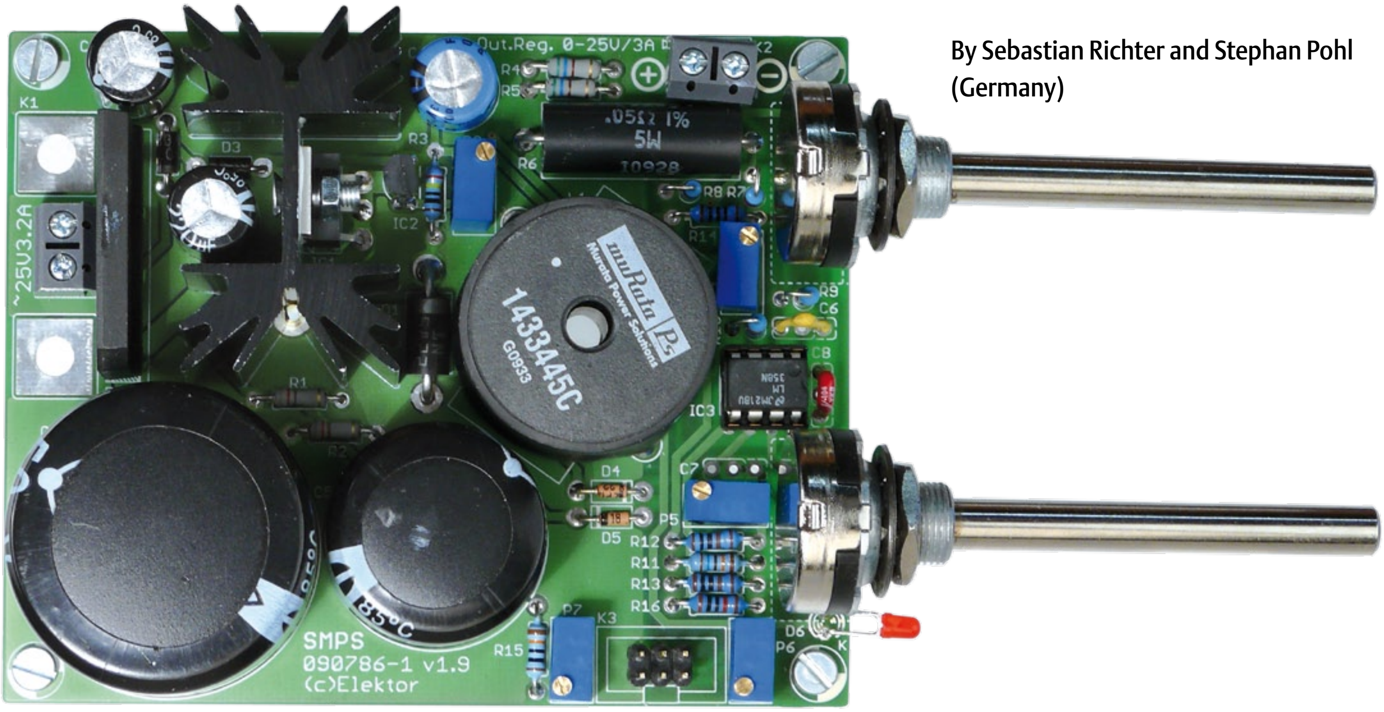
UniLab

A switch-mode 0–30 V / 3 A bench supply



By Sebastian Richter and Stephan Pohl
(Germany)

A power supply with adjustable output voltage and current limiting is part of the basic equipment of every electronics lab. However, the increased complexity of a switch-mode design scares away many potential builders, even though it actually isn't all that complicated if you use a suitable combination of well-known technologies. The circuit described here is suitable for a building a single or dual power supply.

The idea of developing a switch-mode laboratory power supply arose in the electronics enthusiasts group [1] of the Institute for Power Electronics and Electrical Drives (ISEA) [2] at RWTH University in Aachen, Germany. Conceived as a starter project for novice electronics designers, it manages without a microcontroller and can be implemented at low expense.

This power supply is based on an integrated switching regulator to keep the component count within reasonable limits. The functional units of this IC include voltage regulation, switching signal generation, and integrated power switch. This means that only a few external components are necessary.

