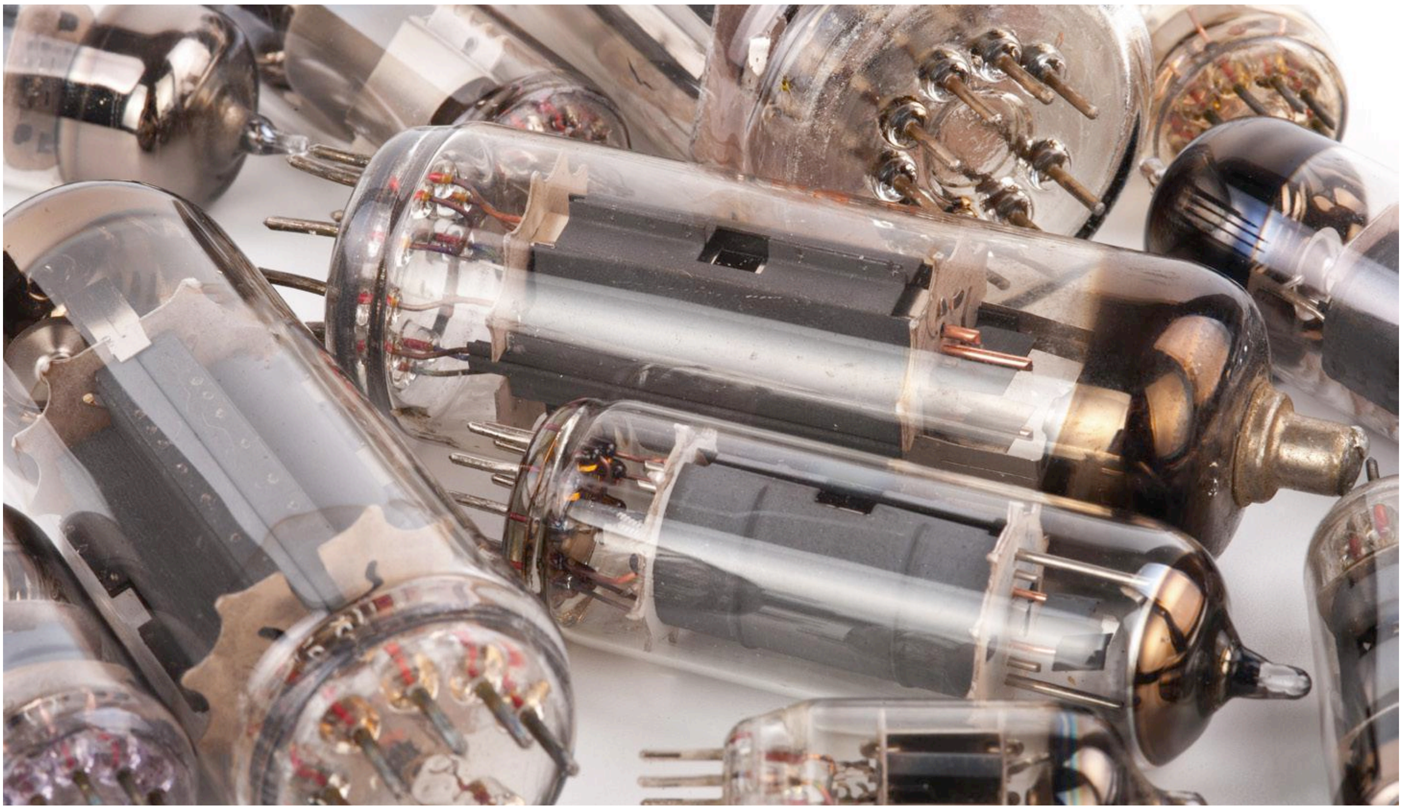
HOMELAB PROJECT

Vacuum Tube Curve Tracer

'Remake' of the Tektronix 570



In order to test salvaged vacuum tubes, the author required a tube tester. Because a 'real' tester like the Tek 570 was an unattainable ideal, he decided to build one himself — based on a modern microcontroller. The version presented here can measure the cathode current as a function of either anode voltage or grid voltage.

