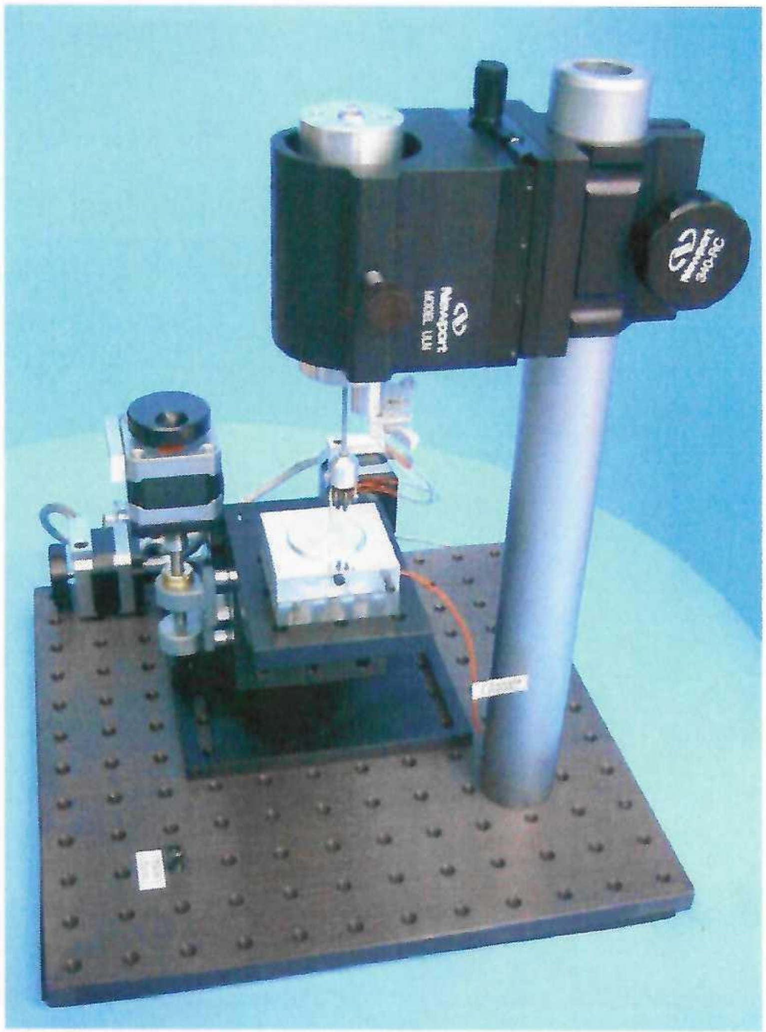
Scanning Kelvin Probe User Manual



Manual Version SKP KP 5.00

Software Version SKP 5.05

Windows XP™ Driver and Signal Acquisition and Data Processing Software

© KP Technology Ltd
Burn Street
Wick
Caithness
KW1 5EH
UK

Tel: +44-1955-602777
Fax: +44-1955-602555

Email: info@kptechnology.ltd.uk
www.kptechnology.ltd.uk
www.kelvinprobe.info

CONTENTS

AN INTRODUCTION TO THE KELVIN PROBE

The Kelvin Probe is a non-contact, non-destructive vibrating capacitor device used to measure the work function difference, or for non-metals, the surface potential, between a conducting specimen and a vibrating tip. The Kelvin method was first postulated by the renowned Scottish scientist W. Thomson, later Lord Kelvin, in 1861.

WHAT IS THE WORK FUNCTION?

The work function (wf) is the least amount of energy required to remove an electron from the surface of a conducting material, to a point just outside the metal with zero kinetic energy. As the electron has to move through the surface region, it's energy is influenced by the chemical, optical, electric and mechanical characteristics of the region. Hence the wf is an extremely sensitive indicator of surface condition and is affected by absorbed or evaporated layers, surface reconstruction, surface charging, oxide layer imperfections, surface and bulk contamination, etc.

