The DESY FH E-Lab Probe Station

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Abstract

This document describes the operation of the probe station in the clean room of the FH E-Lab at DESY and the use of the corresponding software. Chapter 1 lists the available hardware and how the devices should be connected. In chapter 2 the steps needed to perform a measurement are explained, together with details on how to use the measurement software.

The most recent versions of this manual and the software can be found at [1].

Contents

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1 Hardware Setup

This chapter gives an overview of the probe station's devices and their default connections. After finishing your measurements, all connections should be returned to this default state and the devices turned off.

1.1 Cold Box

The cold box case contains the probe needles and the chuck with their electrical connections. An outside view of the cold box is shown in figure 1a, an inside view in figure 1b.

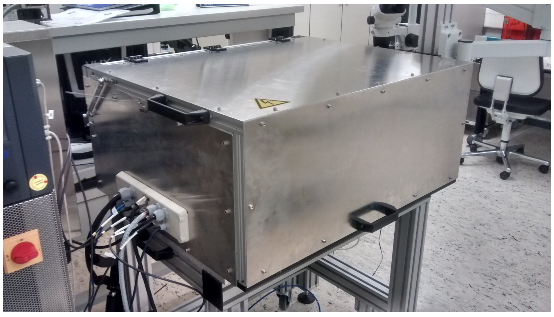

Figure 1a: Outside view of the cold box.

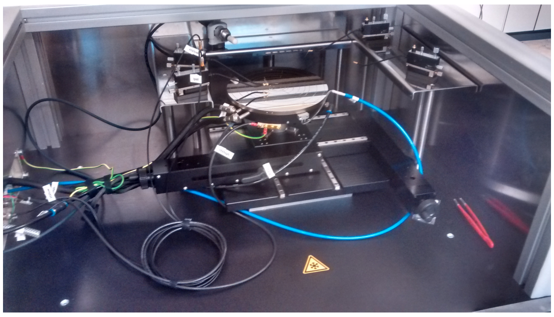

Figure 1b: Inside view of the cold box with the chuck.

When opening and closing the lid of the cold box, beware not to trap any cables. All cabling and piping should be routed via the connection panel on the lower left side of the cold box. For safety reasons, any voltage output should be turned off before opening the lid. This also prevents possible excess currents on the DUT (*device under test*) due to ambient light.
Especially for low-temperature operations, the cold box should be flushed with dry air to prevent condensation. To activate the flow of dry air to the cold box, open the valve beneath the window of the clean room, next to the door. The hose leading to the probe station is marked. To change the flow of air, pull out the knob. Turning counter-clockwise decreases the air flow, clockwise turns increase it.

1.2 Microscope

The Olympus SZ61 microscope is attached to the cold box via a movable arm. A switch on the lower part of the black lens casing turns on the light. While moving the microscope, be careful that the light's power cable does not get trapped inside the cold box. The microscope is used for placement of DUTs on the chuck and the positioning of the probe needles. An example operation is shown in figure 2a.

1.3 Compressor

The compressor shown in figure 2b is connected to the mains and to the chuck inside the cold box via a blue vacuum pipe. The vacuum created by the compressor is used to fix DUTs on the chuck. Currently, the outer vacuum hole on the chuck is connected. The compressor is operated by its orange switch.

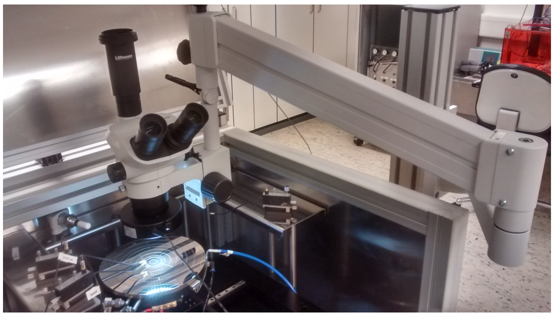

Figure 2a: The microscope being used for positioning the needle probes.

Figure 2b: The compressor on the floor beneath the cold box.

1.4 Chuck and XY-Stage

The chuck inside the cold box is connected to the high voltage from the CV/IV box, the vacuum line from the compressor and the coolant inlet and outlet from the chiller. A dry air connection and a serial cable from the chiller control unit are also connected. The position of the chuck can be adjusted manually by turning the wheels, the levers allow for larger movements. When moving the chuck, the probe needles should be well away from the chuck surface as to avoid damage and scratching.

1.5 Probe Needles

There are four probe needles on manipulators, sitting on magnetic rails in the cold box. One needle is for the pad/high voltage connection, one needle for the guard ring connection. Both these needles are clearly marked. The two remaining needles are for strip measurements. Figure 3 shows a manipulator and how to adjust its position. The probe needles should be handled extremely carefully, as they can break very easily. They should be far away from any moving objects. For positioning, the microscope should be used.

