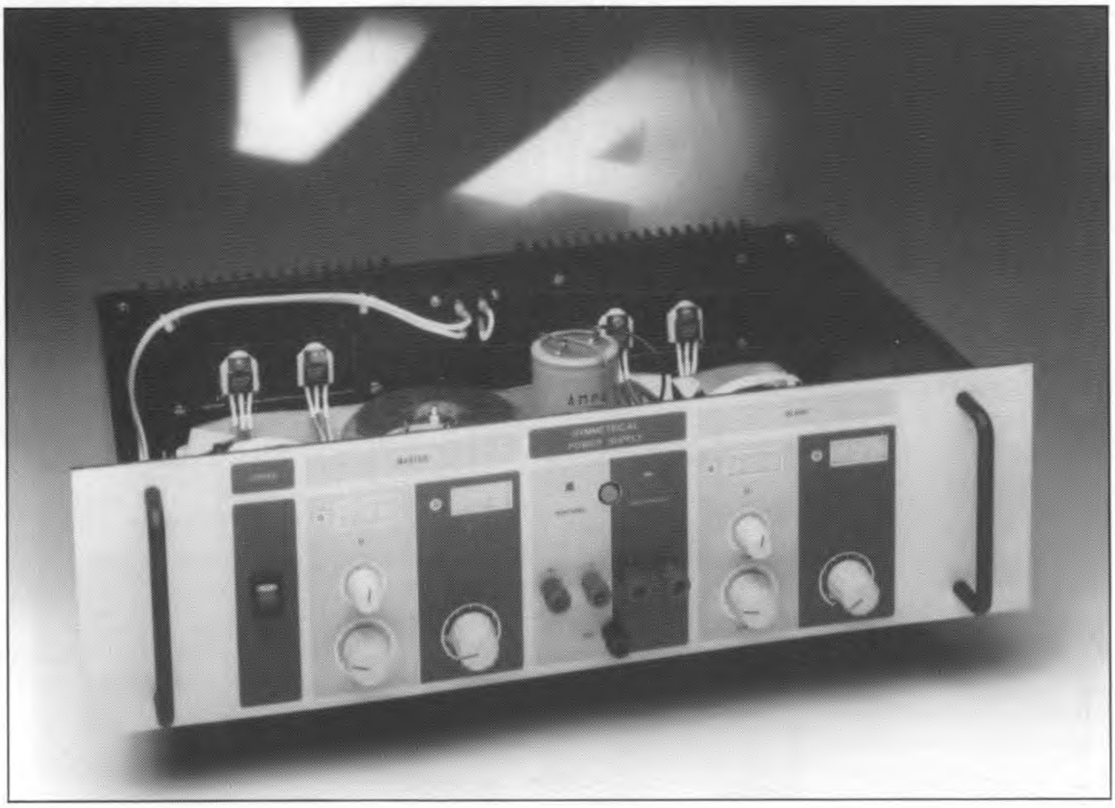
400-WATT LABORATORY POWER SUPPLY



PART 1: CIRCUIT DESCRIPTION

Here is an all-purpose d.c. power supply for symmetrical as well as asymmetrical use, and capable of supplying high output currents and voltages. An all-analogue design based on discrete parts only, this 400-watt PSU deserves a prominent place on your work bench.

G. Boddington

The problem with power supplies in an electronics laboratory or workshop is that their application range is often limited because of their specifications. Any one who has been involved in practical electronics will admit that finding a suitable power supply for a particular test is not at all easy, when none of the available ones (say ±15 V/2 A, 0–60 V/100 mA and 5 V/10 A types) seem to be fully geared to the job. Obviously, what is needed is a supply that combines the most frequently used voltage and current ratings, both symmetrical and asymmetrical, while offering a properly operating overload protection.

Although the user manual with many an inexpensive, ready-made power supply will confidently inform you that the power transistors are protected against overloads, this type of protection has an inherent disadvantage. True, the supply will happily supply the maximum output current at the maximum output voltage, but it will typically shut down the moment the voltage is reduced just one volt or so. The reason is clear: the overload protection is actuated because the extra dissipation, which is the product of the output current and the voltage difference across the series transistors, exceeds the cooling capacity of the heat-sink, or the power rating of the (expensive) series transistors.

The present power supply puts an end to

MAIN SPECIFICATIONS

- **Mode: Single**
  - one adjustable power supply with current and voltage controls.
  - Output: 0 – 40 V at 0 – 5 A
- **Mode: Independent**
  - two identical, electrically separated, power supplies.
  - Outputs: 2 × 0 –4 0 V at 2 × 0 – 5 A
- **Mode: Tracking**
  - two identical, series connected, power supplies.
  - Outputs: ±0 –± 40 V at 0 –5 A; 0 – 80 V at 0 – 5 A
  - Voltage and current of *slave* follow *master.*
- **Mode: Parallel**
  - two identical, parallel connected, power supplies.
  - Outputs: 0.6 – 39.4 V at 0 – 10 A
- **Maximum output voltage:** **40 V (at full load)**, **48 V (no load)**
- **Maximum output current:** **5 A**
- **Ripple:** **10 mV (no load)**, **50 mV (at full load)**
- **Voltage difference in tracking mode:** **50 mV**

these problems. It can be set up to supply either 2×40 V/2×0–5 A, ±0–40 V/0–5 A, or 0 – 80 V/0 – 5 A, and is capable of supplying the maximum output current at low voltage settings. Special ICs or microprocessors are not used: just straightforward analogue electronics based on readily available components. The result is a power supply with an excellent price/performance ratio.