By **Charles van den Ouweland**
(Netherlands)

Do you suffer from this too? That you can't actually throw anything away, and therefore from of all those hopelessly defective 'Retronics' devices, donations from family, friends or neighbors (three categories that do not necessarily overlap) who thought that they were doing you a favor, you occasionally try to salvage some useful part? The author too, and after a number of years there was a large collection of vacuum tubes in the attic, which looked visually intact and that were really only collecting dust.
What do you do with a chest full of parts salvaged from old equipment? You use them, of course – for quick & dirty experiments they are often perfectly usable. Things like resistors, capacitors, inductors, etcetera are measured easily enough, and also for transistors

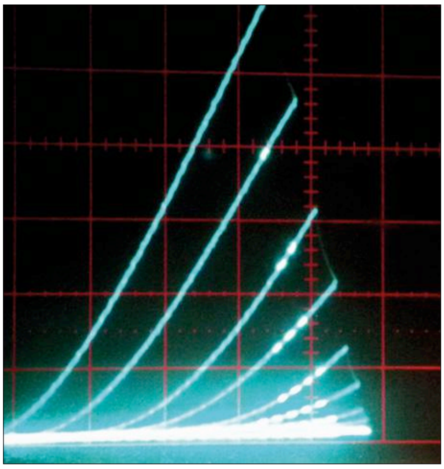


Figure 1. This is what the characteristics produced by the vacuum tube tester a.k.a. "tracer" look like.

Figure 2. The original Tektronix 570 is a monster in the truest sense of the word.

and diodes their usefulness can be ascertained quickly. With vacuum tubes this is not that simple, however. Okay, severe damage may be recognizable with the naked eye, and a potential short circuit between electrodes could be detected using an ohmmeter, but that is about all. On the other hand, there is little point in building a circuit and using a tube of which it is unknown whether it is “good” or not, because when the circuit then doesn’t work, where is the problem likely to be? The design, the defective tube, or both?

The Tektronix 570

Even if you have no intention of doing something yourself with these tubes, you can always try to sell them. Browsing through eBay, the author came across a French vendor who accompanied every tube for sale with a photo of its characteristic, made with the aid of an old Tektronix 570 curve tracer.

To generate these characteristics (**Figure 1**) the tester applies different grid voltages to the tube under test (0 V, –1 V, –2 V, etcetera) and then varies the anode voltage from zero to a few hundred volts. Then, on the screen of the cathode ray tube the cathode current is displayed as a function of anode voltage at different grid potentials. These characteristics make it clearly visible whether the tube is suitable for a certain application.

The first thing that came to the author’s mind was “I want that too”. The only problem is that the Tektronix 570 (**Figure 2**) has now become a collector’s item; if there is even one to be found, then you will certainly need a well-filled wallet. Apart from that, the ‘570 is a real monster with dimensions of 42 x 33 x 62 centimeters and weighs around 80 pounds.

As with any right-minded electronics engineer this was immediately followed by a second thought “I can do this myself”. With modern semiconductor and microcontroller technology and using an existing oscilloscope, this should be possible at a fraction of the cost (and also much lighter). The idea of the ‘Neptronix