Thanks to the compact construction, it is easy to build a dual power supply in a single enclosure. A dual power supply is especially handy when you need more than one supply voltage. Naturally, both supplies are galvanically isolated, so they can also be connected in series to achieve higher voltages or used in parallel (connected via diodes) to provide more current.

Architectures

A conventional power supply architecture has a mains transformer followed by a rectifier and a linear regulator that controls the output voltage. At high power levels with a large difference between the input and output voltages, a linear regulator dissipates a lot of power as heat and needs a large heat sink. This high power dissipation makes the power supply inefficient, and it means that the transformer must provide the dissipated power as well as the useful power. This makes the transformer unnecessarily heavy and expensive.

Another option, which results in significantly lower power dissipation and thereby improved efficiency, is to use a switching regulator instead of a linear regulator. Although secondary-side switch-mode power supplies are somewhat more complicated than power supplies with linear regulators, they have only slightly higher component counts thanks to the availability of integrated circuits. The higher efficiency allows a more compact design, and in particular a distinctly smaller heat sink. Although the mains transformer cannot be eliminated, it is smaller than with a linear regulator because the higher efficiency means that transformer does not have to provide as much power that is dissipated as heat.

By contrast, a primary-side switch-mode power supply rectifies the mains voltage straight away without a mains transformer and filters the rectified voltage to obtain a high DC voltage (325 V). This is then converted into a low AC voltage by the combination of a suitable converter (such as a full-bridge circuit) operating at a high frequency (in the kilohertz range) and a small high-frequency transformer. This voltage is in turn rectified to obtain a low DC voltage. A galvanically isolated sensing circuit feeds this voltage back to the regulator section of the converter, which in turn maintains the desired output voltage. The major advantages of this technology are the very small transformer (depending on the switching frequency) and high efficiency (90% or better is possible). However, this form of low-voltage generation requires a very high component count and a complex design, and due to the high input voltage it can be hazardous in the construction and test phases. In addition, the inductive components in particular must often be custom-made.

Consequently, we decided to use the secondary-side switch mode option for this project, which is intended to be suitable for novices. It utilises a step-down (buck) converter topology [3].

Switching regulator

Many ICs are available to simplify the construction of buck converters. The National Semiconductor LM2576 used here is a member of the Simple Switcher family [4] and has already become almost a classic example of its type. Along with a power switch, it contains the functional units for generating the pulse-width modulated drive signal and regulating the output quantity. **Figure 1** shows a block diagram of the internal structure of the LM2576 as well as the standard configuration for output voltage regulation.

The regulator operates by comparing the voltage on pin 4 of IC1 with an internal 1.23-V reference voltage. The difference signal is amplified and compared with a sawtooth waveform. The sawtooth signal goes to zero at the start of each switching cycle, and the power switch is switched off at the same time. When the instantaneous value of the sawtooth signal exceeds the value of the amplified difference signal, the power switch is switched on and remains on until the start of the next switching cycle. As a result, the output voltage (V_{out} in the schematic diagram shown in **Figure 2**) is regulated such that the voltage on pin 4 of IC1, which is taken from the junction of voltage divider P1/R12, is 1.23 V. If P1 is adjusted to a higher resistance, the voltage on pin 4 drops. This causes the switch to remain on longer, and the output voltage increases to the point that the voltage on pin 4 is again 1.23 V. In the opposite direction, reducing the resistance of P1 causes the switch to remain off longer, which causes the output voltage to drop. However, it is not possible to reduce V_{out} below 1.23 V with the standard circuit. If P1 is set to 0 Ω, the output voltage is connected directly to pin 4 via R14. R14 is included in the circuit to prevent the output of IC3b from being connected directly to the power supply output when P1 is set to its minimum value (0 Ω).

A negative auxiliary voltage is generated to allow V_{out} to be adjusted down to 0 V. On the positive half-cycles of the input AC voltage, D2 conducts and charges C2. On the negative half-cycles, D2 is cut off and D3 conducts whenever C2 is charged to a higher voltage than C3. Capacitor C2 discharges into C3, causing C3 to be charged to a voltage that is negative relative to ground. This voltage is stabilised by an LM377 linear regulator (IC2), and it can be adjusted with P3 so that the reference ground potential (PGND) for IC1 is negative relative to the power supply ground by the amount of the reference voltage. This means that the voltage on pin 3 of IC1 is –1.23 V. This offset only affects the regulator circuit in IC1, while the output voltage V_{out} remains referenced to GND. This trick makes it possible to adjust V_{out} down to 0 V.