Block diagram

The instrument consists of two identical, electrically isolated, power supplies, which may be connected in a number of ways to give different operating modes. The block diagram in Fig. 1 shows relatively many functional blocks, which together form three partly 'interwoven' regulating circuits. The first of these, the outer circuit, is a transformer preregulator that serves to keep the voltage drop across the series transistors (T4-T5) constant at about 10 V, so that the maximum dissipation remains smaller than 50 W (or 25 W per transistor). The other two regulation circuits are for the output voltage (*U*) and current (*I*). These circuits are almost identical, the only difference being that the current control obtains its control information from a series resistor, and the voltage control from a potential divider fitted across the output terminals. In contrast to the transformer preregulation, the *U* and *I* control circuits allow the range of the regulating action to be adjusted manually. Interestingly, the series transistors, T4 and T5, function in all three regulation circuits.

The block diagram shows a second power supply, which provides auxiliary ±12 V rails for use in the main circuit. The ground line of this symmetrical supply is connected to the positive output terminal of the main supply. This means that all references to '+12 V' and '–12 V' in the following text, and in the circuit diagram, are actually '+12 V and –12 V with reference to the positive output terminal'. The auxiliary power supply also functions as a voltage reference.

Finally, the block marked 'current limit' stands for a circuit that keeps the output current of each supply below 5 A. This circuit may be fitted with an optional temperature monitor to prevent overheating.

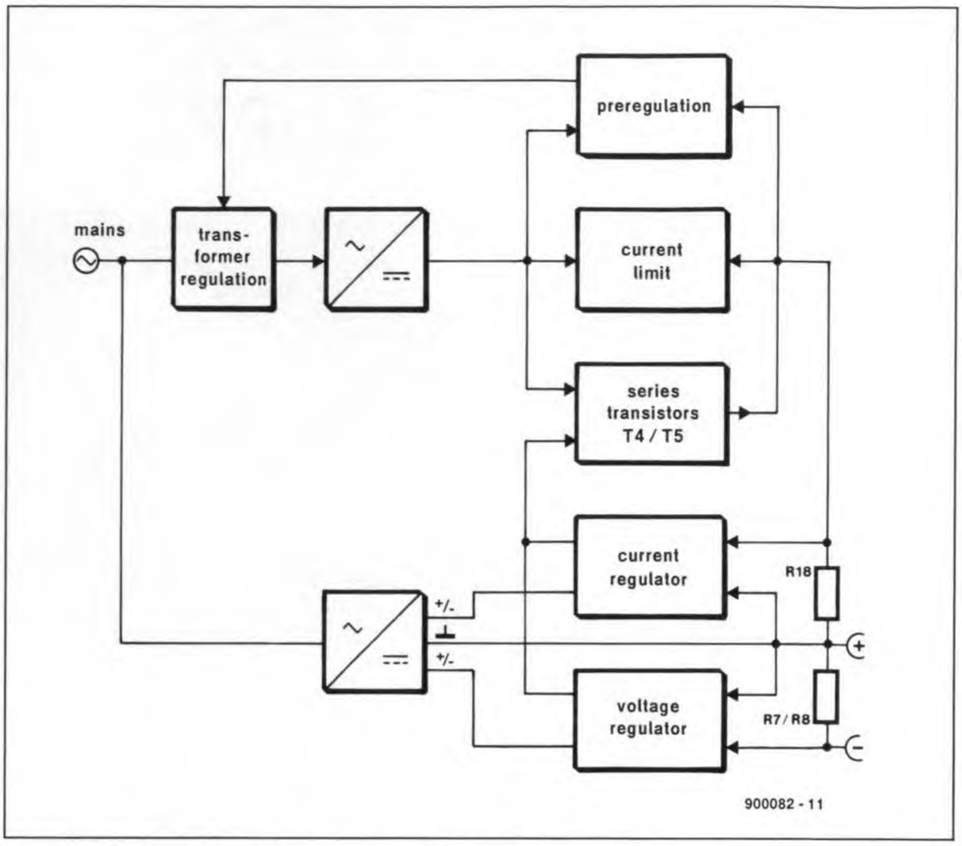


Fig. 1. Block diagram of the power supply. The design is based on three interactive control circuits: (1) transformer preregulation, (2) current control and (3) voltage control.

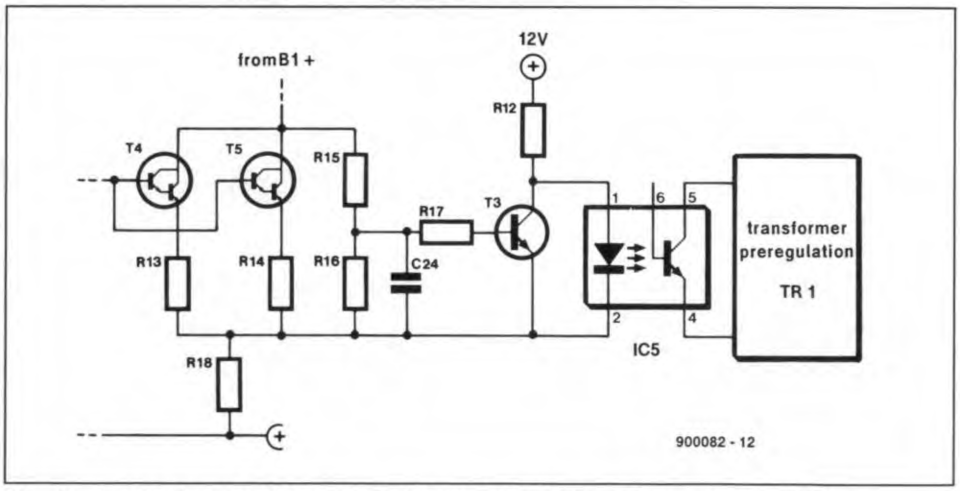


Fig. 2. Basic diagram of the circuit that controls the transformer preregulation.