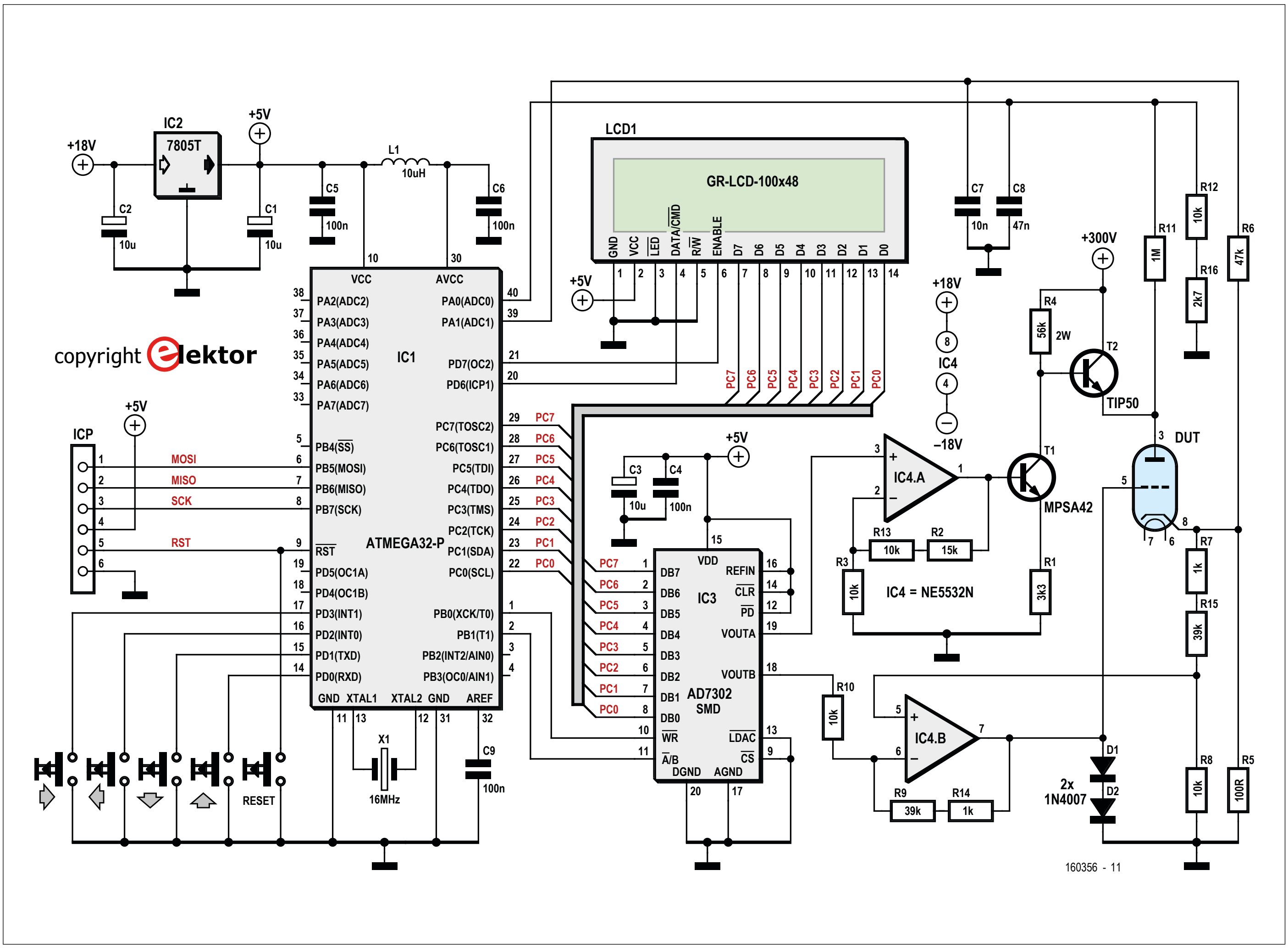


Figure 3. The schematic of the vacuum tube tester.

570' (where, 'nep' is Dutch for 'fake' or 'bogus') was born.

Design

The circuit has been designed such that two types of measurement are possible:
- varying the grid voltage with several different fixed values of anode voltage;
- varying the anode voltage with several different fixed values of grid voltage.

This is seamlessly controlled using a microcontroller and for the user interface serves a small LC Display with a set of four pushbuttons. The software has been designed in such a way that it is also possible to display the measured characteristics on the display instead of on the display of an external oscilloscope. The Neptronix 570 is and remains built on a breadboard; no circuit board has been designed for it.

Birds-eye view of the schematic

The schematic for the tracer is drawn in **Figure 3**. On the left is drawn the outline of IC1, the microcontroller — an ATMega32-P. This µC was selected because it has a large number of I/O lines, is available in a DIP package for not much money, and because the author had a couple on hand.
To the left of IC1 we see the ICP programming connection and the four pushbuttons for the user interface (and also the reset button). The 8-bit wide data bus from the µC goes in one direction to the LC Display (LCD1) and in the other direction to a dual-channel D/A-converter (IC3). This provides the control voltages for the different drive voltages for the tube that is to be tested.

Finally, on the right, two opamps are drawn; the top one (IC4.A) supplies, via two high-voltage transistors, the anode voltage for the tube (DUT = *Device Under Test*), while the bottom one (IC4.B), generates the grid voltage.

