H.V. Power Supply

Tube Curve Tracer

Semiconductor Curve Tracer

Description

This versatile equipment can either be used as a power supply for tube experiments, or as a curve tracer. Originally, it was planned as a tube curve tracer, but during development, the idea came up to extend the functionality to a semiconductor curve tracer – especially for high voltage transistors/ Mosfets and Zenerdiodes. It is controlled by a Raspberry Pi (model 2 or 3) together with a 7” touch screen. Voltage and current can be controlled via virtual potentiometers on the touch screen. Actual voltages and currents are displayed via “7 segment displays” also located on the touch screen. The graphical user interface was designed wit Qt designer (see also Software).

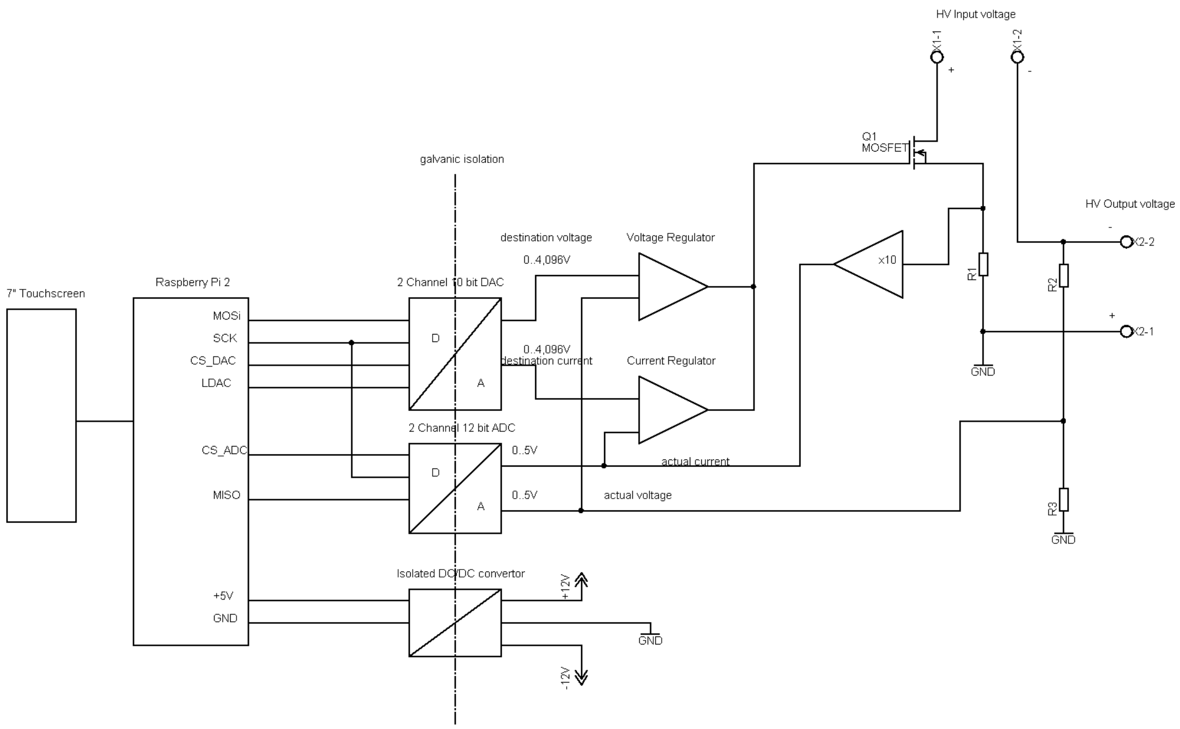
The hardware consists of 4 independent and galvanically isolated voltage/current regulators which can deliver the following voltages/currents:

- Anode supply: 0…400V , 0…350mA
- Grid1 supply: 0…100V,   0…30mA (for Control grid)
- Grid2 supply: 0…400V,   0…30mA (for Screen grid)
- Heater supply: 0…14V,   0….3A

For triode operation on pentodes, Screen grid voltage can be tracked to Anode voltage.

Heater voltages can be set either by potentiometer or to fixed values of 4 – 6,3 – or 12V

Principle of operation



Each regulator board is connected to the SPI interface of the Raspi and has individual chip select lines for the AD and DA converters. All data lines are isolated with optocouplers from the HV section of the board. The 5V supply of the Raspi is connected to a DC/DC converter which generates +/-12V for the Opamps on the HV side. These voltages are also galvanically isolated from the Raspi power.

For voltage regulation, the HV output voltage is controlled via Mosfet Q1. For enabling regulation of voltage/current in the range of “normal” OpAmps (~12V), the positive HV output is connected to (internal) GND. Voltage regulation divider R2/R3 must be calculated so that the maximum HV output voltage is equal to 4.096V on the OpAmp input.

For current regulation, HV current produces a voltage drop across R1. This voltage drop is amplified by 11 for minimizing voltage drop on R1 and to generate also a voltage of 4.096V at maximum output current.

Dual 10bit DAC

For setting voltage and current, a 2 channel 10 bit DAC is used (MCP4812). This DAC has an internal 2.048V reference, but the maximum output voltage can be doubled by setting the Gain x2 via SPI commend (see also data sheet for details).

An additional signal LDAC is necessary to latch the contents of the input registers to the DAC registers. Since the resolution is 10bits and the reference voltage is 2.048V, output voltage can be set in steps of 2mV (Gain x1) or 4mV (gain x2). This results in 400mV steps for the Anode and Grid2 voltages.

Dual 12 bit ADC

For reading the actual voltages and currents, a 2 channel 12bit ADC (LTC1298) is used. The reference voltage for this ADC is derived from the +12V supply with a 5V regulator.

The (analog) input configuration for the ADC is “Single ended”. For reading the analog values, see also data sheet for details.

Since the resolution is 12 bits and the reference voltage is 5V, the resolution is 1,2mV /Bit

Voltage/Current regulator board

The files “Voltage_current_regulator_schematics.pdf” and “Voltage_current_regulator_layout.pdf” contains schematics and the layouts for each of the regulator boards:

All regulator boards have the same layout, but different assemblies:

Board	C1	C2	C5	Q6	R14	R17
Anode supply	47n/630	47n/630	0,47u/630	SPW32N50C3 *	1Ω/1W**	1M***
Grid1 supply	47n/630	56u/450	0,47u/630	IRFBE30 on Heatsink SK129	10Ω	270k
Grid2 supply	47n/630	47n/630	0,47u/630	IRBE30 *	10Ω	1M
Heater Supply	150n/100	100/63	4,7u/63	IRFP044 *	0,1Ω/1W	33k

* mounted on Heatsink 0,7K/W

** R14= 4,096V/(11 * Imax)

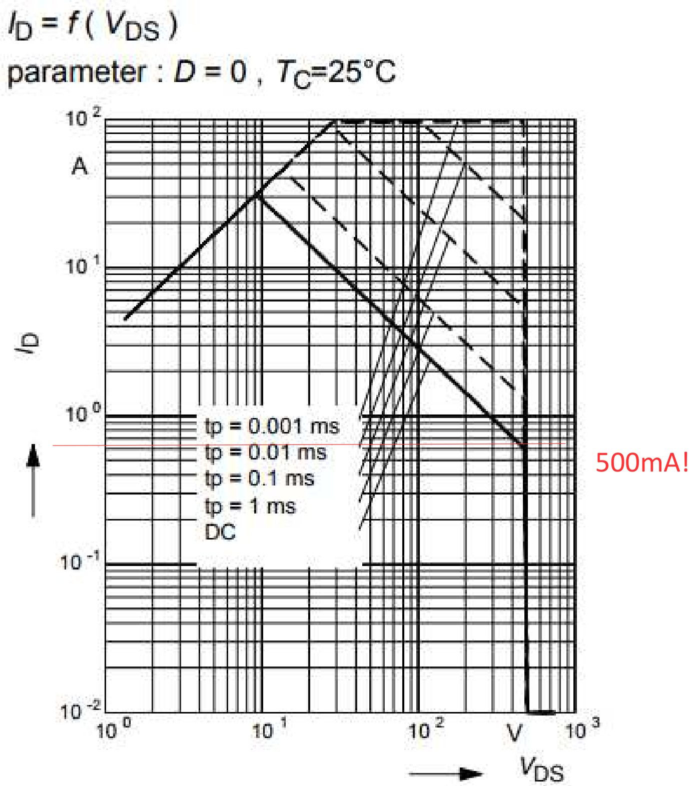
*** R17 = Umax * 2,441kΩ - 10kΩ

Selection of a suitable Mosfet:

For selection of the Mosfet, Uds max. is one important parameter:

For Anode and Grid2 supply, Uds must be >500V, while Id max is not the critical parameter (350mA for Anode supply and 30mA for Grid supplies). Especially for the Anode supply, the safe operating area for DC operation is important:

The SPW32N50C3 has a maximum Uds of 560V and an Id of max. 32A. This seems to be far too much for the maximum Anode current, but a look into SOA diagram shows the truth:



At an Uds of 560V, the maximum Drain current must not exceed 0,5A at DC operation!