The preregulation circuit

The basic operation of the preregulation circuit is best explained with reference to Fig. 2. The current flows from the positive connection of the bridge rectifier to the positive output terminal via two parallel-connected darlington transistors, T4 and T5, and resistors R13, R14 and R18. The regulation circuit tries to maintain a constant drop of 10 V across the series transistors and their emitter resistors. Transistor T3 is driven via potential divider R15-R16 and network C24-R17. The network introduces a small delay to eliminate the effect of noise spikes in the preregulation. The current through the LED in optocoupler IC5 is inversely proportional to the voltage across R15-R16.

The power fed to mains-connected ohmic loads is relatively simple to control. Usually, an adjustable *R-C* network connected across the mains terminals supplies the trigger voltage for a triac. The timing of the trigger (or firing-) pulse with respect to the start of the half-cycle is determined by the *R-C* delay. After being fired, the triac conducts until the mains voltage drops to a level below the minimum hold current. This happens close to the zero-crossing. The triac remains blocked until it receives another trigger pulse at a particular phase angle during the next half-cycle of the mains voltage. The current supplied to the load is inversely related to the phase angle, i.e., to the delay of the trigger pulse following the zero-crossing. This principle of phase-angle control works as long as voltage and current are in phase, i.e., as long as the load is a pure resistance.

Unfortunately, the mains transformer in the power supply forms an inductive rather than an ohmic load, so that the mains voltage and the load current are out of phase. Hence, a simple 'dimmer' with conventional triac control as described above will not do as a preregulation circuit. With an inductive

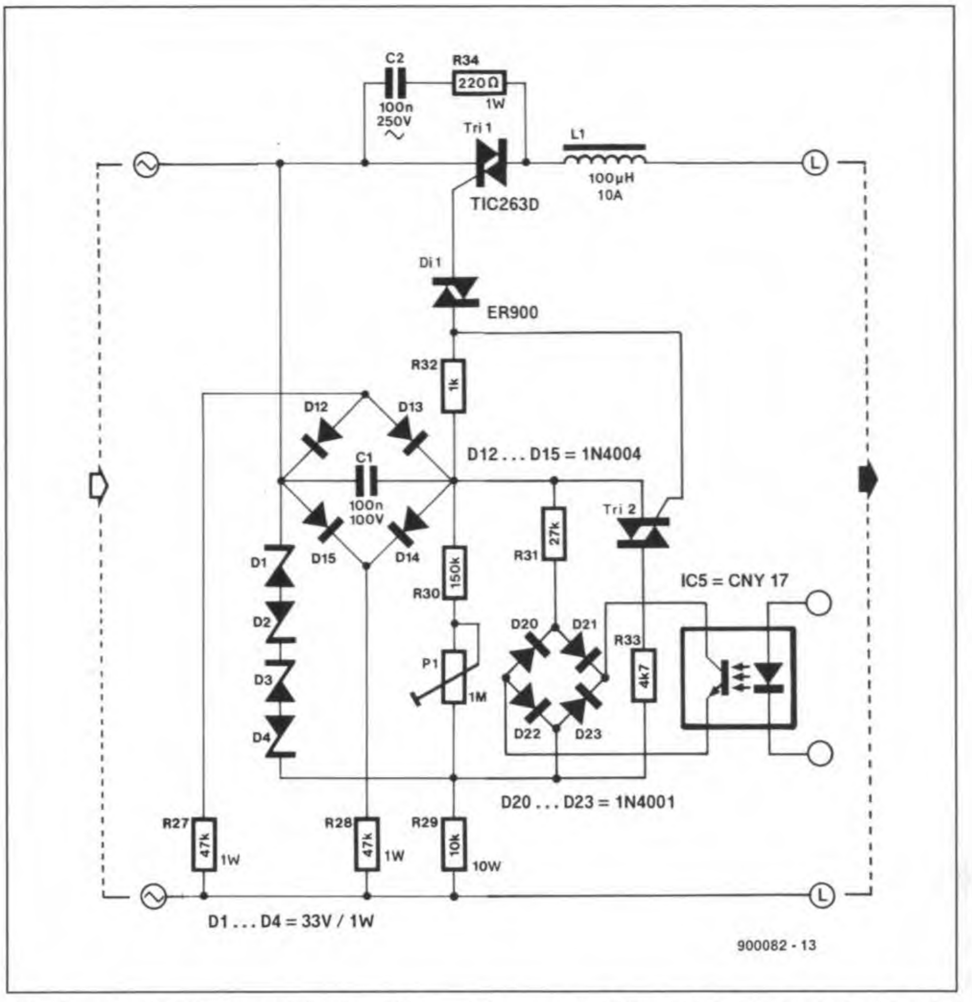


Fig. 3. Circuit diagram of the transformer dimmer. The trigger delay is controlled by the circuit in Fig. 2 via an optocoupler, IC5, and an adjustable bridge rectifier, D20–D23.

load, it may happen that although the instantaneous voltage is high enough to fire the triac, there is no current to 'hold' the device. Therefore, the firing may take place only when the load current is sufficiently high to keep the triac conductive. However, since the load current in a power supply is variable, the phase shift between voltage and current is also variable. This means that the width of the trigger pulse rather than the position must be controlled. If the pulse were simply shifted, the result would be an asymmetrical output current with a high d.c. component, causing rapid saturation of the transformer winding. When the pulse is stretched, however, due care must be taken to prevent it from extending over the zero crossing of the mains voltage.