Power supply

As is known, tubes generally operate at (very) high voltages. In the schematic several different power supply voltages are indicated – first let's take a look where these come from.
The power supply voltage for the digital electronics and the display (5 V) is supplied through a simple 7805T (IC2 in **Figure 3**), which in turn is powered from +18 V that comes from a lab power supply. Note: this 7805 needs to have adequate cooling! The same lab power supply also generates the negative voltage of −18 V; this ±18 V is used to power both opamps. Since everyone is likely to have a (dual) lab power supply on the workbench there is no need to go into any further details.
The high-voltage supply is a bit more complicated. Not everyone will have an adjustable DC high-voltage power supply on hand (in any case, the author didn't), so a solution has to be found for that. A very big problem this fortunately is not – see the schematic of **Figure 4**. This is a standard application of the step-up converter MC34063AP.
The author used a power supply, salvaged from a worn-out Canon Pixma printer, that generates the input voltage of 32 V. However, if the available input

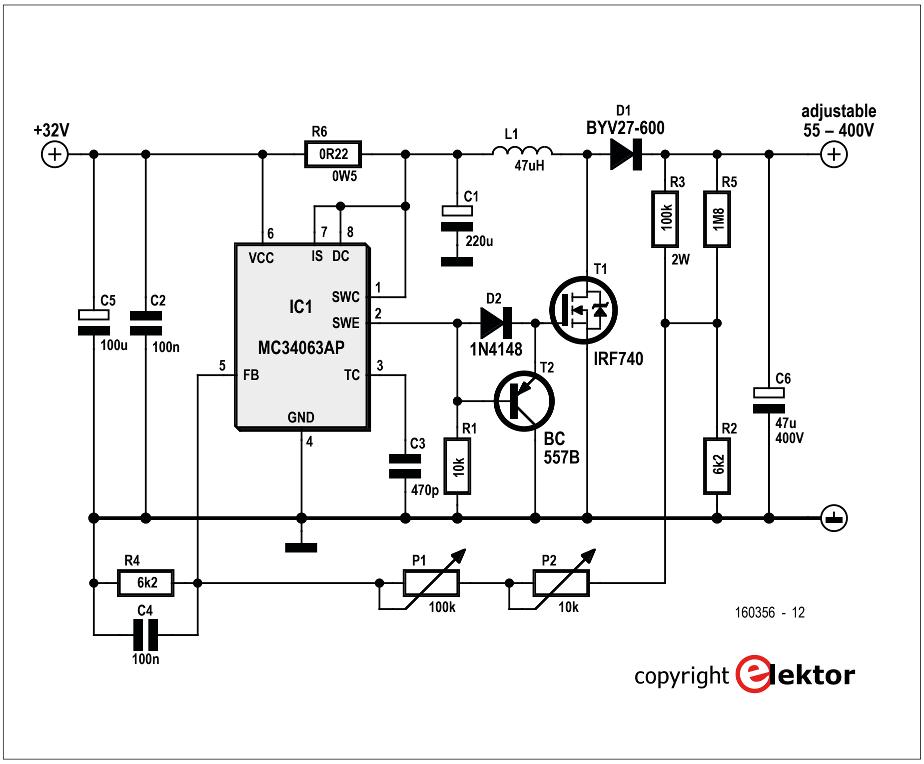


Figure 4. The high-voltage power supply; the input voltage of 32 V is supplied from an old printer power supply.

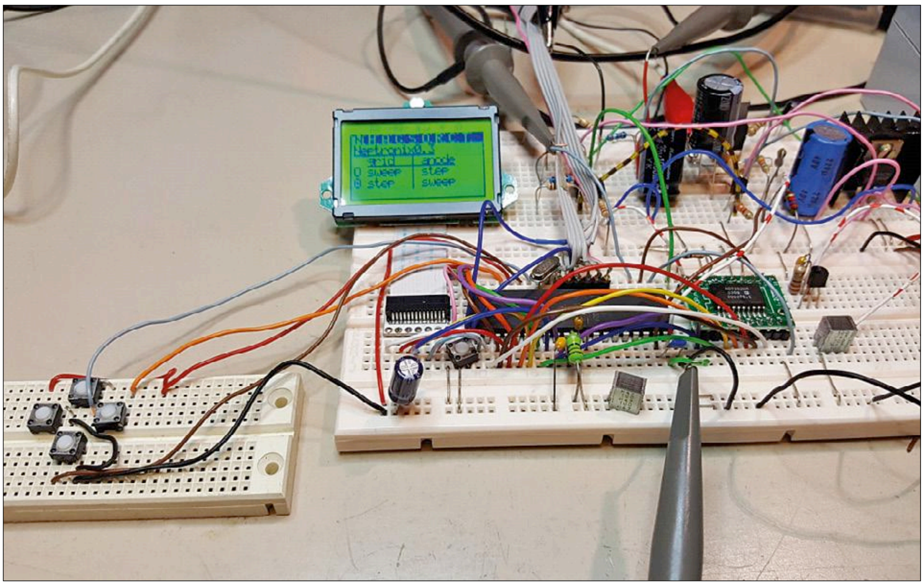


Figure 5. The vacuum tube tester as described in this article.

