variable power supply

0–24 V, 1 A or 2 A

ideal for the small workshop

The variable power supply described in this article is the latest in a long line of power units published in this magazine over the past fifteen years or so. Because of its wide voltage range and presettable current limiting, it is ideally suited to general-purpose applications in a small electronics workshop.

Design by K.A. Walraven

A variable power supply, a soldering iron and a multimeter form the minimum basic equipment required in a small electronics workshop. Unfortunately for many, a commercial variable power unit is not exactly cheap, which is an excellent reason for building one from scratch. The power source described in this article is ideal for that purpose. It has a number of preset facilities, its design is straightforward, and it has the facility to be connected to a digital voltmeter – DVM – module to display the output voltage and current. Moreover, apart from some power field-effect transistors – FETs – it is constructed from readily available standard components. Finally, it may be constructed to provide an output current of 1 A or of 2 A.

DESIGN

The basic setup of a power source is fairly simple—see **Figure 1**. The alternating voltage available at the secondary of the mains transformer is converted into a direct voltage by full-wave rectifier bridge B_1. The level of the direct voltage is raised by two parallel-connected field-effect transistors, T_1 and T_2, located between the negative output terminal and ground.

The transistors are driven by two control circuits based on operational amplifiers – op amps – IC_1 and IC_2. These circuits continuously compare the output voltage and the output current with preset wanted values.

In contrast to usual power supply designs, the FETs are not arranged as source followers. This is a deliberate choice intended to save energy. This becomes clear when it is realized that the potential at the gate of the transistors needs to be about 6 V higher than that at the source. In the present design, this is effected by driving the gate with reference to the internal earth of the power unit and not with reference to the positive output rail as is usual.

An auxiliary voltage of +9 V for the control circuits is provided by regulator IC_3. This voltage also functions as reference potential: the wanted values for the voltage control and current control circuits are set with P_1 and P_2 respectively.

VOLTAGE REGULATION

The output voltage across capacitor C_2 floats, that is, the positive capacitor terminal is linked to the non-regulated supply voltage (++). The negative output rail is linked to the drains of transistors T_1 and T_2.

The reference voltage is measured with reference to the negative output rail, which is why the input of IC_1 is connected via R_3-R_4 and R_6-R_2. These resistor combinations ensure that the output voltage is compared with the wanted value set by P_1

This arrangement works fine as long as the ratios R_3:R_4 and R_6:R_2 are precise, which means that the resistors must have a tolerance ≤ 1%.

The differential voltage at the output of IC_1 is used to control the potential at the gates of the FETs via diode D_1. Normally, the transistors are driven into saturation via R_5 and cut off by the voltage circuit or the current control circuit. Diode D_7 is added to limit the maximum gate potential of the two transistors; this shortens the reaction time when the devices are in the saturation mode.

Resistors R_{10} and R_{11} prevent any high-frequency oscillations.

CURRENT REGULATION

The output current is monitored in the traditional manner by measurement of the voltage drop across a shunt resistor. In the present circuit, this shunt resistor is formed by the source resistors, R_{12} and R_{13}, of the FETs.

Since the differences between individual FETs may be significant, the transistors have been given a fairly large source resistor of 1 Ω. So, when the output current is, say, 2 A, that is, a current of 1 A flows through each transistor, the potential drop across each resistor is 1 V.

The two voltages are averaged by resistors R_9 and R_{14}, so that, even if the split between the two transistors is far from ideal, the total current is measured at all times. The average voltage level is compared with the wanted value, set with P_2, in IC_2. If the current is unduly large, the output voltage of the op amp drops and the transistors are cut off via diode D_3. To ensure that they are firmly cut off, diodes D_1 and

Figure 1. Circuit diagram of the variable power supply. The output voltage is set with P_1 and the output current limit with P_2. Digital voltmeter and ammeter modules may be connected to +V and –V, and +I and –I, respectively.

