

Transistor Curve Tracer

On USB, for bipolar transistors and FETs

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This practical instrument can be used to measure and record the characteristic curves of NPN and PNP bipolar transistors, N- and P-channel JFETs, and N- and P-channel MOSFETs. The circuit is based on an R8C/13 microcontroller, which transfers the measurement data to a Windows application program via USB.

Quick Project Specs

- R8C/13 microcontroller control module
- PC link via USB port
- User-friendly PC program with Help function (runs under Windows 2000 and XP)
- Curve data can be exported to and imported from Excel
- Checking transistor matching
- Records characteristic curves of NPN and PNP transistors, N-channel and P-channel MOSFETs, and N-channel and P-channel JFETs
- Plotted curves can be printed out or embedded in other applications

Curve tracers have a long history in *Elektor*. The first article on this subject appeared in the 1979 Summer Circuits issue, followed by an article in June 1980, one in October 1988, and another one in December 1989. However, none of these circuits had a computer interface, and except for the circuit published in the December 1989 issue, they were limited to NPN transistors.

This situation changed with the project published in the May 1990 issue, which provided a control interface for connection to the Centronics port of an Atari computer. A version for use with a PC followed in September 1993. The circuit was upgraded in April 1998, including control software running under Windows 95.

Now, more than 10 years on it's time for a new curve tracer with features that definitely outclass all the previous versions.

Curve tracer operating principle

The operating principle of curve tracers has not changed much since the first article appeared in *Elektor*. The basic idea is to generate a time-dependent collector current by combining a ramp-shaped collector-emitter voltage with a base current that is increased either in discrete steps or continuously. The collector voltage is plotted on the X axis, and the collector current is plotted on the Y axis. The block diagram in **Figure 1** is based on this operating principle.

Control module

The curve tracer described here is built around an R8C/13 microcontroller, which is linked to a USB to serial converter (type PL2303). The complete circuit diagram is shown in **Figures 2a** and **2b**. It does not require much comment, since the circuitry of the R8C/13 section was described earlier in the

February 2006 issue [1] and the USB controller is wired as described in the March 2006 issue [2]. All of this is fitted on a PCB measuring only 80 × 35 mm. Power is supplied via the USB port. Various I/O port pins, +V and ground are fed out to a 20-way socket header so the microcontroller module can also be used for other tasks.

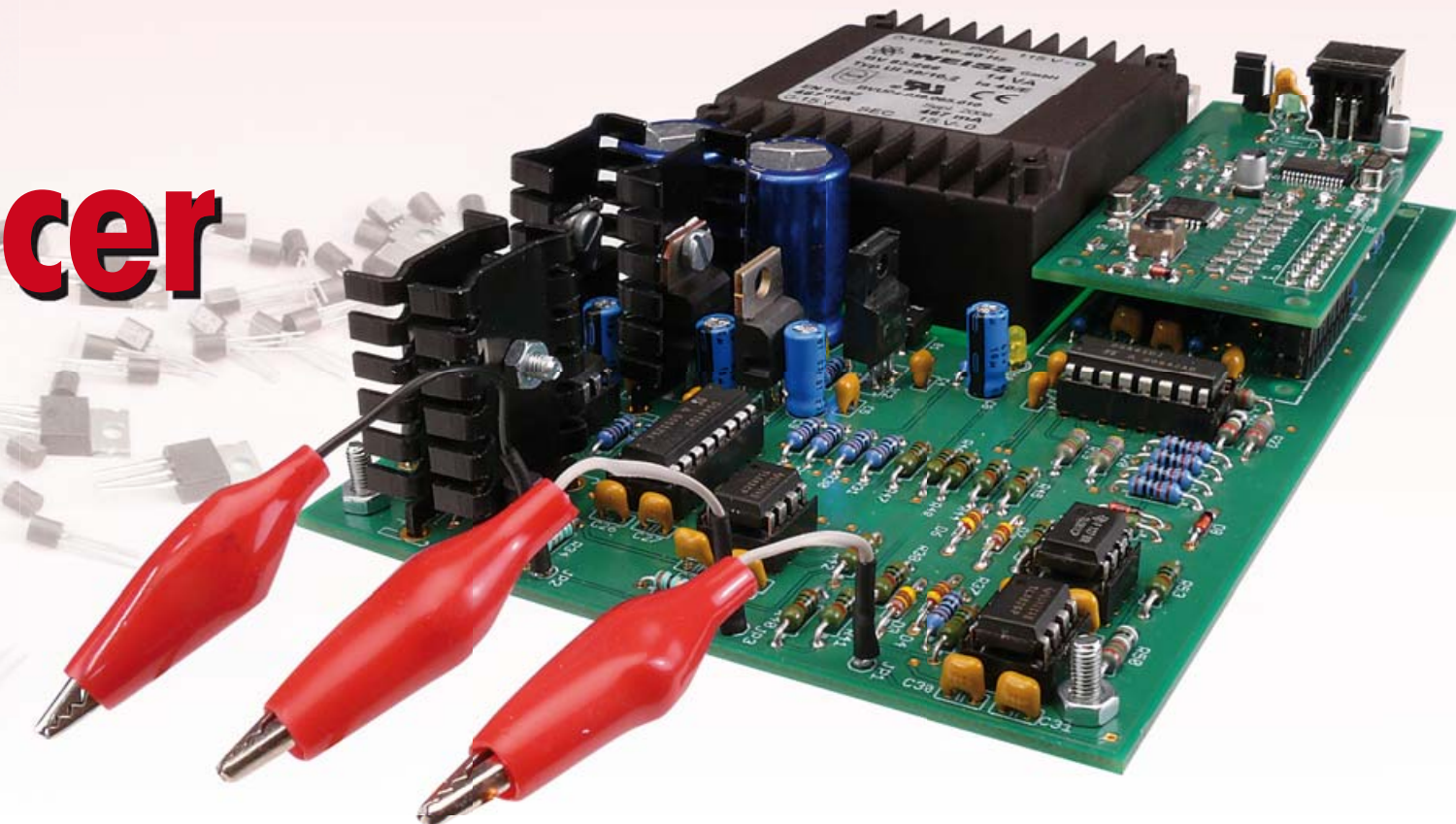
The microcontroller can be reset whenever desired by means of Reset push-button S1. A set of eighteen 470-Ω resistors limit the output currents of the I/O pins to approximately 10 mA in order to protect the board against the potentially fatal consequences of a connection error.