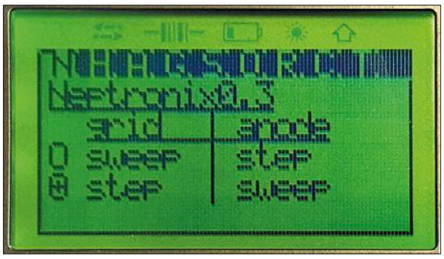


Figure 6. The Start tab.

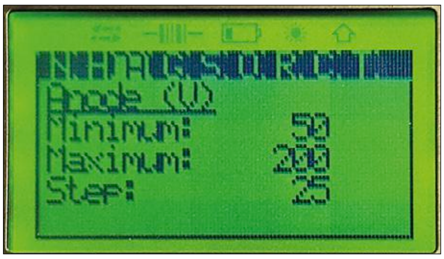


Figure 7. The Anode tab.

Figure 8. The Grid tab.

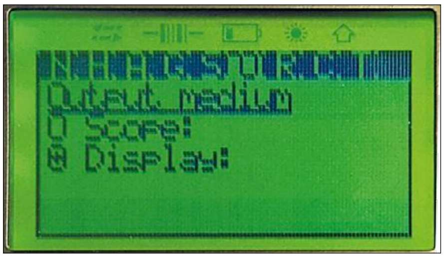


Figure 9. The Output tab.

Figure 10. The Run tab.

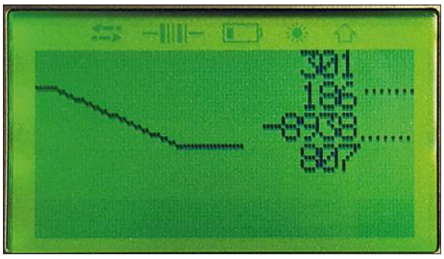


Figure 11. The calibration screen.

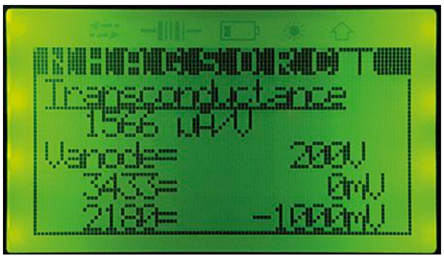


Figure 12. Calculation of the transconductance.

voltage is (much) lower, then it can be difficult to obtain a sufficiently high output voltage. In that case a voltage-doubler could offer a solution.

A few details

The (dual-channel) D/A-converter IC2 (an AD7302) is unfortunately not (at an acceptable price, at least) available in a DIP package. The author therefore mounted the SMD version of this IC on an adapter board, so that it would still be possible to built the tube tester on a breadboard without any difficulties.

The anode voltage of the tube to be tested amounts to maximum of around 320 V. For this purpose, opamp IC4.A multiplies the voltage at the output A of the DAC (0 to 5 V) by 3.5. Subsequently, T1 multiplies this voltage again with a ratio of 17. Transistor T2 ensures that sufficient current is also available.

When we only want to vary the anode voltage ('sweeping'), then it is not necessary to know the exact amount of gain from IC4.A and T1. There is, however, also a 'reversed' operating mode implemented (variation of the grid voltage for different fixed values of anode voltage) and for this the anode voltage needs to be exactly regulated to known voltages. For this reason, the voltage divider built from R11, R12 and R16 is used to feed back one-eightieth part of the anode voltage to A/D-input ADC0 of the microcontroller. In this way the controller can calibrate the anode voltage.

The other output of the DAC goes to opamp IC4.B. Because the grid voltage needs to be negative, this opamp converts the 0 to 5 V from output B of the DAC into a range of 0 to -18 V. Diodes D1 and D2 protect the circuit from voltages that are too high.