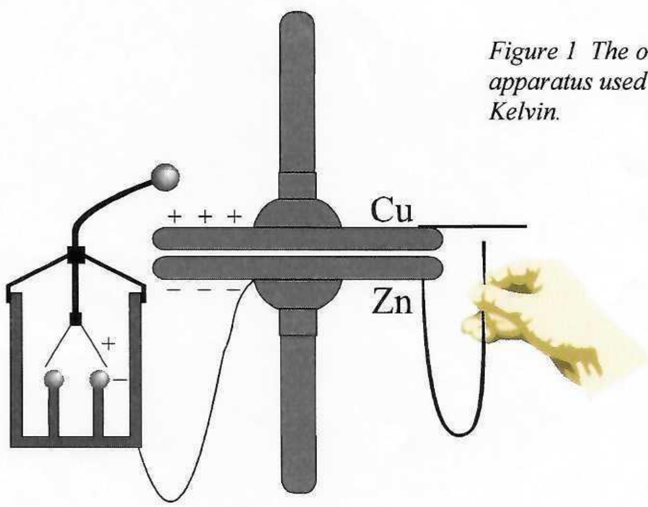


Figure 1 The original apparatus used by Lord Kelvin.

The Kelvin Method is an indirect technique, i.e., electrons are not extracted directly from the surface, instead using a reference surface (a vibrating tip) as the counter electrode the surface under study forms one plate of a parallel plate capacitor. Electrons flow back and forth in the external circuit as the tip vibrates. The work function difference is determined by the addition of an external voltage, termed the backing potential (V_b) as explained in the next section.

MODE OF OPERATION

The traditional Kelvin Probe method consists of a flat circular electrode (termed the reference electrode) suspended above and parallel to a stationary electrode (the specimen), thus forming a simple capacitor. Figure 2 ***a*** to ***c*** depict electronic energy level diagrams for two conducting specimens, having respective work functions (ϕ_1, ϕ_2) and Fermi-levels (ε_1, ε_2).

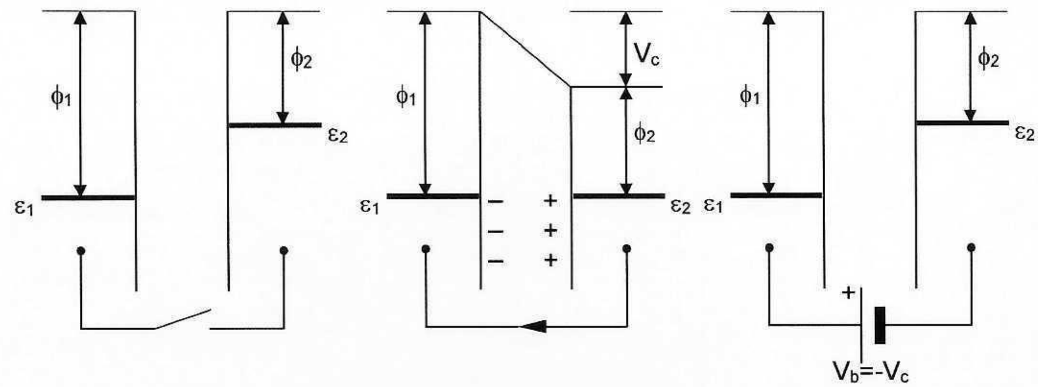


Figure 2 *a.* *b.* *c.*
(a) The electron energy level diagram for two conducting but isolated samples. ϕ_1 and ϕ_2 represent the work functions of the materials, with $\phi_1 > \phi_2$. (b) If an external electrical contact is made between the two electrodes their potentials equalise and the resulting flow of charge (in direction indicated) produces a potential gradient, termed the contact potential V_c, between the plates. The two surfaces become equally and oppositely charged. (c) Inclusion of a variable "backing potential" V_b in the external circuit permits biasing of one electrode with respect to the other. At the unique point where $V_b = -V_c$ the (average) electric field between the plates vanishes, resulting in a null output signal.

Traditionally, the wf difference between two surfaces was determined by vibrating the reference surface above the sample and adjusting V_b until a zero or null output resulted. However this mode of detection is extremely sensitive to noise since the Kelvin Probe signal is diminishing with respect to the noise background. The noise background spectrum consists of several components: overtalk from the power signal used to drive the tip vibration mechanism, termed the driver; background mains (or net) noise; and a contribution from other surfaces that are capacitively coupled with either the tip or the sample. The Kelvin Probe systems manufactured by KP Technology utilise many features to perform the highest quality work function/surface potential measurements: firstly we utilise off-null detection where the signal is measured at high signal levels far from balance, driver talk-over is greatly suppressed by good probe design, lastly we employ a specially developed tracking system or 'Baikie Method' which is unique to KP Technology. This substantially reduces the effects of other surfaces that are in capacitive coupling with the tip/sample.