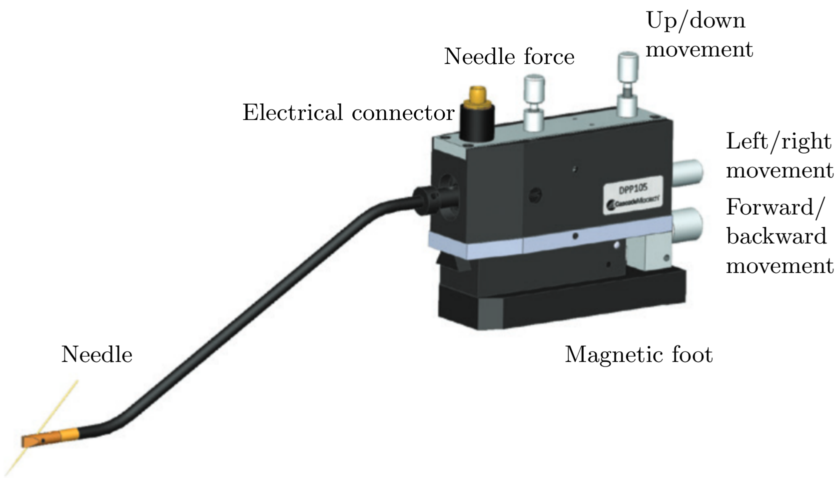

Figure 3: A needle probe. The bottom screw can be used to adjust the position in forward/backward direction, that is in the direction of the needle. By using the up/down screw, the needle is placed on the device under test.

1.6 Keithley 6517B

The Keithley 6517B is used as a voltage source for the setup and to measure the DUT currents. It is controlled by the software running on the read-out computer. Figures 4a and 4b show the front and back views of the device. The connection schematic is shown in figure 9 and explained in section 1.11. A manual can be downloaded from [2]. It can take a while for the Keithley 6517B to warm up after switching it on, so for comparable and accurate measurements it is advised to wait a few minutes. After finishing your measurements, the Keithley 6517B should be turned off again, especially before opening the cold box and (dis-)connecting the probe needles.

Figure 4a: Front view of the Keithley 6517B. The on/off switch is at the bottom left.

Figure 4b: Rear view of the Keithley 6517B. The cable labelled `ImeasHV` goes to the top left triax input connector. The source outputs connect to the `HVout` cable.

1.7 Agilent E4980A and the CV/IV Box

The Agilent E4980A LCR-Meter is used for capacitance measurements. Via the CV/IV box it can be switched into the connection between the Keithley 6517B and the DUT/chuck. A manual can be downloaded from [3]. The CV/IV box shown in figure 5b is plugged into the front of the Agilent E4980A and allows the user to select between IV (bottom switch to top) and CV (bottom switch to bottom) measurement modes.

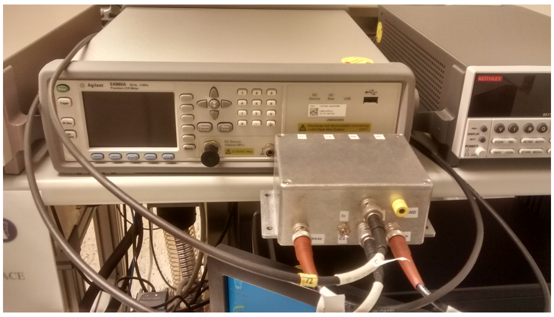

Figure 5a: Front view of the Agilent E4980A with the old CV/IV box attached. The on/off switch is at the bottom left of the device.

Figure 5b: Close-up of the CV/IV Box. A description of all the connections can be found in section 1.11.

A circuit diagram of the box is shown in figure 6. The top switch can be used to connect (`C`$_{\texttt{int}}$/`R`$_{\texttt{int}}$) or disconnect (`Ext`) the Agilent E4980A to the top row connectors. Switching should **never** be done during a measurement or whilst a voltage is applied. Note that if the CV/IV box is in CV mode, the current measurement of the Keithley 6517B will no longer be accurate. This is because of the large internal resistance of the Agilent E4980A and the CV/IV box. Thus, the following operation modes are available:

- **IV Mode:**
  The bottom switch is in the top position (`IV`). The position of the top switch is not relevant as only the Keithley 6517B and optionally the Keithley 6485 are used.
- **CV Mode:**
  The bottom switch is in the bottom position (`CV`), the top switch is in the top position (`External`). The Keithley 6517B and the Agilent E4980A are used via a single probe needle.
- **C_{int} or R_{int} Mode:**
  The bottom switch is in the top position (`IV`), the top switch is in the bottom position (`C`$_{int}$/`R`$_{int}$). The Keithley 6517B and the Agilent E4980A are used via different probe needles.
- **External Mode:**
  The bottom switch is in the top position (`IV`), the top switch is in the top position (`External`). The Keithley 6517B is used to provide bias voltage, an optional external device is usable via the spare inputs to the CV/IV box.