With this buck converter topology, output capacitor C5 can be 'actively' charged by switching on the power switch, with the result that V_{out} rises. However, C5 can only be discharged 'passively' by the connected load while the power switch is off. It is there-

Features

- Adjustable secondary-side switch-mode power supply (buck converter)
- Output voltage 0–30 V (typical) (25 V minimum)
- Adjustable current limiting up to 3 A
- Maximum output power 90 W
- Compact PCB layout
- Switching frequency 52 kHz
- Parts kit available from the Elektor Shop

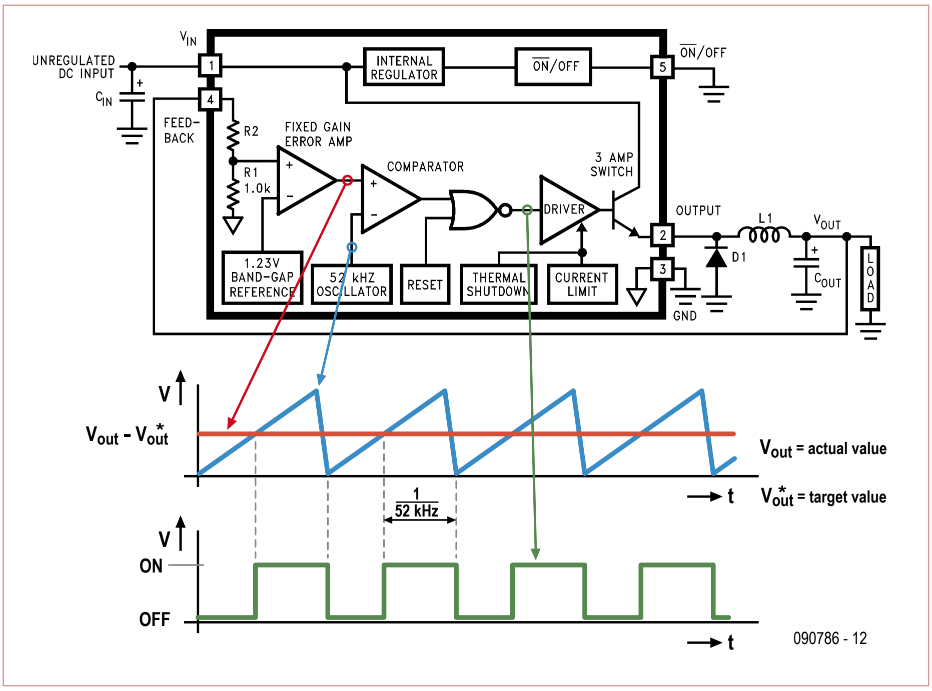


Figure 1. Block diagram and basic circuit of the switching regulator.

fore a good idea to provide a minimum load, here consisting of R4 and R5, to allow the output voltage to quickly reach the set level even when no external load is connected.

Current limiting

Adjustable current limiting is often very helpful in a lab environment in order to protect the connected circuitry. For this purpose, the circuit detects the voltage across sense resistor R8, which is proportional to the output current. IC3a amplifies this signal by a factor of approximately 4, and C6 attenuates high-frequency noise. P4 is used to compensate for the offset of the current sensing circuit (including the offset of IC3a). IC3b is wired as an adjustable non-inverting amplifier, with D6 and D7 at the output allowing only positive output currents. As a result, IC3b can increase the voltage on R12 but not reduce it. If IC3b increases the voltage on pin 4 of IC1 above the value resulting from the setting of P1, the current limiter causes the power switch to switch off earlier. This reduces the value of V_{out} and thus limits the output current to the maximum level set by P2.

If the current is less than the set maximum value, the anode of D6 (and D7 as well) is negative relative to the cathode, which causes the diodes to be cut off. In this state, the switch-off point of the power switch is determined solely by the voltage regulator. D6 is connected in series with D7 to prevent reverse-voltage breakdown of the LED, since the maximum allowable reverse voltage of the LED is only around 5 V.

