SINGLE POINT KELVIN PROBE SYSTEM

Manual Version: Rev 4.2, November 2017

for Hardware Revison 1.1

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Table of Contents

I. SYSTEM SETUP AND SPECIFICATION

1 Part list

- Controlling System **AFT-KPTT**
    - PC (LCD-Monitor, keyboard, mouse) with
        - Windows Window 7
        - TFT-Monitor
        - USB-Keyboard, USB-Mouse
        - Kelvin Probe Software
    - KP-Controller Thomson I (S/N: Th2017-01)
- mechanical set-up with stepper driven rail in Z-direction
- two KP-Heads (2 x with 1.4 mm Au-electrode)

2 Mechanical Set-up

Hardware Connections (Connect Before Power ON!!)

1. Connect mouse, keyboard and monitor to the PC
2. Connect Thomson I controller through a USB-cable (black)
3. Connect the Humidity sensor through USB cable (blue)
4. Connect the Power Supply cord and switch the PC on.

Connect Thomson I controller front panel to the instrument:

- Excitation (LEMO → directly to any KP head)
- Stepper (15 pin SUB-D) → to the instrument
- KP-Head (25 pin SUB-D) → to the instrument

Connect the USB-Cable to the backside of the Thomson I Controller.

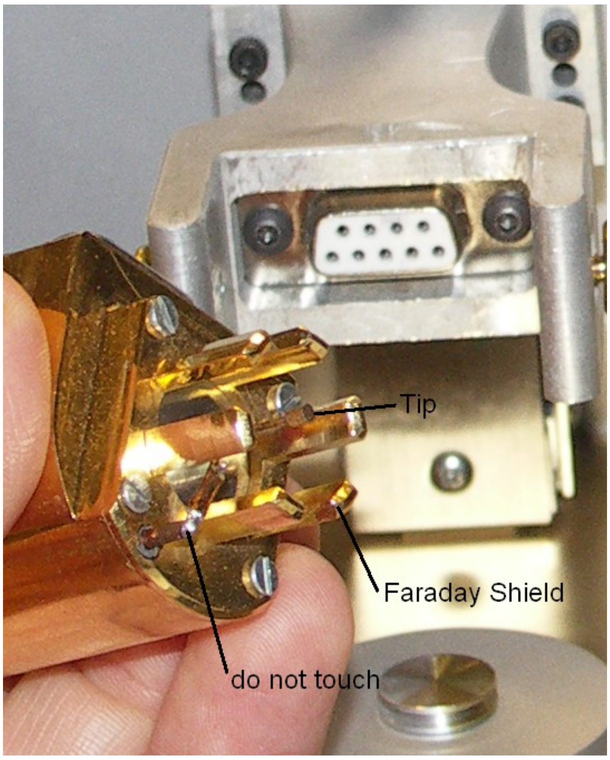
Connect the Power supply.

DO NOT SWITCH ON, if the Head is not mounted yet !

Mount KP Head

- Software MUST be OFF !!
- Turn the Wheel UP
- remove the KP head from the special head carrier (see chapter Operational Instruction / 2)
- take care not touch the KP sensor tip nor the wire to the tip

  ELECTROSTATICALLY SENSITIVE
- plug the head into the 9 pin connector and press tenderly so that the connection is o.k.



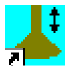
- fasten the two side screws to fix the KP head

- connect the LEMO cable
  (SOFTWARE MUST BE OFF)
  so that the two red points of the connector are
- take care that the axis does not move onto the sample while connecting the cable

First Simplified functionality test

These test can be used to check in a short time, whether the system works. They are not necessary!

1. Communications-Test:

- Open "Kelvin" program. 
- communication errors are tested and displayed here.

2. Toggle-Test

- move the Kelvin sensor close to the surface of a conducting sample (Use the wheel on top of the system. Clockwise == UP-wards.)
- Set Toggle-time to 1 s
- approach step-wise
- check the values of X or Y in the oscilloscope.

✗ Criteria: each second, the signal should change

✗ while approaching, the signal amplitude should increase

3 Software updates & driver updates

Instructions for later software updates:

✗ Close all programs
✗ **Log on as administrator**

Step 1): Copying the new files onto the system

- Rename the old file Kelvin.exe (for example into Kelvin_150821.exe)
- Copy the new file Kelvin.exe into the directory C:/Program Files/Anfatec/
- Create a directory „C:/Program Files/Anfatec/Disk150821“
- Copy all files from the directory C:/Program Files/Anfatec/Driver
  into this new directory „C:/Program Files/Anfatec/Disk150821“
- Copy the provided new driver to the hard drive

Step 2): Updating the driver (if necessary):

- execute the setup.bat (the command screen should show a message, that the driver has been successfully updated and you should restart the PC).

4 System Specification

Mechanical Properties

Kelvin Probe Head:

Slope of the fine adjustments	0,5 mm /turn

Amplifier electronics:

circuit type:	current voltage converter
amplification:	27 V/mA (27 kΩ)
Band width:	> 700 kHz
Output noise:	typ. 10 mV_{pp} at full bandwidth

Kelvin Probe Base for Table Top Device KP-TT

Slope of the vertical rail	2 mm /turn
Total movement range of the vertical rail	

Stepper Motor

Model:	Oriental Motor, PK223PB
Type:	2 phase
Step angle:	1,8° (200 steps/turn)
Maximum moment:	0,033 Nm
Current /Phase:	0,67 A
Stepwidth:	10 µm /step

Vertical Rail

Model:	Oriental Motor, PK223PB
Type:	2 phase

PC for Control

Hardware

Mainboard:	current voltage converter
Processor:	27 V/mA (27 kΩ)
Band width:	> 700 kHz

Software

Operating system	Windows 7, 32 Bit, English

Thomson I Controller

D/A-converters for Bias /

Nominal resolution	24 bit
real resolution	17 Bit
sample rate	40 kHz
noise	2 mVpp @ 20 Mhz bandwidth with oscilloscope 100 nV/Hz$^{(0.5)}$ @ 100 Hz and 50 Hz

A/D-converters

Nominal resolution	24 bit
real resolution	17 Bit
sample rate	40 kHz
noise	0.3 mVpp in SXM-program

Connectors of the DS4L

Computer control ***see APPENDIX 3***

type	15-pin High density SUB-D cable (Monitor cable)
function	Connection between AMU2.0 PCI board inside SPM PC and DS4L controller.

Power

supply voltage	12 V
polarity	plus (red cable) on inner electrode
current	1 A

Head connectors *see* ***APPENDIX 6***

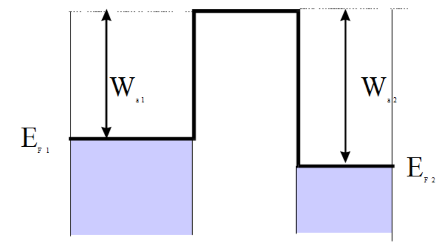
type	15 pin conventional SUB-D
function	power supply for STM head
supply voltages	+ 7 V, - 7V ; 5 V for light and camera, -5 V for laser
current	80 mA each
inputs	T-B, L-R, SUM, SGX, SGY, SGZ
outputs	tunneling voltage to “Ut”

II. BACKGROUND AND BASICS

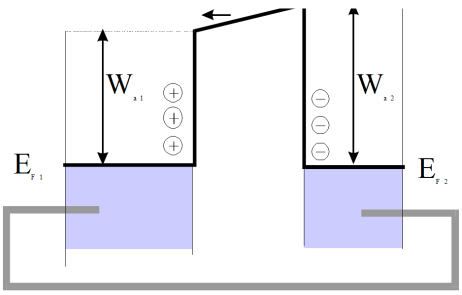
1 Lord Kelvin's idea

More than 100 years ago, Sir Thomson, the later Lord Kelvin, had the idea for an experiment that allows to determine work function difference between two metals. He took to different metal surfaces and placed them in close distance to each other, so that they built a kind of plate capacitor. He charged one plate and disconnected the plates from each other. Then, he moved one plate and measured the current with an electrometer.

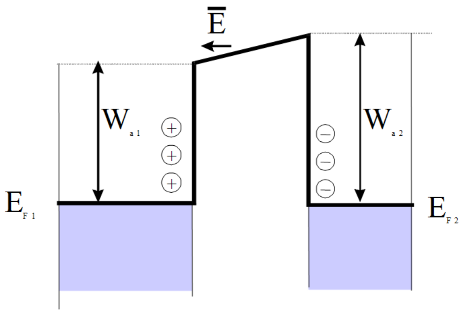
two metal electrodes in vacuum



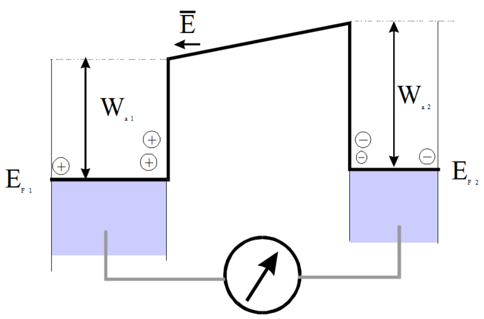
Lets take the band diagram of two metals with different work functions. If there are no charges on their surfaces, no electrical field between them and thus no electrical force, then their vacuum levels are aligned to each other.



With the electrical contact, the Fermi levels align to each other.
In order to align, electrons flow from the metal with lower work function to the metal with higher work function.
The charges accumulate on the metal's surfaces. In between the surfaces, an electrical field is found.



After contact removal, the Fermi levels of the metals stay aligned.



If the capacitor plates are now moved to a different distance, the potential difference cannot change (as there is not electrical contact); but the electrical field must change and the charges move away from the surface.
With an electrometer (that has a very might resistance and measures potential differences due to charges on its electrodes) , this charge movement can be detected.

In a more modern practical realization of the experiment, the capacitor plates are oscillated according to $z = z_0 + z_1 \sin(2\pi f t)$ with z_0 as zero distance between the plates and z_1 as oscillation amplitude. The resulting AC current is detected with a lock-in amplifier. It can be estimated using I = dQ/dt with Q=C*U and C ~ 1/z resulting in:

or in a 1st approximation $I \propto \frac{A}{z^2} z_1 \sin(2\pi f t) U$.

Thus, the detected current increases linearly with the size of the sensor A, the oscillation amplitude and the applied bias voltage U.

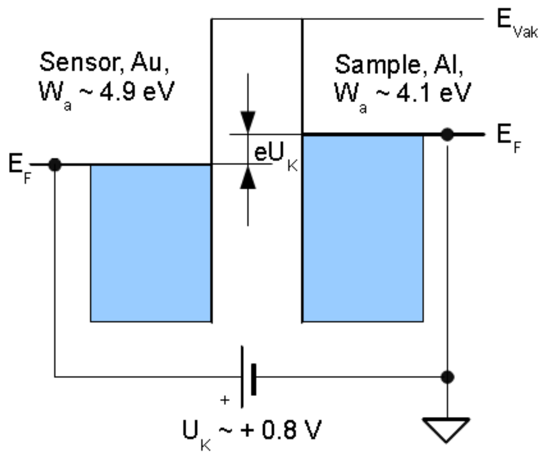
There are two possibilities to determine the Kelvin potential:

(1) the measured current can be nullified with the external bias
The disadvantage of this methods is, that the currents get very small so that the result can be very noisy.

(2) one can measure two current with two large bias voltages and use a linear fit to calculate the crossing point. (see chapter 12)

2 Compensation method and Referencing Work Functions

The following scheme shows the band diagram of two metals whose work functions difference is compensated with an applied bias voltage of U_K ~ 0.8 V:



In the experiment, the sample (here: Aluminum) usually is connected to ground (gold plate of the systems), while the compensation voltage is applied to the tip (here: Au-coated). **If the work function of the sample becomes larger, the compensation voltage becomes more negative.** The applied voltage is a measure for the work function of the tip minus the work function of the sample.

A good method to calculate the work function of the sample is to measure the a reference sample with a know surface. A freshly evaporated or sputtered polycrystalline Au film, for instance, should show a work function of 5.1 eV. On an HOPG without top-contamination (freshly cleaved) one expects a work function of 5.0 eV.

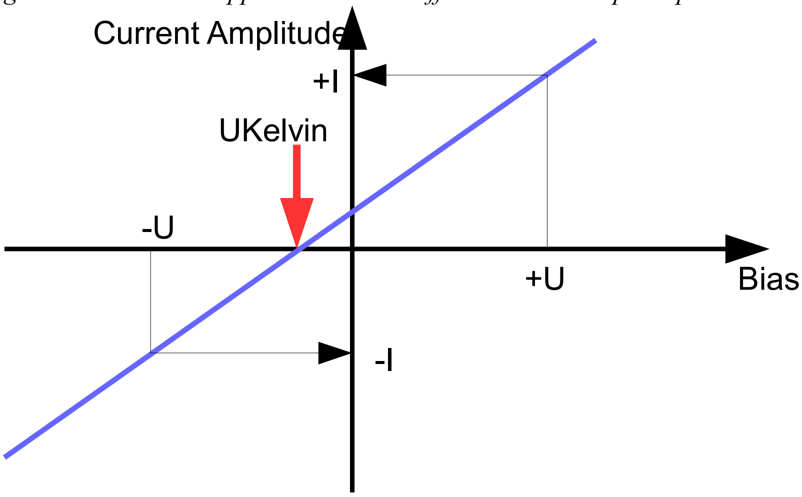
Work Function of Sample = Work Function of Tip - Uk on Sample

Work Function of Sample = (5.1 eV + Uk on Au) - Uk on Sample

3 The Off-Zero Detection Scheme

The measured current amplitude I rises proportionally with the applied bias voltage U:

Figure 1: Current vs. applied Bias. The Off-Zero detection principle.



In the AFT-KP150 device, the applied bias is toggled between a positive bias +U and a negative bias -U resulting in two 180° phase shifted ac currents. With the lockin amplifier, these oscillating currents are demodulated into an in-phase (X) and an out-of-phase (Y) signal. The in-phase signal X is then taken as measure for "+I" and "-I" in Figure 1 and used to determine the crossing point of the linear curve with the abscissa. This crossing point euqals the measured Kelvin Potential.

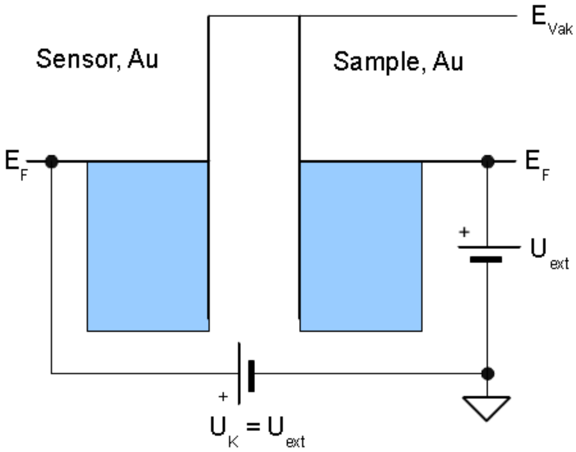
In some cases (e.g. close to the mechanical resonance), the measured current is not 100 % in phase with teh excitation. Then, an additional phase shift can be used to correct for the intrinsic phase shifts and thus to maximize the X.