When jumper JP1 is fitted, program code can be downloaded into the microcontroller via the USB port. One way to do this is to use the Renesas Flash Development Toolkit, which can be downloaded free of charge from the Web address for this project [3]. The previously mentioned *Elektor* articles and the R8C topic on the *Elektor* forum [4] provide adequate information about generating the software, downloading the hex file to the microcontroller, and installing the USB driver on the PC.

Circuit description

Generating the base current or gate-source voltage

Timer Y is operated in PWM mode to drive the base or gate of the transistor under test (TUT). See the description of the firmware for more details. The pulse rate is 2 kHz, and the pulse



width can be set over a range of 0 to 100%. A Butterworth low-pass filter built around IC5a converts this signal into a variable DC voltage, which is amplified by a factor of 2 in IC5b to provide a voltage at the output of IC5b with an adjustment range of 0 to +10 V. The linearity of the output voltage can be seen clearly in the oscilloscope images (Figure 3).

The output voltage is inverted by IC8a to generate the base current for PNP transistors or the gate voltage for P-channel MOSFETs and N-channel JFETs. Switches S1 and S2 (IN1 and IN2) of analogue switch IC7 connect either a positive voltage or a negative voltage to the base or the gate of the TUT (see the firmware description for the associated truth table).

Switches S3 and S4 (IN3 and IN4) of IC7 are used to select the desired current range (0–10 μ A, 0–100 μ A, or 0–1 mA). The 0–1 mA range is always used with the 'FET' setting to set the gate voltage.

Generating the collector-emitter or drain-source voltage

Timer Z of the R8C/13 is also operated in PWM mode with a fixed pulse rate of 2 kHz. A Butterworth low-pass filter converts the pulse width into an analogue voltage and amplifies the voltage by a factor of 2 to again provide an output voltage with a range of 0 to +10 V. The voltage is inverted by IC8b to generate the collector-emitter voltage for PNP transistors or the drain-source voltage

for P-channel MOSFETs and P-channel JFETs. Switching between positive and negative voltages is provided by analogue switch IC9. The current gain is provided by IC10 in combination with a transistor output stage formed by T1–T4. Resistors R34 and R35 limit the output current to approximately ± 0.5 A.

Measuring the characteristics

The configured base current is not

measured, but instead calculated by the software from the configured base-emitter voltage and the selected base current range.

In order to measure the configured collector-emitter voltage, it is first rectified by IC11 because it can be either positive or negative. After being divided by a factor of 2 by R42/R43, the rectified voltage is fed to the microcontroller A/D converter input AD0. The