So this is OK for the Anode supply.

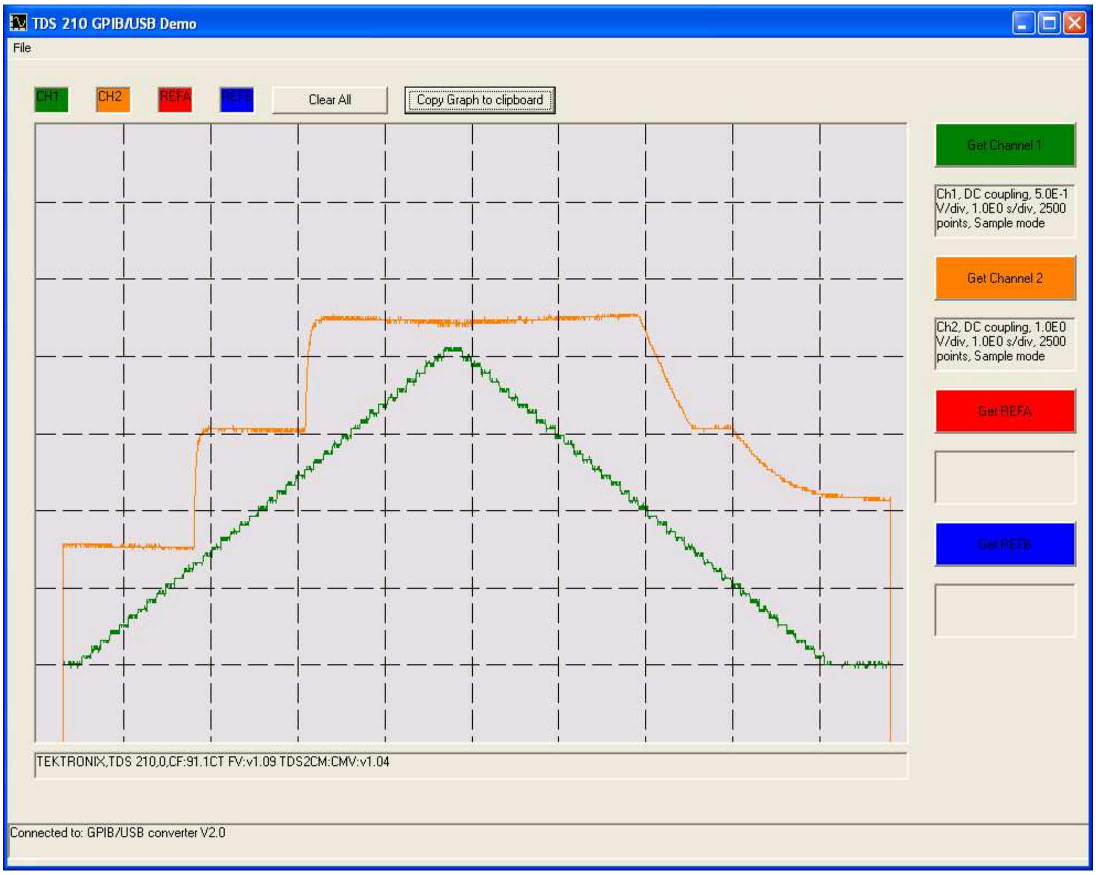
Power distribution board

In the General schematics below you can see how the 4 regulator boards are connected.

The Power Transformer is connected to the power distribution board, which contains rectifiers, capacitors and fuses for all power supplies. A 40pin flat cable connector to the Raspberry Pi provides communication with the Raspberry Pi and distributes the SPI signals and 5V power supply to the regulator boards.

The Anode supply part on the distribution board has two relays (RL1 and RL2) , which selects suitable transformer voltages (110-220-330V) to reduce power dissipation of Q6 of the Anode regulator. The relays are switched by software via GPIO pins 20 and 21.

In the diagram below you can find the DC input voltage (orange trace) as a function of the Anode output voltage (green trace):



X= 1s/div, Y= 100V/div

General schematics:

Refer to the file “General schematics.pdf” for connectio of all components

The files “Distributionboard_schematics.pdf” and “Distributionboard_layout.pdf” contains schematics and layout for the distribution board.

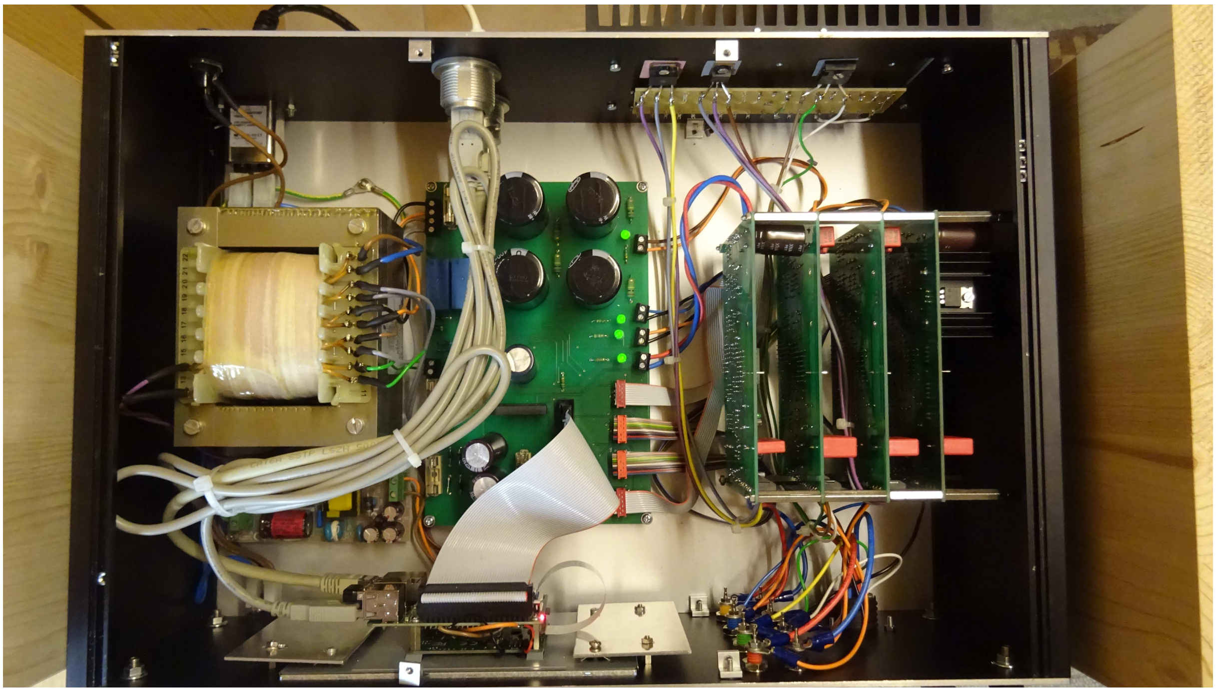
Power supply for Raspberry Pi

You can use any switch mode power supply which is able to deliver at least 2A @5V for the Raspberry Pi.

Remark: Connect the power supply to the Connector J8 – do not use the USB connector, since the voltage drop on the cable ist too high!