If the sample it not metallic (e.g. semiconductive) or even allows charging of the surface, it might be useful to acquire U_K for different bias voltages U.

4 Potential calibration

The accuracy of the potential detection depends on the accuracy of the applied external bias.

In order to calibrate this external bias, a gold sample is used whose surface



5 Table of selected Work functions

The measurement of work functions is not trivial. Under ambient conditions, oxides or other surface layers might change the detected work function. For crystalline materials, work functions depend on the crystal orientation. Thus, literature proposes a wide range for certain metals that usually depends on the crystal orientation.

As the orientation of an HOPG surface is clear, the work function of a freshly cleaved HOPG is the best reference.

Material	***Work function in eV***
BaO + SrO	1,0
Cs	1,7 … 2,14
Ba	1,8 … 2,52
Rb	2,13
Li	2,2
K	2,25
Na	2,28
LaB_6	2,4 … 2,7
Al	4,06 … 4,41 *
Ag	4,05 … 4,6
Mo	4,16 … 4,2
Ta	4,19
Cu	4,3 … 4,5
Ti	4,33
Zn	4,34
HOPG	4,46 +/- 0,04
W	4,54 … 4,6
Au	4,8 … 5,47

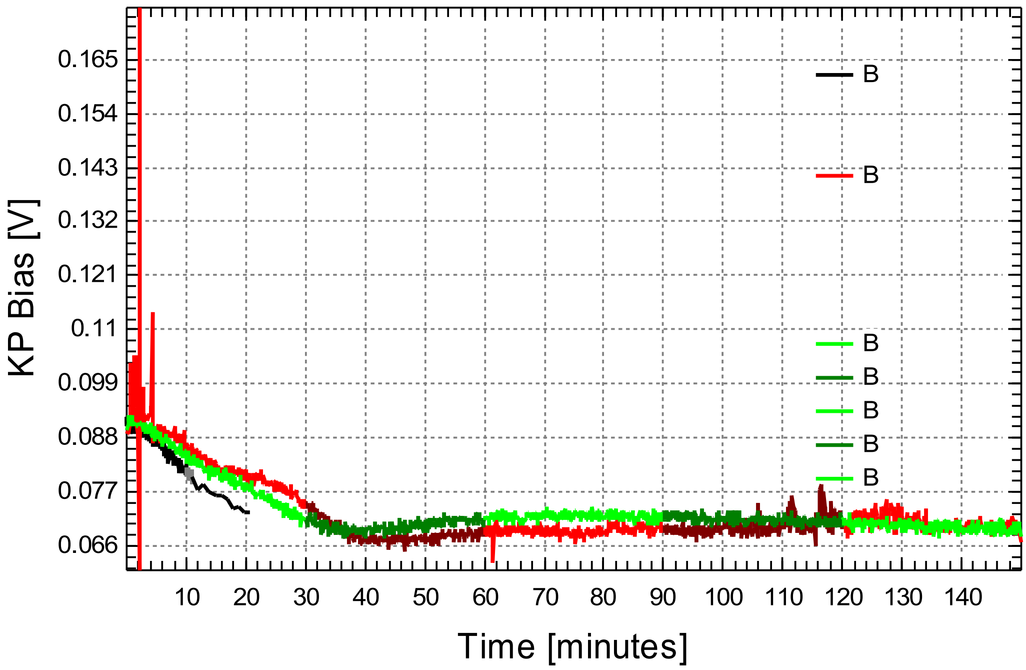
Material	***Work function in eV***
Ni	5,0
Pt	5,32 … 5,66

Another source for a Work function table is on
https://www.fh-muenster.de/ciw/downloads/personal/juestel/juestel/chemie/Austrittsarbeit.pdf

6 Reference Sample HOPG

HOPG (Highly Orentied Pyrolytic Graphite) is, due to its very well defined atomic surface structure and low affinity to adsorbates - a suitable reference sample for Kelvin Probe measurements with a ewll know work function of (4.46 ± 0.04) eV. As layered material, it is easy to bring this surface back to its original condition.

However - after being freshly cleaved - even HOPG physisorbes and chemisorbes molecules and water from the environment. The following measurement result takes at room temperature 22°C and 45% RH shows how HOPG changes its work function within ~ 40 minutes after cleaving from (90 ± 1) mV down to (69 ± 2) mV:



The initial work function value of 90 mV is very reproducible. Also the time scale for forming a stable surface configuration (40 minutes) is nicely reproducible. After reaching the new surface condition after 40 minutes, one observes a long term drift of the surface potential over many hours; but the general surface potential stays constant within a few mV for more than 1 day as long as the environmental lab conditions are not completely changed.

[1] "Die Austrittsarbeit von HOPG wird in der Literatur mit=4,6eVangegeben[2], [3]. Frisch im Vakuum gespaltene HOPG-Oberflächen weisen hingegen eine Austrittsarbeit von = 5,0 eV auf [4]." zitiert aus: Thomas Madena, Kelvinsondenmikroskopie an organischen Dünnschicht-Halbleitern:Einfluss der Schichtprozessierungauf elektrische, optische und morphologische Eigenschaften organischer Solarzellen, Carl von Ossietzky UniversitätOldenburg, Oldenburg, Dissertation, 2011.

[2] Ch.Sommerhalter, Kelvinsondenkraftmikroskopie im Ultrahochvakuum zur Charakterisierung von Halbleiter-Heterodioden auf der Basis von Chalkopyriten. Freie Universität/ Hahn-Meitner-Institut, Berlin, Dissertation, 1999.

[3] T. Takahashi, H.Tokailin, T. Sagawa,Angel-Resolved Ultraviolet Photoelectron Spectroscopy of the unoccupied Band Structure of Graphite. Physical Review B. 1985, 32, 8317

[4] M. Böhmisch, F. Burmeister, A. Rettenberger, J. Zimmermann, J. Boneberg, P. Leiderer, Atomic Force Microscope Based Kelvin probe Measurements: Application to an Electrochemical Reaction. Journal of Physical Chemistry B. 1997, 101,10162

III. OPERATIONAL MANUAL

1 TERMINOLOGY

Head: is the KP measurement head, which holds the oscillator and the sensor tip.

Sensor axis: is the vertical axis which translates the Head in z-direction

Base plate: is the gold plated base plate, on which the whole translation system is mounted

2 Z-AXIS OPERATION

The z-axis can be operated

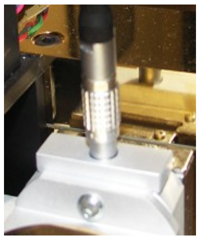
1 manually with the wheel on top of the motor axis

2 with the software (relative positioning – like 100 steps up, or single step, automated approach)

A) the yellow knob can be turned manually independently on whether the software is ON or OFF. It is the fastest way to approach the sensor to to the sample surface. Please make sure not to crash the tip into the sample.

3 HOW TO CHANGE THE MEASUREMENT HEAD

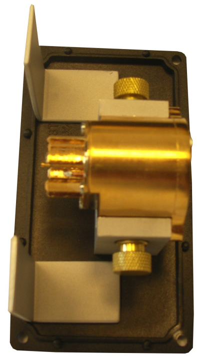
- Close the Kelvin program or Switch the Excitation off:
- Remove the excitation-cable (Only Pull, NEVER turn around) and plug it in the silver fixture



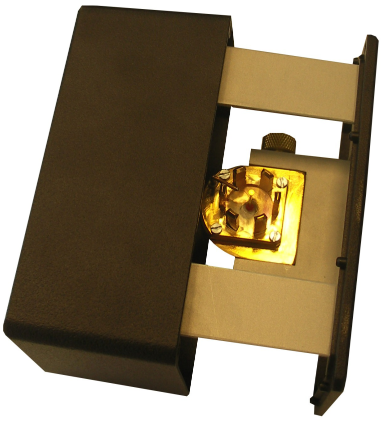
- Loosen the two golden screws which fix the head
- Pull the head out of the connector
- Plug in the new head
- Fix the head with the two golden side screws
- Reconnect the excitation-cable (Only Push)
- Switch the Kelvin program on
- Before starting with measurements, the system needs to be homed

For a more detailed description, please refer to Chapter III.

4 Safekeeping of KP-Heads

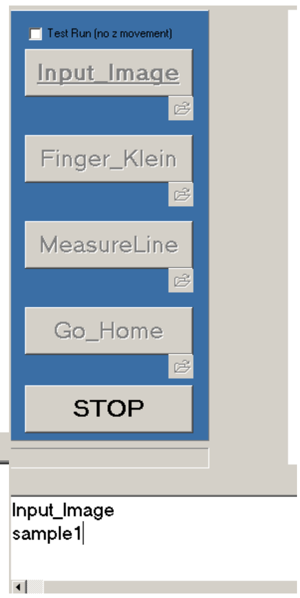


- Unused KP-heads are kept in the provided black head-boxes
- Plug in the unused head in the fixture
- Attend that the tip should show toward the two silver brackets
- Fix the head with the two golden side screws

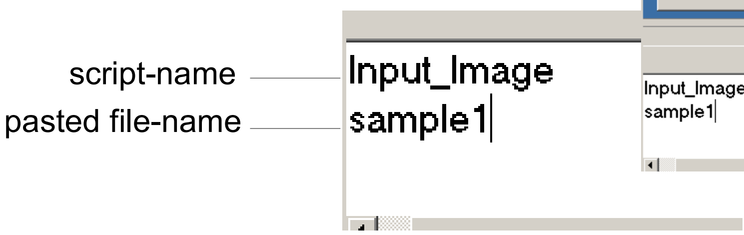


- Stick together carefully the lid with the housing of the head-box
- The two silver brackets are directed downwards along the inner surface of the housing; so the tip is protected for breaking
- Fix the lid on the housing with the four silver screws

5 Add self made File-names



- Create a new script
- Change Filename(' xxx') in Filename(input);
  (word input without ' ')
- Open the Kelvin program and load the new created script 
- Start the script (click on the button with the name) – the measurement starts immediately and the file-name is paste into Memo-window (below the script-name)
- outputs of Writeln-commands are also displayed in the Memo-window.



6 Short User Manual 1
(for standard users and head with large tip diameters)

- Boot PC
- mount the KP head
- connect the excitation cable
- switch controller 'Thomson I' ON at backside
- start the link on the desktop that refers to the mounted KP head
  for example: for the Kp head No 9, use the start button 'Head9'
- Login window:
  User. user
  Pwd: test
- press “Enter”
- place the sample under the tip
- approach manually with the wheel to a close distance
- use “Auto Approach” to start a measurement

7 Short User Manual 2
(for standard users and head with small tip diameters)

- Boot PC
- mount the KP head
- connect the excitation cable
- switch controller 'Thomson I' ON at backside
- start the link on the desktop that refers to the mounted KP head
  for example: for the Kp head No 16, use the start button 'Head9'
- Login window:
  User. user
  Pwd: test
- press “Enter”
- place the sample under the tip
- approach manually with the wheel to a close distance
- open the oscilloscope window
- check that the signal X toggles (changes its sign with the toggle frequency) and that Y is close to zero
- if not, use refer to Chapter III to setup the tip-properties
- use “Auto Approach” to start a measurement

8 Short User Manual 3

(for ADMIN users and head with standard tip diameters)

- Boot PC
- switch controller 'Thomson I' On at backside
- mount the KP head
- connect the excitation cable
- start the link on the desktop that refers to the mounted KP head
  for example: for the Kp head No 9, use the start button 'Head9'
- Login window:
  User. admin
  Pwd: test
- press “Enter”
- place the sample under the tip
- approach manually with the wheel to a close distance
- one can adjust the parameters of the KP head in order to get better results (see chapter:)
- one can Autotune in order to improve the results (see chapter:)
- use “Auto Approach” to start a measurement OR
- load a program : 
- start the program by pressing the related button>
  e.g. 

- after program run, the data are stored in C:\Program Files\Anfatec\data
- copy the data into a user folder
- after this, please delete all data in C:\Program Files\Anfatec\data

9 Benutzerhandbuch (Deutsch)

- Computer hochfahren
- gewünschten Messkopf an die vorgesehene Halterung montieren und mit beiden Schrauben fixieren
- das Anregungskabel in die Buchse am Messkopf stecken (nicht drehen!)
- Controller 'Thomson I' an der Rückseite anschalten
- um das Messprogramm zu starten, den Startknopf mit der entsprechenden Messkopfnummer auswählen
  z.B.: bei Benutzung von Messkopf 11, den Startbutton 'Head11' verwenden

nur für Scanning System:

- die Information 'Home now?' erscheint
  'Yes' drücken
- es folgt die Nachfrage 'Set all Encoder to HOME?'
  'Yes' drücken
- das Login-Fenster erscheint, um den Zugang zum Messprogramm zu ermöglichen
  User. user
  Pwd: test
- um die Eingabe zu bestätigen, die 'Enter'-Taste drücken

- mit dem Ordner-Knopf  das gewünschte Skript laden
- die Messung wird gestartet, indem der Knopf mit dem gewählten Skript gedrückt wird
  z.B.: 

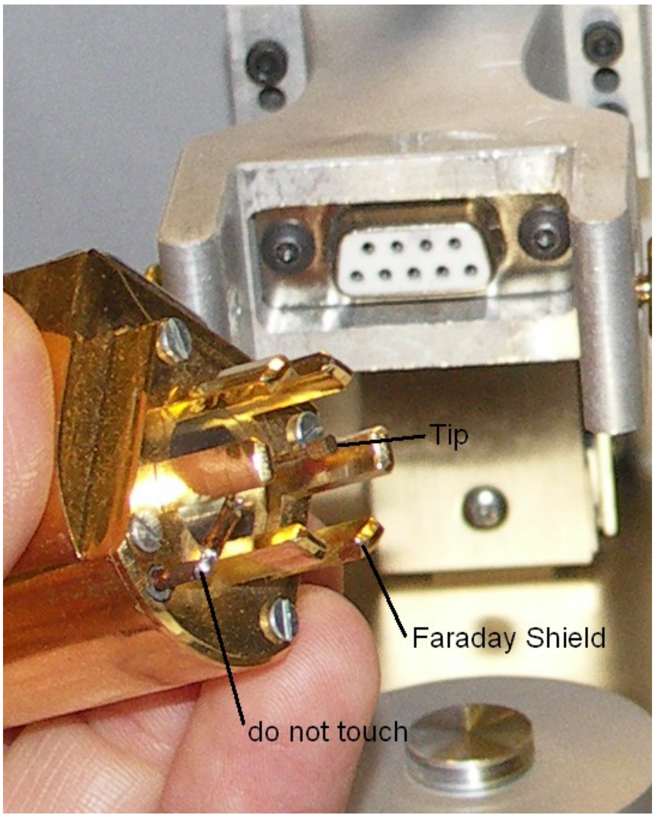
- am Ende der Messung werden die Daten automatisch unter C:\Program Files\Anfatec\data abgespeichert
- die eigenen Messdaten sind in einen eigenen Ordner zu kopieren
- alle unbenötigten Daten bitte stets löschen

nur für Scanning System:

- alle Bilder ('Image') werden unter C:\Program Files\Anfatec\picture abgespeichert

IV. INSTALLATION & USE OF KP HEADS

1 Mount KP Heads



- Software MUST be OFF !!
- Turn the Wheel UP
- remove the KP head from the special head carrier (see chapter Operational Instruction / 2)
- take care not touch the KP sensor tip nor the wire to the tip

  ELECTROSTATICALLY SENSITIVE
- plug the head into the 9 pin connector and press tenderly so that the connection is o.k.