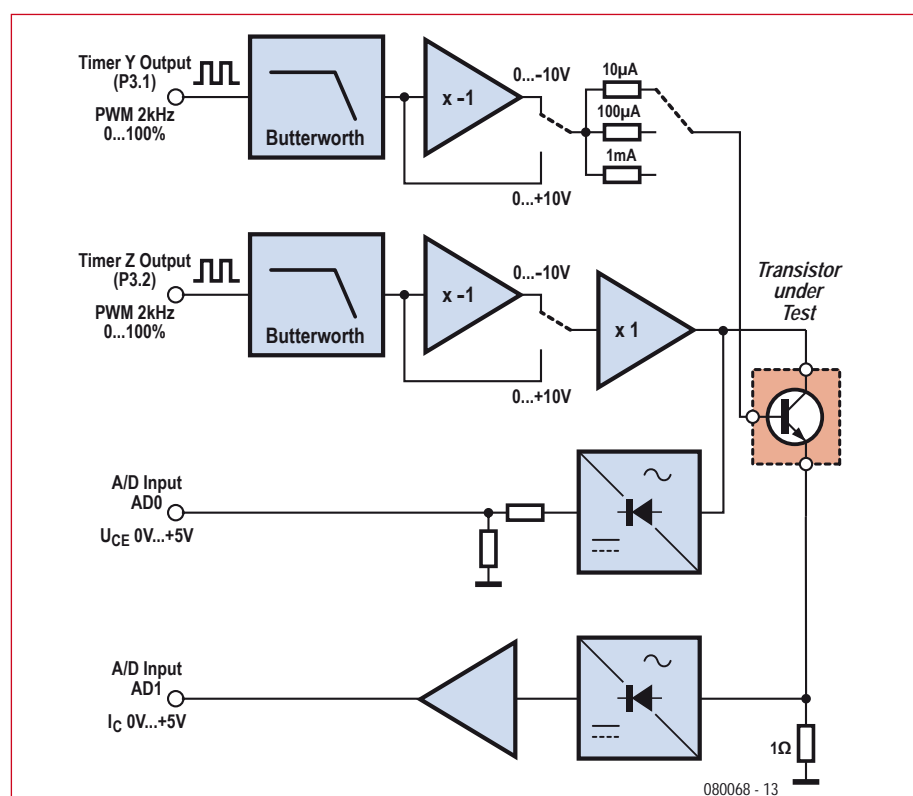


Figure 1. Curve tracer block diagram.

measurement range of 0 to ± 10 V for the collector–emitter voltage thus corresponds to a range of 0–5 V at the A/D converter input. Diode D5 prevents the A/D input voltage from rising above 5 V in the event of a fault and protects the input from negative voltages. The collector or drain current flows through R49 and generates a positive voltage at the output of IC12b. The output voltage ratio is 1 mV/mA. IC13 amplifies the voltage by a factor of 10 to yield a ratio of 10 mV/mA at the A/D converter input (AD1). The voltage and the A/D input is 4 V at the maximum collector or drain current of 400 mA. Here again, diode D8 prevents the A/D input voltage from rising above 5 V in the event of a fault and protects the input from negative voltages.

Table 1: Pin assignments of K1.

Pin	Signal	Pin	Signal
1	P1.7	11	P3.0
2	GND	12	P3.1
3	P1.3	13	P0.7
4	P1.6	14	P0.6
5	P1.1	15	P0.4
6	P1.2	16	P0.5
7	P4.5	17	P0.2
8	P1.0	18	P0.3
9	P3.2	19	+5V
10	P3.3	20	P0.1

Power supply

The curve tracer is powered by an on-board PCB-mount transformer with two secondary windings, each rated at 15 V / 0.5 A. The rectified DC voltages of approximately ± 20 V are fed to IC2 and IC3, which produce regulated voltages of ± 15 V to power all of the analogue circuitry with the exception of the output stages. LEDs D10 and D11 indicate the presence of the supply voltages. The ± 12 V supply voltages for the output stages are provided by IC1 and IC4, which require heat sinks. Here LEDs D9 and D12 indicate the presence of the supply voltages.

R8C firmware

The microcontroller firmware was written in C using the Renesas High-performance Embedded Workshop. The details of the development environment fall outside the scope of this article. It has been described in the R8C articles in previous issues of *Elektor*