The upper limit of the adjustable current range can be preset with P5. The lower limit is determined by the maximum gain of IC3b. The desired current limit level (maximum current) can be set within these limits by adjusting P2. As an LED, D7 provide a visual indication when current limiting is active.

Construction and initial use

The transformer should be rated for at least 1.2 times the nominal output power of the power supply, which means at least 90 watts or so for a single power supply. The secondary voltage should not be higher than 25 V, since the maximum voltage that IC1 and IC2 can handle is 42 V. With a 25-V transformer, you still have some safety margin even with 10% overvoltage on the AC mains. If you want to build a dual power supply, you can use a toroidal transformer with twice the power rating and two secondary windings as an alternative to two separate transformers. For sense resistor R6, you can use a length of inexpensive resistance wire instead of a 'real' sense resistor. With the specified resistance wire, a length

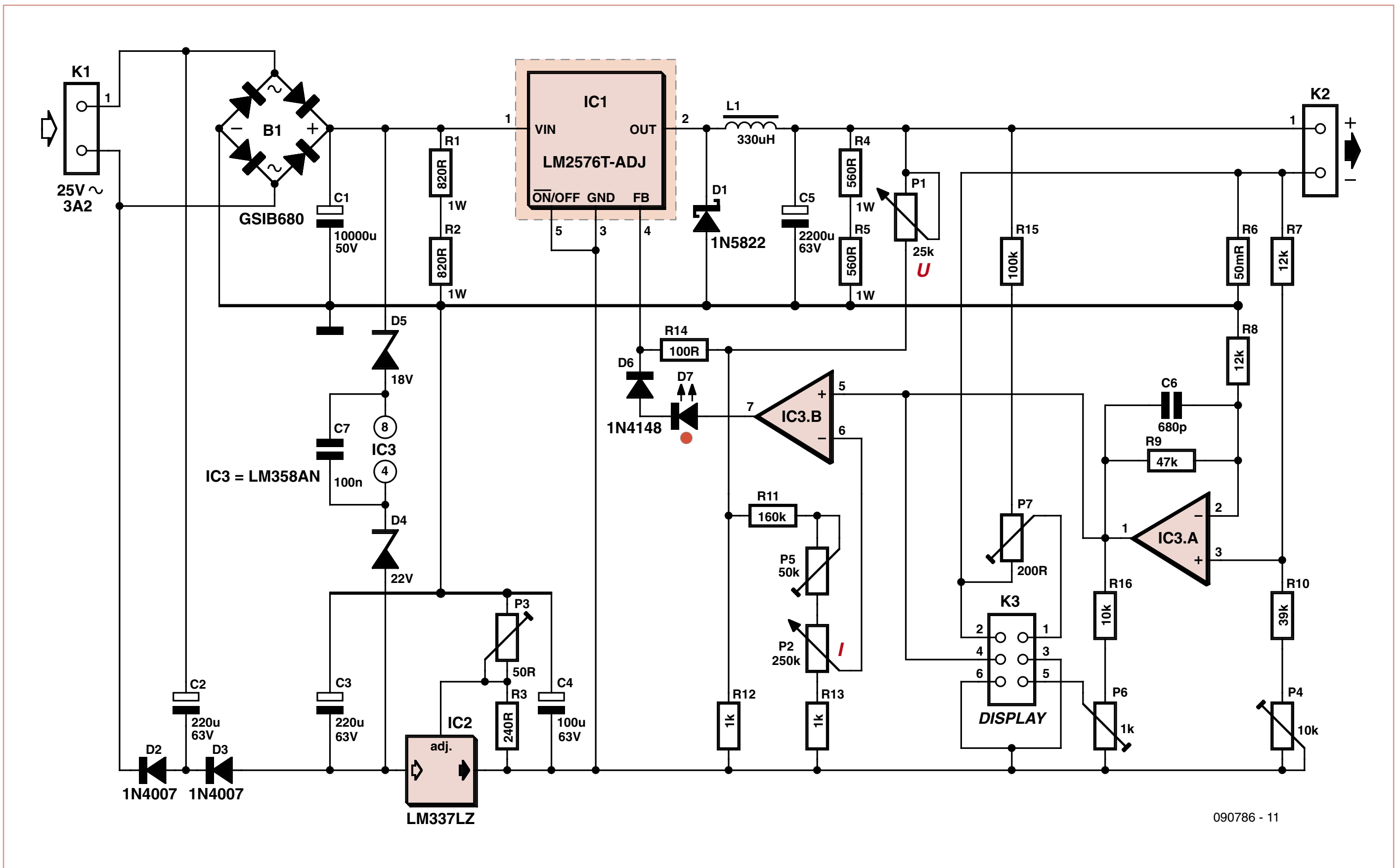


Figure 2. Power supply schematic diagram. A negative auxiliary voltage allows the output voltage to be adjusted down to 0 V.

COMPONENT LIST

Resistors
(default: 250 mW 1%)
R1,R2 = 820Ω
R3 = 240Ω
R4,R5 = 560Ω 1W
R6 = 0.05Ω 5W (Vishay Dale type LVR-05R0500FE73 or 1.73Ω/m resistance wire, see text)