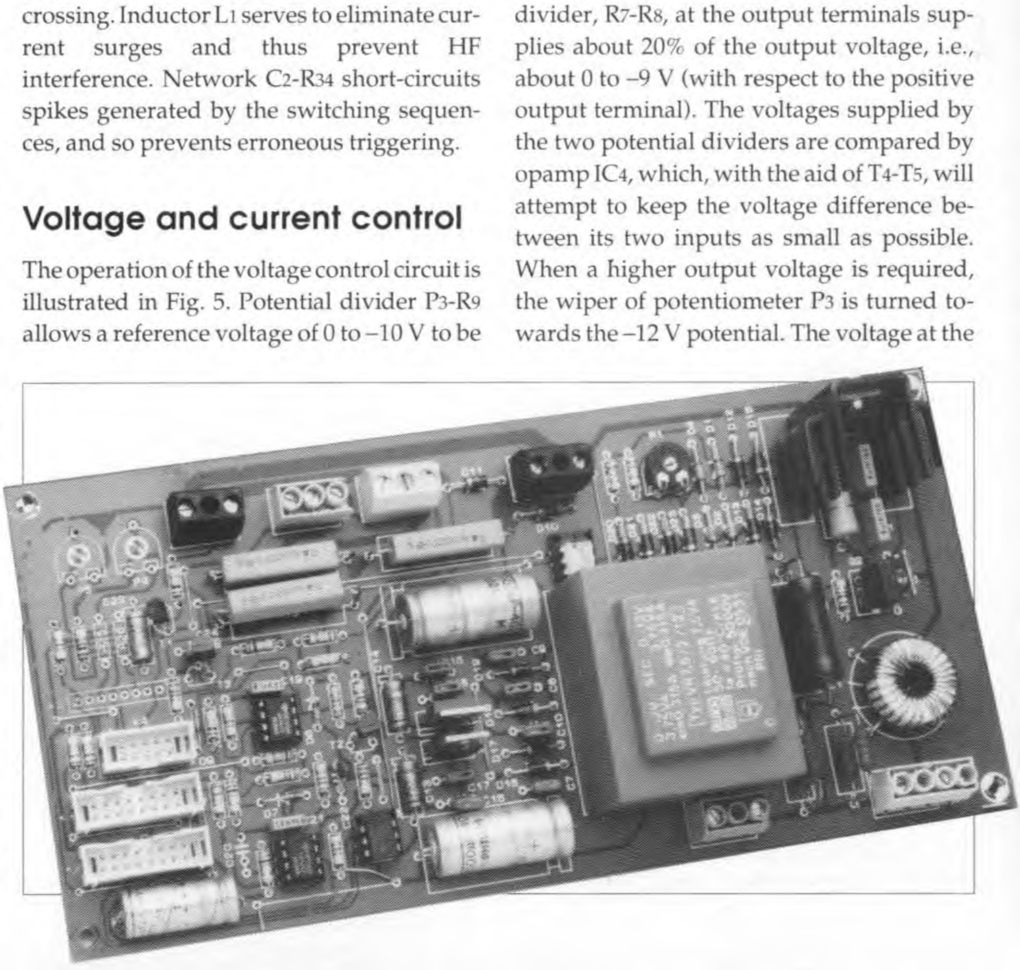
The circuit section in Fig. 3 stretches the first pulse by means of pulse sequence triggering, an approach which is particularly suited to applications with load currents that are prone to variation. The *R-C* network connected between the live and neutral lines of the mains serves to delay the trigger instant. The network consists of C1, potential divider R29-P1-R30 (branch 1), series resistor R31 and bridge rectifier D20–D23 (branch 2). The combination of the bridge rectifier and the optocoupler it powers simply forms an adjustable resistor for alternating voltages, so that both branches have the same function: making the trigger delay, ϕ, variable (see Fig. 4a). The basic delay is determined by P1.

When the power supply is switched on, C1 is charged. When the trip voltage of the diac is reached, both Di1 and Tri1 are fired. When a trigger current flows from C1 to Tri1, resistor R32 drops a voltage which is high enough to trigger a smaller triac, Tri2. The result is that the discharge time is no longer determined by the two branches, but by (R33+R29)C1. When C1 can no longer supply the hold current for Tri2—which happens fairly quickly because of the small resistors R33 and R29—the triac blocks and C1 charges again. This sequence is repeated until just before the zero-crossing, when the mains voltage can no longer charge C1 (see Fig. 4a). The waveform across the thyristor is shown as a dashed line in Fig. 4b. Figure 4c, finally, shows the waveform of the current shifted by an angle φ as a dashed line, and the waveform produced by the dimmer as a solid line. Asymmetry of the waveform occurs during the first half-cycle only. The triac conducts up to instant 'B', when the load current falls to zero.