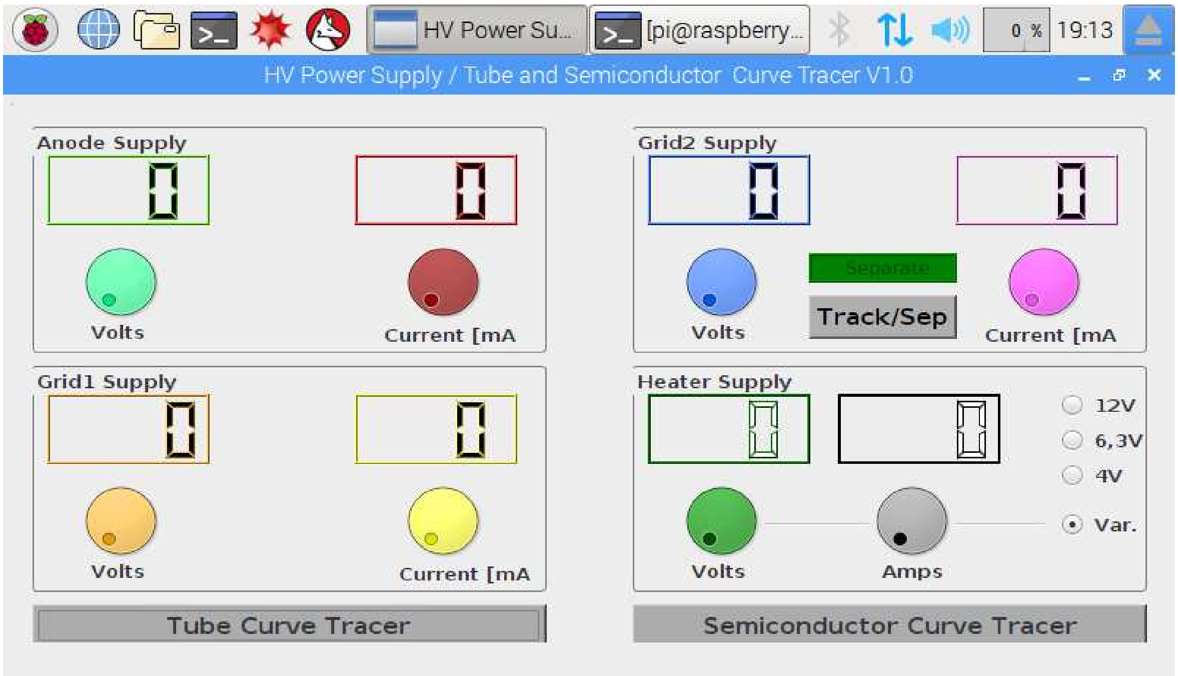
Mechanical assembly

The photo below shows how I assembled all parts of the power supply. The Tube adapter socket is for connection of a tube or transistor adapter. One USB and one Ethernet connector on the rear is connected to the Raspberry Pi.



Power supply mode

After powering up the device, the Tube Curve Tracer will be automatically started in "Power Supply Mode":



Now you can adjust Anode volts/amps, Screen grid volts/amps, Control grid volts/amps and Heater volts/amps either by touch screen or by external keyboard/mouse.

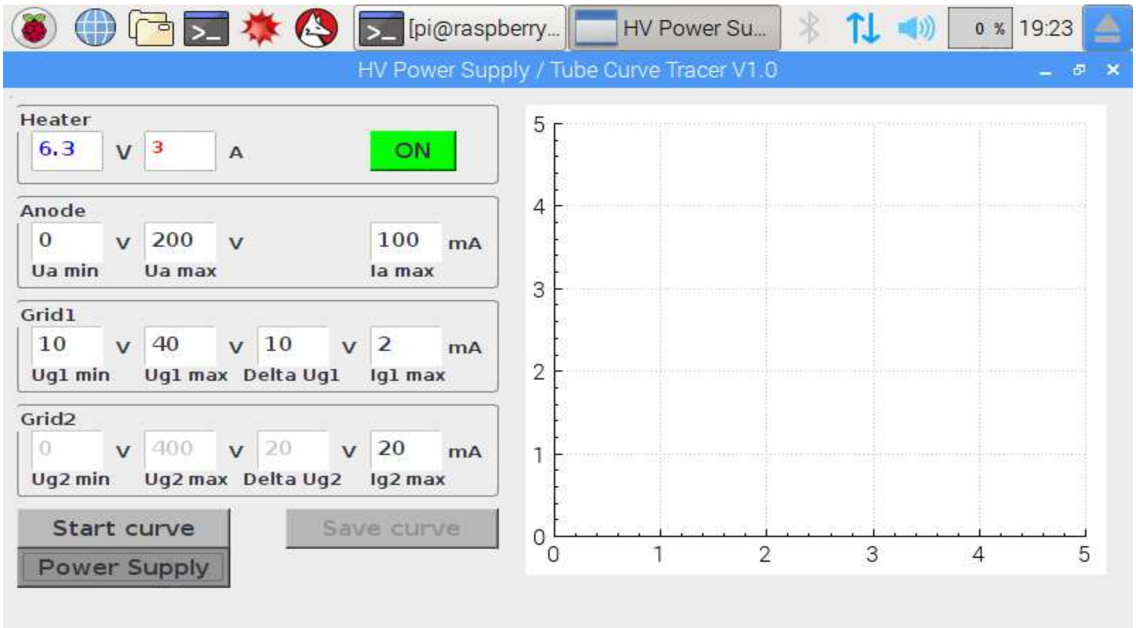
With the button "Track/Sep" you can switch on tracking mode. In this mode, the Screen grid voltage is linked to the Anode voltage supply for Triode operation of a Pentode.

The Heater voltage can either be adjusted from 0 to 14V wit the Potentiometer – or you select predefined Voltages of 4- 6,3 or 12V.

Pressing the Button "Tube Curve Tracer" switches off all voltages, closes the Power supply window and shows the Tube Curve Tracer Window.

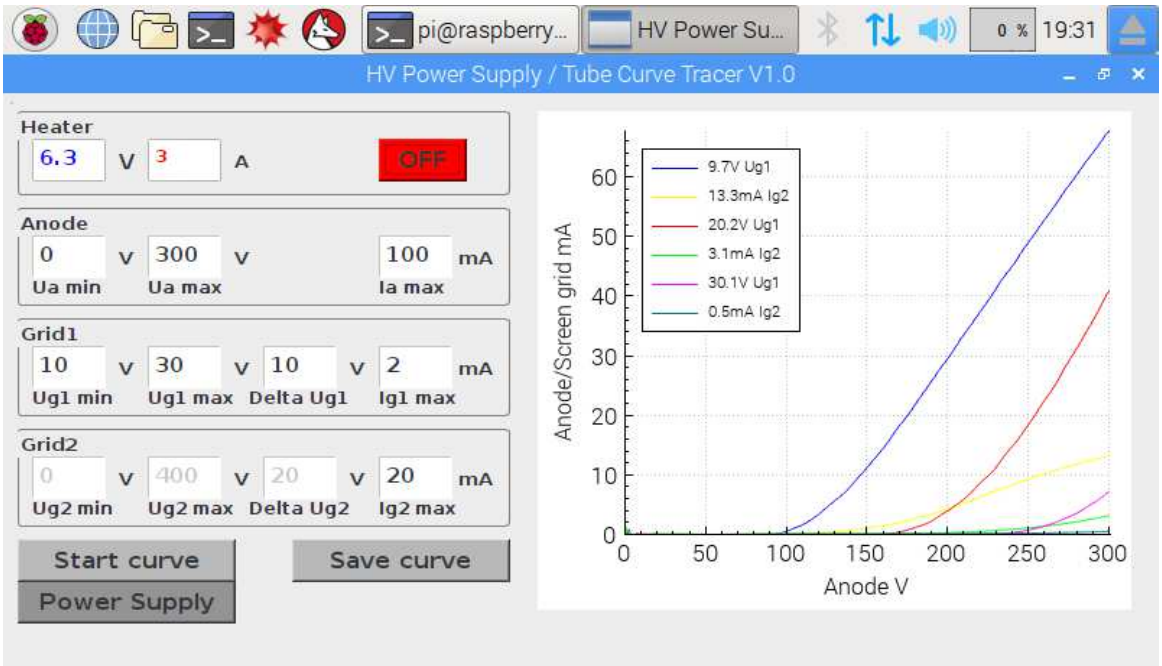
Tuber Curve Tracer Mode

In this mode, tube curves can be recorded and saved as “Comma separated value” - files, readable with Excel:



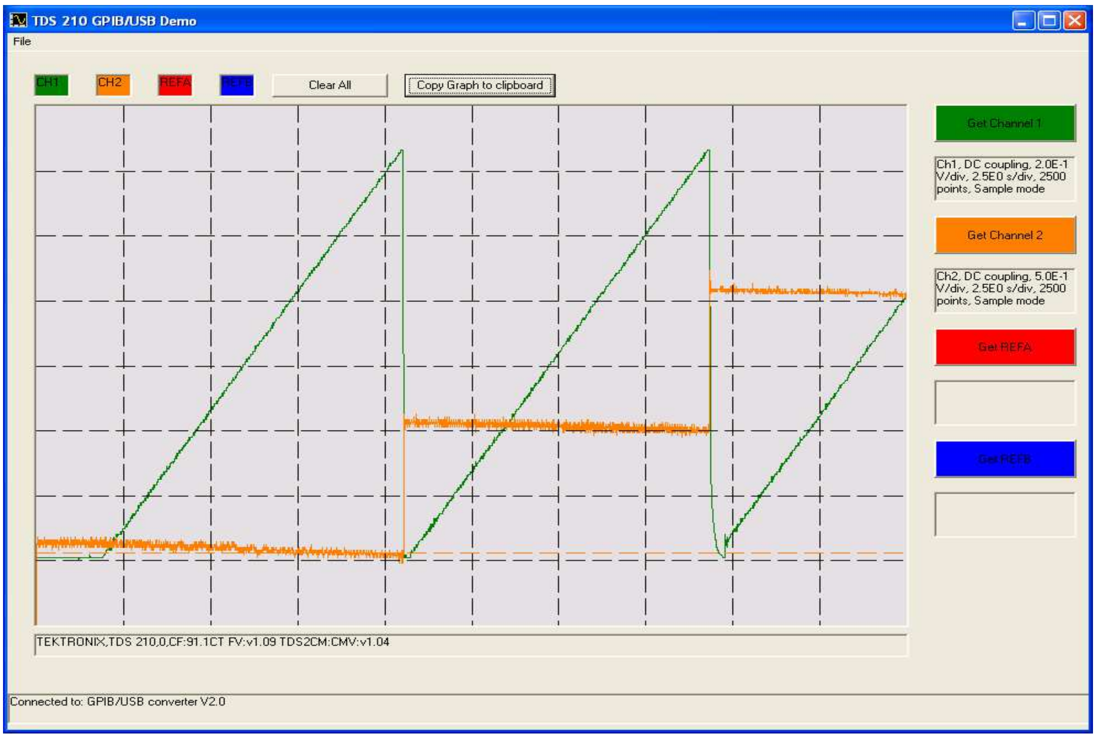
Here also the Heater Voltage and current can be adjusted, button “ON” switches on the heater. Then you can adjust the minimum and maximum Anode Voltage and the maximum Anode current. The screen grid voltage is connected to the Anode voltage, but you can adjust the maximum screen grid current. Then you can adjust the minimum and maximum control grid voltage and the steps. A maximum of 5 curves can be plotted.

Example of an EL34:



The curves show the Anode current as function of the Anode voltage with control grid voltage as parameter. Also recorded are the screen grid currents.

This picture shows the Anode voltage (green trace) and the control grid voltages (orange trace) during curve recording:



Saving curve files:

Pressing the button “Save curve” will save all voltage/current values in a “.csv” file format. This file can be transferred via “WinScp” to the PC for further evaluation in Excel.

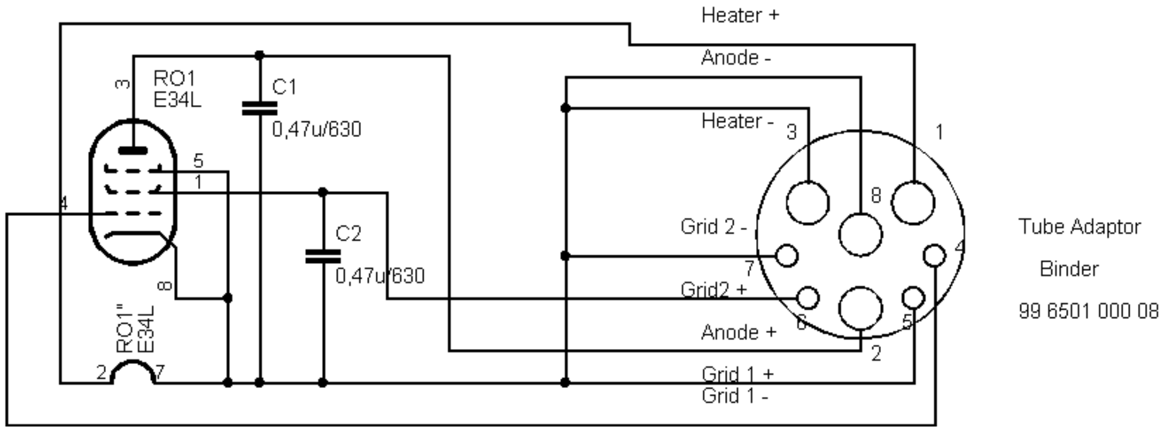
Example:

Grid1 Volts	Grid1 mA	Anode Volts	Anode mA	Grid2 Volts	Grid2 mA
0.5	0.0	0.0	0.0	0.0	0.0
0.6	0.0	0.0	0.0	0.0	0.0
1.0	0.0	0.0	0.0	0.0	0.0
0.9	0.0	0.0	0.6	0.0	0.0
0.7	0.0	19.9	3.4	19.1	0.6
0.3	0.0	24.3	8.6	24.4	1.5
0.4	0.0	29.8	11.2	29.8	1.6
0.5	0.0	35.1	14.1	34.8	2.1
0.9	0.0	40.4	15.4	40.7	1.9
0.9	0.0	44.8	17.1	44.0	2.5
0.7	0.0	50.1	22.8	49.9	3.4
0.3	0.0	54.6	30.1	54.5	4.7
0.4	0.0	59.9	35.3	59.8	5.0
1.0	0.0	66.2	34.9	65.3	4.8

Tube Adapter

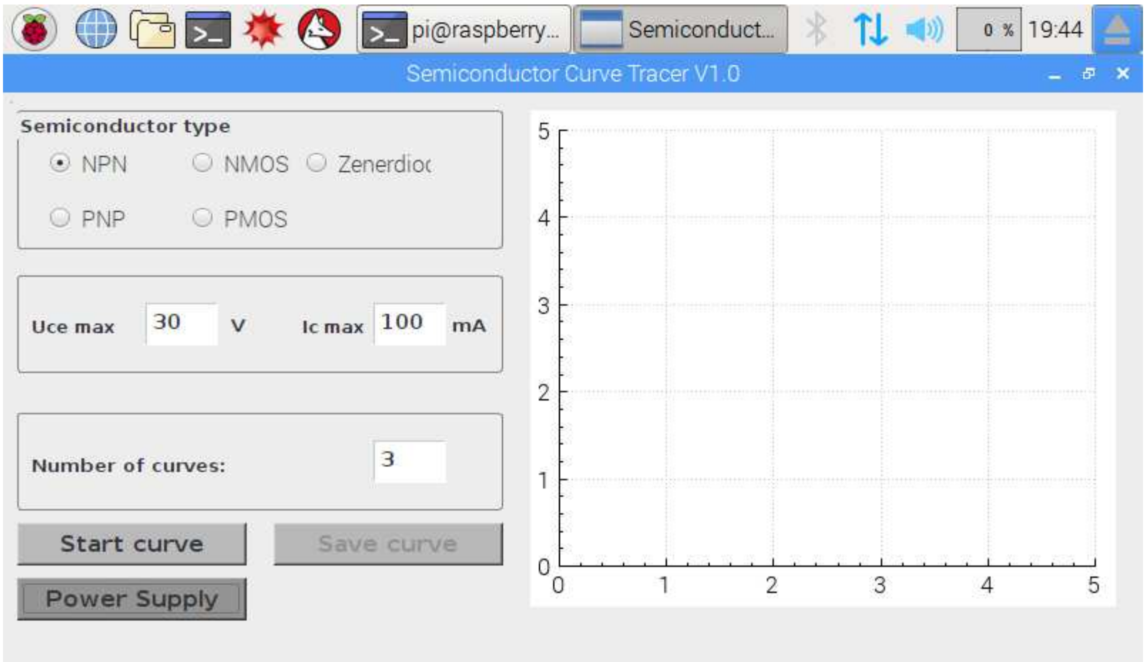
The Tube under test must be connected to the Tube Adapter plug on the Tube Curve Tracer:

Schematics for the EL34 Adapter:

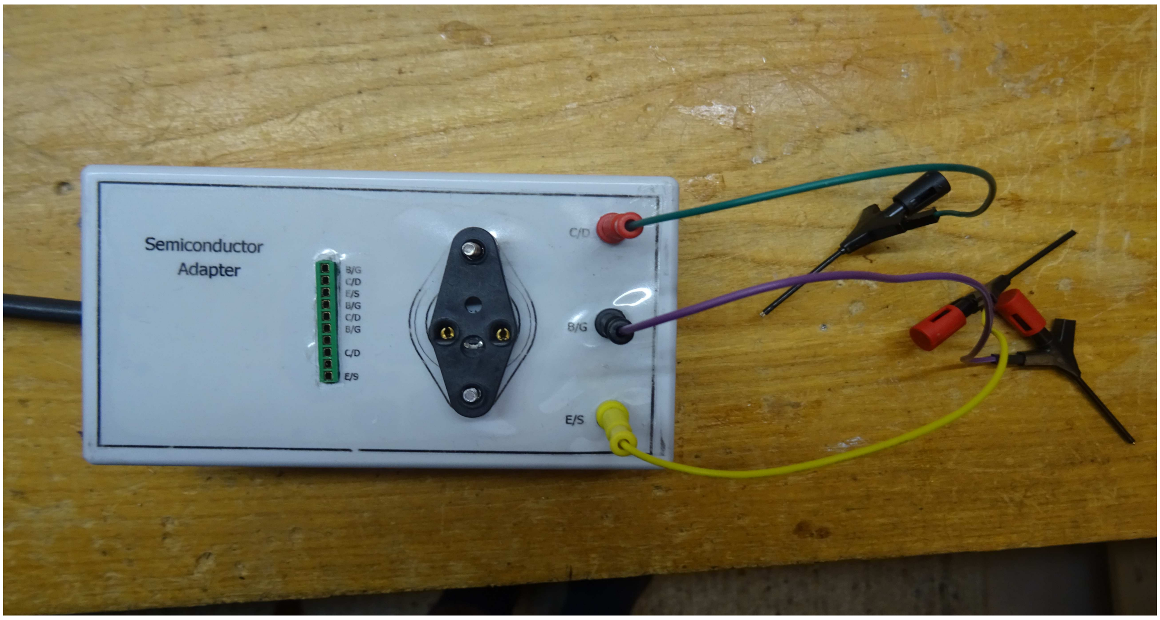

Heater +
Anode -
Heater -
RO1
E34L
C1
0,47u/630
C2
0,47u/630
RO1"
E34L
Grid 2 -
Grid2 +
Anode +
Grid 1 +
Grid 1 -
1
2
3
4
5
6
7
8
Tube Adaptor
Binder
99 6501 000 08

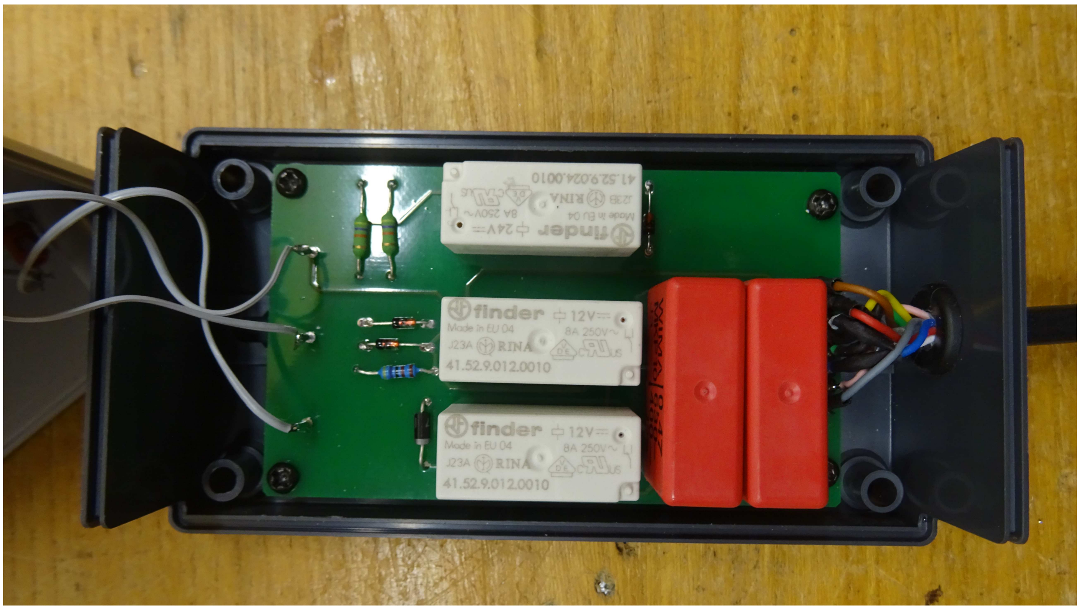
Semiconductor Curve Tracer

After pressing the button "Semiconductor Curve Tracer" in Power Supply mode, the Semiconductor Curve Tracer Window appears:



For testing semiconductors, a special semiconductor adapter must be connected to the tube adapter connector of the device.





The files “Semiconductor Adapter_schematics.pdf” and “Semiconductor Adapter_layout.pdf” contains the schematics and layout for the semiconductor adapter.

Description:

Connector SV1 connects to the Tube adapter plug on the HV Power supply. Heater supply switches relays K1 and K2 to select NPN/PNP and NMOS/PMOS polarity. Grid 1 supply switches relay K3 for selection of Ib /Ugs. Transistor Collector/Drain or Zenerdiode Cathode is connected to Anode supply +, Emitter/Source/Anode is connected to Anode supply -.

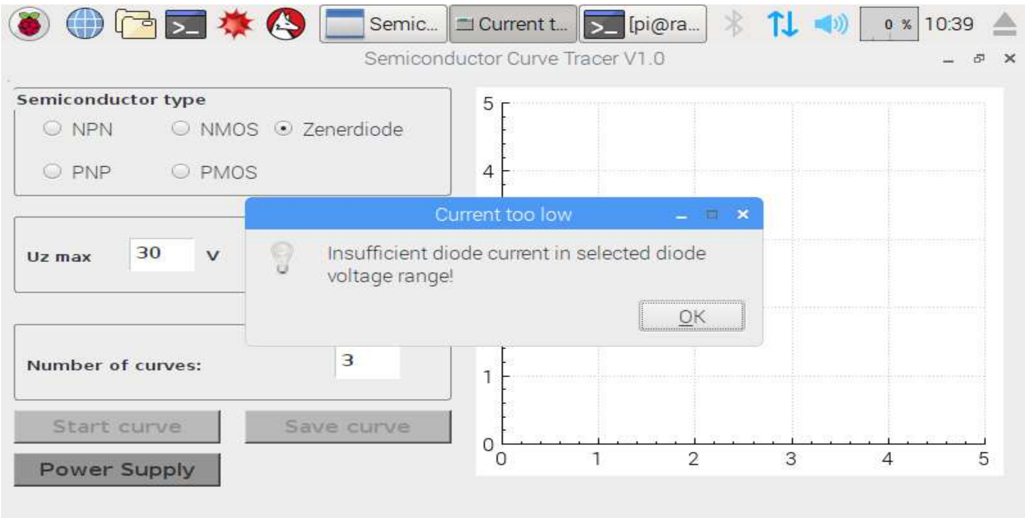
For NPN/PNP transistors, Grid 2 supply provides base current via R2 and R3. With a maximum Grid2 voltage of 400V, a maximum base current of 4mA can be provided.

For NMOS/PMOS transistors, K3 adds a voltage divider (R1) to the Grid2 supply. D3 and D4 limits the max Ugs to 19V.

Testing Zenerdiode voltage and Uce max of bipolar transistors

After selecting “Zenerdiode”, Uce max and Ic max fields changes to Uz max and Pmax, since Zenerdiodes usually are designated with their maximum power dissipation.