R7,R8 = 12kΩ
R9 = 47kΩ
R10 = 39kΩ
R11 = 160kΩ
R12,R13 = 1kΩ
R14 = 100Ω
R15 = 100kΩ
R16 = 10kΩ
P1 = 25kΩ potentiometer, linear
P2 = 250kΩ potentiometer, linear
P3 = 50Ω trimpot, multiturn, vertical
P4 = 10kΩ trimpot, multiturn, vertical
P5 = 50kΩ trimpot, multiturn, vertical
P6 = 1kΩ trimpot, multiturn, vertical
P7 = 200Ω trimpot, multiturn, vertical

Capacitors
C1 = 10,000µF 50V radial
C2,C3 = 220µF 63V radial
C4 = 100µF 63V radial
C5 = 2200µF 63V, radial
C6 = 680pF ceramic
C7 = 100nF ceramic

Inductors
L1 = 330µH 4.5A (muRata Power Solution type 1433445C) or 330 µH 3A (Würth type 744137)

Semiconductors
B1 = 800V 6A bridge rectifier (e.g. Vishay type GSIB680)
D1 = 1N5822 (Schottky diode, 40V 3A)
D2,D3 = 1N4007
D4 = zener diode 22V 1W
D5 = zener diode 18V 1W
D6 = 1N4148
D7 = LED, 3mm, red, low current (2mA)
IC1 = LM2576T-ADJ (National Semiconductor) (see text)
IC2 = LM337LZ
IC3 = LM358AN

Miscellaneous
TR1 = power transformer, secondary 25V 3.2 A (see text)
Heatsink for IC1 (T0-220 <9.9K/W, e.g. Fischer Elektronik type SK129 25,4 STS)
K1,K2 = 2-pin PCB terminal block, lead pitch 5mm
K3 = 6-pin DIL pinheader, lead pitch 2.54mm (0.1'')
PCB, order code 090786-1
Kit of parts, contains all components except power transformer. Order code 090786-71, see Elektor Shop section or www.elektor.com/090786.