- fasten the two side screws to fix the KP head
- connect the LEMO cable (SOFTWARE MUST BE OFF) so that the two red points of the connector are
- take care that the axis does not move onto the sample while connecting the cable

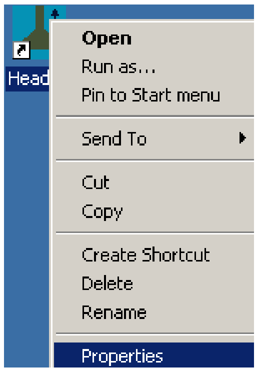
2 Add new KP-Heads to the Software

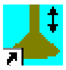
Each KP head uses its own parameter set. In order to make it easier for the user, the program is started with a parameter that describes the KP head in use. In Windows, for each KP-head a start-button needs to be created on the desktop.

Each of the start-buttons is connected to its own ini-file which includes the parameter setup for the head.

If you want to add a new KP-head, paste the provided ini-file to the following folder:

C:\Program Files\Anfatec



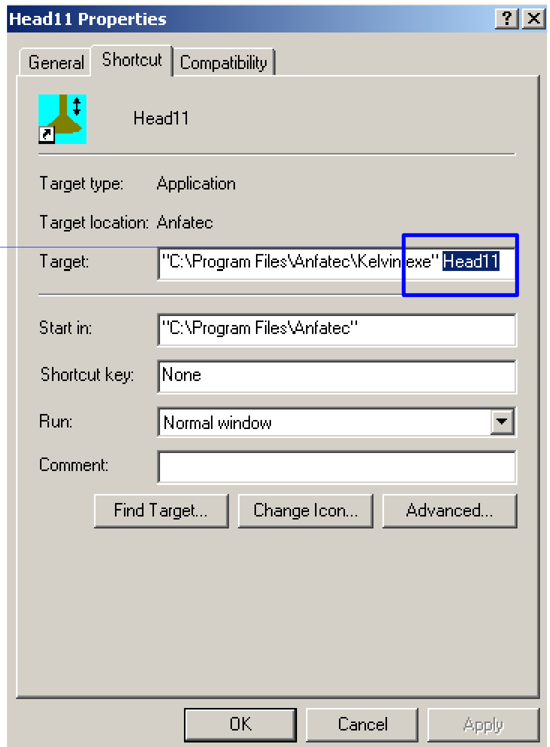


Create a new start-button for the new head by copy and paste of an existing link on the desktop. Change the name of the parameter file as follows:

- Click with the right mouse button on the start-button
- Open 'Properties'
- Replace the last part of the field 'Target' with the name of your new ini.file
- For example Head11:

  name of the ini-file: 'Head11.ini'

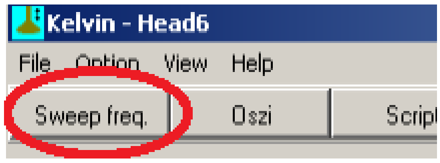
  so, last part of the field 'Target' is named: Head11
- Press OK
- now if you open the Kelvin program with the new start-button, the related parameter setup for the new KP-head should appear



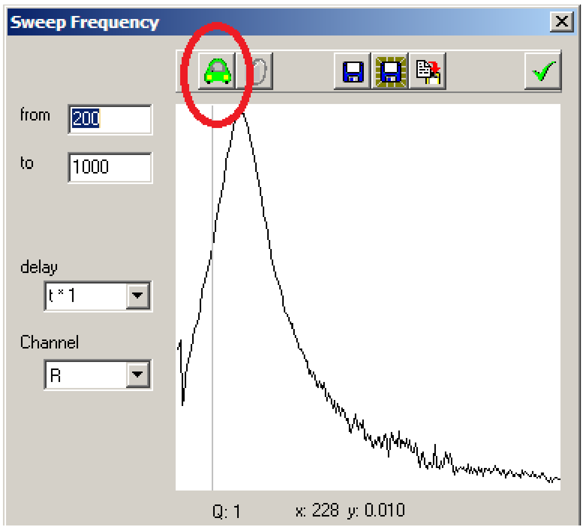
3 AutoTune working Frequency for KP-Heads

Manual adjustments of the settings are required only, if the the obtained results on standard samples do not match the expected values anymore.

- Start the software with the correct Head name
- mount a reference sample (for example Pt/Au)
- approach the KP tip close to a conductive surface (Manually)
- click on the icon „Sweep freq." in the head line:

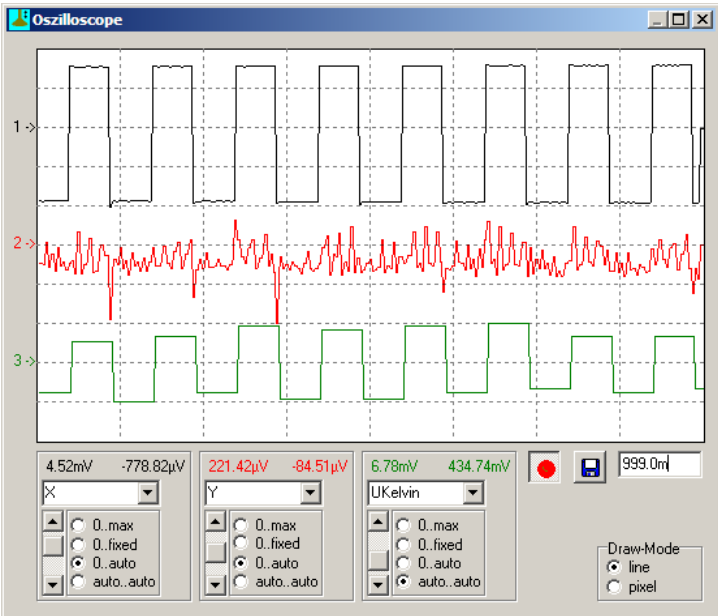


- this opens the window "Sweep Frequency" :



- Click the "AutoTune"- function. It starts an automated tune and sets frequency and phase correctly.

- The parameters are set optimum, if the current signal is mainly visible in X (and not in Y):



4 Automated Offset Correction

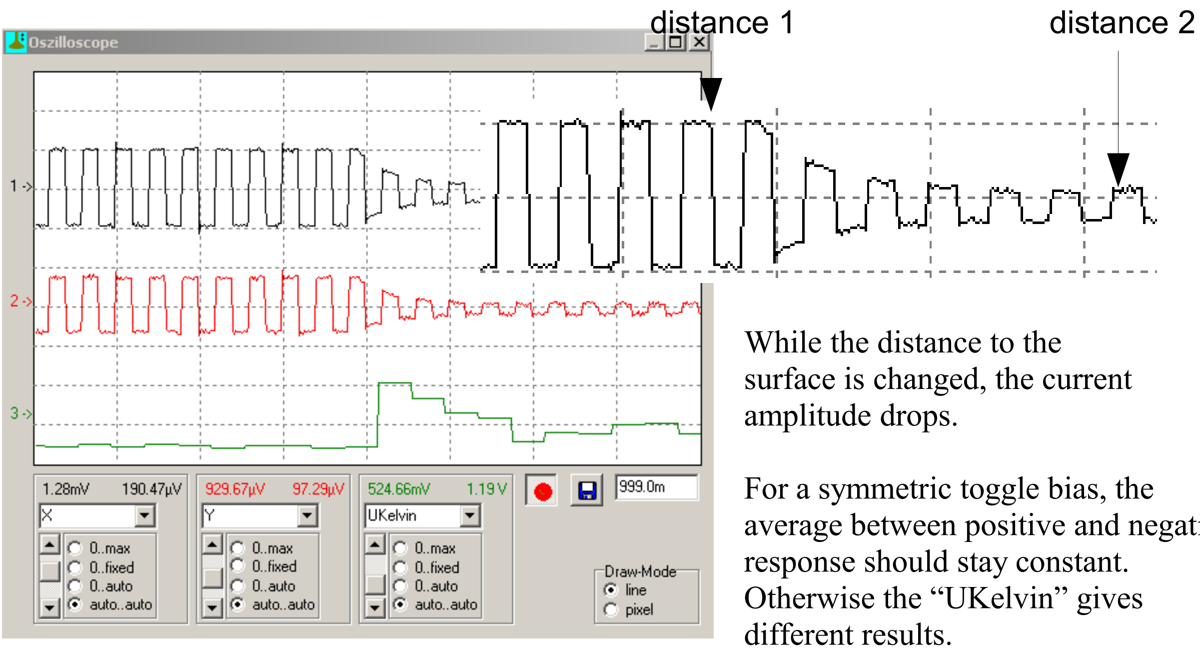
The lockin amplifier used for the detection of the oscillating current might detect a background signal. This background signal depends on:

- some offsets inside the pre-amplifier (very small impact)
- the electrical field distribution in the tip-sample interface (especially for small tip diameters)
- a cross talk inside the KP head between unintended oscillating parts (wires) that add signal to the intended signal from the tip.

Under the assumption that this background signal is constant in amplitude and phase, it is possible to correct for it and thus produce a KP result, which is less distance dependent.

Correction procedure:

- measure the current amplitudes at positive and negative bias with a long integration time in two different distances.
- Calculate correction coefficients that result in the same KP result for both distances.

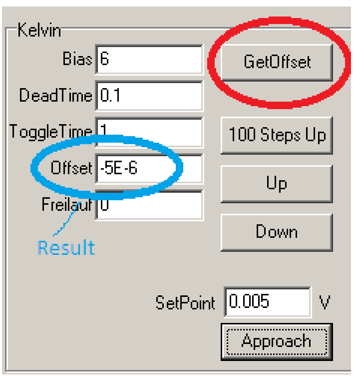


While the distance to the surface is changed, the current amplitude drops.

For a symmetric toggle bias, the average between positive and negative response should stay constant. Otherwise the "UKelvin" gives different results.

If "UKelvin" is distance dependent, then it might help to correct the Offset:

The procedure takes about 2 minutes and is fully automated. The result is shown in V and should be in the µV range. Only for very small tips, larger offsets might be accepted.

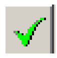


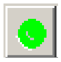
5 Manual Frequency Settings for KP-Heads

Manual adjustments of the settings are required only, if the the obtained results on standard samples do not match the expected values anymore.

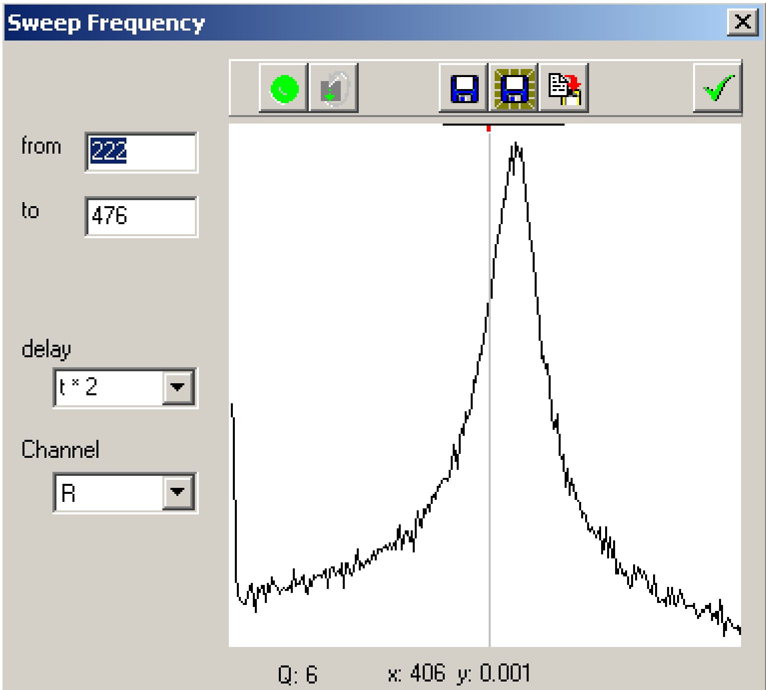
- Start the software with the correct Head name
- mount a reference sample (for example Pt/Au)

If the user likes to use a manual frequency sweep,

- dispable the "AutoTune" function inside the options/ Autotune: 

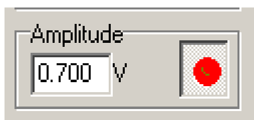
- select the value behind „from" well below the operating frequency of the KP tip
- select the value behind „to" well above the operating frequency of the KP tip
- acquire a spectrum by using 

- the grey line shows the position of the current operating frequency inside this spectrum



- IF the resonance is far away from the operation frequency, follow these steps:

  - select visually a new operation frequency close to / but below the resonance as shown in the image above by clicking inside the frequency sweep curve.
  - increase or decrease the excitation amplitude in the main window:
    (typical values are between 0.6 V and 1.1 V)
  - the excitation is too high, if the sound of the head contains higher harmonics!!!
  - during the sweep at higher excitation, the sound should change continuously from low frequencies to high frequencies

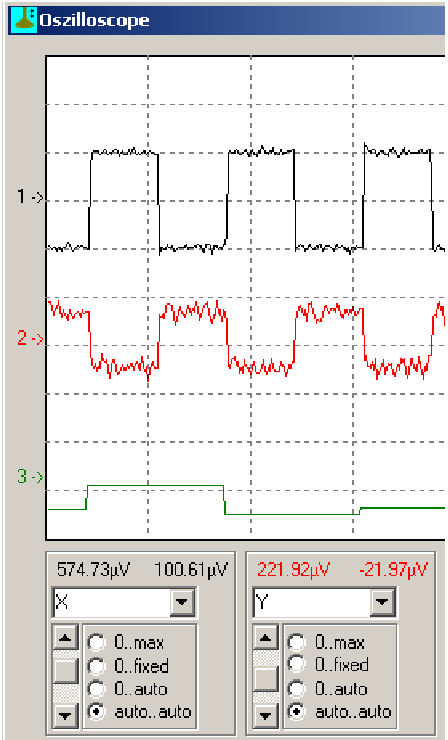


- ◦ Open the oscilloscope and check the amplitudes of X and Y using the scaling factors displayed after automatic scaling

In the example image:

- the automatic scaling of X is 574 µV
- the automatic scaling of Y is 222 µV

→ the phase is not optimized

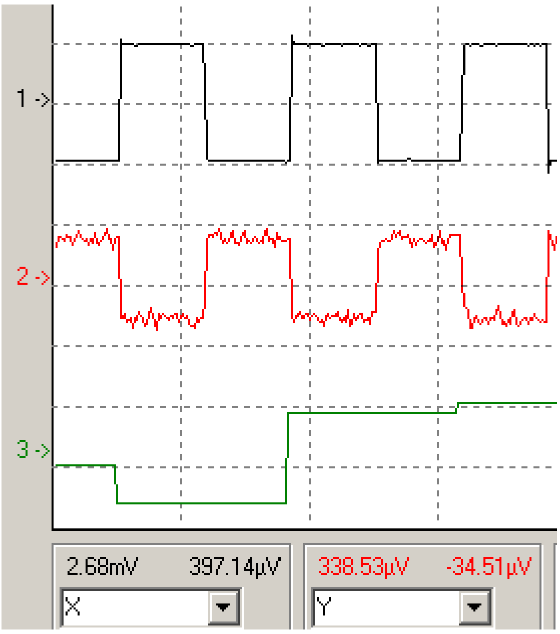


Before the phase is optimized:

- go step-wise down (manually) with visual checking of the distance until a definite increase of the amplitude is visible – the maximum value of X shown in the meter should be about 3 mV

Phase adjustment:

- change the phase in steps of 1°, until the amplitude scaling during toggling shows that the amplitude in X is much larger than in Y
- IF the phase value is above 20°, reselect the frequency a bit more far away from the resonance and readjust the phase once more



Example here:

- the automatic scaling of X is 2.6 mV
- the automatic scaling of Y is 338 µV

→ X almost is 10 times larger than Y

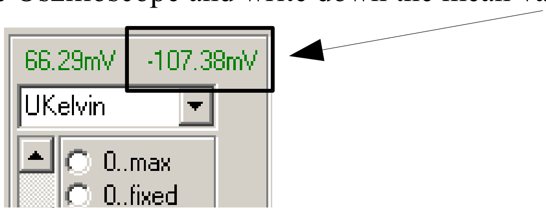
After these settings, the parameter „Offset“ need sto be readjusted in order to achieve a quantitative surface potential measurement.