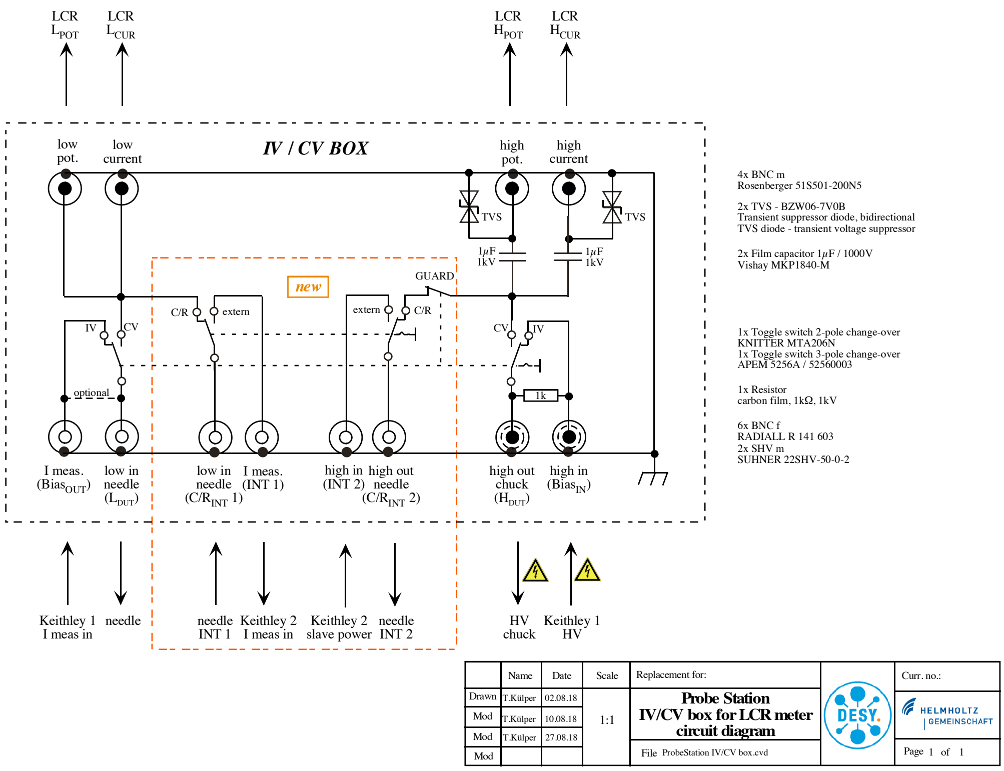

Figure 6: Schematic of the CV/IV Box [4].

1.8 Keithley 6485

The Keithley 6485 Picoammeter shown in figures 7a and 7b is used to measure guard ring currents. Its usage is optional for IV measurements and it is not needed for CV measurements. A manual can be found at [5]. The Keithley 6485 can also take a while to warm up after powering on, so also here for comparable and accurate measurements it is advised to wait a few minutes.

Figure 7a: Front view of the Keithley 6485. The on/off switch is at the bottom left.

Figure 7b: Rear view of the Keithley 6485. The cable labelled `Iguard` goes to the input connector.

1.9 Chiller and Control Unit

The chiller can be used to cool the chuck and thus the DUT. It is switched on by the large red switch on its front. The chiller control unit (c.f. figures 8a and 8b for front and back views) is located on the shelf above the read-out computer and has a power switch on its rear. The control unit is operated via the front touch pad. Beware that to operate the chiller, it must have sufficient coolant inside (check the markings). Furthermore, to prevent condensation, the cold box should be flushed with dry air. To monitor the dew point, a pipe with dry air is routed into the chiller control unit and from there into the chuck. Inside the cold box, a dew point sensor probe connected to the control unit (connector `X5`) measures temperature and humidity. Two serial cables (attached at connectors `X4` and `X7`) connect the chiller control unit to the chiller (connectors there `X8` and `X9`). The large DIN connector (`X2`) is connected to the chuck and can be used for heating the chuck and for temperature read-out. Whilst there is a GPIB connection to the read-out computer, a computer-controlled operation has not yet been implemented. An overview of the dry air and chiller connections is shown in figure 10 in section 1.11.

Figure 8a: Front view of the chiller control unit. It is operated via the touch-pad screen.