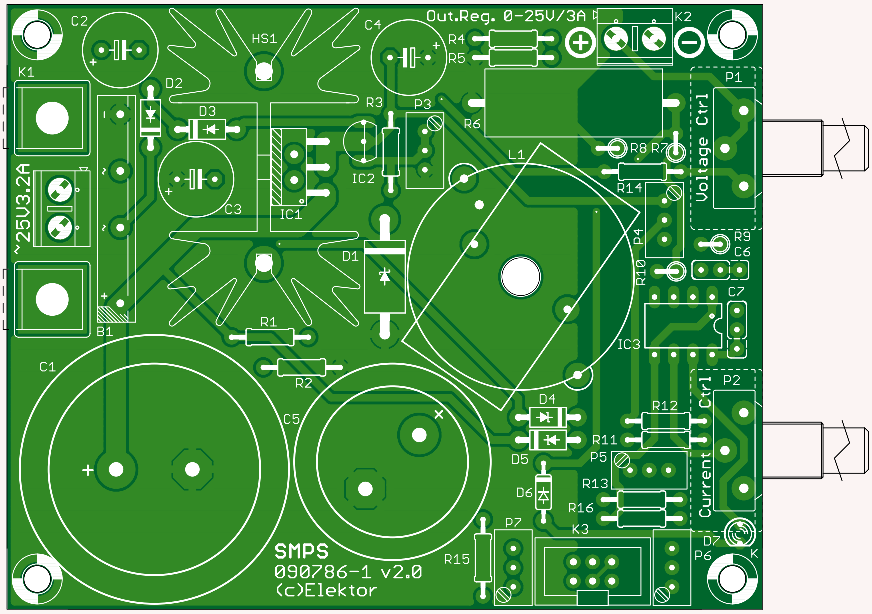
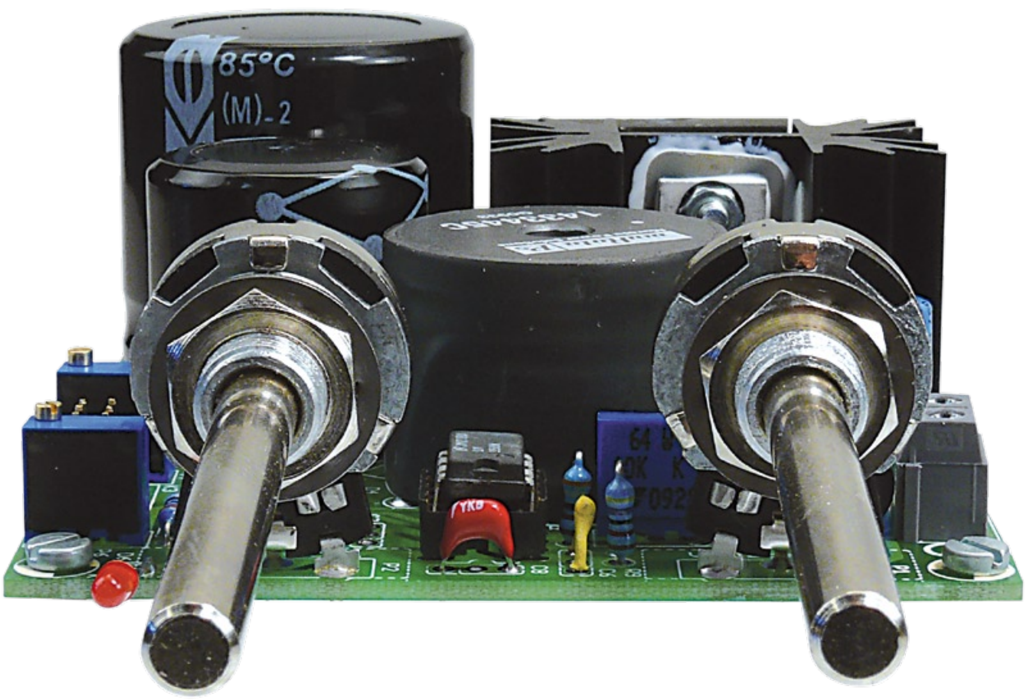


Figure 3. The double-sided circuit board allows very compact power supply construction.



About the authors

Sebastian Richter completed his studies in Electrical Engineering at RWTH Aachen University in 2005 and was awarded the degree of Diplom-Ingenieur (equivalent to an MSc). Since then he has been working as a research assistant at ISEA in the field of power electronics. He is also actively involved in teaching and is one of the co-founders of the Institute's electronics enthusiasts group.

Stephan Pohl completed his studies in Electrical Engineering at RWTH Aachen University in 2008 and was awarded the degree of Diplom-Ingenieur. Since then he has been working as a hardware designer at PicoLAS GmbH, where he is involved in the development of current sources for laser diodes. During his studies, he served as an advisor for the electronics enthusiasts group at ISEA, in which role he was primarily involved in teaching students analogue circuit technology.

of wire equal to the distance between the through-plated lead holes will have a resistance of approximately 50 mΩ. Any small difference can be compensated by adjusting P5.

With regard to parts selection, it is important to use a genuine National Semiconductor LM2576-ADJ, since problems may arise with 'type-equivalent' components from unknown manufacturers.