6 Manual Offset Correction for small Tip Diameters

- Approach tip and sample
- Change these settings in the main window of the Kelvin program:

  1. Set TimeConstant t = 50 ms

  2. Set ToggleTime = 0.5
- Open the Oszilloscope and write down the mean value for UKelvin



- Press 'Up' 15 times and compare this mean value for UKelvin with the first one;

  both values should be the same (difference +/- 10 mV)
- If not, change the Offset manually:

  for example from 4E-5 to 2E-5
- Write down the mean value for UKelvin
- Approach tip and sample
- Compare the UKelvin value for both distances again
- Two possibilities could appear:

  1. Both values are now more similar than for the Offset of 4E-5. That means the Offset was changed in the correct direction. If the difference of both UKelvin values is still more than 10 mV, change the Offset a second time and compare both UKelvin values (first when system is approached and second when the system is 15 steps above) again. Repeat the process till both UKelvin values have a difference smaller than 10 mV.

  2. Difference between both UKelvin values become bigger. That mean the Offset was changed in the wrong direction. Then make the Offset bigger than 4 E-5, for example 6E-5.

  If you recognize that both UKelvin values are here more similar, change the Offset in this direction still the difference between the two UKelvin values is less than 10 mV.
- After Offset correction, following settings in the main window of the Kelvin program have to be recovered:

  1. Set TimeConstant t = 10 ms

  2. Set ToggleTime = 0.2

V. KELVIN PROBE SOFTWARE

The Kelvin Probe software package provides two operation modes:

- the ADMIN mode (user name = 'ADMIN', password required) allows
  - ☑ to access all system specific parameters
  - ☑ to develop script files
  - ☑ to observe the current system state
  - ☑ an unlimited rails operation (for the scanning KP systems)
  - ☑ measure frequency dependence and
- the USER mode (user names can vary, no password required) enables
  - ☑ manual and automatic rails operation (for scanning systems, only)
  - ☑ run scripts
  - ☑ soft emergency STOP and reactivation of rails position (including Homing) – (for scanning systems, only)

QUICKSTART

After the system is fully installed and any KP head is mounted:

- double click on the icon on the desktop, that is related to the mounted KP head (one can hear the sound of the tip oscillation)
- use “admin” as user and “test” as password
- place a sample under tip sensor tip
- approach the tip manually, until the distance to the surface is less than 1 mm
- open “oscilloscope”
- check, that one observes a rectangular shape of X vs. time(toggling of the voltage is ok)
- auto-approach the tip with the standard set-point
- take data versus time

First trouble shooting:

- there is not sound when the program is started → check SMB cable conections
- the sound changes during approach → tip might touch the surface → please retract stepwise
- no toggling visible → check SMB cable connection, then check that the sample is electrically contacted, check that Bias >> 0 V, if still no current signal → restart the software, if still no signal → use another KP-head as the current amplifier might be broken. Note: the small tip requires verz close distances to show a toggling signal
- how can one make the results more repeatable? → use the following function in series: approach (in order to get a signal), frequency auto-sweep (adjusts the resonance in case of a shift), approach again (regains the signal), offset correction (takes some time and corrects offset errors of the lockin amplifier, so that the Kelvin Bias becomes distance independent), approach again (to have an appropriate signal) → now repeat the measurement within a short time period on a series of samples with exactly the same setpoint.
- What does the Offset-correction do? → it corrects dc offset errors of the lockin amplifier in a way, that the measured Kelvin Bias gets independent on the distance.
- For small tip diameters, AutoOffset might not work! Use a manual routine.

Explanation of the Windows / Buttons and Keys

Figure 2: Main window of the Kelvin program with description of the functions

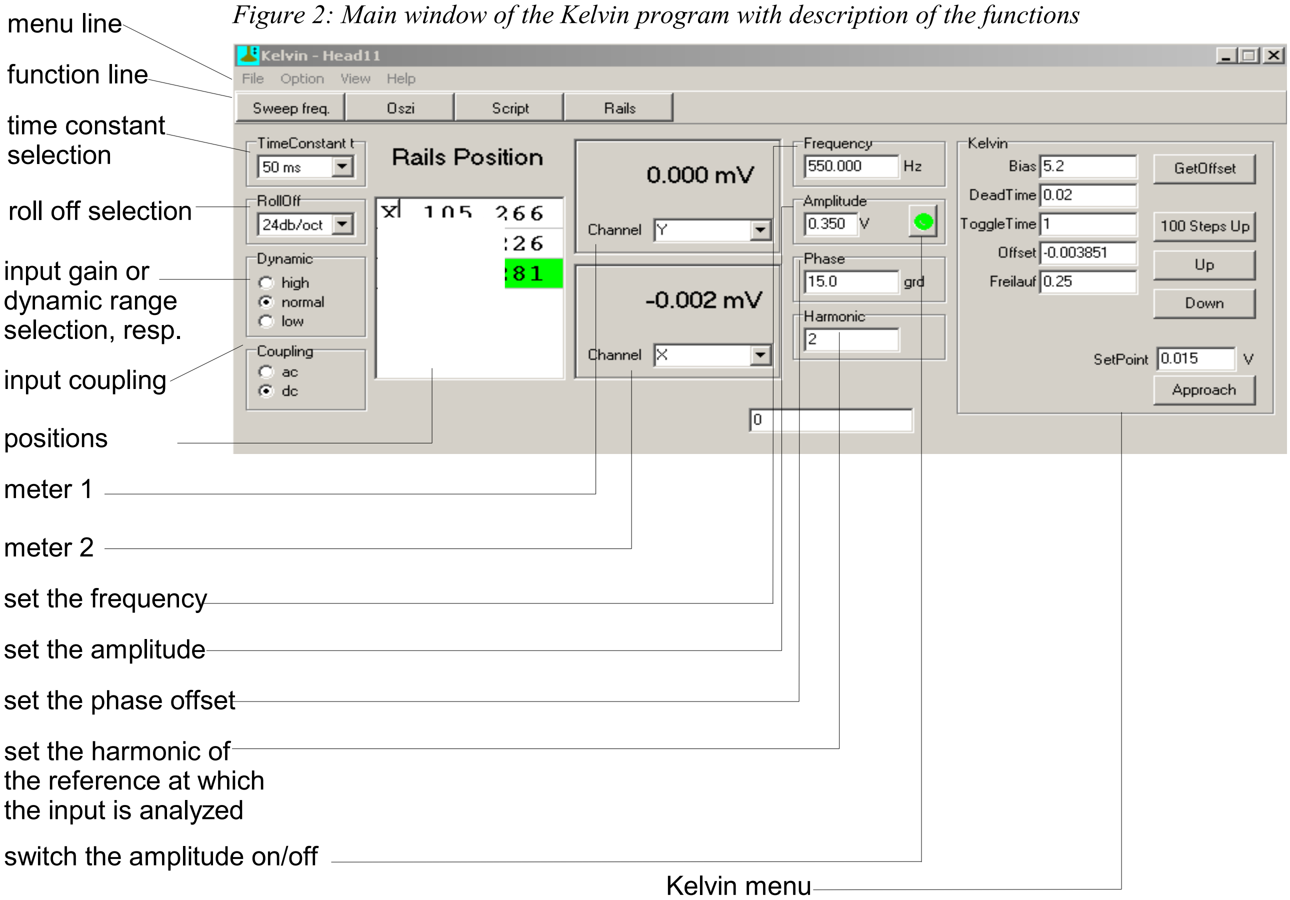


Figure 3 shows the main window of the Kelvin program, which appears when the program is opened in ADMIN mode with explanations of the single program parts.

The current position of the two rails is written into the “Rails Position” table. For checking the actually detected values of any of the input channels, the two meters are available. Basic input parameters for the lockin amplifier (frequency, amplitude, offset phase and harmonic) can be selected in the par right of the meters. Parameters, which concern the input stage (time constants, RollOff, and input gain) are chosen in the left part of the window. Settings referring to the Kelvin measurement (Bias, Offset, DeadTime, ToggleTime, Freilauf) are set in the Kelvin Menu.

The menu line allows typical Windows functions, while the buttons in the function line open new windows with specific functions.

Functions in the Menu Line

File

Exit - Exits the program.

Option

- **Scale AUX** … is a hidden window which contains the scaling factors for the A/D- and D/A-channels

- **AutoOffset AUXIn** … is a hidden window for the offset correction of the input current
- **Joystick**

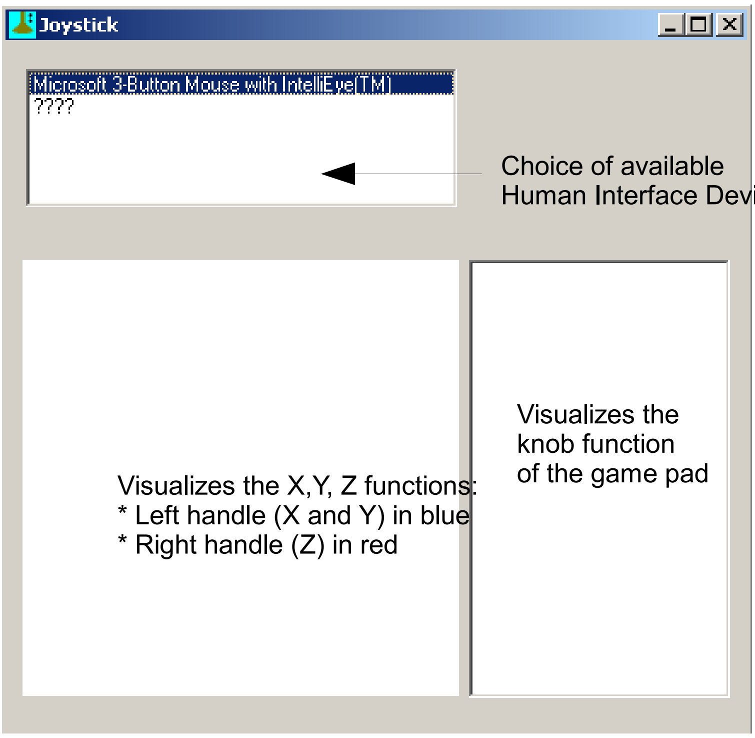
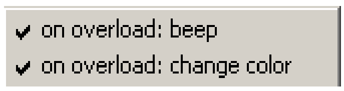


Figure 3: Joystick window

Opens a window, which allows to check the function of the joystick.

If the joystick does not operate properly, one can open this window, chose the “Logitech Rumple Pad” from the list and test, that the input knobs and the handles are working properly.

- **Overload**
  Overload occurs, when the dc input signal exceeds the full scale sensitivity for the selected range. This full scale sensitivity is 7 V_{rms} for high reserve, 700 mV_{rms} for normal reserve and 70 mV_{rms} for low reserve. With this option you can select whether a beep and/or a color change is shown in case of overload.



View

Select, which of the meters should be shown.

Help

About – shows the current program version.

Functions in the Function Line

The function line might contain a list of useful functions for the analysis of the system state. Some of the functions are switched off in the ini.file. If you want to switch on any functions, see appendix

1 – Description of the ini.file.

- ☑ Sweep freq. – allows to check the frequency response of the sensor head
- ☑ Oszi – opens a 3-channel software-oscilloscope, which allows to check that the toggling of the Kelvin Probe sensor works properly
- ☑ Generator – sets output values to single D/A-channels or digital outputs
- ☑ Display A/D – allows to check the encoder values and the stepper deviation as well as the input value of the capacitive reference contact
- ☑ Sweep bias – allows to sweep the bias voltage for the sensor head
- ☑ Rails – Rails window for the relative and absolute positioning
- ☑ UI – user interface window used to run scripts (top-most window in user-mode)
- ☑ Humidity – shows the current humidity

Sweep Frequency

This window serves the acquisition of frequency dependent spectra of any of the LockIn input channels.

The number of data points, parameters for the visualisation as well as for the saving and copying the acquired data can be changed in the option window.

Window description

“Delay”: is the time delay between each acquired data point. During spectrum acquisition, the frequency is set to the next value. Then, the system waits “Delay” and takes one single value from the acquired Channel.

