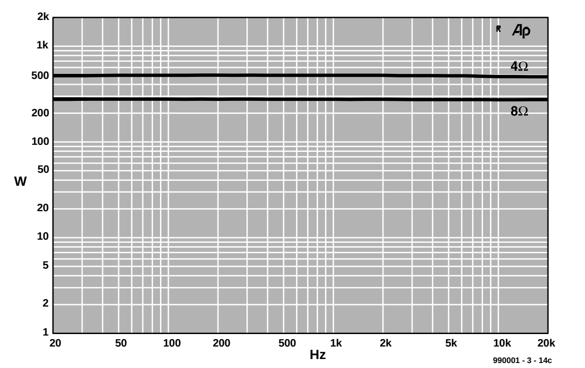
A



B



C



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