We proceed now to develop the numerical relationships that explain the mode of operation of the Kelvin Probe. Firstly when the probe or tip is vibrated, a varying capacitance is produced. This can be represented by:

Error! Bookmark not defined. $C_K(t) = \varepsilon_0 \varepsilon_r A/d(t)$ *(1)*

where $C_K(t)$ is the time-varying Kelvin capacitance, ε_0 is the permittivity of free space, ε_r is the relative permittivity ($\varepsilon_r = 1$ in vacuum), A is the surface area of a capacitor plate and d(t) is the time-dependent plate separation.

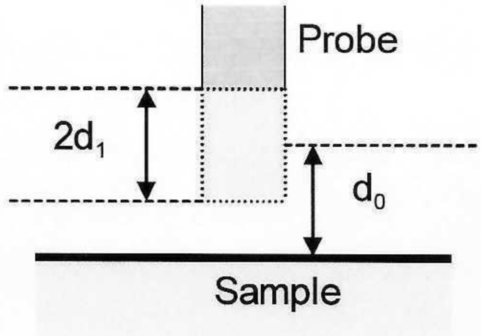


Figure 3
Schematic diagram of the tip-sample spacing during tip oscillation. Here d_0 represents the mean spacing and d_1 the amplitude of tip motion, thus $2d_1$ represents the total tip displacement.

If we assume that the tip-sample spacing can be represented by a periodic sinusoidal displacement of the form: $d(t) = d_0 + d_1 \sin(\omega t)$ where d_0, d_1 are defined in Figure 3, and ω is the angular frequency of vibration in radians/sec. Substituting into equation 1 gives:

$$C_K(t) = C_0/(1 + \varepsilon \sin(\omega t)) \qquad (2)$$

Where C_0 represents the mean capacity and ε is the modulation index (d_1/d_0). The Kelvin Probe detection circuit is shown schematically in Figure 4.