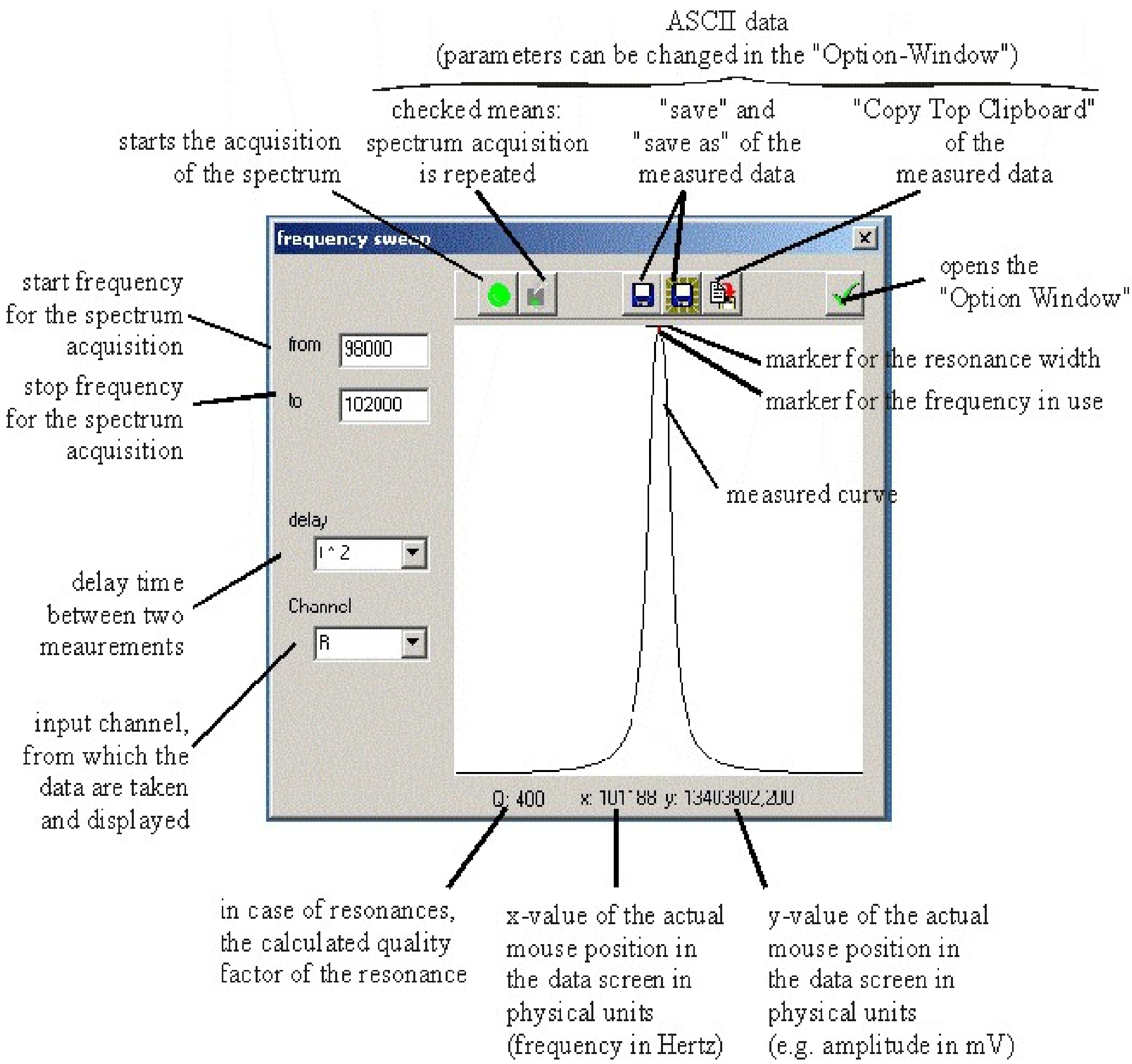


Figure 4: Window for the spectra acquisition.

As this delay has to be related to the time constant of the LockIn, the options in the drop down list for the delay are given in multiples of τ. Thus, independently of the time constant τ given in the main window, the time constant for the acquisition of the spectrum is always correct.

“from” and “to” define the values of the start frequency and the stop frequency. For the spectrum's acquisition, one chooses the wanted frequency range, and presses the “start-button”. If the time constant was very high, the spectrum might take a while. In order to stop the acquisition, the start-button can be pressed a second time.

“Channel” is a drop down list of available data channels (X, Y, R, and Phi).

“Range back” - click with the right mouse button in the data screen, and a pop-up menu with list of four frequency ranges appears. The upper one is a standard range, which can be changed in the “Option/acquire” part. The next three are, from the bottom to the top, the last three used frequency ranges.

Options for the frequency sweep

The option window provides three cards:

"Save" - parameters about the saving and copying format of data,

"Acquire" - parameters about the data acquisition, and

"View" - parameters, that specify how to show the data

"**AutoTune**" - automated acquisition of spectra

SAVE

The saved files and the data copied to the clipboard have an ASCII structure. The data are written in lines (each frequency value one line) and delimited by the given delimiter ("TAB" in the example) are saved. The frequency values are only saved, if "Save x-Axis" is checked. All history data are saved too and also delimited the same character.

Data file example:

1000,00 234,09
1200,00 237,98 ...

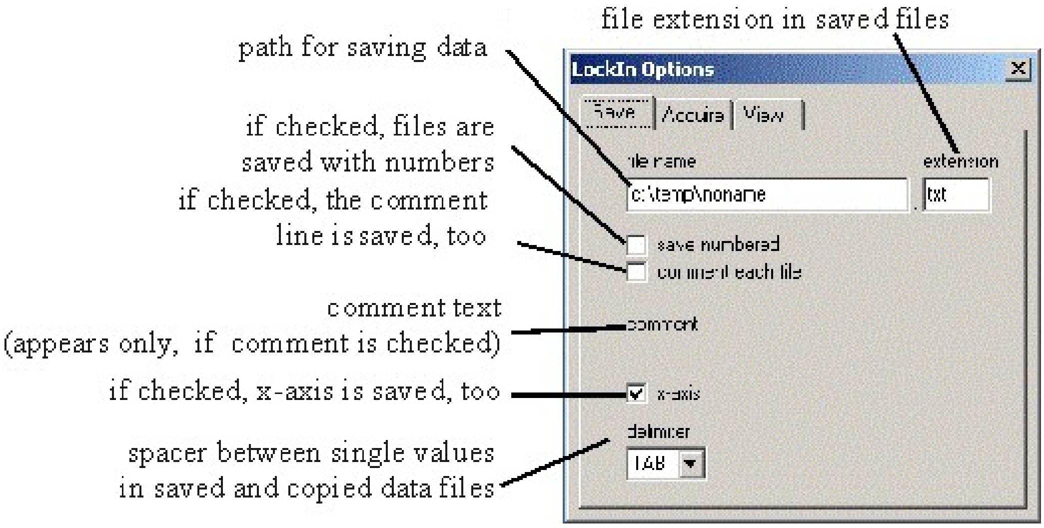


Figure 5: description of the card "save" in the sweep frequency options.

ACQUIRE

"Wobbel" - if a large range is scanned for overview purposes and the frequency peak, which should be found, is too small to be excited (because the single frequency steps are too big), the wobble option can help. If wobble is checked, the frequency is not kept constant during scan. It is varied (wobbled) between the neighboured values while the data are taken. This makes sure, that even small peaks can be found in an overview spectrum with only some 100 data points.

"Standard frequency" - is the range, which appears at the topmost position, if the right mouse button is used in the data screen of the "Sweep Frequency" window.

In the data screen, several data curves can be displayed simultaneously.

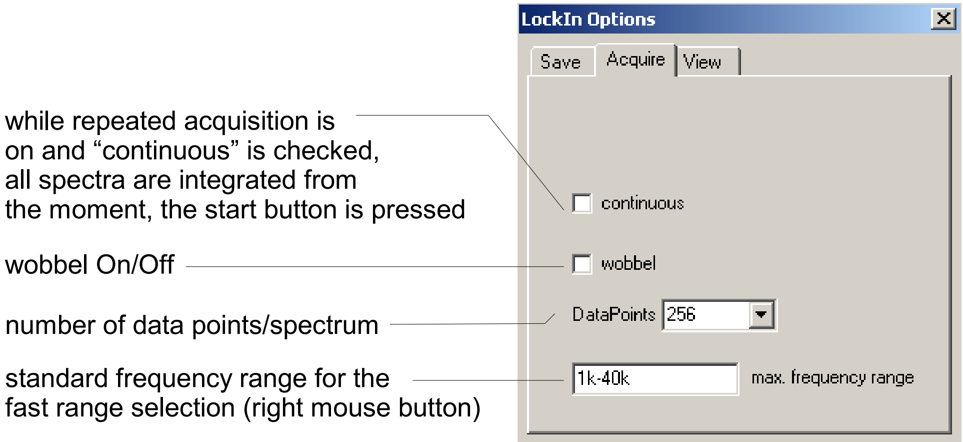


Figure 6: Parameters in "Acquire" of the frequency sweep options.

VIEW

Therein, the "History depth" is the number of old curves added to the actual one. If the depth is 2, the actual, the last and the last but one curves are displayed. The actual curve is always of black colour. The last is red, and the last but one is green. More curves get the next colours from the Windows™ palette.

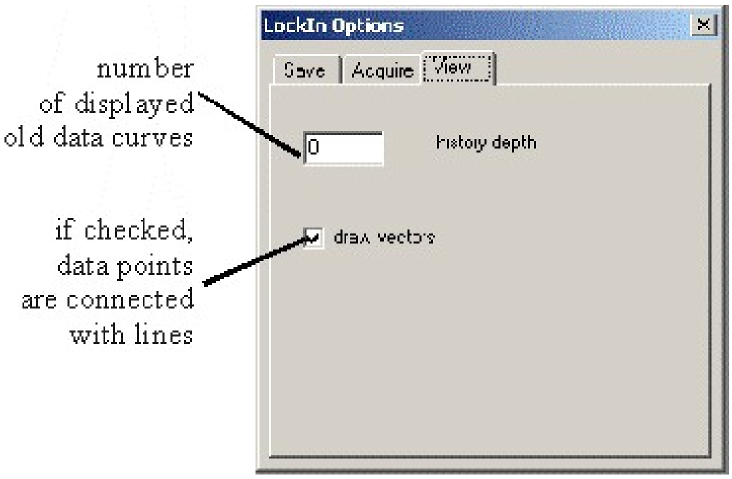
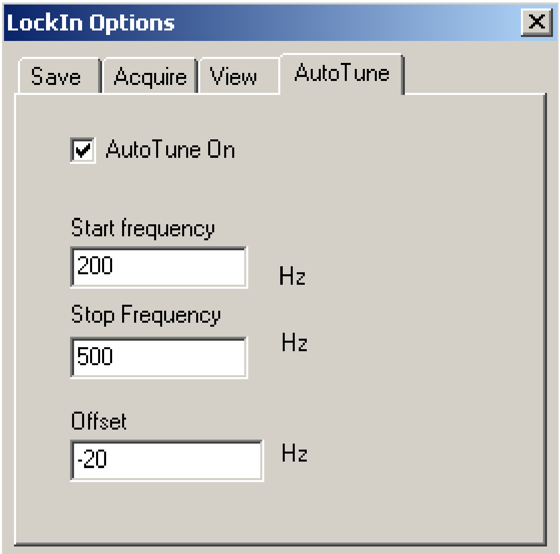


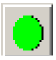
Figure 7: View options for the frequency sweep.

It can be chosen between pixel and vector drawing of data.

AutoTune



The „AutoTune“ tab allows to set parameters for the automated acqusition of the frequency spctrum. This function is useful for long term measurements, when temperature drift might change the resonance of the KP head.

„AutoTuneOn“ activates the automated spectrum acquisition and changes the look of the Start button from  into a “car” (German:  Auto).

„Start frequency“ / „Stop frequency“ – are the two frequencies, between which the resonance is expected. When AutoTune is started, these values are overtaken from „Autotune“ into the inout fields „from“ and „to“ of the „Sweep Frequency“ window.

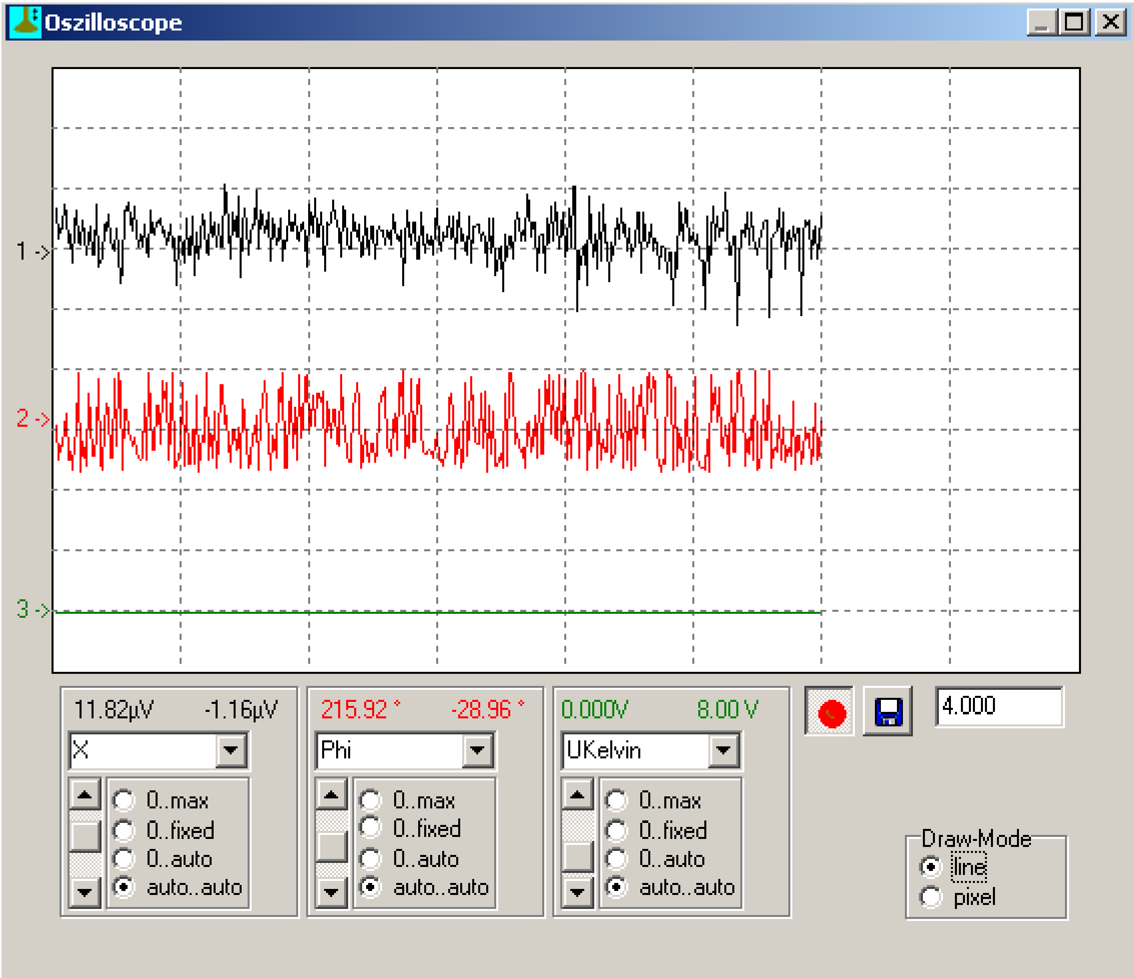
„Offset“ – is a frequency offset from the resonance at which the system is operated. At the resonance, the phase shift between excitation and measured current would be 90 deg. Small changes of the resonance would result in strong changes of the measured value X. Thus, the system best is operated below the resonance, far enough, that frequency drift is not important and close enough so that one gets an amplification of the amplitude due to the resonant behaviour. Typical Offset values are between -10 deg. and -30 deg. A good value results in a phase offset close to zero.

after the spectrum acquisition, the following operations are performed automatically:

- the maximum amplitude in the curve is used to determine the resonance frequency f_r
- the used frequency is set to a value (f_r – Offset)
- the phase offset at the new resonance is determined and corrected

Oscilloscope

The oscilloscope works like a real 3-channel-oscilloscope. Content, scaling type and offset of the three channels are selectable.



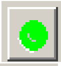
Channel selection: is done from a drop down list, which shows only the available channels.

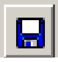
The two ***numbers*** above the drop down list for channel selection display the "scaling factor per vertical division" (= left number, hint: "y-scale in /div", example: 11.82 µV/div) and the mean value. Both are calculated from all data acquired from the left oscilloscope edge till the current oscilloscope time. Therefore, these numbers are subsequently re-calculated.