The function of the remaining parts in this section of the circuit is quickly explained: the zener diodes limit the voltage across Tri2 to about 66 V whilst providing a stable reference voltage for the trigger circuit. Components D12, D13, D14, R27 and R28 ensure that C1 discharges during the zero-crossing. Inductor L1 serves to eliminate current surges and thus prevent HF interference. Network C2-R34 short-circuits spikes generated by the switching sequences, and so prevents erroneous triggering.

Voltage and current control

The operation of the voltage control circuit is illustrated in Fig. 5. Potential divider P3-R9 allows a reference voltage of 0 to –10 V to be set between ground (the positive output terminal) and –12 V. A second potential divider, R7-R8, at the output terminals supplies about 20% of the output voltage, i.e., about 0 to –9 V (with respect to the positive output terminal). The voltages supplied by the two potential dividers are compared by opamp IC4, which, with the aid of T4-T5, will attempt to keep the voltage difference between its two inputs as small as possible. When a higher output voltage is required, the wiper of potentiometer P3 is turned towards the –12 V potential. The voltage at the



non-inverting input of IC4 drops, so that the output voltage of the opamp rises. Conversely, when a lower output voltage is set either by the user turning P3, or by the actuation of the voltage limiting circuit, the inverting input is at a higher potential than the non-inverting input, so that the opamp output voltage drops.

The current control circuit (Fig. 6) operates in a similar manner. Like IC4, opamp IC3 will attempt to keep its output voltage at 0 V. The main difference with the voltage control circuit, however, is that the reference voltage for the opamp (applied to the non-inverting input) is permanently grounded via R1, while the current is measured as the drop (max. 1.1 V) across series resistor R18. Potential divider P2-R3 is arranged so that its junction carries a voltage between −1.1 V and +1.1 V with respect to the positive output terminal. When no current flows through R18, the positive side of P2 is at ground potential. When P2 is advanced to the 5-A position, i.e., to its full resistance of 2.2 kΩ, the inverting input of IC3 is at a voltage of −1.1 V. Consequently, the voltage at the opamp output rises.

When a current of 5 A flows, R18 supplies 1.1 V. When P2 is turned to the other extreme position (i.e., a resistance of 0 Ω), the voltage at the inverting input is higher than that at the non-inverting input, so that the opamp output voltage drops.

As shown by Figs. 5 and 6, and also by the complete circuit diagram in Fig. 7, the anodes of D8 and D24 share a common connection, R23, where the opamp outputs of the current and voltage control circuits are joined. This means that the opamp that supplies the lower output voltage determines the base voltage of the current booster, T4-T5. Resistor R23 serves to hold the bases of T4-T5 at about +11.5 V. Diodes D7 and D9 decouple the opamp outputs, preventing current from flowing between them. One of the series-connected LEDs lights when the voltage at the associated opamp output drops to a level below 11.5 V minus two diode voltages (D24-D7 or D8-D9). This happens when the relevant limiter (current or voltage) starts to operate.