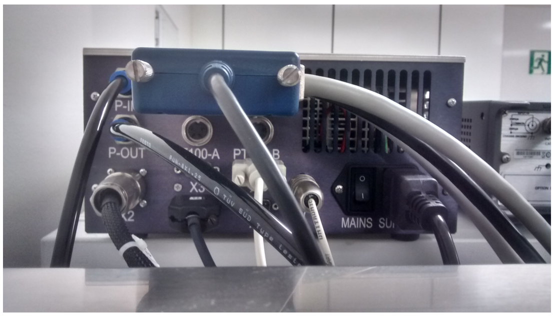

Figure 8b: Rear view of the chiller control unit. The on/off switch is located at the bottom right.

1.10 Read-Out Computer

The read-out computer (computer name: `fhlprobest.desy.de`) is connected to the measurement devices via an GPIB-to-USB connector. As the operating system is Windows 7, a login is only possible if your DESY user account is in the group `win`. Your group administrator or the UCO can add you to this group. Also, a remote connection is possible via the `rdp` protocol if your account is in the group `winterm`, so you can remotely connect to the read-out computer via the command

```
xfreerdp --ignore-certificate -u my-user-name -d win fhlprobest.desy.de
```

The read-out software can be used both from local or remote login and is detailed in section 2.

1.11 Electrical, Dry Air, and Chiller Connections

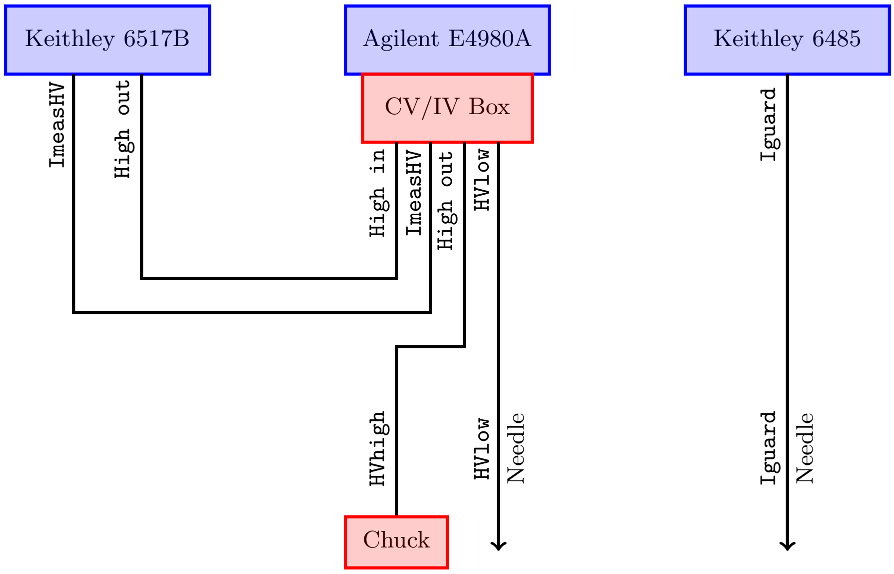

Figure 9: Sketch of the electrical connections.

The electrical connections between devices are shown in figure 9. The triax measurement input of the Keithley 6517B is connected to the `I meas (needle)` connector of the CV/IV box with a BNC cable that is labelled `ImeasHV` on both ends. The Keithley 6517B's back side HV source output is connected to the `High in (chuck)` connector of the CV/IV box with a red SHV cable labelled `High in (chuck)` on the box side and `High out (chuck)` on the device side. From the CV/IV box the connector `High out (chuck)` is connected to the chuck, via a red SHV cable marked `High out (chuck)`. The connector `Low in (needle)` is connected to the `Lo` needle via a BNC cable labelled `HVlow`. The backside measurement input of the Keithley 6485 is directly connected to the `GR needle`. The BNC cable is labelled `Iguard` on both ends.

From the dry air outlet on the lab wall next to the door, a hose runs towards the probe station. It is connected to a t-piece, from which one line goes directly to the cold box, another to the chiller control unit. From the chiller control unit, a line then goes into the cold box towards the chuck. Figure 10 shows the default connections.