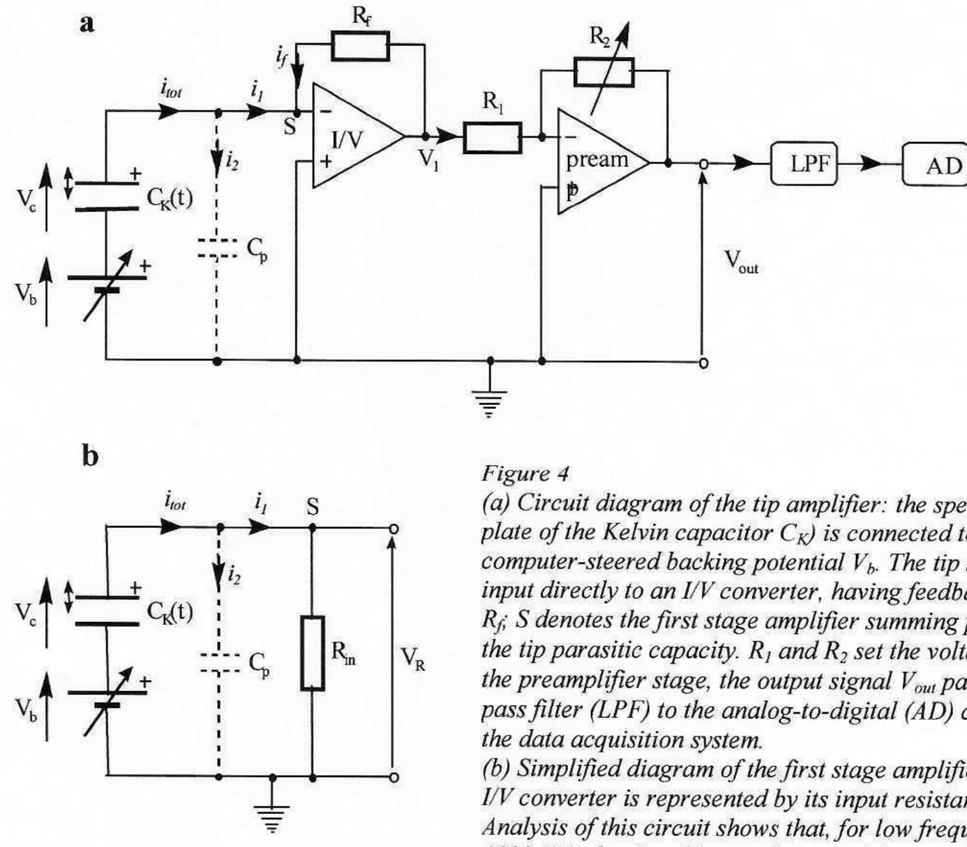


Figure 4
(a) Circuit diagram of the tip amplifier: the specimen (bottom plate of the Kelvin capacitor C_K) is connected to earth via a computer-steered backing potential V_b. The tip signal i_{tot} is input directly to an I/V converter, having feedback resistance R_f; S denotes the first stage amplifier summing point and C_p the tip parasitic capacity. R_1 and R_2 set the voltage gain of the preamplifier stage, the output signal V_{out} passes via a low pass filter (LPF) to the analog-to-digital (AD) converter of the data acquisition system.
(b) Simplified diagram of the first stage amplifier where the I/V converter is represented by its input resistance R_{in}. Analysis of this circuit shows that, for low frequencies (< 1000 Hz), the signal lost to the parasitic capacity i_2 is negligible thus $i_{tot} = i_1$.

Here we use a signal detection circuit composed of two amplifiers: a current-sensitive high gain amplifier located close to the tip and a variable gain voltage amplifier to accommodate different tip sizes and operational spacings. The vibrating Kelvin capacitor is represented by $C_K(t)$, parasitic capacity, i.e., the effect of the surroundings on the Kelvin circuit, by C_P and the backing potential by V_b.

The instantaneous total surface charge on the tip of the Kelvin Probe is thus: $Q_S = (V_c + V_b)C_K$, and the output current $I_K(t) = \delta/\delta t\ Q_S = (V_c + V_b)\ \delta/\delta t\ C_K$.

If we solve this for the peak-to-peak output voltage V_{ptp} present at the output of the variable gain voltage amplifier we obtain:

$$V_{ptp} = (V_c + V_b)\ R_f\ G\ C_0\ \omega\ \varepsilon \sin(\omega t + \varphi) \qquad (3)$$

where V_c represents the voltage difference between probe tip and sample, V_b is the external voltage used to balance (or null) the circuit, R_f is the I/V converter feedback resistance, G the gain of the preamplifier (R_2/R_1), C_0 is the mean Kelvin Probe capacitance, ω the angular frequency of vibration and φ a phase angle.

The output signal, under the condition of fairly high modulation index ($\varepsilon \approx 0.7$), is shown in Figure 5: we observe that the signal displays sharp peaks and troughs and is asymmetric in time and about the origin of the voltage axis. This asymmetry is induced by the position dependency of the Kelvin capacity C_K (see eqn. 2). The sharp trough located at -1.7 V corresponds with closest sample approach.

