Digital Benchtop Power Supply (1)

Part 1:
analogue electronics controlled by microcontroller

Every electronics laboratory needs a powerful regulated bench supply. In the model described here a microcontroller monitors the actual and desired current and voltage settings.

There are many types of laboratory benchtop power supplies available, from the very simple to the highly sophisticated. They range from linear, purely analogue supplies with only voltage regulation to switching supplies with both current and voltage regulation using a microcontroller, also offering programmable signal patterns and various monitoring functions, while also driving an IEEE interface.

Our benchtop power supply lies in the middle of this spectrum. Depending on the rating, it offers a voltage range of 0-25 V at up to 2.5 A or 0-20 V at up to 1 A. The voltage and current settings are adjustable digitally using four buttons each (two for coarse and two for fine control). These provide a resolution of 100 mV in voltage and 10 mA in current. The desired and the actual voltage and current values are shown on a backlit LCD panel. The device can be controlled remotely over its built-in RS232 interface, and the measured current and voltage values are available continuously over this interface. The communication protocol uses only ASCII characters, so that, in the simplest case, HyperTerminal suffices to display and adjust the values. A proper power supply control

program is also available for free download from the author's website at www.pic-basic.de. The source code of this program is also published, so that it can be modified for other applications.

A Microchip PIC16F84 microcontroller controls the power supply, running a program written in PIC-BASIC 1.3. The source code, assembler listing and machine code hex dump for this program are also freely available from the address above.

Classical
analogue regulation

The circuit consists of an analogue part and a digital part, which are assembled on the same circuit

board. Only the pass transistors, the LCD module and the mains transformer (along with the mains input and switch) are not fitted to the board. The classical analogue regulator circuit is brought up-to-date using an LT1491. This IC is a quad

operational amplifier, which has the same pinout and practically the same (or better) characteristics as the legendary LM324. Also, the LT1491 offers rail-to-rail operation on its inputs and outputs. **Table 1** shows a few of the characteristics of the two ICs. The LT1491 earns its place in this circuit despite its