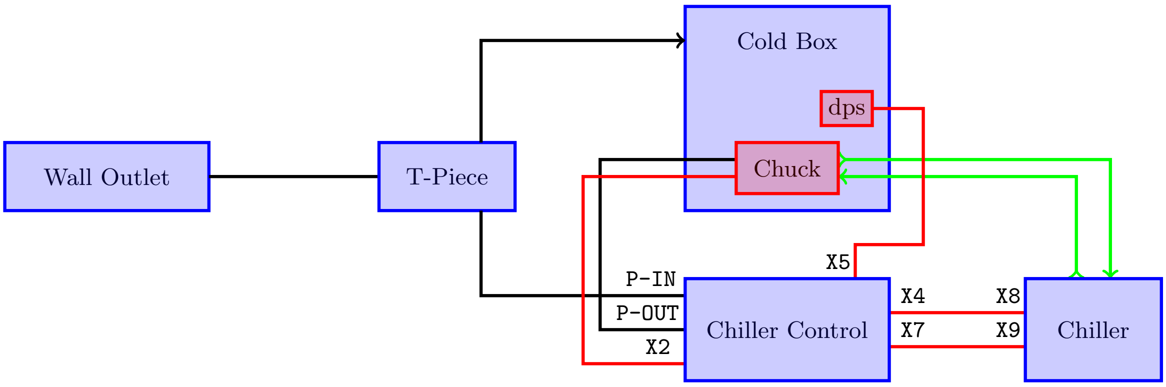

Figure 10: Sketch of the dry air and chiller connections. Dry air piping is shown in in black, electrical connections in red, coolant pipes in green.

2 Performing Measurements and Using the Read-Out Software

This chapter describes how to do an IV, a CV measurement and a strip measurement of a generic DUT. It is assumed that the entire setup is switched off with no active measurement running. Please make an entry into the setup's log book, stating your name, the date, the measurement you performed and any possible changes you made to the setup.

2.1 General Device Setup

- Verify that there is no active output from the Keithley 6517B with no ongoing measurement and that all devices (Keithley 6517B, Keithley 6485, Agilent E4980A and chiller control unit) are switched off.
- You can then open the cold box and, using the microscope, place the DUT on the chuck. The probe needles should be well out of the way to prevent damage.
- With tweezers, gently move the DUT over the outer vacuum hole on the chuck and then switch on the vacuum pump to fix the DUT on the chuck.
- For a measurement in a dry air atmosphere or for measurements at low temperatures, turn on the dry air flow, as described in section 1.4.
- If needed, operate the chiller via the touch panel of the control unit and wait for thermal equilibrium.

2.2 Setup for an IV Measurement

- By operating the probe needles as described in figure 3, carefully place the `HVlow` needle on the DUT surface. On most DUTs you will want to contact the bias ring.
- To additionally measure the guard ring current, place the `Iguard` needle on the guard ring of the DUT.
- Afterwards, close the cold box lid.
- You can then switch on the Keithley 6517B with its switch on the front side of the device.
- Set the bottom switch on the CV/IV box to the top (IV) position if it is not already there. The state of the top switch is not important.
- If you placed the guard ring needle, you can then switch on the Keithley 6485 with its front-side switch.
- Then perform an IV measurement, as described in 2.5.

2.3 Setup for a CV Measurement

- Before doing a CV measurement, first perform an IV measurement, as described above. With the IV measurement, verify that your DUT can handle the measurement polarity and range you want to cover in the CV measurement.
- After the IV measurement is done, turn on the Agilent E4980A with its front-side switch and wait for it to start up. The cold box can remain closed and the needles can stay on your DUT.

- Set the bottom switch on the CV/IV box to the bottom (CV) position.
- The top switch on the CV/IV box should be in the top (External) position.
- Then run a CV measurement, as described in 2.5.

2.4 Setup for a Strip Measurement

For a strip measurement (C_{int} or R_{int}), the recommended operation procedure is slightly different:

- First, follow all the steps described in section 2.1 with all devices (Keithley 6517B, Keithley 6485, Agilent E4980A and chiller control unit) switched off.
- Before connecting any probe needles, you should perform an open measurement for calibration. For this, turn on the Agilent E4980A.
- Then press the `Meas Setup` button on the front of the device[1].
- With the keys on the right of the display, select `Correction` and then `Meas Open`.
- Press the button `Display Format` to return to the main screen.
- After a successful calibration, you can place the `HVlow` needle on your device as for an IV measurement. Again, for most DUTs you will want to contact the bias ring.
- Afterwards, connect the two inter-strip needles to the AC- or DC-pads of the strips you want to measure.
- You can then switch on the Keithley 6517B. The Keithley 6485 (and the guard ring needle) is not needed for a strip measurement and can remain switched off.
- Set the bottom switch on the CV/IV box to the top (IV) position. The top switch on the CV/IV box should be in the bottom (C_{int}/R_{int}) position.

2.5 Performing a Measurement

Log in to the read-out computer with your user credentials. Navigate to

```
D:\Probestation
```

and run the software by double-clicking the shortcut `Probestation`. This will execute the command

```
C:\Programfiles\Anaconda3\python.exe gui.py D:\Measurements
```

in that folder[2]. The software GUI will start with the IV tab open, as shown in figure 11a.

For an IV measurement, select the starting voltage and the end voltage in the respective fields. Both positive and negative numbers are accepted. The field `Abs step` is used to select the absolute value of each step of the voltage ramp. `Wait time` specifies the time in seconds the Keithley 6517B waits before incrementing the voltage output in a ramp.