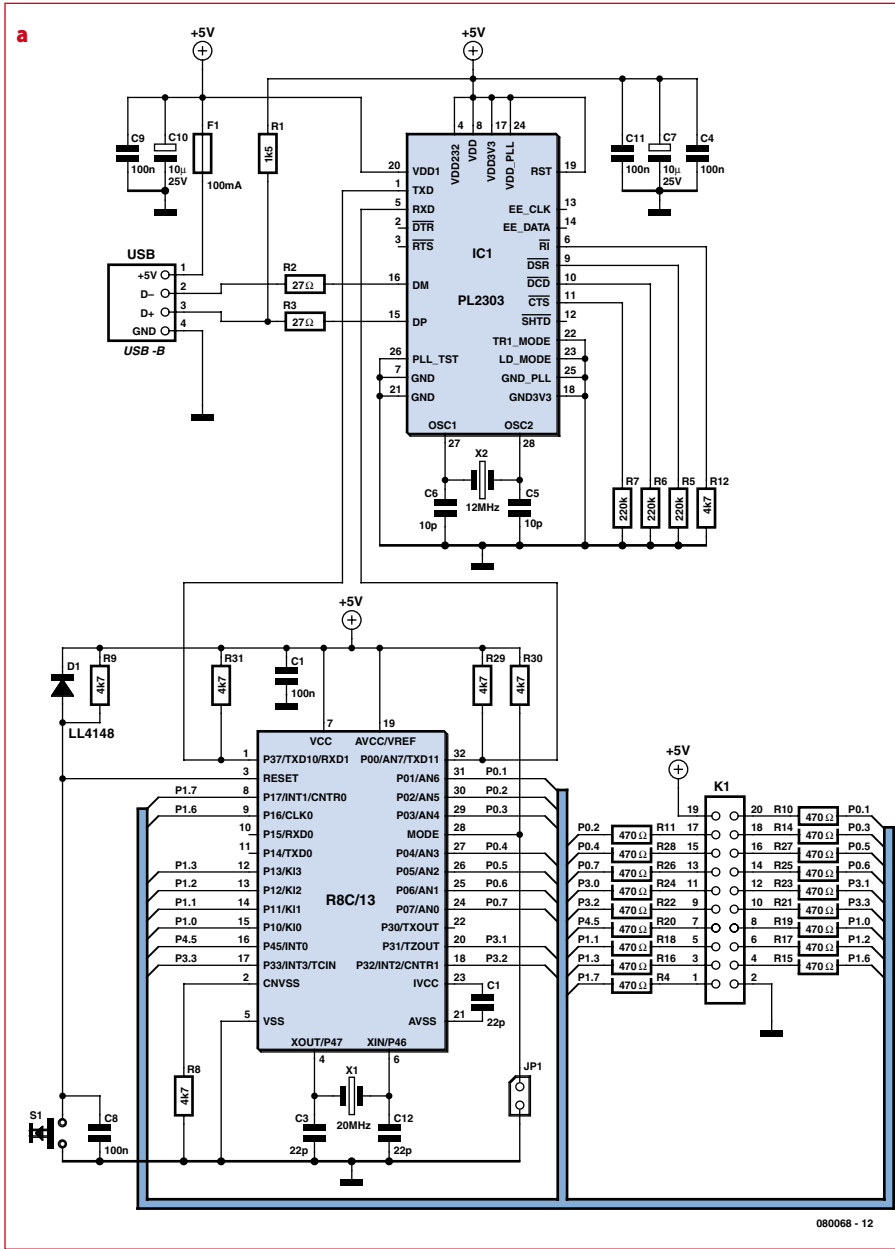


Figure 2. Schematic diagram of the microcontroller module (a) and control circuitry (b).

[1][2][4]. HEW can also be downloaded from the project Web address [3].

Program flow

Initialisation

Timers Y and Z are first initialised as PWM timers with a pulse rate of 2 kHz. Timer X is used to execute wait loops. The UART1 interface is initialised to 9600 baud, 8 data bits, 1 stop bit, and no parity. The interrupt for this interface is enabled with a priority of 6. The following default values are then set:

- Maximum collector or drain current: 100 mA
- Transistor type: NPN
- Base current range: 10 μ A
- Number of curves: 5

Configuring the base current range
The base current range is set using I/O pins P1.2 and P1.3 as follows:

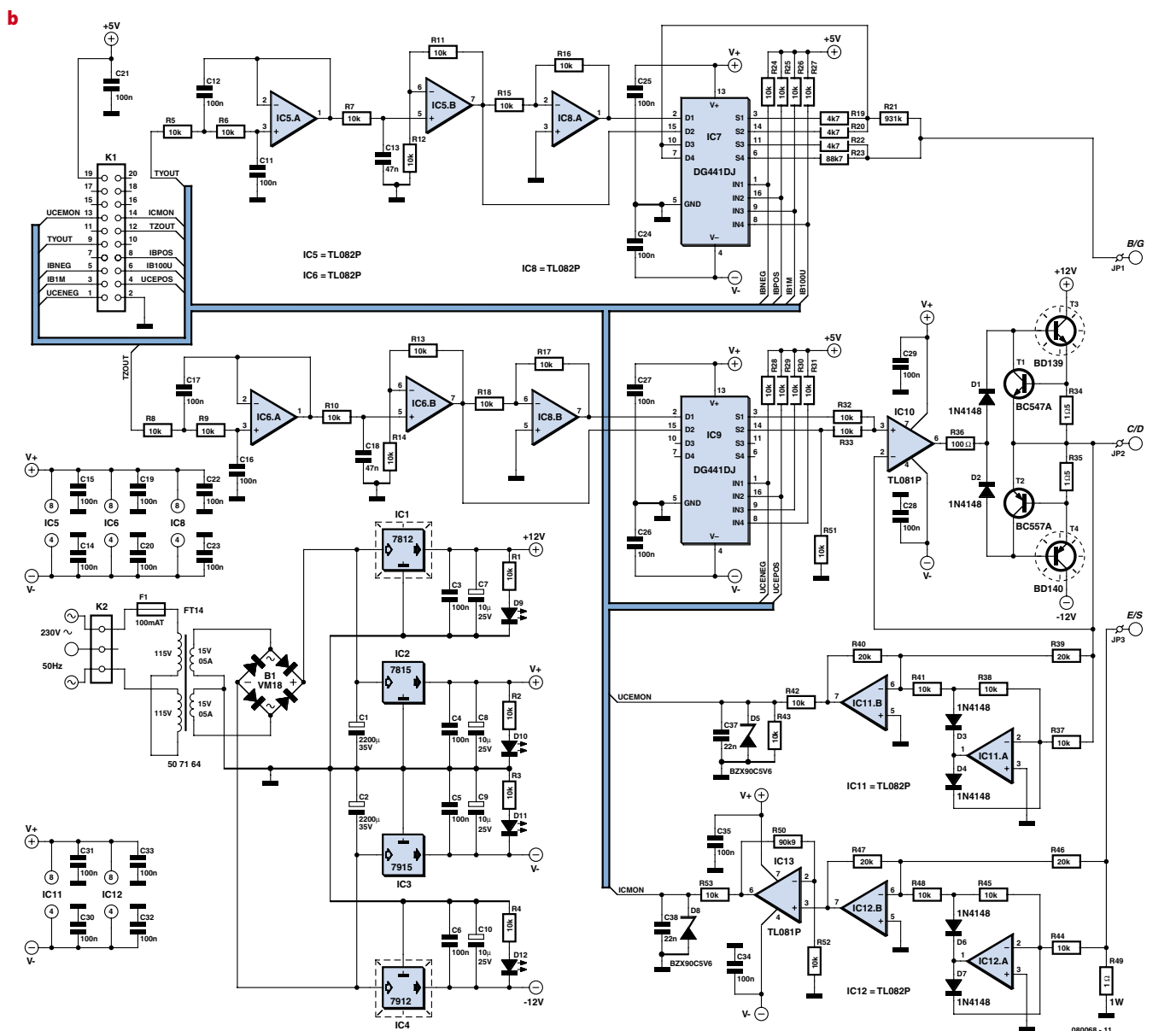
P1.2	P1.3	Base current range
1	1	10 μ A
0	1	100 μ A
1	0	1 mA

Configuring the transistor type

The polarity of the base current or gate voltage and the collector–emitter or drain–source voltage are set using I/O pins P1.0, P1.1, P1.6 and P1.7 (see Table 2).

Main program loop

The main program loop constantly polls the UART1 serial interface to see



whether any characters have been received. This interface is connected to the PC via the USB to serial adapter (PL2303). The protocol described below has been implemented for data transmission.

Each command consists of a command code (a letter in the range A to Z) optionally followed by one or more parameters, which are always written as ASCII character strings separated by commas. The defined command string terminators are CR (0x13) and LF (0x10). This protocol applies to transmissions in both directions (from the PC to the curve tracer module and from the curve tracer module to the PC), although the curve tracer module does not send commands to the PC

Table 2: Transistor type setting.

P1.0	P1.1	P1.6	P1.7	Base or gate polarity	Collector or drain polarity	Transistor type
0	1	0	1	+	+	NPN transistor or N-channel MOSFET
0	1	1	0	+	-	P-channel JFET
1	0	0	1	-	+	N-channel JFET
1	0	1	0	-	-	PNP transistor or P-channel MOSFET

on its own initiative. It can only send replies in response to requests from the PC. The commands are summarised in **Table 3**.

Initiation of curve measurement

The curve measurement process starts

with the configuration of the output parameters.

For bipolar transistors, the base current range is set to 10 μA and the base-emitter voltage (U_{BE}) is set to 0. For MOSFETs, the base current range is set to 1 mA and the gate-source