During the switching-on sequence the

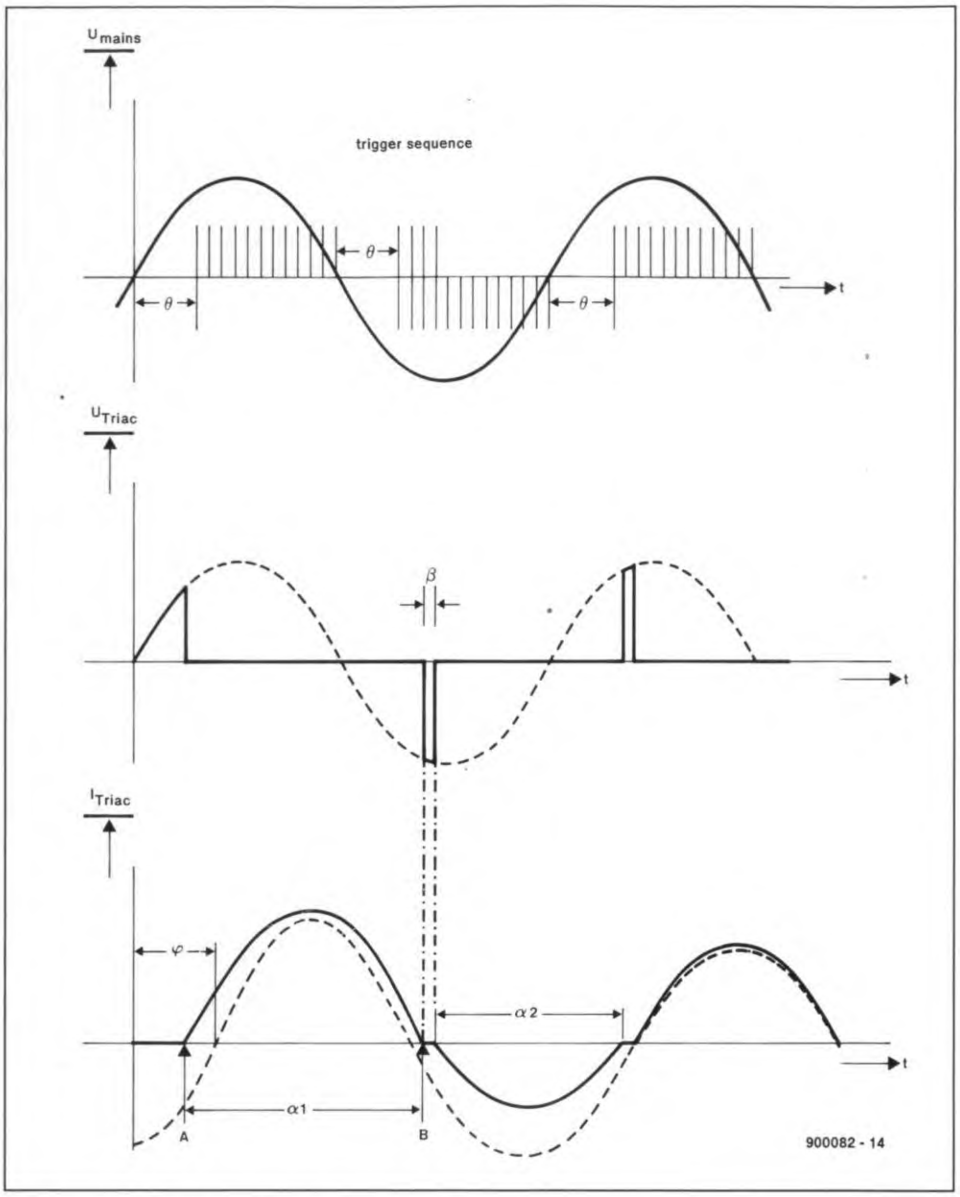


Fig. 4. Illustrating the basic operation of the dimmer for inductive loads, applied here for the purpose of transformer preregulation. Fig. 4a shows the position of the trigger pulses with respect to the mains voltage. The voltage across triac Tri1 as compared to the mains voltage (dashed line) is shown in Fig. 4b. Fig.4c, finnaly, shows the current shifted by an amount of φ, without (dashed line) and with (solid line) phase angle control.

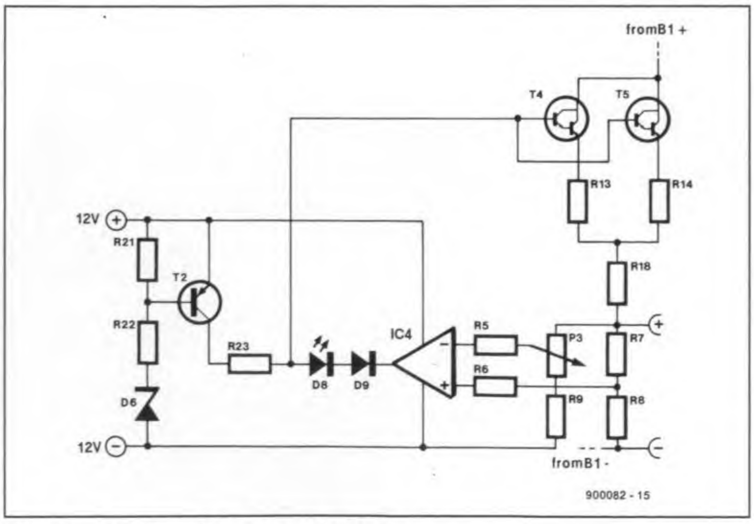


Fig. 5. Basic voltage control circuit.

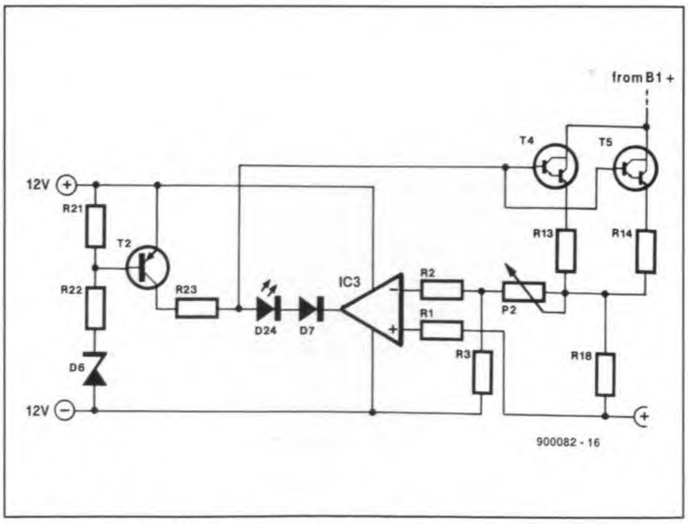


Fig. 6. Basic current control circuit.