[1] If the device does not react to the buttons, verify that no read-out software is running. If the Agilent E4980A is being accessed via USB, GPIB or LAN connection, the control buttons on the device are deactivated.

[2] Opening the shortcut `Debug Probestation`, or appending a `-d` to the command will start the software in debug mode. The console output is more verbose and the user is not asked if the CV/IV box switches are in the correct position.

The following field, `Abs compliance current`, should be set to the software compliance limit for this measurement. If the absolute value of the current measured by the Keithley 6517B exceeds this value, the voltage source will immediately switch the output off and ramp the voltage down to 0 V. The following check box enables a guard ring measurement with the Keithley 6485, which of course has to be switched on for this. If activated, the Keithley 6485 will also check for current compliance and, if reached, turn the Keithley 6517B's voltage output off.

The final field allows the user to select a folder in which the measurement results will be saved. It defaults to the first command-line argument. All measurements are saved as a `.csv` file with the file name corresponding to date and time of the beginning of the measurement. Furthermore, an `.svg` image is saved of the final measurement window.

The CV tab shown in figure 11b looks similar to the IV tab, with additional fields where the frequency parameters can be set. The first one sets the measurement frequency of the Agilent E4980A, the `AC Voltage level` field sets the AC voltage.

The strip measurement tab looks similar to the CV tab, but has an additional field to select either a capacitance or a resistance measurement.

Beware that in CV and strip measurements, there is no software current compliance![3]

You should therefore **always** first do an IV measurement to verify that your desired voltage range is safe for your DUT.

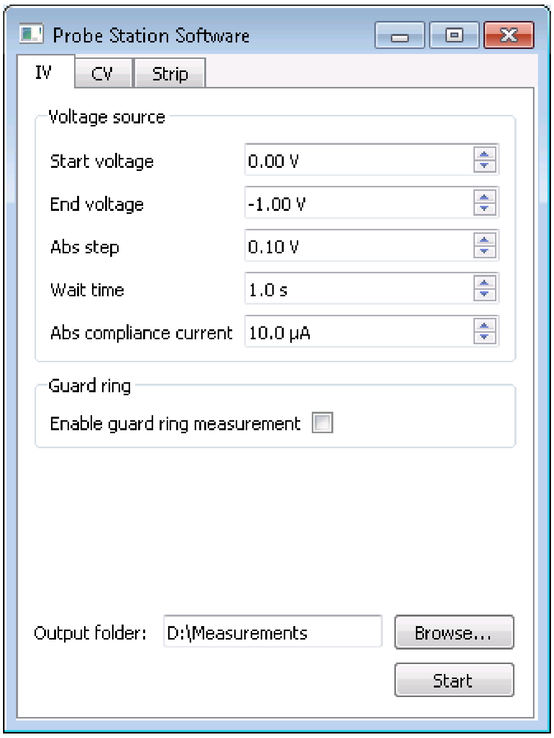

Figure 11a: Initial window of the measurement software, with the IV tab open.

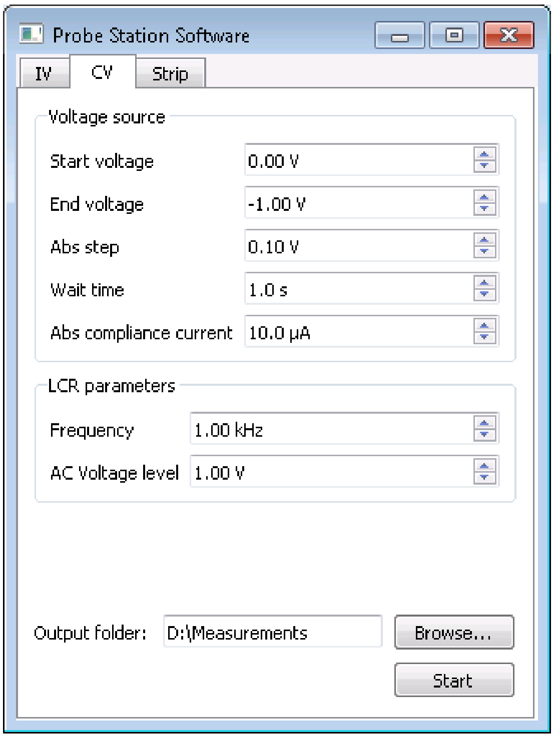

Figure 11b: The measurement software with the CV tab selected.

For all measurement types, clicking on `Start` begins the measurement. If you are not running in

[3]This is because the large internal resistances of both the Agilent E4980A and the CV/IV box distort the current measurement of the Keithley 6517B.

debug mode, the software will ask you if the switches on the CV/IV box are in the correct position. Clicking `no` will abort the measurement, otherwise a new window will open with a live display of the measurements. An example ongoing IV measurement with guard ring current measurement is shown in figure 12a, a running CV measurement in figure 12b.