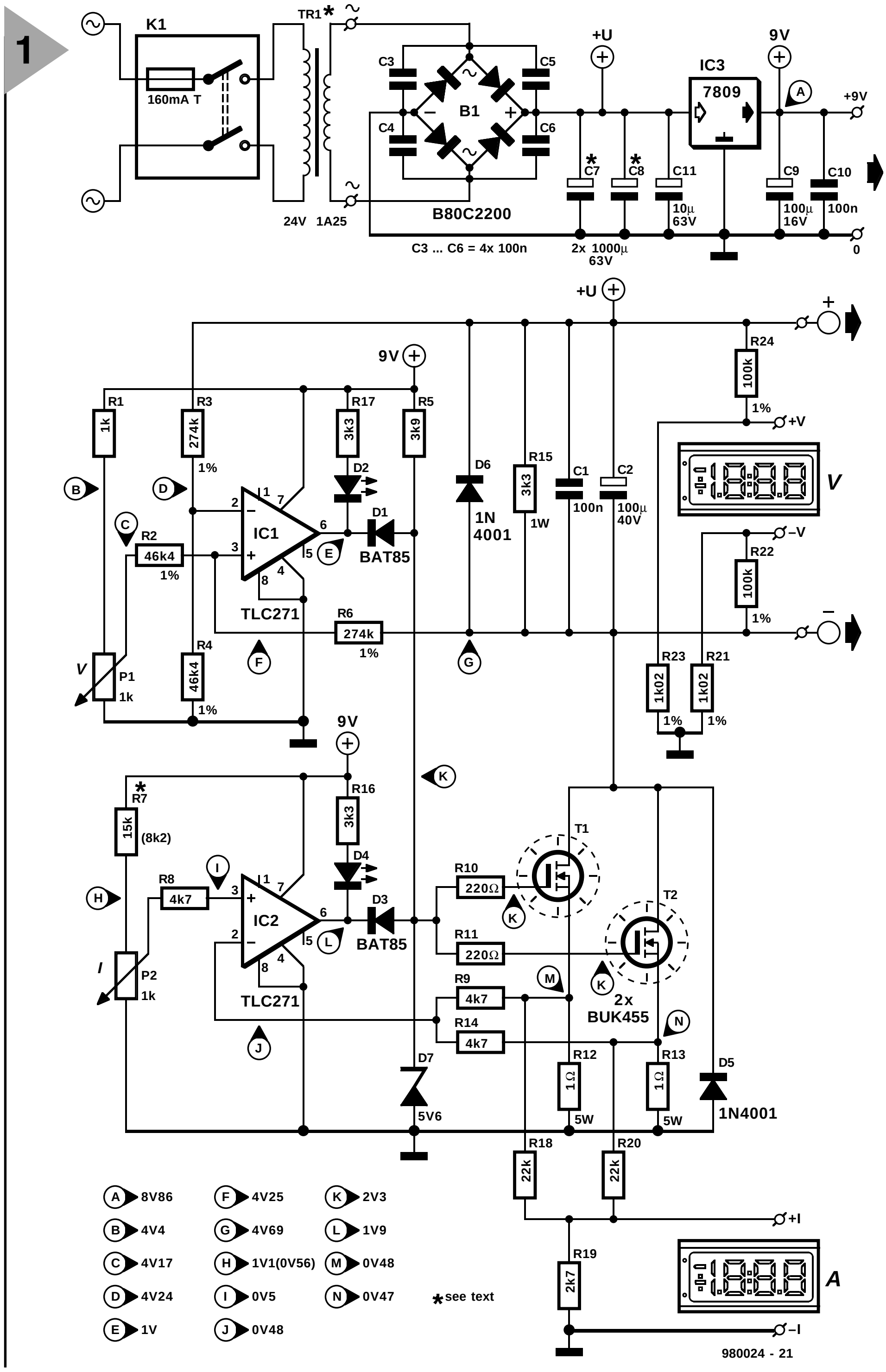

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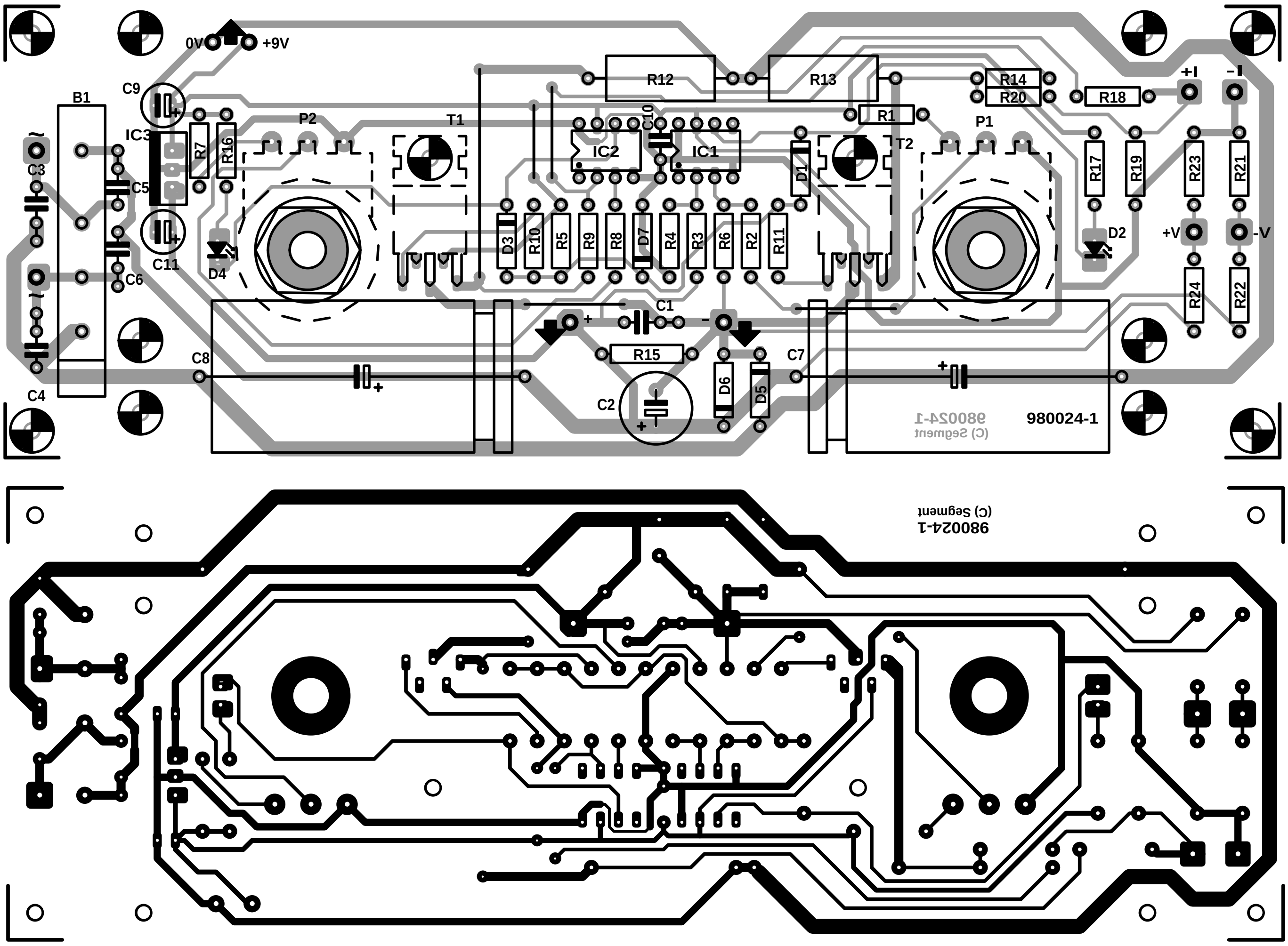
Figure 2. The design of the printed-circuit board allows it to be mounted behind and in parallel with the front panel of the enclosure.



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D_3 are Schottky types.

Light-emitting diodes D_2 and D_4 serve to indicate that the voltage regulation and current regulation respectively operate correctly. Note that these diodes cannot be connected in series with D_1 and D_3, since then the transistors cannot be cut off completely.

It would be possible to give the op amps a negative supply line, but it is, of course, much simpler (and less expensive) to place the LEDs as shown. It is true that this raises the current by about 2 mA, but in a power unit this hardly matters.

ALSO ...