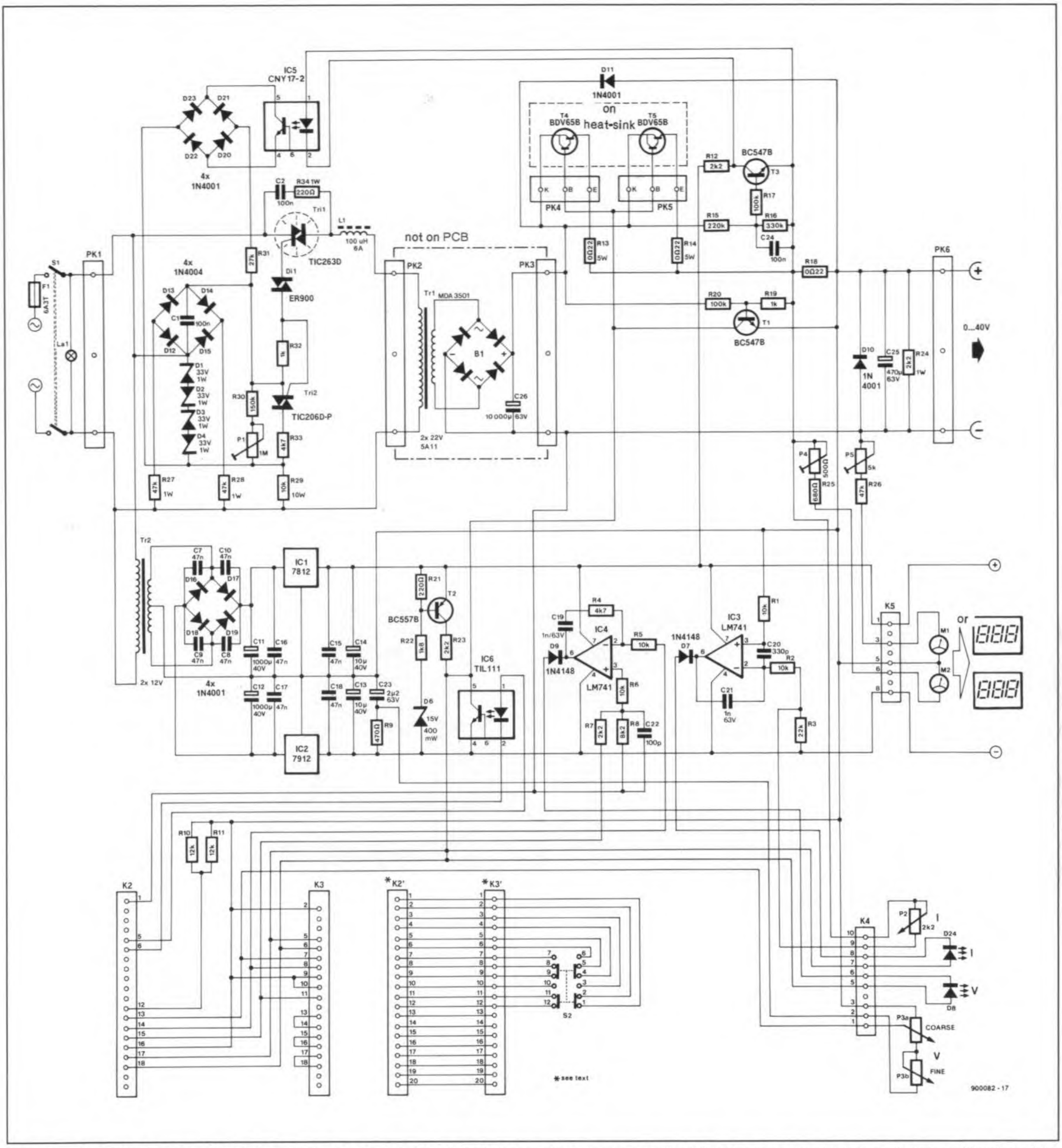


Fig. 7. Circuit diagram ofthe laboratory power supply. Two of these circuits are required for the parallel, series and symmetrical modes.

circuit around T2 keeps the series transistors off until the zener voltage of D6 is reached. This happens when the negative supply voltage of the opamp is sufficiently high. In this way, the voltage peak at switch-on is limited to about 2.5 V above the set output voltage, which is available after a few milliseconds. Although the switch-on peak is not likely to cause damage to most equipment powered by the supply, it is recommended to first switch on the PSU and then connect the load.

The current limiting function of the PSU is provided by the circuit in Fig. 8. As long as the pre-regulation circuit operates correctly, there exists a constant voltage difference across T4-R13 and T5-R14. In a fault condition of any kind (overcurrent, overvoltage), T1 is switched on via potential divider R19-R20. This reduces the base voltage of the darlington transistors, so that the output current is limited. To implement a combined current/temperature overload function, replace resistor R20 by a 100-kΩ NTC (negative temperature coefficient) resistor which is bolted on to the heat-sink, close to T4-T5. ❑

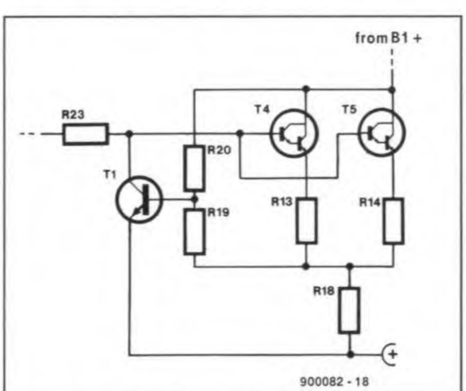


Fig. 8. Basic layout of the current limiter.

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400-watt laboratory power supply

October 1989 and November 1990

A number of constructors of this popular project have brought the following problems to our attention.

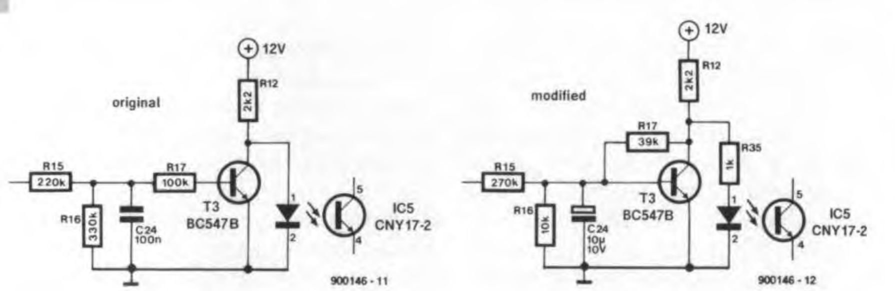
1. The onset point of the current limit circuit lies at about 3 A, which is too low. Solve this problem by replacing T1 with a Type BC517 darlington transistor, and R20 with a 82kΩ resistor.