To measure the cathode current, a resistor R5 (100 Ω) is inserted between the cathode and ground. The voltage drop across R5 goes via R6 to the second A/D-input (ADC1) of the microcontroller. To compensate for the voltage drop across R5, voltage divider R7/R15/R8 applies one-fifth part of the cathode voltage to the non-inverting input of IC4.B. **Figure 5** gives an impression of the vacuum tube tracer/tester during the development phase.

User interface

The LC Display, together with four pushbuttons (up, down, left, right), are used for operating the vacuum tube tester. The display shows a series of tabs in which different settings can be made. Navigating between the different tabs is accomplished with the left and right pushbuttons; the corresponding tab is opened using the down pushbutton. Now the left and right buttons can be used to change the settings within that tab. Below is a brief description of the implemented tabs.

Start (N)

On the start screen (**Figure 6**) the selection can be made between the two operating modes:

varying the grid voltage with different values of anode voltage (*step plate/anode, sweep grid*) or

varying the anode voltage with different values of grid voltage (*step grid, sweep plate/anode*).

The right button advances to the next tab.

Anode (A)

In this tab (**Figure 7**) the minimum and maximum anode voltage and the step size of anode voltage are set. Up/down are used to navigate to a particular value, after which it can be changed using left/right. The step voltage is used when in the Start tab the selected mode is *step plate, sweep grid*. This value determines the amount that the minimum and maximum voltages are increased or decreased.

Grid (G)

Here the minimum and maximum grid voltages are set, as well as the grid step voltage (**Figure 8**). The latter is used when the operating mode *step grid, sweep plate/anode* has been selected. This value also determines the amount that the minimum and maximum are increased or decreased.

Output (O)
Here the selection is made for output to an oscilloscope or to the LC Display (**Figure 9**).

Run (R)
Push the down button on the tab (**Figure 10**) to start the measurement process. When the output is selected to go to the LC Display, the results will appear here. The sweep-parameter is displayed on the horizontal axis.

In this context a few remarks. If an oscilloscope is used to display the characteristics, then it has to be connected as follows. In the mode *sweep grid, step anode*: x-axis is grid, y-axis is cathode; in the mode *sweep anode, step grid*: x-axis is anode, y-axis is cathode.
In the LCD mode the measurements are performed relatively slowly, and the firmware calculates the average of a number of measurements before sending this to the display. On the other hand, in the oscilloscope mode the measurements are made quickly, to prevent flickering of the display.
Calibrate (C)
After a press on the down button this tab appears (**Figure 11**), showing a graph of the anode voltage (0 to 230 V) versus the DAC value (0 to 255). The numeric values in the example of **Figure 11** from top to bottom: maximum voltage at a DAC value of 0; minimum voltage at a DAC value of 255; gradient; intercept of the straight line with the y-axis.
After a press on the up button, this graph disappears and the theoretical curve appears (same axis).

Transconductance (T)
In this tab (**Figure 12**) the transconductance *S* can be measured. This works as follows: first the anode voltage is set to the maximum value (anode tab). The grid voltage is also set to the maximum value (grid tab). Now the current I_1 is measured. Subsequently, the grid voltage is lowered by one step value and the current I_2 is measured. The transconductance then follows from:

$$S = (I_1 - I_2) / \text{grid step voltage} \qquad [A / V]$$

In the example of **Figure 12** the anode voltage is 200 V and the grid voltages are 0 V and –1 V. The measured values are I_1 = 600 µA and I_2 = 11000 µA. This results in a transconductance of –10.4 mA/V.
The tabs *H* (filament voltage/current) and *S* (screen grid) were not yet implemented at the time of writing.
The firmware for the vacuum tube tester (which can be programmed into the microcontroller via the ICP interface using any regular AVR programmer) can ('as is') be downloaded from the Elektor Labs page for this project ('vacuum tube curve tracer'). There you will also be kept informed about future developments and updates, and you can add your own contributions and comments. ⏮

(160356)

About the Author

Charles van den Ouweland (Breda, 1963) studied Electrical Engineering at the Eindhoven Technical University, Holland. He currently works as a software architect for ProRail, but in his spare time he keeps busy with electronics — in particular the fusion of modern microcontrollers with 'old fashioned' tubes.