Diodes D_5 and D_6 protect the circuit against too high a voltage and against an incorrectly polarized voltage.

Resistor R_{15} drains away the tiny

Figure 3. Photograph of the completed prototype of the variable power supply. The mains transformer dictates the height of the enclosure.

Parts list

Resistors:
R_1 = 1 kΩ
R_2, R_4 = 46.4 kΩ, 1%
R_3, R_6 = 274 kΩ, 1%
R_5 = 3.9 kΩ
R_7 = 15 kΩ (1 A version); 8.2 kΩ (2 A version)
R_8, R_9, R_{14} = 4.7 kΩ
R_{10}, R_{11} = 220 Ω
R_{12}, R_{13} = 1 Ω, 5 W
R_{15} = 3.3 kΩ, 1 W
R_{16}, R_{17} = 3.3 kΩ
R_{18}, R_{20} = 22 kΩ
R_{19} = 2.7 kΩ
R_{21}, R_{23} = 1.02 kΩ, 1%
R_{22}, R_{24} = 100 kΩ, 1%
P_1, P_2 = 1 kΩ linear potentiometer

Capacitors:
C_1, C_3–C_6, C_{10} = 0.1 μF
C_2 = 100 μF, 40 V, radial
C_7, C_8 = 1000 μF, 63 V (1 A version); 2200 μF, 63 V (2 A version)
C_9 = 100 μF, 16 V, radial
C_{11} = 10 μF, 63 V