2. Depending on the current transfer ratio of the optocoupler used, the transformer produces ticking noises. This effect, which is caused by overshoot in the pre-regulation circuit, may be traced with the aid of an oscilloscope monitoring the voltage across C26 at a moderate load current. The capacitor must be charged at each cycle of the mains frequency, and not once every five cycles. The problem is best solved by reducing the amplification of the regulation circuit. Replace R17 with a 39 kΩ resistor, and create feedback by fitting it between the base and the collector of T3. Also add a resistor in series with the optocoupler. These two changes are illustrated in Figs. 1 and 2. Lower R16 to 10 kΩ, increase C24 to 10 µF, and increase R15 to 270 kΩ.

3. Excessive heating of the transformer is caused by a d.c. component in the primary winding. This is simple to remedy by fitting a capacitor of any value between 47 nF and 470 nF, and a voltage rating of 630 V, across the primary connections. This capacitor is conveniently mounted on to the PCB terminal block that connects the transformer to the mains.

4. One final point: when using LED DVMs for the voltage/current indication, their ground line must be connected to the **positive** terminal of C12.

1



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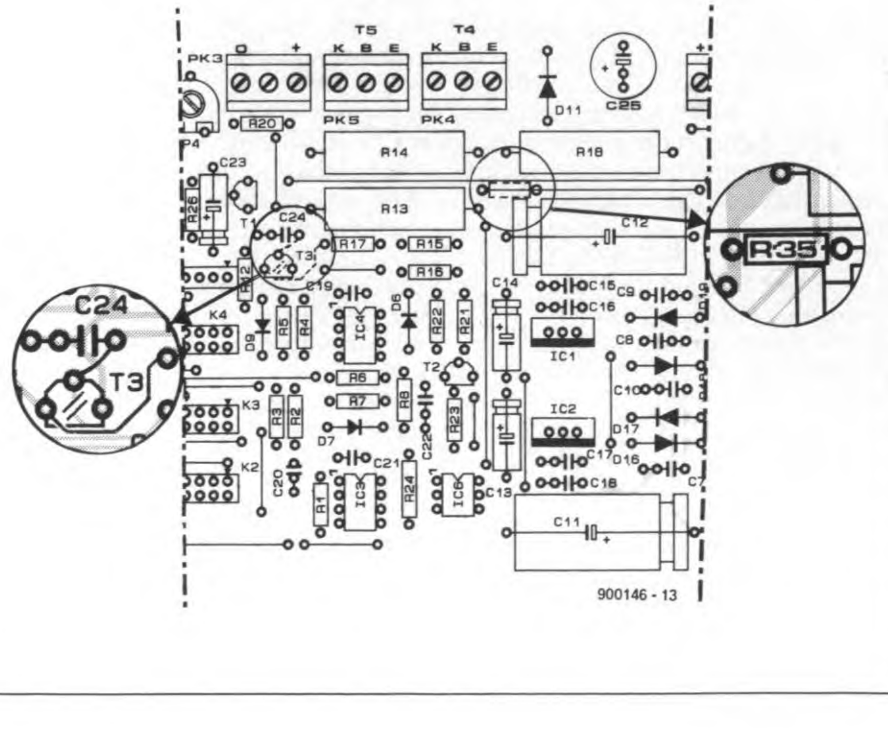

Hard disk monitor

December 1989

In some cases, the circuit will not reset properly because the CLEAR input of IC3A is erroneously connected to ground. Cut the ground track to pin 3 of IC3, and use a short wire to connect pin 3 to pin 16 (+5 V).

Microprocessor-controlled telephone exchange

October 1990

In some cases, the timing of the signals applied to IC17 causes a latch-up in the circuit, so that the exchange does not detect the state of the connected telephones properly. Solve this problem by cutting the track to pin 1 of IC17, and connecting pin 1 to ground (a suitable point is the lower terminal of C6).

The text on the fitting of wires on the BASIC computer board (page 19, towards the bottom of the right-hand column) should be modified to read: 'Finally, connect pin 6 of K2 to pin 7 of IC3 ($\overline{Y7}$ signal).'

S-VHS/CVBS-to-RGB converter (2)

October 1990

The capacitor marked 'C37', next to R21 on the component overlay (Fig. 7b and ready-made printed circuit board), should be marked 'C39'.

In case they are difficult to obtain locally, inductors type 119-LN-A3753 (L1) and 119-LN-A5783 (L2) may be replaced with the respective types 119-ANA-5874HM and 119-ANA-5871HM, also from Toko, Inc. Suggested suppliers are Cirkit Distribution Ltd., and C-I Electronics.

EPROM simulator

December 1989

Counters IC3 and IC4 may not function properly owing to a too low supply voltage. This problem may be solved by replacing IC12 with a 7806. Alternatively, use BAT85 diodes in positions D1 and D2.

Programmer for the 8751

November 1990

The ready-programmed 8751 for this project is available at £35.25 (plus VAT) under order number **ESS 7061**, not under order number ESS 5951 as stated on the Readers Services pages in the November and December 1990 issues.