Vertical scaling types:

- 0..max — the scaling is set to maximum value of the channel
- 0..fixed — the maximum value can be changed by a slider appearing on the right sight of the scaling type selection
- 0..auto — the program calculates the optimum, but takes always "0" as minimum
- auto..auto — automatically scaled

Time scaling is done with the edit window (right side) in seconds.

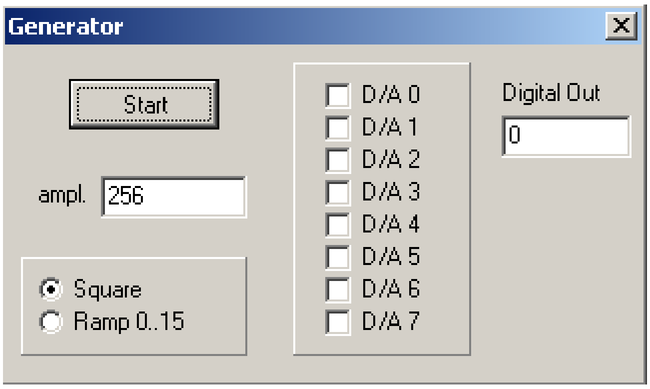
If **"Scan"** is shown in red, then the Oscilloscope is scanning, press the button in order to stop the scan. The button will be shown in green then.

 **"Save Pic"** saves the oscilloscope screen in a bitmap file.

"Draw mode" selects whether the data are drawn as dots or lines.

If you want to move one of the three channels, drag&drop the arrow, at the start of your scan, to the place you want your scan shown.

Generator



This window allows to test the D/A-channels as well as the digital output settings.

ampl. Allows to set the output amplitude in digital units (0 = no output, 1 = last bit toggles, maximum value: 2047).

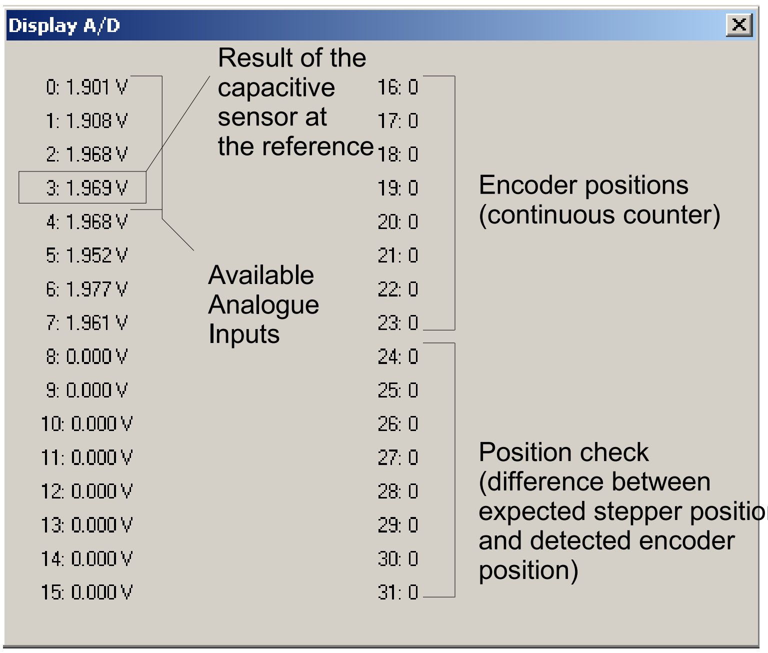
Square / Ramp 0..15 the output is either a triangular ramp. Then, "ampl." is the height of the steps. Or the output is a square pattern with "ampl." as height.

Digital Out defines the digital output channel to access single bits in the digital output chain.

One selects the D/A channels to be tested. With "Start", the output of the ramp or triangle is enabled. It ca be stooped with the 2nd click onto the start button.

D/A 1 = bias output for the Kelvin toggling.

Display A/D



This window is for service purposes, only. It allows to check the values for the encoders and steppers.

Channel 3 of the inputs detects the output signal of the capacitive sensor mounted at the reference electrode.

SWEEP BIAS

WINDOW DESCRIPTION

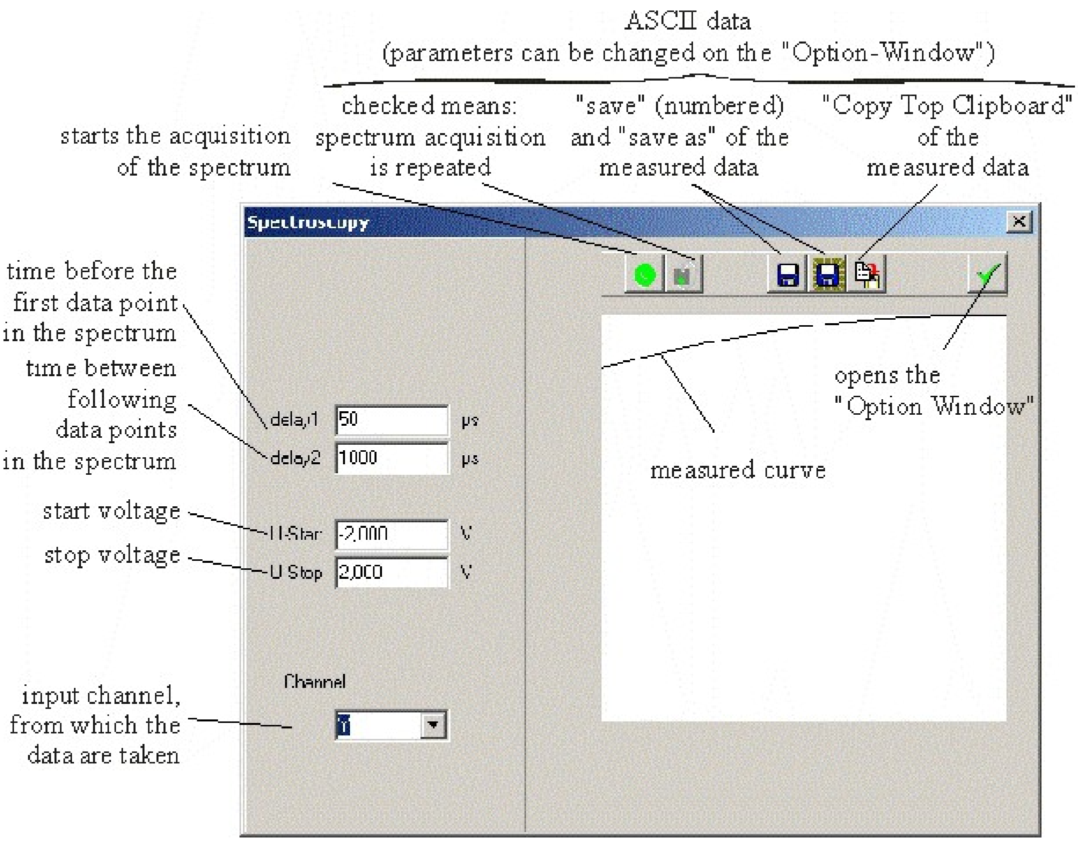


Figure 8: Window for the spectra acquisition.

This window serves the acquisition of voltage dependent spectra of any of the LockIn input channels. Usually, the time constant has to be related to the time constant of the LockIn.

The number of data points, parameters for the visualisation as well as for the saving and copying the acquired data can be changed in the option window.

OPTIONS FOR THE BIAS SWEEP

The option window provides, in analogy to the option window of the frequency sweep, three cards: **“save”** - parameters about the saving and copying format of data, **“acquire”** – parameters about the data acquisition, and **“view”** – parameters around the screen of showing the data.

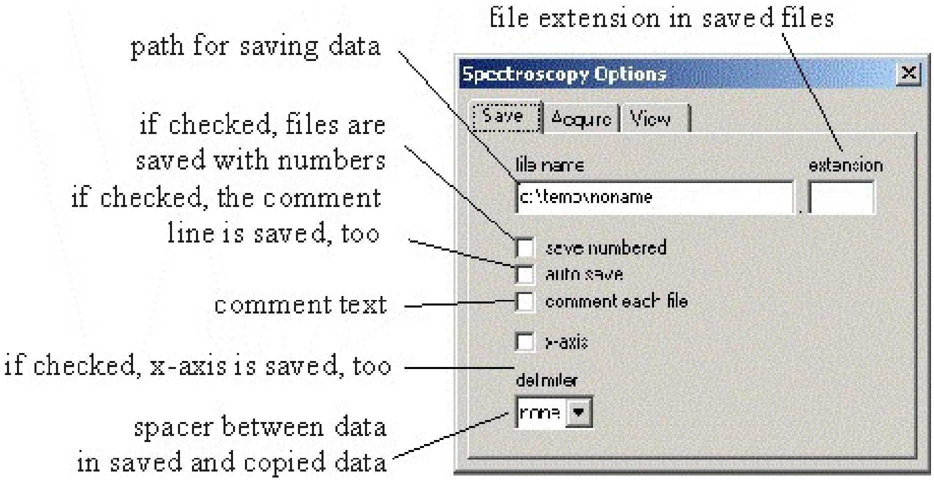


Figure 9: description of the card "save" in the sweep bias options.

The saved files and the data copied to the clipboard have an ASCII structure. The data are written in lines (each frequency value one line) and delimited by the given delimiter ("TAB" in the example) are saved. The voltage values are only saved, if "Save x-Axis" is checked. All history data are saved too and also delimited by the same character.

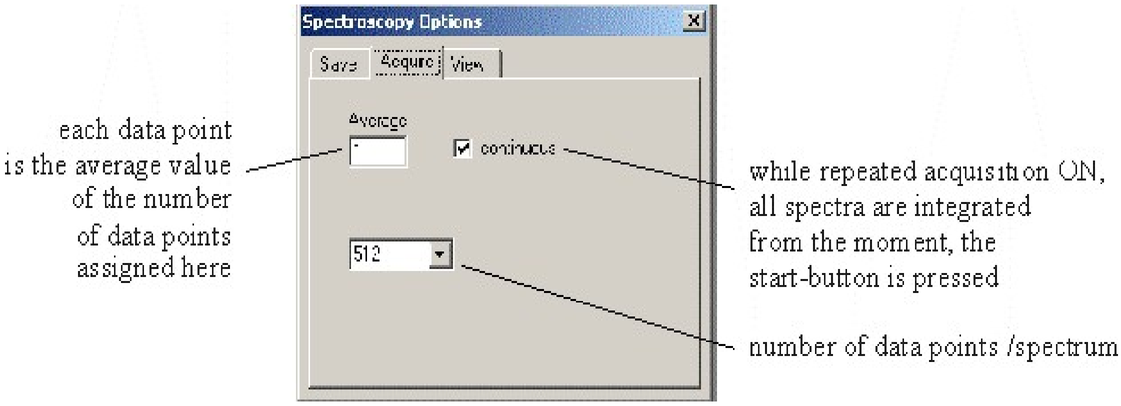


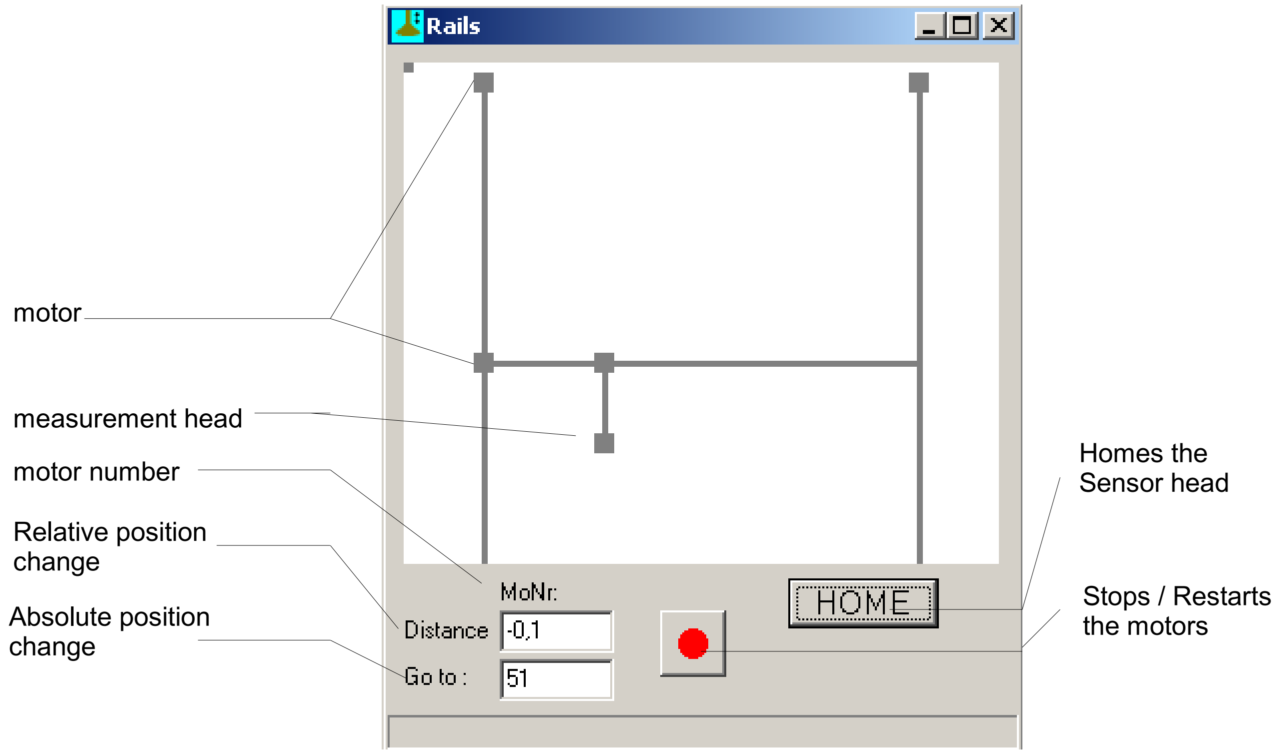
Figure 10: Description of the card "acquire" of the sweep frequency options

Therein, the "History depth" is the number of old curves added to the actual one. If the depth is 2, the actual, the last and the last but one curves are displayed. The actual curve is always of black colour. The last is red, and the last but one is green. More curves get the usual next colours from the Windows^{TM} palette.

The card "View" is almost equal to the card "View" of the sweep frequency options window.

RAILS

This menu makes it possible to move a distinct rail.



When selecting an axis at its motor, the motor number is shown after the label "MoNr". Simultaneously, the selected axis gets green. When selecting the Y-Axis, always two axes will be marked in green, because these axes are linked. Therefore two motor numbers will appear in the label.