Semiconductors:
B_1 = B80C3300/2200 rectifier
D_1, D_3 = BAT85
D_2, D_4 = LED, red, high efficiency
D_5, D_6 = 1N4001
D_7 = zener diode 5.6 V, 400 mW
T_1, T_2 = BUK455-100A or BUK106-50S (Philips Semiconductors) – see text

Integrated circuits:
IC_1, IC_2 = TLC271CP
IC_3 = 7809

Miscellaneous:
K_1 = mains entry with integral on/off switch and 0.16 A slow-blow fuse
Tr_1 = mains transformer, 24 V, 1.25 A (1 A version) or 24 V, 2.5 A (2 A version)
heat sink (for T_1-T_2): 1.2 K W^{-1}
2 off chassis socket, 3.5 mm
enclosure 80–100×200×180 mm (1 A version) or 100–120×200×180 mm (2 A version)
PCB order no. 980024 (see Readers Services towards the end of this issue)
optional: instruments for measuring the output voltage and output current – see text

current through R_6 and any leakage of the FETs and so, in fact, determines the minimum output voltage.

Capacitors C_1 and C_2 improve the stability of the circuit and its performance at sudden variations in load.

VOLTMETERS AND AMMETERS

Several potential dividers (R_{18}–R_{24}) are provided on the printed-circuit board to enable digital measuring instruments to be connected.

Divider R_{18}–R_{20} is intended for current measurement. It is in parallel with source resistors R_{12} and R_{13} (I_1 and I_2). The digital ammeter or DVM module is connected to +I and –I. Most digital modules have a sensitivity of 0.2 V. Since the potential drop across R_{12} and R_{13} is 1 V when the output current is 2 A, the attenuation of R_{18}-R_{19} is × 5.

The attenuator for voltage measurement consists of resistors R_{21}–R_{24} (remember that the output voltage floats). Assuming the same sensitivity of the module (0.2 V), the attenuation should be ×100 (20/0.2). The module is connected between +V and –V.

Since most standard 3½-digit modules can measure up to 1.999 only, the maximum voltage that can be displayed is 19.99 V. This difficulty may be overcome by the use of a module that can measure up to 3.999, or by increasing the attenuation to ×1000 (that is, giving R_{21} and R_{23} a value of 100 Ω). In the latter case, the 'hundredths' digit is no longer available.

MODULE SUPPLY LINES

Power for the modules may be drawn from the regulated +9 V rail (via 0 V and +9 V), but this is not always possible. Many standard inexpensive modules need a separate supply. In fact, the available +9 V line may be used only when the supply rails and the test voltage can be equal, that is, the common-mode range must lie within the power supply range. Modules with an IC from the 7106 family do not meet this requirement and these must, therefore, be given a separate supply.

There are, however, digital modules that can be used with the aid of a small integral voltage converter. The specification of these invariably states emphatically that they do not need an auxiliary voltage. In all other cases, it must be assumed that the module needs an auxiliary voltage.

CONSTRUCTION

The power supply is best built on the printed-circuit board shown in **Figure 2**.

Depending on the enclosure, potentiometers P_1 and P_2 may be mounted directly on the board, since this is to be mounted behind, and in parallel with, the front panel on a number of spacers. The heat sink for the power transistors is mounted at the back of the board. With luck, the fixing holes of the board coincide with the space between two adjacent fins of the heat sink. This would give a compact unit and ensure that the heat sink cannot be touched accidentally – it gets pretty hot!

The transistors are soldered to the underside of the board and screwed firmly to the heat sink. It is best to do this in reverse order: bend the terminals of the transistors to the required shape, mount the board on the heat sink, screw the transistors in place and then solder them carefully with the soldering iron between board and heat sink.

It is not necessary to isolate the transistors; in fact, from a thermal point of view, it is better not to. It is, however, essential to make sure that the heat sink does not touch other parts and is well isolated from its surroundings. The use of insulating washers, provided they are of good quality, is safer (use aluminium oxide types, not mica). Also, the use of heat conducting paste is a must.

Drill some additional ventilation holes in the enclosure, both above and underneath the heat sink. Consideration should be given to the use of a small fan, because the inside of the small enclosure gets very hot. Standard 12 V PC fans run well on 9 V (and are then also quieter). It is, of course, possible to provide a 12 V line with the aid of an additional 7812 voltage regulator.