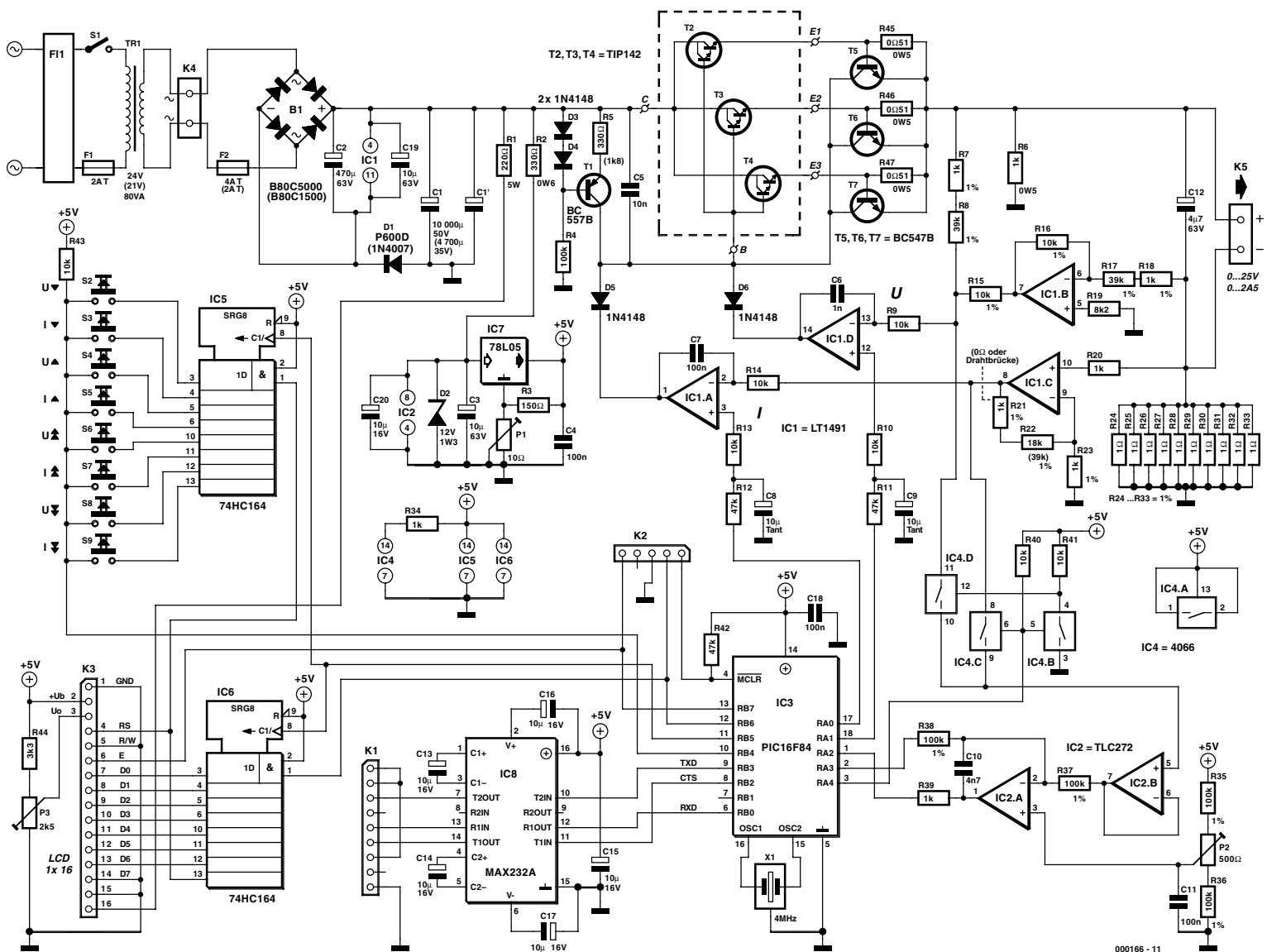| DIGITAL PSU SPECIFICATION IN BRIEF		
	2,5-A version	**1-A version**
Input voltage 230V	−0/+10 % @ 2.5 A / 25 V ±10 % @ 2.5 A / 24 V	±10% @ 1 A / 20 V
Set voltage accuracy	+30 mV typical	+30 mV typical
Set current limit accuracy	+5 mA typical	+5 mA typical
Output voltage ripple	5 mV (voltage regulation) 10 mV (current regulation)	5 mV (voltage regulation) 25 mV (current regulation)

Figure 1. Circuit diagram of the 2.5 A power supply. Values in brackets refer to the 1 A version.

higher price. With the aid of a few close-tolerance metal film resistors the op-amps work sufficiently accurately that only a few calibration points are required.

In a power supply with classical analogue regulation such as the circuit in **Figure 1**, the output voltage and current are measured and continuously compared against the desired values by comparators. For this, the output voltage is taken directly from the output connectors (thereby avoiding errors due to the resistance of the tracks and contacts) and brought into the input voltage range of the comparator using a simple voltage divider.

Current measurement is somewhat more complicated, since in general a shunt resistor is required in the current feedback loop. The resistance of the shunt must be as low as possible in order not to reduce the output voltage range too severely and to keep the power losses low, but on the other hand must be high enough and accurate enough to ensure that the voltage drop (which is proportional to the current) is practically measurable by the comparator and not lost in the offset voltage or noise of the electronics.

The shunt resistance consists of ten 1 Ω resistors (R24-R33) wired in parallel. This is rather cheaper than a 0.1 Ω resistor with a tolerance of 1 %, and the expected deviation from the true value is rather lower. The layout is organised so that only a little track resistance affects the measurement.

With an output current, or load, of 2.5 A, 0.25 V is dropped across the shunt resistance. Op-amp IC1.C multiplies this voltage by a factor of 20, in the 2.5 A version, and 40, in the 1 A model. This amplified voltage is measured and taken to the comparator via R14.