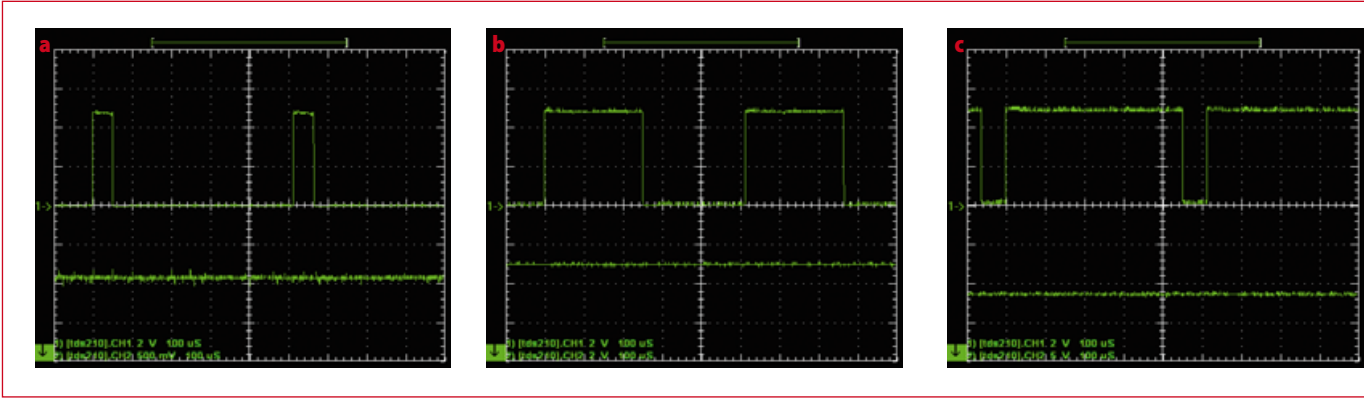


Figure 3. Pulse width and IC5b output voltage at pulse width ratios of 10% (a), 50% (b), and 90% (c).

voltage (U_{GS}) is set to 0. For JFETs, U_{GS} is set to the maximum level, which is +10 V for P-channel JFETs or -10 V for N-channel JFETs. The collector-emitter voltage (U_{CE}) or drain-source voltage (U_{DS}) is set to the maximum value (+10 V or -10 V), and curve tracing is started. The base current (I_B) or gate-source voltage (U_{GS}) is increased until the maximum collector or drain current is reached. With bipolar transistors, the base current range is also incremented if the maximum collector current has not been reached. With JFETs, U_{GS} is reduced until the maximum drain current is reached. If the maximum collector or drain current is not reached with the maxi-

um value of I_B or U_{GS} , curve tracing is terminated and the error message 'M1<CR><LF>' is sent to the PC. The message 'M2<CR><LF>' is sent if the maximum collector or drain current is reached with a very low value of I_B or U_{GS} , which can occur with a shorted transistor. This message is also sent if too many curves are set with the "K" command. After the base current or gate-source voltage corresponding to the maximum collector or drain current has been calculated, the delta (increment value) is calculated from the base current and the number of curves to be measured (delta = $I_{B(max)}$ divided by number of curves). The previously mentioned error message is also sent if the increment is zero.

The actual measuring process begins if no error has been detected. For each value of I_B or U_{GS} , the collector-emitter or drain-source voltage is swept from 0 to 10 V while the associated collector or drain current is measured. The results are sent to the PC in the following format:

```
P<curve_no.>,<IB>,<Range><CR>
<LF>
N<UCE>,<IC><CR><LF>
```

curve_no.: the number of the curve presently being measured;
IB: xbase current or gate-source voltage (0-10 V);
Range: base current range; 0 = 10 μ A, 1 = 100 μ A, 2 = 1 mA;



Table 3: Commands.

Command letter	Parameter	Meaning	Response from curve tracer module
A	-	Query I_D of curve tracer module	Note 1)
B	0 - 255	Pulse width for I_B or U_{GS} ; range 0–10 V	–
C	0 - 255	Pulse width for U_{CE} or U_{DS} ; range 0–10 V	–
D	0 = 10 μA 1 = 100 μA 2 = 1 mA	Base current range	–
E	0 = Positive 1 = Negative	Polarity of I_B or U_{GS}	–
F	0 = Positive 1 = Negative	Polarity of U_{CE} or U_{DS}	–
G	–	Query current value of U_{CE} or U_{DS}	G0 - 1024 Voltage [V] = parameter value divided by 100
H	–	Query current value of I_C or I_D	H0 - 1024 Current [mA] = parameter value divided by 2
I	0 - 1024	Maximum collector or drain current Current [mA] = parameter value divided by 2	–
J	1 = NPN 2 = PNP 3 = N-MOSFET 4 = P-MOSFET 5 = N-JFET 6 = P-JFET	Transistor type setting	–
K	0 - 10	Number of curves (see text)	–
L	–	Start curve measurement	See text

1) The curve tracer module responds by sending its ID code: 'A + Curve_Tracer VX.X + <CR><LF>' (X.X = current version number). After this, the curve tracer module sends the current settings of the following configuration parameters:

- Maximum collector current (default = 100 mA)
- Transistor type (default = NPN)
- Number of curves (default = 5)

U_{CE} : collector–emitter voltage; range 0–1024 (0–10.24 V);

I_C : collector or drain current; range 0–1024 (0–512 mA).

The base current is calculated as follows:

Range = 10 μA : base current = $I_B \times 0.025$ [μA];

Range = 100 μA : base current = $(I_B - 14) \div 2.3$ [μA] if $I_B \geq 14$; otherwise base current = 0;

Range = 1 mA: base current = $(I_B - 16) \div 2.6 \times 10$ [μA] if $I_B \geq 16$; otherwise base current = 0.

After all the values have been transferred, the curve tracer module sends 'O<CR><LF>' to the PC, which can then process the data and display the curves.