After pressing “Start curve”, Anode voltage is ramped up from 0 to Uz max or to Pmax (depends on what comes first). If Zener current is less than 1% of the maximum Zener current, a warning message appears:



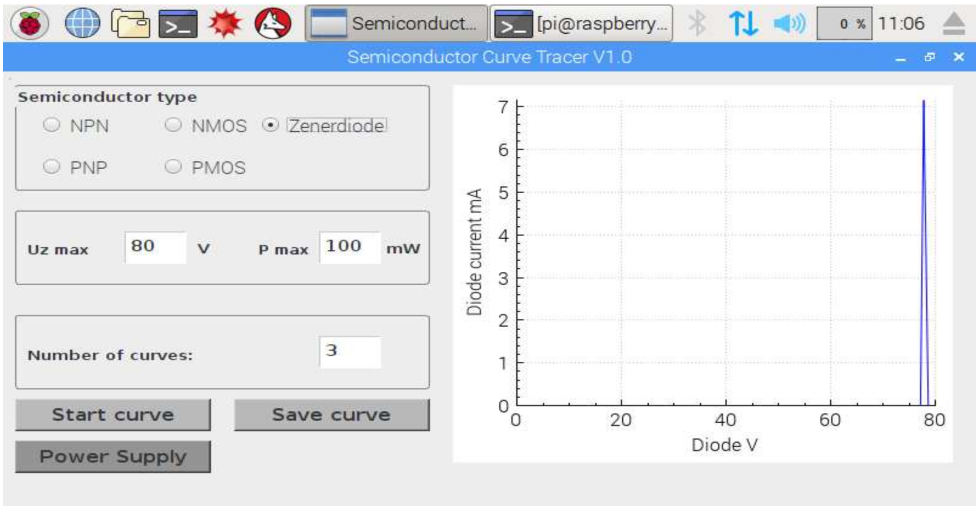
The Zenerdiode is either defective, or you have to extend Uz max.

Only one curve will be plotted, independent what number of curves entered.

In principle, also diodes and LEDs can be tested, but since the Anode voltage step is 1V, you will not get suitable results.

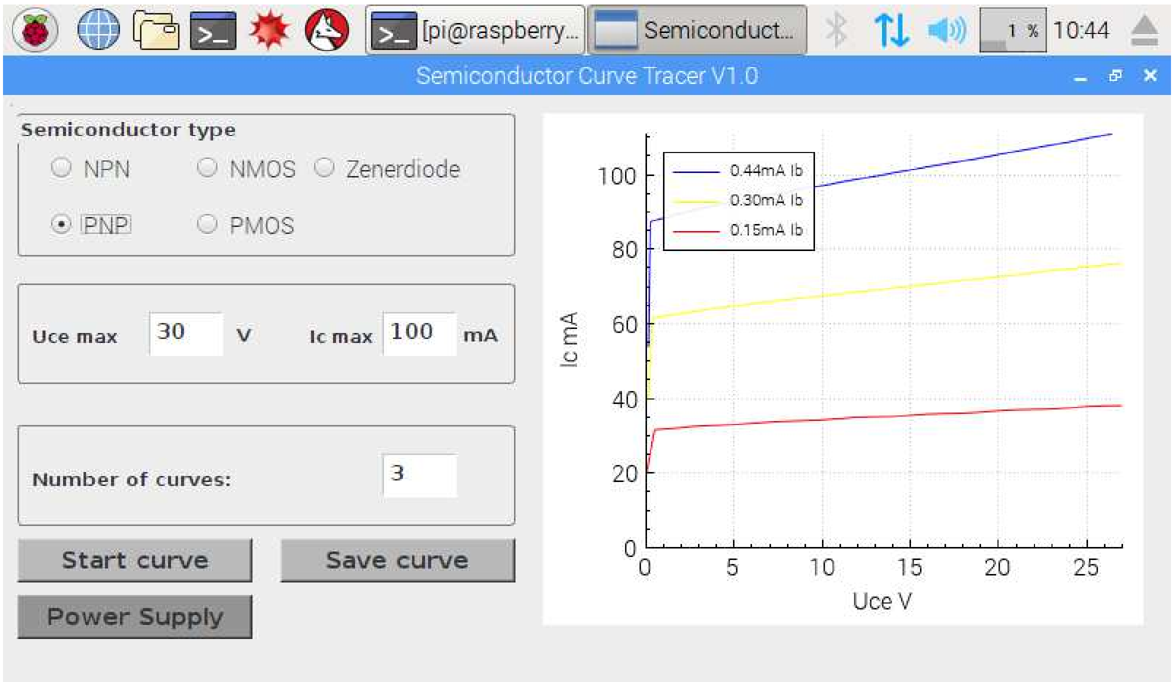
But because of the high Anode voltage, this mode can also be used for measuring Uceo max of bipolar transistors: Since the Collector==> Emitter diodes behaves also as a zenerdiode, you can check Uceo max by connecting a PNP/NPN transistor with an open base.

Here an example of a BC547C. According to the datasheet, this transistor has an Uceo max of 45V:



This diagram shows that the BC547 has an Uceo max of ~80V!

Testing Bipolar Transistors



When selecting NPN or PNP, bipolar transistors will be tested. Uce max, Ic max and number of curves can be entered. Software first checks if no collector current flows with no base current up the Uce max. Otherwise, an error message will be displayed. On Uce max, ib will be increased until Ic max reached. If there is no collector current on Ib max (4mA), also an error message will be displayed. Otherwise, Ib will be divided by number of curves.

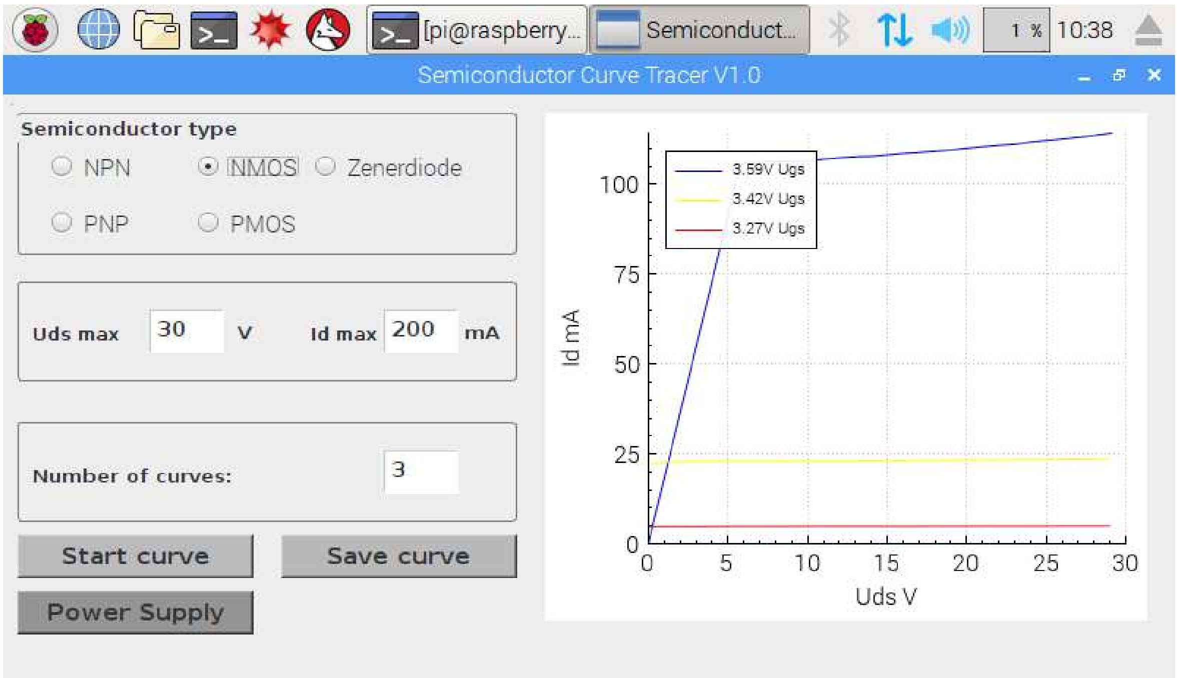
Curves Ic = f(Uce) will be displayed, showing the correspondent Ib in the legend.

Pressing “Save curve” stores the Ib, Ic and Uce values in a “.csv” format file, which can be read by Excel.

Remark

Be careful with the Uce/Ic settings: Setting Uce max to 400V and Ic to 300mA will result in a power dissipation of 120W of the transistor under test. Take a look into the S.O.A. Diagram of the appropriate transistor before setting the values.