However, the current also has an effect on the voltage measurement. Op-amp IC1.B divides the voltage drop across the shunt by four and inverts it, giving –0.0625 V. If the voltage across the output terminals (i.e., across the load) is 25 V, then 25.25 V relative to the circuit's ground appears at the positive output terminal. Voltage divider R7/R8 and R15 have a total value of 50 kΩ. Across the voltage divider we have 25.25 V+0.0625 V=25.3125 V. Of this, 4/5th is dropped across R7 and R8, and 1/5th is dropped across R15. Across R15 we therefore have a drop of 5.0625 V. At the voltage divider output (at the junction of R8 and R15) we therefore have exactly 5 V relative to the circuit's ground. The voltage at the output of the voltage divider (relative to ground) therefore reflects exactly the output voltage, independent of the current flowing in the shunt resistor. Without this compensation for the voltage error the voltage across the shunt resistor (up to 0.25 V)

would affect the measurement of the output voltage. So that the op-amps can operate with negative voltages relative to ground a negative auxiliary supply is required, which is derived from the input voltage with the aid of diode D1.

The divided-down, amplified and compensated measurement voltages are finally taken to the inverting inputs of op-amps IC1.A and IC1.D via R9 and R14. Op-amp IC1.D, connected as a comparator, compares the actual voltage (at the inverting input) with the desired voltage, and IC1.A does the same for the current. The desired values originate from the PIC16F84 microcontroller (IC3) which can generate two precise analogue voltages thanks to R/C combinations R11/C9 and R12/C8. The voltages are produced using pulse-width modulation of the microcontroller's output pins. These two D/A converters have a resolution of 8 bits.

C6 and C7 cause the two comparators to exhibit a lowpass response. The outputs drive the base connection of the pass transistors via D5 and D6 in a 'wired OR' configuration. If one of the measured values exceeds the desired value, the base is pulled towards ground (or even slightly below) and the transistors are switched off. If neither the desired current nor the desired voltage is reached, constant current source T1 delivers a base current of 2 mA (for a 2.5 A power supply) or 360 μA (for a 1 A power supply), independent of the output voltage.

Such a low base current is only practical because power Darlington transistors (T2, T3 and.T4) are used. For the 2.5 A unit three Darlington transistors are fitted. In order that the current is properly shared between the transistors, 0.51 Ω emit-

ter resistors are provided. If the voltage across one of the three resistors rises above 0.65 V (at around 1.3 A), one of the transistors T5, T6 and T7 will turn on and thereby turn off the base current to the Darlington transistors. This affords effective protection against current spikes that may occur if the output is short-circuited and which would otherwise damage the power transistors. In the 1 A power supply only one Darlington transistor is fitted. The emitter resistors and protection circuit can therefore be dispensed with. For the 2.5 A power supply a 0.6 K/W heatsink is required, and for the 1 A power supply a 2.4 K/W heatsink is fitted. At maximum load — that is with a short-circuited output at the highest current possible — a temperature of 80 °C will be reached. The two versions of the power supply are therefore (without active cooling) suitable for continuous use at full load.

Values set by the microcontroller

The connecting link between the analogue and digital domains is the PIC microcontroller IC3. In order to accurately measure and produce voltages an accurate and stable reference voltage is of course required, which it derives from its supply voltage. For this reason a few components are added around D2 (pre-regulation to 12 V) and IC7, a fixed voltage regulator. The pre-regulated +12 V supply is also used to feed IC2.