Before assembling the circuit board (**Figure 3**), you should preset multi-turn trimpots P3 and P4 for minimum resistance (for this purpose, connect the wiper to the appropriate potentiometer terminal as indicated by the PCB layout). After assembling the board, you should again check the polarisation of the electrolytic capacitors (C1, C2, C3 and C5) and setting P1 and P2 to mid travel before switching the circuit on for the first time.

If the circuit is working properly, it should be possible to adjust the output voltage from approximately 0 V to around 25 V after it is switched on. To precisely adjust the zero point, rotate P1 (preferably a multiturn potentiometer) to its minimum resistance and connect a load. Now you can adjust P3 to set the output voltage to exactly 0 V.

To calibrate the current sensing circuit, measure the voltage across the series connection of R15 and P6 (between (IC3a pin 1 and K3 pin 6) with no external load connected. Adjust P4 until this voltage is set to zero.

If you now connect a low-resistance load to the output and turn P2 to its upper limit, you can adjust P5 to set the upper limit of the adjustable current limit range (do not exceed 3 A).

A proper lab power supply also has voltage and current displays. Voltage dividers R15/P7 (voltage) and R16/P6 (current) are provided for this purpose. Potentiometers P3 and P4 are used to set the zero points for the output voltage and current, while P6 and P7 are used to calibrate the built-in instruments. For this purpose, set the power supply output to a point near the upper end of its voltage or current range and calibrate the built-in instruments by comparing the displayed values with reference values measured using a multimeters.

If you want to build a dual lab power supply with two UniLab boards, a tailor-made display unit with a backlit four-line LCD module is being developed in the Elektor lab. It continuously shows the voltage and current of the two outputs. Along with this display unit, Elektor provisionally plans to publish an article on a suitable enclosure and a front panel design in a future edition.

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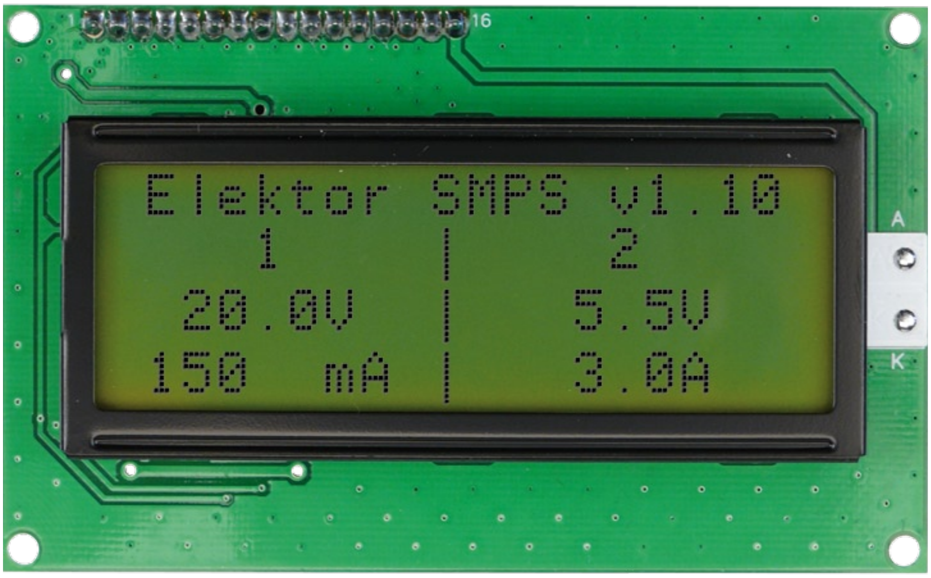

Figure 4. A tailored display unit with a backlit four-line LCD module is being developed in the Elektor lab for building a dual lab power supply with two UniLab boards.

Links and Reference Documents

[1] Bragard, Michael and Richter, Sebastian: 'LED Top with Special Effects', Elektor December 2008 (download from www.elektor.com/080678)

[2] www.isea.rwth-aachen.de/en

[3] Sánchez Moreno, Sergio: 'Cool Power', Elektor June 2008 (download from www.elektor.com/080198)

[4] LM2576 data sheet (download from www.national.com/ds/LM/LM2576.pdf)