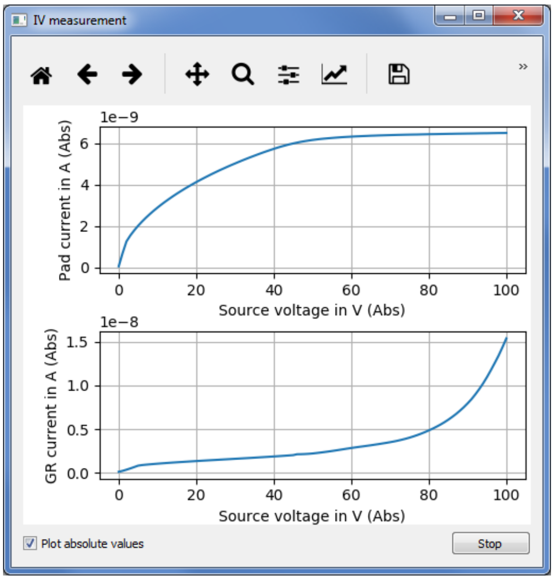

Figure 12a: Ongoing IV measurement. The top plot shows the IV characteristic, the bottom plot the guard ring current vs. applied bias voltage.

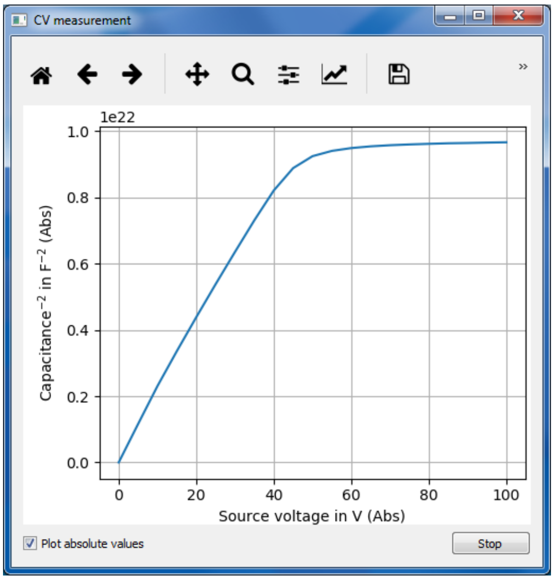

Figure 12b: Ongoing CV measurement. The y-axis shows the inverse square of the measured capacitance.

In all measurement windows, there is a button to show the absolute measurement values instead. Clicking the `Stop` button will ramp down the output voltage to 0 V and switch the output off. This will also happen if the measurement window is closed or should crash. If an IV with guard ring measurement is selected, the bottom plot will show the guard ring current against bias voltage. In a CV measurement, the inverse square of the measured capacitance against bias voltage is displayed. In a capacitive strip measurement (C_{int}), the measured capacitance is shown, in a resistive strip measurement (R_{int}), the top plot shows the measured resistance, the bottom plot the measured impedance.

On reaching the specified end voltage, the voltage will safely be ramped down to 0 V. After finishing your measurements, close the software and switch off the Keithley 6517B and 6485 and the Agilent E4980A. If you used the chiller, set the temperature to room temperature and wait for thermal equilibrium. Then switch off the chiller control unit and then the chiller via the large red switch. After verifying that there is no voltage output, you can open the cold box and, using the microscope, detach the probe needles. Then switch the vacuum off and carefully remove your DUT before closing the cold box.

The read-out computer should be left running, also so that measurement data can be retrieved over the network.

2.6 Additional Software Features

The probe station software can also be used beyond the setup described here. For all devices, serial or USB-to-serial connections are usable from a software point of view instead of GPIB connections.

The program will automatically detect the correct connection type. Furthermore, a Keithley 2410 can be used as an alternative to the Keithley 6517B as a high-voltage source . The software detects the model connected and adjusts the commands. Beware that if both high-voltage source devices are detected, the software will display an error message, since it is not clear which device should be used. Switch off one of the devices to proceed.

2.7 Installing the Software

The software has been tested to run on Ubuntu 18.04, Raspbian Stretch, CERN CentOS 7 and Microsoft Windows 7. It is already preinstalled on `fhlprobest.desy.de`.

2.7.1 Ubuntu 18.04

Normal Installation

On Ubuntu 18.04 you first have to install `git` and `pip` for python

```
sudo apt-get install git python3-pip
```

Then upgrade `pip` to the latest version

```
sudo pip3 install --upgrade pip
```

You can then install the required python packages

```
sudo pip3 install pyvisa pyvisa-py numpy matplotlib pyserial pyqt5
```

For a serial connection, your user account has to be added to the `dialout` group

```
sudo usermod -a -G dialout $USER
```

Then download the repository with

```
git clone https://github.com/thomaseichhorn/probestation.git /where/you/want/to/install
```

After logging off and logging in again to refresh the user permissions, you should be able to run the software from the directory you specified before with the command

```
python3 gui.py
```

Advanced Options

These commands should not be needed, but are listed here as reference.