Downloading the firmware

The Renesas High-performance Embedded Workshop generates a Motorola (!) hex

file (Curve_Tracer.mot), which can be downloaded via the USB interface with the aid of the Flash Development Toolkit [3].

To enable downloading, fit jumper JP1 on the microcontroller board and press the Reset button. After the firmware has been downloaded, remove the jumper and press the Reset button again.

Application program

The application program provides the user interface for the curve tracer module and is written in Visual Basic 6.0. All program components were packaged using the VB6 Packaging Wizard. They can be installed in any desired folder by running the Setup.exe program. The application program can run under Windows 2000, XP, and Vista. All DLL files and ActiveX components are registered during installation, except for the Prolific driver for the USB to serial converter. This driver must be installed by running PL-2303 Driver Installer.exe. The Curve_Tracer.exe program can be started after the curve tracer module is connected to a USB port of the PC.

Functions

The window shown in **Figure 4** appears after the program starts up and establishes a connection to the



Figure 4. Example characteristic curve chart.

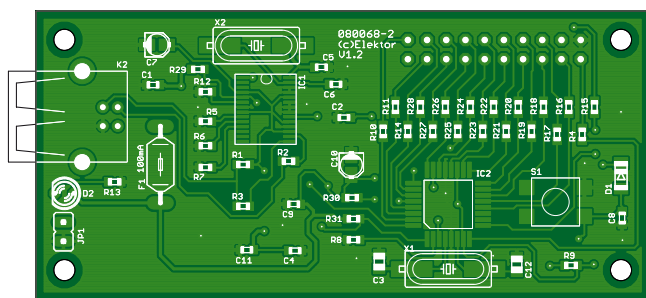


Figure 5. Layout of the microcontroller PCB.

COMPONENT LIST

Controller board # 080068-2

Resistors

R1 = 1k Ω 5, SMD 0603
 R2,R3 = 27 Ω , SMD 0603
 R4,R10,R11,R14-R28 = 470 Ω , SMD 0603
 R5,R6,R7 = 220k Ω , SMD 0603
 R8,R9,R12,R29,R30,R31 = 4k Ω 7, SMD 0603
 R13 = 1k Ω , SMD 0603

Capacitors

C1,C2,C4,C8,C9,C11,C13 = 100nF, SMD 0603
 C3,C12 = 22pF, SMD 0603
 C5,C6 = 10pF, SMD 0603
 C7,C10 = 10 μ F 25V, SMD case A

Semiconductors

D1 = LL4148
 D2 = LED, 3mm, low-current
 IC1 = PL2303X

curve tracer module. The following functions are available in this window:

- Recording the characteristic curves of NPN and PNP transistors, N-channel and P-channel MOSFETs, and N-channel and P-channel JFETs.
- Exporting curve data to Excel and importing curve data from Excel.
- Checking transistor matching.
- Printing curve charts or embedding them in other applications.

The program has an extensive Help function, so the operation of the program is not described in detail here.

Construction

As can be seen from the schematic diagrams, the hardware is divided between two PCBs. The small microcontroller board (Figure 5) holds the R8C/13 and the PL2303, along with the associated components (Figure 2a). The main board (Figure 6) contains the rest of the hardware (Figure 2b), including the transformer.

All of the components on the microcontroller board are SMDs, so a reasonable amount of soldering experience is necessary for assembly. The main board is more roomy, and all of the components have leads or pins. The two 12-V voltage regulators, as well as power transistors T3 and T4, are fitted with heat sinks. Here you must take care that the heat sinks of the two transistors do not