Testing Mosfet Transistors



By selecting NMOS or PMOS, Mosfets can be tested. Uds max, Id max and number of curves can be entered.Software first checks if no Drain current flows with no Ugs up the Uds max. Otherwise, an error message will be displayed. On Uds max, Ugs will be increased until Id max reached. If there is no Drain current on Ugs max (18V), also an error message will be displayed. Otherwise, Ugs will be divided by number of curves. Curves Id = f(Uds) will be displayed, showing the correspondent Ugs in the legend.

Pressing “Save curve” stores the Id, Ugs and Uds values in a “.csv” format file, which can be read by Excel.

Remark

Be careful with the Uds/Id settings: Setting Uds max to 400V and Id to 300mA will result in a power dissipation of 120W of the transistor under test. Take a look into the S.O.A. Diagram of the appropriate transistor before setting the values.

Software

The software for the Raspberry Pi was written in C++ within the Visual Studio IDE on a Windows PC. Cross compiling and transferring the executable file on a Linux system was done by the VisualGDB Add On. GUI was developed with the Multi-platform developing system QT.

Necessary software installation on the Raspberry Pi

If you only want to run the "TubeCurveTracer" Application, you have to install the following components on the Raspberry Pi. I only give a link to YouTube videos (example) for each component:

- Install operating system NOOBS, see NOOBS Installation
- Install "7" touch display, see Touch display
- Install wiring Pi library, see Wiring Pi

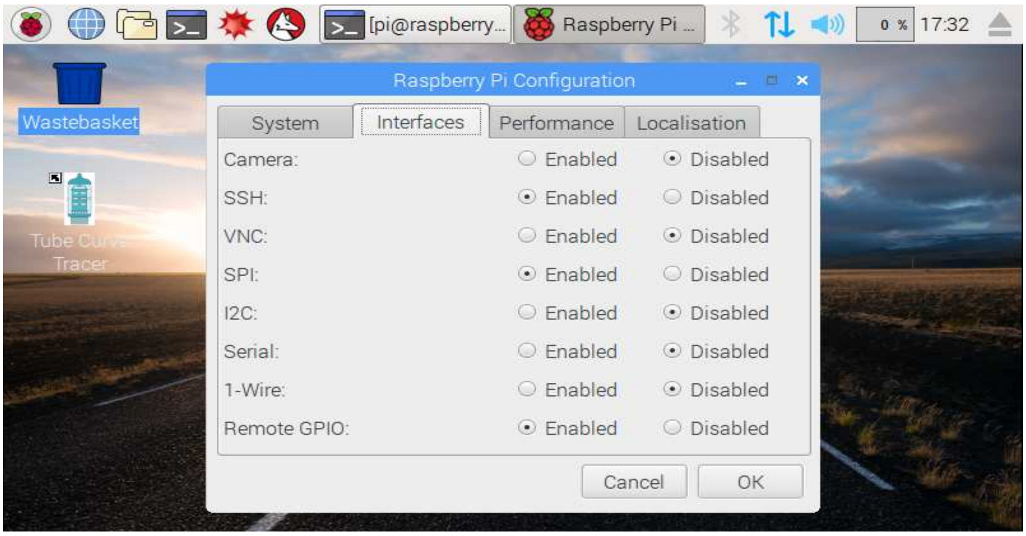
Now install the necessary files for the Tube Curve Tracer Application:

- TubeCurveTracer
- Tube.xpm
- Tube.png

You can copy the files by using WinScp (can be downloaded from https://winscp.net/eng/download.php). Files must be copied to „/home/pi/TubeCurveTracer/.

If you want to start the application automatically after booting, you have to copy the file „TubeCurveTracer.desktop" to the directory /home/pi/desktop.

To give the application access to the GPIO pins, finally you have to modify the configuration:



Necessary Software installation on a Windows PC

If you want to modify the application – or you want to develop your own applications, you have to install Visual studio with **all components** (from https://docs.microsoft.com/de-de/visualstudio/install/install-visual-studio). For compiling and linking the files for raspberry Pi, you also have to install VisualGDB (http://visualgdb.com/download/). VisualGDB has a 30 day free trial version with full functionality – then you have to buy the Linux – version (minimum), the price is 94.-€ at the moment.

Copy all files of the TubeCurveTracer Project to suitable directory and run the project file „TubeCurveTracer.sln“ to start Visual studio.

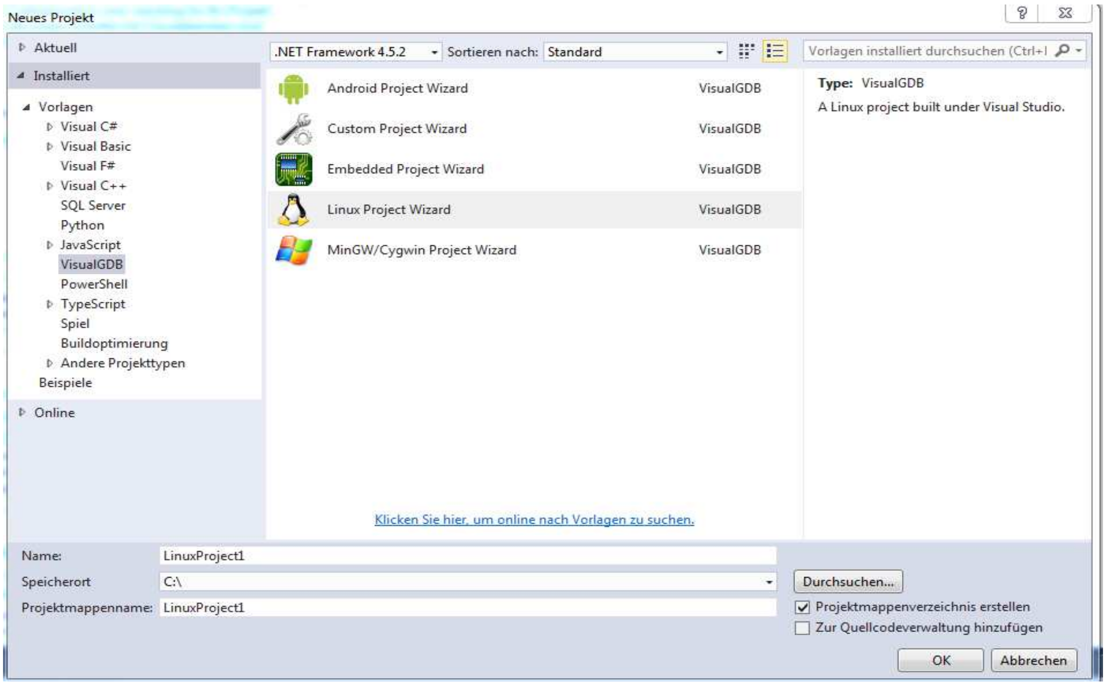
The project contains the following source files:

- Mainwindow.h, Mainwindow.cpp: Header and Source for the HV power supply window
- ui_Mainwindow.h: Header file for the HV power supply GUI (created by QTDesigner)
- CurveTracerWindow.h, CurveTracerWindow.cpp: Header and Source for the Tube Curve Tracer window
- ui_CurveTracerWindow: Header file for the Tube Curve Tracer GUI (created by QTDesigner)
- TransistorCurveTracerWindow.h, TransistorCurveTracerWindow.cpp: Header and Source for the Semiconductor Curve Tracer window
- ui_TransistorCurveTracerWindow: Header file for the Semiconductor Curve Tracer GUI (created by QTDesigner)
- hardware.h, hardware.cpp: Header and source file, containing functions for setting /reading voltages and currents, using also wiringPi library.
- Qcustomplot.h, qcustomplot.cpp: Header and source file for plotting curves (free library)
- CurveTracerWindow.cpp: Source file for the main application (created by VisualGDB)