It is advisable to use a mains entry with integral fuse mounted at the back of the enclosure. This keeps the presence of mains voltage inside the unit to a minimum

Note that DVM modules with integral lighting draw a current of 20–30 mA, and it is, therefore, advisable to mount the voltage regulator on a separate heat sink of about 20 K W^{-1}.

A photograph of the completed prototype is shown in **Figure 3.** Note that the operating controls on the front panel are limited to the two potentiometers, the indicator LEDs, and two chassis sockets for the output.

CHOICE OF OUTPUT CURRENT

If the power unit is intended to provide a current of up to 1 A only, a 2×12 V, 1.25 A mains transformer can be used. It may then be possible to fit the unit in an enclosure of 8–10 cm high. If an output current of up to 2 A is envisaged, the current rating of the transformer must be doubled, in which case the enclosure needs to be 10–12 cm high.

The values of the components in Figure 1 are for the 1 A version. Some alterations in addition to the transformer are necessary for the 2 A version: the value of smoothing capacitors C_2 and C_7 must be increased to 2200 μF, and the value of R_7 must be halved to 8.2 kΩ to ensure that when P_2 is fully open, the output current is 2 A.

TEST AND INSPECTION

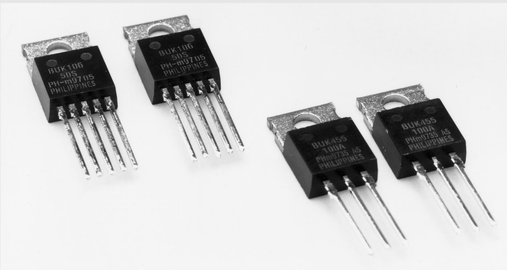
When the construction has been completed, switch on the mains and check the voltage at the test points indicated in Figure 1 with a digital voltmeter. Note that the values in the voltage regulation section based on IC_1 refer to an input voltage of 28 V, an output voltage of 24 V and no load. Those in the current regulation section based on IC_2 and around the transistors refer to an input voltage of 28 V, an output voltage of 20 V, and a load of 1 A.

The circuit does not require setting up or calibration, but after verification of the test voltages, it should be ascertained that the output voltage is 24 V and that an output current of 1 A or 2 A, depending on the version, can be attained.

Also, check that the output voltage can be reduced to nearly 0 V with P_1. A value of 0.2–0.3 V is acceptable, but if the output voltage cannot be reduced to below 1 V, the ratios R_3:R_4 and R_6:R_2 are not equal. This may be remedied by shunting R_2 or R_4 with a resistor of about 1 MΩ (the precise value needs to be ascertained by trial and error) until the output voltage is a minimum.

In case of the voltage module connected to +V and –V, the meter may show a voltage that is not there. The only possible reason for this is an apparent inequality in the ratios R_{22}:R_{22} and R_{24}:R_{23}, which may happen even if resistors with a 1% tolerance are used. The error may be eradicated by shunting R_{21} or R_{23} with a resistor of about 100 kΩ (the precise value needs to be ascertained by trial and error). [980024]

BUK series field-effect transistors



Many readers will be familiar with the BUZ and IRF types of field-effect transistor, but the BUK series used in the present power supply is not (yet) so well-known.

The BUK series comprises a number of versions permitting ever larger voltages and currents. The BUK455-100A used in the power unit, for instance, can handle voltages up to 100 V. A noteworthy property of this FET is its low thermal resistance of 1.2 K W^{-1}. This enables it to dissipate more power (125 W) in a TO220 case than the popular 2N3055 in an SO3 case (115 W). These are, of course, theoretical values (cooling would have to be perfect), but in practice, with a heat sink of 1.2 K W^{-1}, the transistor would be able to dissipate 62.5 W at a ΔT of 150 °, which is a lot. Nevertheless, to play safe, the dissipation in the power supply is divided over two transistors.

The BUK106-50S, a so-called TOPFET from the same series, may also be used. This device is more expensive but has some special properties. It has two additional pins: one for a protection supply input and the other for a flag output. When a supply voltage is applied to the protection supply input, the device will auto-protect itself against voltages higher than 50 V. When that happens, the transistor conducts slightly, which is not necessarily a good thing in a power unit. It will switch itself off when its temperature rises above 150 °C, which is a worthwhile facility in a power supply.

The flag output indicates when a protection circuit is enabled. This circuit is disabled by briefly switching off the supply voltage at the protection supply input.

Both types of FET may be used on the printed-circuit board. The protection supply input pin of the BUK106-50S is then automatically linked to the +9 V rail provided by IC_3. The flag output is not used.