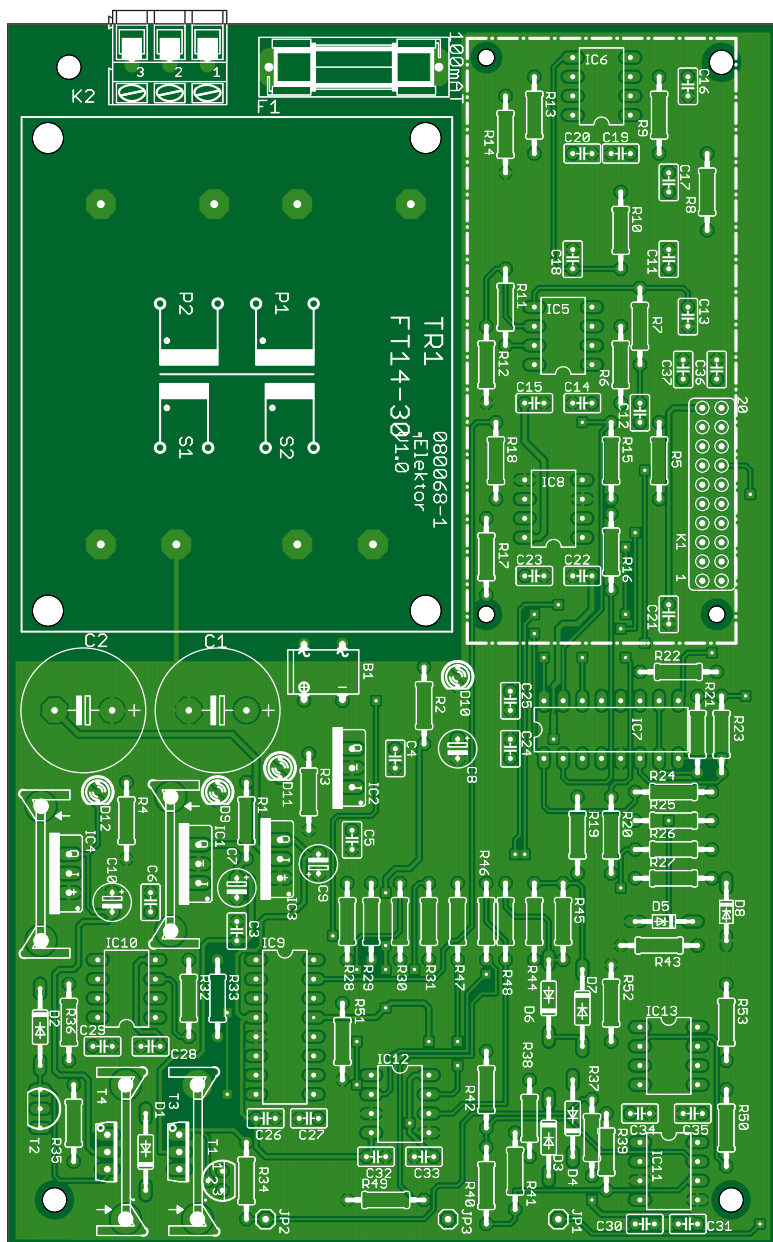


Figure 6. Layout of the main PCB.

IC2 = R5F21134FP (R8C/13)

Miscellaneous

K2 = USB-B socket
K1 = 20-way (2x10) DIL pinheader
S1 = pushbutton, 6mm, SMD
X1 = 20 MHz quartz crystal, SMD
X2 = 12 MHz quartz crystal, SMD
JP1 = 2-way SIL pinheader with jumper
F1 = 100 mA Polyfuse

COMPONENT LIST

Main board # 080068-1

Resistors

R1-R18, R24-R33, R37, R38, R41 -
R45, R48, R51, R52, R53 = 10k Ω
R19, R20, R22 = 4k Ω
R21 = 931k Ω
R23 = 88k Ω
R34, R35 = 1 Ω
R36 = 100 Ω

R39, R40, R46, R47 = 20k Ω
R49 = 1 Ω 1W
R50 = 90k Ω

Capacitors

C1, C2 = 2200 μ F 35V radial
C3-C6, C11, C12, C14-C17, C19-C35 =
100nF, lead pitch 2.5mm
C7-C10 = 10 μ F 25V radial
C13, C18 = 47nF, lead pitch 2.5mm
C36, C37 = 22nF, lead pitch 2.5mm

Semiconductors

D1-D4, D6, D7 = 1N4148
D5, D8 = 5.6 V 500 mW zener diode
D9-D12 = LED, low-current, 3 mm
B1 = VM18, bridge rectifier 1 A / 100 V,
DIP4
T1, T2 = BC547A
T3 = BD139
T4 = BD140
IC1 = 7812
IC2 = 7815

IC3 = 7915
IC4 = 7912
IC5, IC6, IC8, IC11, IC12 = TL082P
IC7, IC9 = DG441DJ
IC10, IC13 = TL081P

Miscellaneous

K1 = 20-way DIL socket
K2 = 3-way PCB terminal block, lead pitch
2.5mm
F1 = 100 mA (slow) glass fuse, with
holder
TR1 = mains transformer, secondary 2x
15V / 14VA
4 heatsinks type FK218/SA32 (21 K/W)

Microcontroller and PC Software: free
download **080068-11.zip** at [3].
PCBs **080068-1** and **080068-2**, avail-
able from the Elektor Shop.
Controller board also with components fit-
ted, Elektor Shop # **080068-91**.

touch. It's a good idea to use a piece of
insulating material here.

The microcontroller board plugs into a
20-pin DIL socket on the main board.
The assembled board set can be fitted
in a suitable enclosure, such as the

Bopla type E450 FVL. Various types
of transistor sockets can be fitted to
the enclosure to provide connections
for the transistors, although a set of
three short leads terminated in alliga-
tor clips is also a workable solution.

(080068-1)

Internet Links

- [1] www.elektor.com/050179-2
- [2] www.elektor.com/050179-3
- [3] www.elektor.com/080068
- [4] www.elektor.com/forum, go to R8C topic.

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