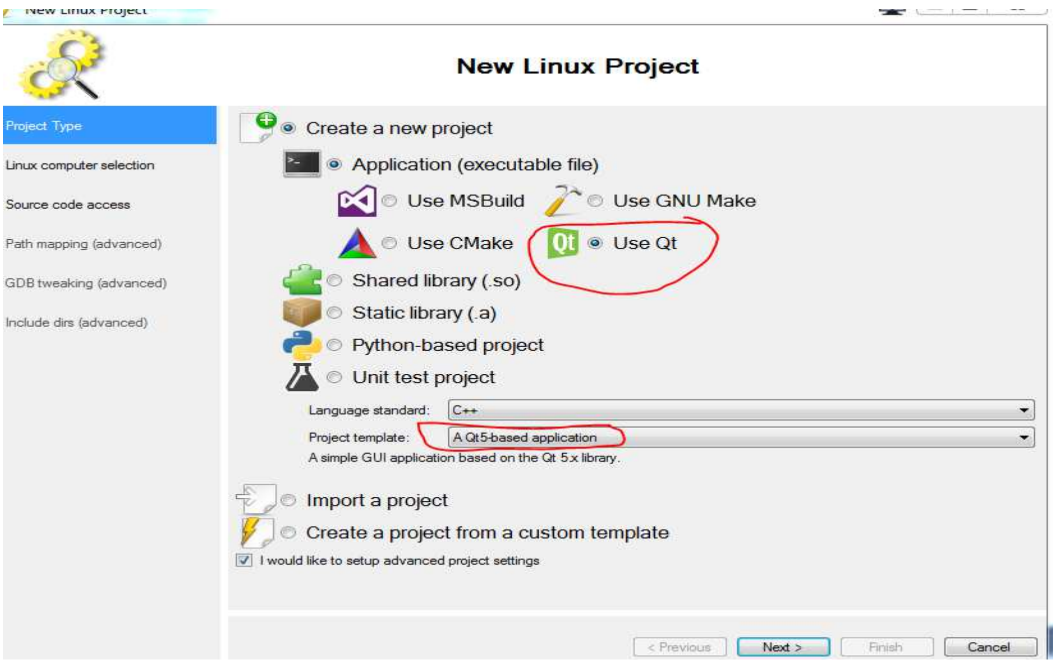
If you want to create your own graphical user interface – or you want to modify the Tube Curve Tracer GUI, you also have to install Qt 5.x (from https://www.qt.io/download). Download the „Open Source“ version, which is free. The GUI source files begin with ui_xxx.

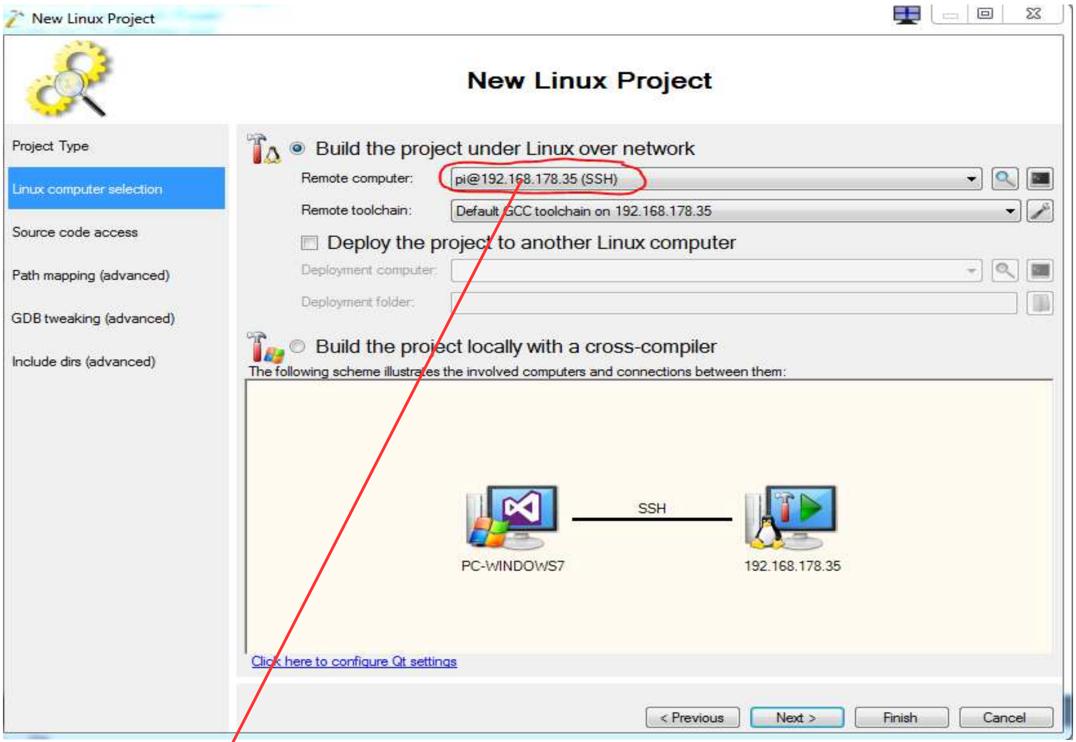
If you want to start a new project from the scratch, follow these installation steps for a correct setup:

Start Visual studio with „New Project“:



Select Linux Project Wizard, then OK:

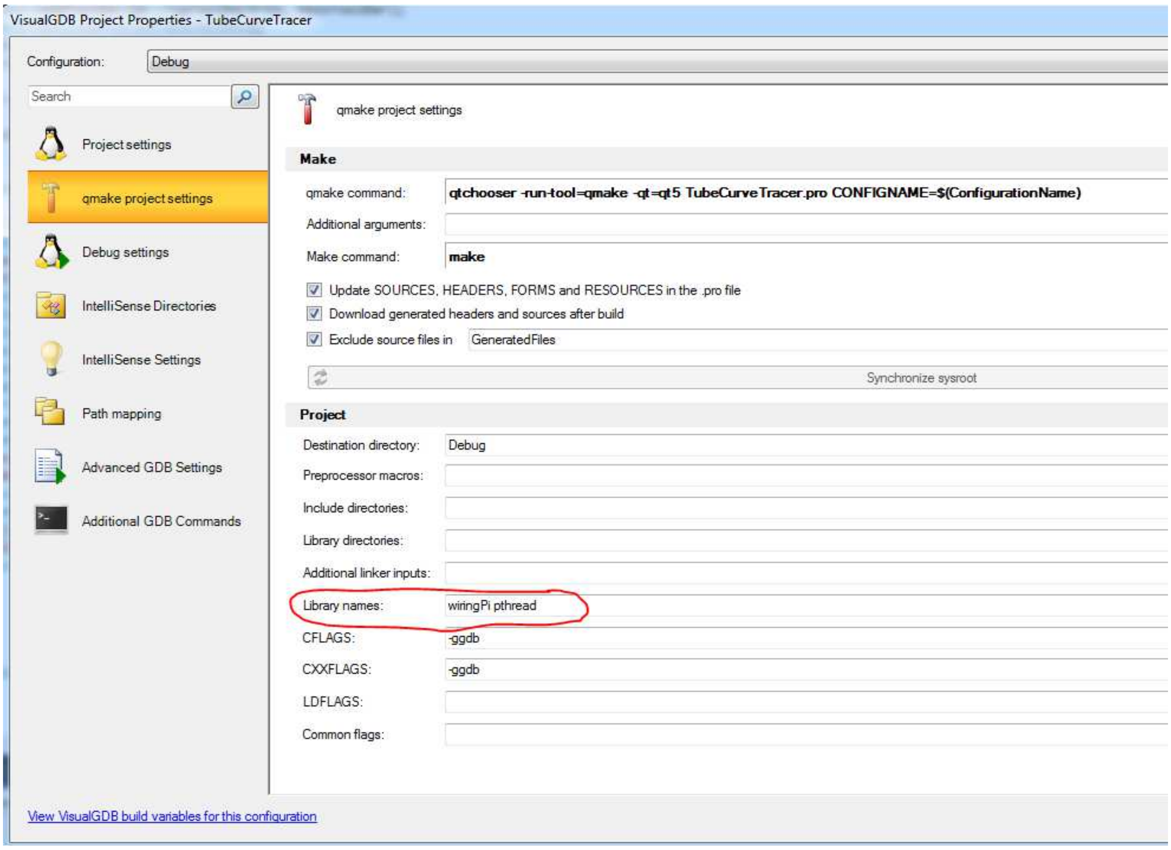




Insert your IP adress here

You can leave the settings of the next windows as they are (eventually change target directories). After pressing "Finish", Visual Studio and VisualGDB generates the Project settings and you can start designing your own project.

If you want to use the wiringPi library in your project, you have to add "wiringPi pthread" in the line "Library name" of the "Project properties":



The Tube Curve Tracer Project uses "Qcustomplot" for plotting curves. If you want to use it also, you have to add "`QT += core gui xml printsupport`" in the „.pro" - file of your project.