Using R3 and P1 the voltage at the regulator output can be set to 5.12 V (in practice 5.14 - 5.16 V). R3 provides a basic load so that a current of at least 33 mA always flows through P3. This current is chosen to be about 10 times as great as the

Table 1. LM324 vs LT1491	LT1491 (typical values)	LM324 (typical values)
Offset voltage	200...350 μV	2 mV
Offset voltage drift	2 μV / °C	7 μV / °C
Input current	4 nA	45 nA
Power supply voltage (max.)	44 V	32 V
Short-circuit output current	25 mA	20 mA

current in the ground connection of the voltage regulator. Load-dependent variations in the common-pin current therefore only have a very small effect. Moreover, the load current varies proportionally less owing to the high basic load current.

As a result of these measures, the reference voltage is very stable and changes only as a consequence of the normal ageing of the components. It is therefore recommended, as with any other electronic test equipment, to recalibrate the device after a few years.

The reference voltage reference voltage is also used for the delta-sigma A/D converter built around IC2. Using this conversion technique a high-precision converter can be built with little circuitry, and, independent of component tolerances, very accurate measurements can be achieved with good reproducibility. However, 1 % resistors have been used to simplify offset calibration using P2. The microcontroller also plays a part, of course, in the analogue-to-digital conversion. Conversion proceeds in the following stages:

In the initial state, microcontroller pin A2 (set as an input) is high impedance and pin A3 (an output) is at 0 V. The voltage to be measured is present at the non-inverting input of IC2.B, and, since the op-amp is connected as a buffer, also at its output. Let us suppose that this voltage is exactly 1.28 V. Then the output of the integrator IC2.A will be at the level of the positive supply. Pin A2 on the microcontroller will interpret this as a high logic level. When a measurement is to be carried out, the microcontroller changes the state of pin A3 from low to high (i.e. to 5.12 V) and waits until the voltage on A2 changes to logic low. Now, by toggling pin A3 the microcontroller holds the output of the integrator in the middle of its range. The varying output signal of the integrator will be interpreted by the microcontroller as high or low. The mark-space ratio of the integrator's output is now measured. It can be seen that pin A3 must be held high for three times as long as it is held low: this is so that, when combined together with the voltage being measured, a voltage can be produced at the inverting

input to the integrator which on average is exactly the same as the voltage on its non-inverting input, namely 2.56 V.

The offset with P2 is required, because this type of A/D converter does not operate with negative voltages: the microcontroller's algorithm would fail. As well as allowing for compensation for component tolerances, P2 also provides a small positive offset. A TLC272, with MOS inputs, is selected for IC2 because the A/D converter will only work accurately when the input currents are considerably smaller than those achieved with bipolar ICs. This benefit is bought at the cost of a relatively high offset voltage. Here however, where an adjustment must be made anyway, this is no real disadvantage.

IC4 is an analogue switch that connects either the voltage at pin 11 (for voltage measurement) or at pin 8 (current measurement) to buffer IC1.B.

Interfaces

The microcontroller has several interfaces at its disposal. The keyboard interface is implemented using IC5 and the LCD panel is connected via IC6. These are 8-bit shift registers (type 74HC164) with serial input and parallel outputs. Digital values are

loaded into the register by the microcontroller using pins B5 (data) and B6 (clock). In the case of IC6 these values are control commands and character codes which are transferred to the LCD module, running in 8-bit mode, using a strobe signal on pin B7. In the case of IC5 these form a bit pattern which allow the microcontroller to identify (via pin B4) when a button has been pressed. P3 is the potentiometer required for adjustment of display contrast. The wiper being at the ground end corresponds to a viewing angle of between 10° and 20° above vertical: this is the recommended setting when the unit is to be used on the bench.

Microcontroller pins B0, B2 and B3 comprise an RS232 port. Using the well-known MAX232 the signal levels are shifted between ±10 V on the RS232 side and TTL levels on the microcontroller side. In addition to the required connections (RXD and TXD), the CTS (clear to send) signal is also connected. The RS232 interface offers remote display as well as remote control. This will not concern us further here: a description of the software and operation of the unit will be presented in the second part of this series, in the next issue. Let us turn instead to the construction of the power supply.

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The construction of the Digital Benchtop PSU will be described in next month's issue.