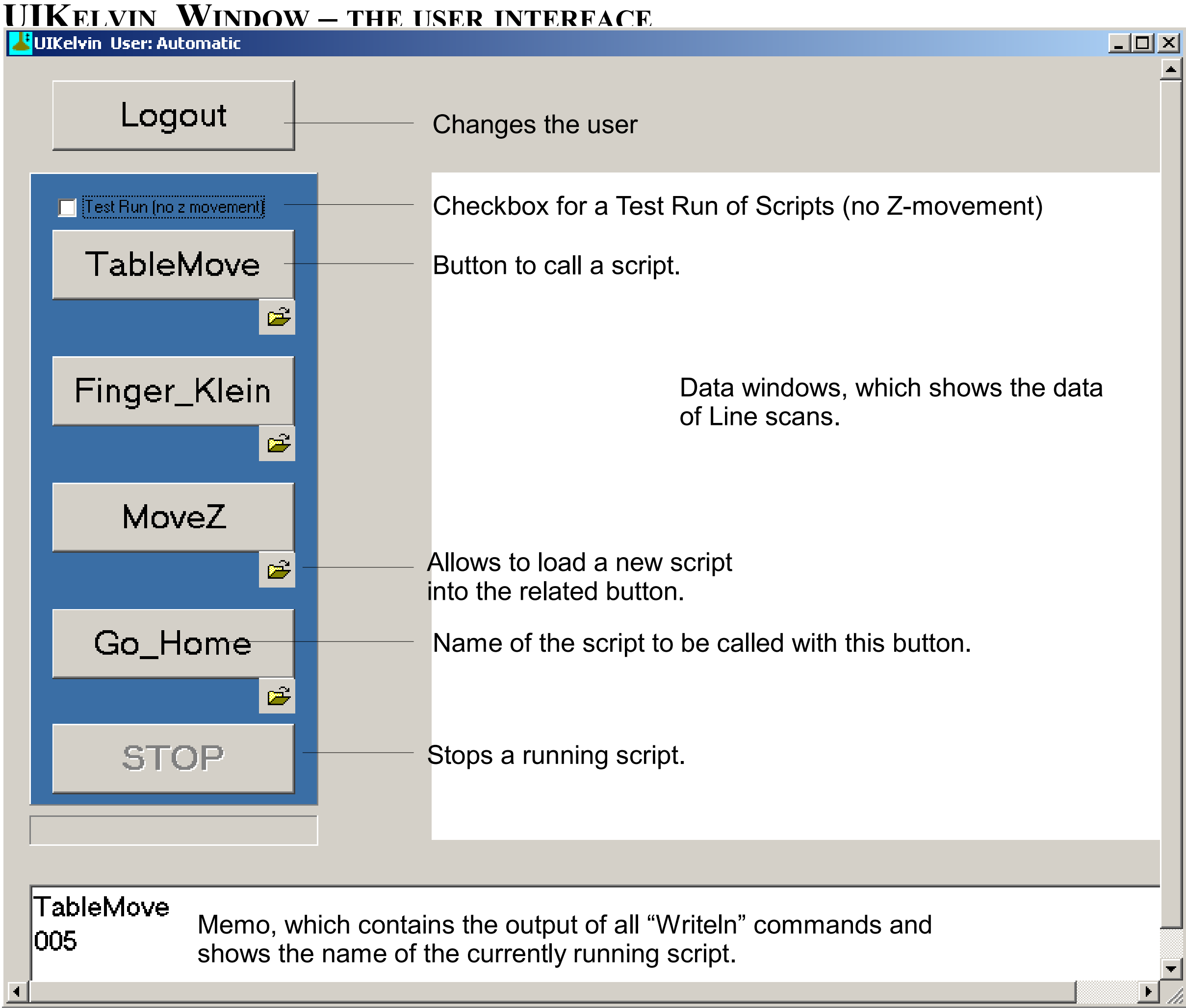
In order to move a rail relatively to its current position, select its motor and type in a value in the field "Distance". As the coordinate system is right handed, a positive value for an X-axis will move the head to the right. A positive value for an Y-axis will move the head upwards (as seen in the picture, this means it will move closer to the Y-motors), while a positive value for the Z-axis will move the selected head upwards (away from the base plate).

An absolute movement is done with "Goto". When any axis is selected, the number behind the entry "Goto" shows the current position. One can enter another position. Which "Enter", the selected motor moves directly to this as final position.

"Start / STOP" – the red knob – is used as emergency STOP for the rails. After a soft emergency STOP with the game pad, this knob is green and pressed. Press it, to enable the motors and overtake the currently detected encoder positions into the currently stored motor positions.

As the position detection of the rails is a counter inside the controlling system, which loses its value after a "Not-Aus" or power fail, the rails need to be homed to find back their original coordinates. Press the "home" button. The upper button will bring home the reference head, while the lower button calibrates the measurement head.

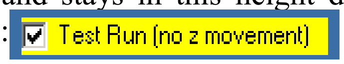
UIKelvin Window – the user interface



The “UIKelvin” window allows the user to run predefined scripts. If the systems fails during a running script, it stops and the rails window pops up to the front display.

In ADMIN-mode (password protected mode), one can change the predefined scripts and load other scripts into the UIKelvin Window.

 This icon is used to load a new script. Scripts are written in ASCII-format and saved with a *.SCR extension (see: Language description).

The test run allows to run a script without the z-movement. The tip is moved to the safe height which is pre-defined in the ini-file and stays in this height during all movements. During test run, the background of the left is yellow: 

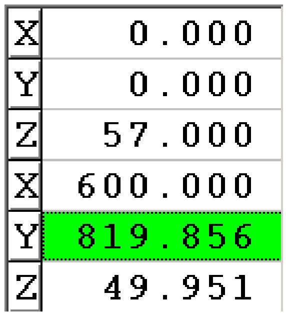
The STOP button allows to stop a script after the running command is closed.

In order to be able to read the whole file name in the button label, save your programs with names not longer than 12 letters. In case your program uses “writeln”, the output will be shown in the Memo below all buttons. Data produced with the “Line”-commands appear in the data window.

HUMIDITY

This button allows to show the room humidity in %.

POSITIONS

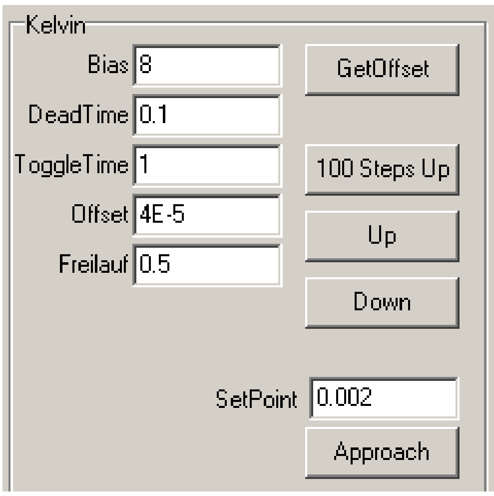


This menu shows the position of the rails.

The first three lines show the position of the measurement head. The coordinates for the reference head are given in the last three lines.

While selecting a coordinate of a head, it turns green, showing that you are now able to copy the given number to clipboard. Press “Ctrl” and “C” to do so.

KELVIN MENU



The “Kelvin Menu” is needed, whenever you want to approach to your sample.

While “100 Steps Up” moves the measurement head 100 steps upwards, the “Up” and “Down” buttons make only one step in the selected direction. To automatically approach the tip, choose “Approach”. Before you do this, make sure that the “Kelvin Menu” parameters are set correctly, in order not to crash your tip.

“Bias” is the voltage in V set between sample and tip.

“Dead time” is the length of the sleep period in seconds after each step.

“Toggle time” is the time for one cycle, in which the bias is applied in one sign.

The “Offset” is a correction value. It can be set by pressing “GetOffset”. Please make sure, that your reference head is approached to your reference sample(e.g. Al, Au) before doing so.

“Freilauf” gives the safety of the tip. The bigger the “Freilauf” value, the safer the trip of your tip.

“SetPoint” is the reference value of X, at which the automated approach stops

LOCKIN AMPLIFIER MENU

TIME CONSTANT

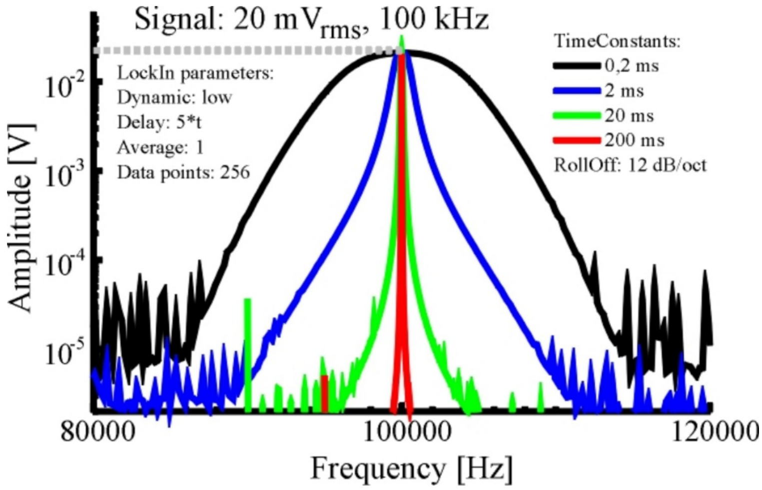


Figure 11: Effect of different time constants.

This option selects the used time constant for the low-pass filter. The internal LockIn functions give the lower limit of 0.2 ms (5 kHz). The possible time constants range in a logarithmic scale between 0.2 ms and 1 s.

The low-pass filter itself is a Butterworth with an effective noise bandwidth of

$$B_n = \int_0^\infty \frac{1}{1+\omega^{2n}} d\omega \quad .$$

The normalized Butterworth filter noise bandwidths are:

Filter order	*Bandwidth*
1	1.570796
2	1.110721
4	1.026172

ROLLOFF

The "RollOff" equals the degree of the lowpass filter. One can chose between 6 dB/oct (1st order), 12 dB/oct (2nd order) and 24 dB/oct (4th order).

DYNAMIC

This switches the input amplification of the LockIn. With "high" dynamic, input amplification is 1.

The maximum signal amplitude is then +/-10 V. The "normal" input amplification is 10, which equals maximum signal amplitudes of +/- 1 V. When the low dynamic is chosen, the resolution of the LockIn is highest, but the signals cannot exceed 100 mV.

Coupling

If the specification of the instrument allows it, this option switches between DC coupled input and AC coupled input. Note: The 3dB corner frequency of the input high pass is around 2Hz. Reference frequencies around 2 Hz and below may cause misleading results.

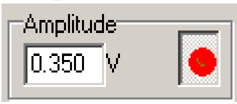
Frequency

If written in black letters, this is the actual reference frequency which is used at the reference output and as reference frequency for the signal evaluation of the input. Click with the right mouse button to switch from external to internal reference. In case of internal reference, the numbers are written in grey.

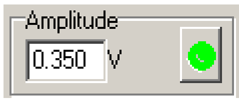
Amplitude

This is the amplitude of reference output. The button right aside sets the amplitude on or off.

Amplitude On



Amplitude Off



Phase

Allows to give a phase offset between the reference output and the input. It can be used to adjust the maximum signal amplitude into the X-part of the signal, so that optimum conditions are reached.

Harmonic

Selects, which harmonic of the reference frequency is evaluated. The possible values range from 1 to 9. When selecting higher harmonics, take care, that, due to low pass filtering, the maximum input frequency the LockIn cannot be higher than 2 MHz.

In this Kelvin Probe set-up, the harmonic should be set to 2.

VI. LANGUAGE DESCRIPTION

1 General Syntax

The general style is Pascal:

- ✗ There is no case sensitivity.
- ✗ The program starts with `begin` and stops at `end.`.
- ✗ `( )` - brackets are used in mathematical formulas.
- ✗ Strings are enclosed in `'  '` (`"  "` is also working).
- ✗ Decimal separator for floating point numbers is a point: "`.`".
- ✗ Each command is completed with a semicolon: "`;`".
- ✗ Available mathematical operations: `+  -  *  /  ^  e`
- ✗ Available relational operations: `=  >  <  <>`

2 Variables & Assignments

Variables are single characters only. The data format of all variables is real.
Predefined variables are:
`Temp` for temperature, `Uk` for the Kelvin potential and `Humi` for the Humidity, the names of the reference samples `AU`, `AL`, `HOPG`, `USER1` and `USER2` as well as `Ch` as result of GetChannel.
Example: `A := A + 1.2;`

3 Command Overview

Command	***Meaning***
ClrScr	Deletes the visible data on the data screen
Color (r,g,b)	Set the color of the next drawn data line
if ... then	Condition
Execute('filename')	Executes another script *./script/filename.scr*
Filename ('name1')	Defines the name of the data storage file as ./data/*name1.txt*
Filename(input)	User set the filename in the Memo
for ... to ...	Loop definition
Freilauf(fl)	Defines the safety height for line and point measurements in steps
GetChannel(ch);	Reads the value of an internal data channel
Goto *marke*	Jumps to the position *marke* defined as Label
Image(s,d)	Acquires a square image with s pixels and d mm x d mm size
Line(dir,s,d)	Measures *s* points from here to *d* along a line in direction *dir*
MoveRef(x,y,z)	Moves the contact to a new absolute position
MoveSonde(x,y,z)	Moves the sensor to a new absolute positions
MoveSondeZRel(z)	Moves the sensor in z direction relatively to current position

Point(x,y)	Measures data set at the absolute coordinate (x,y)
SetEnv('string',value)	Sets the set-Points for humidity and temperature in environmental control via network
SetChannel('string',value)	Sets the output D/A-channels
SetKelvin('string',value)	Changes variables for the Kelvin-Measurement
SetLockin('string', value)	Changes variables for the lockin amplifier
SetPoint(sp)	Sets the Set-Point in V
ToggleTime(tt)	Sets the parameter Toggle Time in seconds
Wait(t)	Waits for a time t in seconds
Writeln('text',..)	Displays text in the Memo

4 Commands (alphabetical)

ClrSrc

deletes all visible data and spectra on the data screen.
Example: `ClrSrc;`

Color (*red,green, blue*)

sets the color for the next graph to be drawn in the diagram
Parameters: **red, green, blue:** integer 0 .. 255
Example: `Color(0,0,0)` → sets the color to black
`Color(255,0,0)` → sets the color to red

Image (*points,delta*)

Scans an image
Parameters: **points:** integer
delta: real
Example:
`Image(64,5);` → scans an image with 64 x 64 points over a range of 5 mm x 5 mm

IF *condition* THEN *command*

Evaluation of conditions. ELSE is not supported.
Example:

```
Point(100.56, 200.87);
if  (U < -1.6) then writeln('Potential in Al out of range =', U)
```

Execute (scriptfilename)

Calls and executes another script file.
Parameters: **scriptfilename:** string
Example:
`Execute('Ref-HOPG');` → calls the script “ *./scipts/Ref-HOPG.scr* ”.