- If you do not have `sudo` rights, append a `--user` to the `pip3` commands to install the python packages for your user only.
- To use `Python 2.7`, run `sudo apt-get install python-pip` to get `pip2`. Then install the python packages, substituting `pip2` for `pip3` and run the program with the command `python gui.py`.
- The program automatically defaults back to `Qt4` if `Qt5` can not be found. The `Qt4` packages can't be installed by `pip`, but have to be installed with `sudo apt-get install python-qt4` for `Python 2.7` and `sudo apt-get install python3-pyqt4` for `Python 3`.

2.7.2 Raspbian Stretch

Currently, `Qt5` is not available via the package manager, so the easiest way to run the software is with `Python 2` using `Qt 4`. You will need to install some packages

```
sudo apt-get install git python-qt4
```

Upgrade `pip` to the latest version with

```
sudo pip install --upgrade pip
```

You can then install the required python packages

```
sudo pip install pyvisa pyvisa-py numpy matplotlib pyserial
```

For a serial connection, your user account has to be added to the `dialout` group

```
sudo usermod -a -G dialout $USER
```

Then download the repository with

```
git clone https://github.com/thomaseichhorn/probestation.git /where/you/want/to/install
```

After logging off and logging in again to refresh the user permissions, you should be able to run the software from the directory you specified before with the command

```
python gui.py
```

2.7.3 CERN CentOS 7

On CERN CentOS 7 you also first have to install `git` and `python3`. Open a root terminal and run

```
yum install centos-release-scl
```

to enable software collections and then run

```
yum install rh-python35 git
```

Then you can load the `python3` environment

```
source /opt/rh/rh-python35/enable
```

and upgrade `pip` to the latest version

```
pip3 install --upgrade pip
```

You can then install the required python packages

```
pip3 install pyvisa pyvisa-py numpy matplotlib pyserial pyqt5
```

For a serial connection, your user account has to be added to the dialout group

```
usermod -a -G dialout <yourusername>
```

You can now close the root terminal. Then download the repository with

```
git clone https://github.com/thomaseichhorn/probestation.git /where/you/want/to/install
```

After logging off and logging in again to refresh the user permissions, load the `python3` environment again

```
source /opt/rh/rh-python35/enable
```

You should be able to run the software from the directory you specified before with the command

```
python3 gui.py
```

2.7.4 Microsoft Windows 7

On Microsoft Windows 7 you need a Python environment, such as `Miniconda`[4]. If you have a DESY Windows installation, use DSM to install `Anaconda` (Software Categories → Programming). With the `Anaconda prompt` (or from the Windows command line) you can install the needed python packages with the command

```
conda install -c conda-forge pyvisa pyvisa-py numpy matplotlib pyserial pyqt
```

Otherwise you can select these packages with the Anaconda Navigator. Assuming you downloaded the software to `C:\some\directory`, you can then run the software with

```
python C:\some\directory\gui.py
```

from the `Anaconda prompt` or from the Windows command line.

2.8 Recompiling the User Manual

To recompile the user manual, you need a working latex installation with some additional packages.

2.8.1 Ubuntu 18.04 and Raspbian Stretch

On Ubuntu 18.04 and Raspbian Stretch you need to install several `latex` packages via

```
sudo apt-get install texlive-latex-base texlive-science texlive-latex-extra
```

You can then build the documentation with the command

```
cd doc && pdflatex manual.tex
```

[4]https://conda.io/miniconda.html

2.8.2 CERN CentOS 7

On CERN CentOS 7 you will need to install several `latex` packages. Unfortunately, the easiest way is to install all available ones from a root terminal

```
yum install texlive-*
```

You then have to download some packages manually

```
cd doc
wget http://www.cs.cmu.edu/afs/cs/misc/tex/common/
  teTeX-1.0/lib/texmf/tex/latex/misc/SIunits.sty
wget http://www.cs.cmu.edu/afs/cs/misc/tex/common/
  teTeX-1.0/lib/texmf/tex/latex/misc/tocbibind.sty
wget http://www.cs.cmu.edu/afs/cs/misc/tex/common/
  teTeX-1.0/lib/texmf/tex/latex/misc/stdclsdv.sty
```

Before you can then build the documentation

```
pdflatex manual.tex
```

2.8.3 Microsoft Windows 7

This is beyond the scope of this document, there are good step-by-step instructions on the internet.

3 References

[1] Thomas Eichhorn and Jonas Rübenach.
Probe Station Manual and Software.
https://github.com/thomaseichhorn/probestation
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