FILENAME (DATAFILE*NAME*)

defines a file name for the data file, which collects all data during the measurements.
Parameters: **datafilename :** string → file is *./data/name.txt*
Example: `Filename('test3');` → the data are written to *./data/test3.txt*

FILENAME(INPUT)

The user gets the possibility to insert the desired filename directly in the Memo.
Example: ***`Filename(input);`***
→ *Memo text:* ***`image5x5,`*** *the data are written to ./data/image5x5.txt*

FOR *START COUNTER* TO STOP COUNTER DO BEGIN *COMMAND(S) END;*

Loop definition based on an integer counter. The commands `begin` and `end` are always required.
Example (measures 20 points along a line in x-direction):

```
X:=100;  Y:= 100;
for i:=1 to 20 do begin
  Point(X,Y);
  X:=X+i/10;
end;
```

FREILAUF (HEIGHT)

defines a relative height above the sample surface in steps (for Single Point KP System) or mm (for Scanning KP systems), which is used during movements between point or linear measurements called with `point(x,y)` or `line('type',steps,endpos)`. **After** each call of `point` or `line`, the KP head is lifted to “Freilauf” relatively from its measurement position.
Parameters: **height:** real
Example: `Freilauf(5.1);`→ enters “5.1” in the entry “Freilauf” in the parameter section of the KP software resulting in 5.1 mm or 5 stepper steps movements

GETCHANNEL(CHANNELNUMBER)

Acquires the data of one A/D input channel.
Parameters: **channelnumber:** integer

Channelnumber	***Meaning***		***Channelnumber***	***Meaning***
0 / 1 / 4 / 5	Auxiliary In1 / In2 / In3 / In 4		16	Temperature (USB)
10 ...13	X, Y, R, Phi		17	Humidity (USB)
14	Uk [V]			
15	Kelvin Slope			

Example: `GetChannel(10);`→ reads the input data of the reference electrode
`writeln("X=",Ch);`→ writes the result of GetChannel in the Memo

GetOffset

Starts the procedure, which detects the offset automatically channel.
Example: `GetOffset;`

Goto *marke*

Allows to jump to a *marke*. It requires:

- the definition of a label with a `LABEL` statement
- a `Goto` command followed by the labels name
- the label followed by a colon

Labels always start with a character..
Example:

```
LABEL foo, foo2;
begin
  Point(100,100);
  if U > 0.05 then Goto foo;
  Goto foo2;
foo:
  writeln('Reference Potential too large. U =',U);
foo2;
end.
```

Image (*steps, distance*)

starts an automated image acquisition from the current position towards the direction +X and +Y.
Parameters: **steps :** number of steps along x- and y-direction (always square image)
distance : size of the image in mm

Example: **Image** `(128 , 20 );` → acquires an image with 128 x 128 point. The points are distributed over an area of 20 mm x 20 mm.
After each measured point, the tip is retracted to the height “Freilauf”; the next position is chosen and the tip is automatically approached until the “SetPoint” is reached. After each line, the tip is additionally retracted in a safer height for long distance movement. After the whole image, the tips back to the start position. Data are stored in “./picture” folder.

Line (*type, steps, distance*)

starts an automated measurement along a line
Parameters: **type :** direction of the line scan, can be `'X'`,`'Y'` or `'t'` for time
steps : number of steps between start and end point
distance : relative position of end point vs. the current position in mm or in seconds for the type = 't'
Example: `Line ('X', 10 , 20 );` → measures 10 points along a line of 20 mm length in x-direction. After each measured point, the tip is retracted to the height “Freilauf”; the next position is chosen and the tip is automatically approached until the “SetPoint” is reached.

MoveRef (x,y,z) – not used in AFT_KP150 !

positions the top contact at the coordinates (X,Y, Z) given in mm.
Parameters: **x, y, z:** real
Example: `MoveRef(200,25.3,5.1);` → the contact is retracted to a safe height of z = 50 mm in z-direction; is laterally moved to the coordinate (x = 200 mm , y = 25.3 mm) – first X then Y movement – and vertically approached to the final height z = 5.1 mm. The safe height is defined in the user.ini as "SafeZPos".

MoveSonde (x,y,z) or MoveSonde (z)

For Scanning KP systems:
MoveSonde(x,y,z) positions the sensor head at the coordinates (X,Y, Z) given in mm.
Parameters: **x, y, z:** real
Example: `MoveSonde(76.2,50,2.6);` → the head is retracted to a safe height of z = 50 mm in z-direction; is laterally moved to the coordinate (x = 76.2 mm , y = 50 mm) – first X then Y movement – and vertically approached to the final height z = 2.6 mm.

For KP-TT Devices:
MoveSonde(z) turns the stepper motor for Z direction z steps.
Parameters: **z:** integer (real is automatically changed into integer)
Example: `MoveSonde(-10);` → lifts the head 10 stepper steps

MoveSondeZRel (z)

For Scanning KP systems, MoveSondeZRel(z) allows tp move the sensor in z direction for a distance given in mm.
Parameters: **z:** real
Example: `MoveSondeZRel(-0.5);` → lifts the head 0.5 mm higher than it currently is.

Point (x,y)

measures a surface potential at the position (x,y) given in mm. The tip is retracted from the current position to the z-value "Freilauf" and moved to the new position. Then, the tip is approached automatically based on the value SetPoint. The Kelvin potential is acquired with an integration time given as 2 * ToggleTime. Finally, the z-position is again set to "Freilauf".
Parameters: **x , y** : real
Example: `Point(100, 200);` → acquires a Kelvin potential at the point x = 100 mm and y = 200 mm.
`Writeln (Uk);` → displays the result in the Memo
Note: for the KP-TT, this function simply acquires a data point and does not recognize xy-position.

SetChannel ('string', value)

Set the D/A-converter outputs to certain values:
Parameters: **integer :** 0...3 → channel number

value : real → value in volts

Example: `SetChannel(2,1.2);` → sets the voltage at Aux-Out1 to 1.2 V

Channelnumber	*Meaning*		*Channelnumber*	*Meaning*
0	Sample		2	Out1
1	Tip		4	Out2

SetEnv ('*string*', *value*)

Changes the set-point for the environmental control via network:

Parameters: **string : Temp**, **Humi**

value : real → value in displayed units

Example: `SetEnv('Temp',20.5);`

→ sets the sample temperature to 20.5°C or

`SetEnc('Humi',40);` → sets the chamber humidity to 40 %RH

SetKelvin ('*string*', *value*)

Changes parameters in the Kelvin-Window as follows:

Parameters: **string : B**ias, **D**eadTime, **T**oggleTime, **O**ffset, **F**reilauf, **S**etPoint (or the 1st character: B, D, T, O, F, or S)

value : real → value in displayed units

Example: `SetKelvin('F',0.1);` → sets the parameter Freilauf to 0.1 mm

or

`SetKelvin('Freilauf',0.1);`

SetLockin ('*string*', *value*)

Changes parameters in the Kelvin-Window as follows:

Parameters: **string :** **F**requency, **A**mplitude, **P**hase, **H**armonic, Tune (or the 1st character: F, A, P, or H)

"Tune" is a boolean, Tune = 1/0 equals Autotune = ON/OFF.

value : real → value in displayed units

Example: `SetLockin('F',1000);` → sets the frequency to 1 kHz

or

`SetLockin('Frequency',1000);`

SetPoint (*value*)

defines the SetPoint for the distance feedback. The automated approach used in point or linear measurements called with `point(x,y)` or `line('type',steps,endpos)` stops, when the signal X reaches this value is given in V.

Parameters: **value :** real → value in volts

Example: `SetPoint(0.0015);` → the auto-approach stops at 1.5 mV

ToggleTime(*value*)

defines the time for each measurement cycle (switching time of the applied backing potential) in s.

Parameters: **value** : real
Example: `ToggleTime(0.8);` → the bias is 0.8 ms positive and 0.8 ms negative in all following measurements.

WAIT (*TIME*)

Allows to pause the operation a time given in seconds.
Parameters: **time** : real
Example: `Wait(1.5);` → waits for 1.5 seconds

WRITELN ('*TEXT1*', *VARIABLE*, '*TEXT2*', *VARIABLE2* ...)

Allows to write additional information in the memo. In the brackets, a series of strings, variables and numbers can be written, which are separated by commas. Strings should be enclosed in `' '`.
Parameters: **text1, text2 :** string; **variable1, variable2** : real
Example: `a := 5 ;` → sets the value of the variable *a* to 5
`writeln("a=", a);` → writes “a=5” in the Memo

VII. EXAMPLE PROGRAMS & SUB-SCRIPTS

This section explains some of the example scripts provided with the Kelvin Probe Tool. Those scripts are useful in order to :

- automatically renew stored values for reference voltages (as HOPG)
- move the sensor to specific predefined positions (for example, close to the Home Position)
- generate fast or safe approach procedures for special external conditions
- program patterns with measurement dots
- program procedures for the determination of the Surface Photo Voltage

Scripts can call each other. In order to combine different scripts successfully and not to get confusion with repeatedly used variables, it is useful to define variable names for a dedicated purpose that can then be used in all scripts. After leaving a sub-script, they should be reset to the entry value.

In the provides scripts the following variables are defined and used:

x, y, z	coordinates of the sensor used in `Point(x,y)` and `MoveSonde(x,y,z)`
i, j, k	counting variables for loops
N, M	upper limits for counted loops
T	Toggle Time in s
V	Bias Voltage in V
D	Slope in V
S	Set Point in V
a, b, e, f, g, h	intermediate storage of values read with `GetChannel(channel)`
u,w	variables that can be overwritten at any time (used to store values for other variables or counter in the last called sub-script)

The output generated in Sub-Scripts (with `writeln()`) is always written into the Edit-Screen, but it is either neglected in the file output or written in a separate file, if the sub-script uses the command `Filename()`.

Labels, on the other hand, can be defined wit duplicate names (example: the Label repeat; is use in several example scripts without conflict).

Predefined Script examples

to be found in the folder C:\Program Files\Anfatec\Scripts:

AcquireAllChannels_vs_Time	Shows how the different data channels get be read and stored into a user defined file
ApproachSignSelect	This script makes the approach safer out, if the potential difference between sensor and surface makes that one of the measured value X is close to zero.
ApprOnSlope	The slope is the difference between X and positive and X at negative Bias. It is a measure for the distance. The sign of Bias during approach is chosen randomly. Thus, if X and -X are quite asymmetric, the automated approach might result in a sign-dependent distance. This script makes sure that the distance is not sign-dependent.
FastApproach	With the function MoveSensor(x,y,z), the achieved and safe z-position is usually quite large. This script takes the signal amplitude as measure for the distance and approaches in larger (e.g. 50 µm) steps until a dedicated amplitude is reached.
GetAuRef	Measures the potential of a gold reference. It is assumed that this reference is placed in Pos. 1
GetHOPG	Measures the potential of a HOPG reference. It is assumed that the HOPG reference is placed in Pos. 2
Go_Home	Moves the table close to the Home position. This makes the start-up for the next measurement easier. It is useful to use this script before shutting down the system.
Mother	… is an example for a kind of main script that defines the general parameters for an experiment and calls other scripts.
Photovoltage2	Uses Aux1 to toggle the power an external light source (LED) and measures the SPV.
SetKelvinParameter	Shows how all KP parameters are set.
SetLockinParameter	Shows how all Lockin Amplifier related parameters are set
TestSingleCommand	Used to test a single command.

APPENDIX 1: DESCRIPTION OF THE INI-FILE

The ini-file is specific for each measurement head.

[dnc]	settings for the frequency sweep
[dncopt]	settings in the option window of the frequency sweep
[Scale]	scaling of D/A and A/D-channels
DAC1Edit2=1	
[LockIn]	settings for the lockin parameters
[Spekt]	settings for the bias sweep
[SpektOpt]	settings for the options window of the bias sweep
[Oszi2]	settings of the oscilloscope window
[DisplayAD]	settings of the window, which displays the A/D channels
[Generator]	settings of the generator window
[Display1]	settings for meter1
[Display2]	settings for meter2
[Main]	general software settings:
FormPosTop=57	window position from top
FormPosLeft=188	window position from left
AutoDemo=0	“0” means, the system is not in demo mode; “1” equals demo mode
AutoUser=Automatic	last user
smKelvin=0	system type: 1 = Small Kelvin Probe, 0 = Scanning Kelvin Probe System – large KP systems use the rails –
HomeAtStart=0	after program start the system asks whether the axis should be homed or not
Contact=1	“0” ... 2nd axis with top contact active; “1” or not listed: 2nd axis inactive
[Kelvin]	specific settings for the Kelvin Probe operation
uKelvin=8	bias voltage
xxStepsUp=100	steps, the system retracts the sensor, when the offset is determined
automatically Approach=8	bias voltage used for automated approach
[Joystick]	initial settings of the game pad
Use=1	without this entry, the game pad is not used at all
JoyName="Logitech Cordless RumblePad 2"	
JoyItemX=0	x-direction
JoyItemY=1	y-direction
JoyItemZ=3	z-direction
SelectPoint=4	
Tolerance=10	
JoyModeByte=6	
JoyModeBit=3	

GainX=-70	x-direction of table movement
Gainy=-70	y-direction of table movement
GainZ=100	
SafeZ=1	safety distance, movement with joystick for z<1 is impossible
[Rails]	settings of the rails window
SafeZPos=5	safety distance, into which the sensor and the reference are retracted during MoveSonde(X,Y,Z) and MoveRef(U,V,W) calls in scripts
AlarmDist=100	maximum deviation between expected step motor position and currently read encoder position (AD channels 24 to 31), which results in a Soft Emergency STOP
FormPosLeft=391	window positin from
FormPosTop=394	
EncOffs0..7=-140218	Offset value the encoder 0..7 detected at last homing of the system
EncPos0..7=-140218	Current Encoder position used if Software is switched OFF while the controller remains ON
Edit1=280.125	
Edit2=10	
MinDelayTime=100	
StepperScale0=-0.000625	Scaling of the rail axis 0 (Y0)
StepperScale1=-0.000625	”” (Y1)
StepperScale2=-0.000625	“” (X)
StepperScale3=0.0000794	“” (Z)
	This scaling is calculated with screw slope in [mm] / (Steps/turn) /8. Example: screw slope: 2 mm (X,Y), 400 steps/turn → 0.000625
EncScale0=-0.000625	
EncScale1=-0.000625	
EncScale2=-0.000625	
EncScale3=0.0000794	
EncHome0=-5.5	home position in mm for Y0
EncHome1=-5.5	... for Y1
EncHome2=-0.8	... for X
EncHome3=11.3	... for Z
SafeZPos=5	safe height (absolute value in mm) for movements with “MoveSonde”
AlarmDist=100	
MaxPos0=100	maximum allowed position of rails in Y-direction
MaxPos2=155	maximum allowed position of rails in X-direction
MaxPos3=13	maximum allowed position of rails in Z-direction
[Scripts]	file names of the last scripts
FileNameN=	N=1..4, file name of the N-th entry in the Scripts-Window
WriteRemarkCh=36	sets a “#” at the beginning of each line written with “write();”
WritelnRemarkCh=0	no character at the beginning of each line written with “writeln();”
WritelnPoint=1	1: function Point in scripts writes full information into data file
FilePathN=	N=1..4, path of script file No N

[UIForm]	settings of the user interface window
Pwd=test	password for the "ADMIN" as user
	(the user Automatic can login and use all functions without password)
[Calib]	last results from calibrations and their calibration date
HOPG=-0.094448697158296	example for HOPG
HOPGDayTime=40049.6689679167	
[Humi]	settings for the humidity sensor
COM=3	used COM port
UseTempviaCOM=1	1 … temperature sensor is realized via COM-port (Humi-Device)
	0 … temperature sensor is IC inside KP-head
Network=1	enables the capability to detect environment control via network
IP=et2.local	IP address of the network device for environmental control
[InputStatus]	control settings for warnings
Beep=1	
Red=1	

APPENDIX 2: CONNECTOR PIN-OUT FOR THE COMMUNICATION PORT