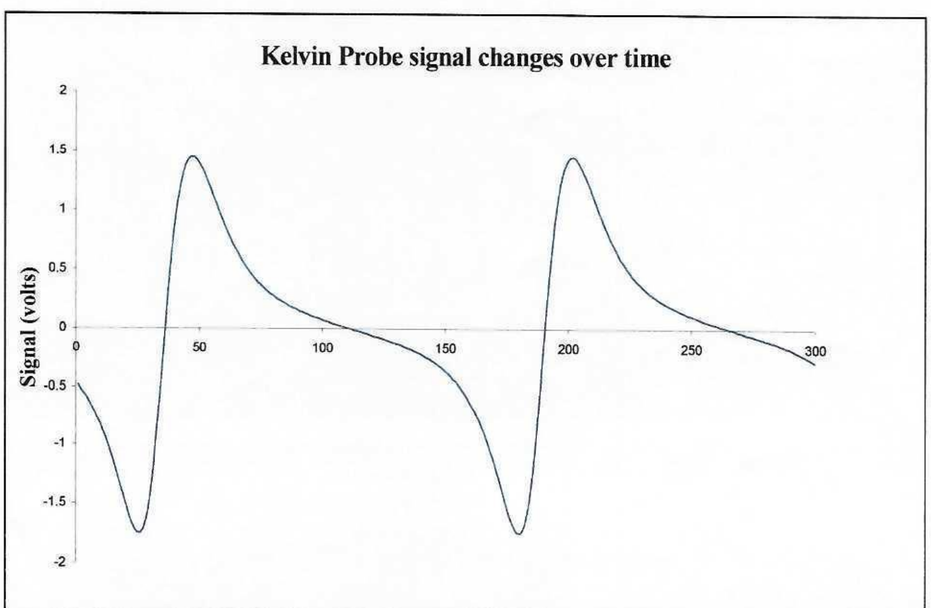


Figure 5. Example of a Kelvin Probe signal under conditions of high modulation index. The peak-to peak voltage V_{ptp} = -3.25 V, where we define the peak to peak height as being negative if the trough appears before the peak as in the above figure.

Equation 3 indicates that, if V_b is set to a range of values, then the corresponding V_{ptp} data set will form a straight line intersecting the origin of the V_b axis at the point $V_c + V_b = 0$. We show this behaviour in Figure 6 where V_b has been changed in steps of 0.33 V between the voltages of 5 and – 5 V. This is termed ***Off-Null*** signal detection.

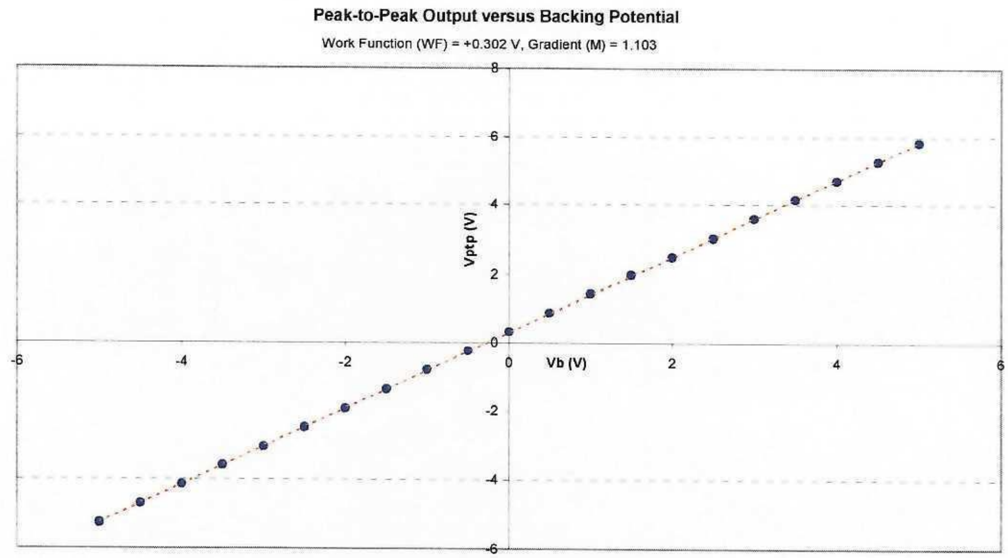


Figure 6. Plot of V_{ptp} versus V_b showing the linear behaviour. Note that the line crosses the V_b axis at the point where the sum of the contact and backing potentials are zero.

In normal operation it is not required to measure a series of points such as that shown in Figure 6, often two points, e.g., at +5V and –5V are sufficient to produce good quality wf data in the 1-3 meV sensitivity range. Because the V_{ptp} data are measured on high signal levels they are far less prone to noise as is the case in alternative self-nulling Lock-In Amplifier based systems. Further the gradient of the line depicted in Figure 6 is a very sensitive indictor of mean spacing and we can use this parameter to keep the tip-sample spacing constant to within a few microns during scanning or normal measurement. Without this distance regulation the apparent work function/surface potential we measure would change due to the effect of other surfaces in the vicinity of the measurement system. This is particularly important if the same surface is to be remeasured at a later time. If the probe parameters or sample-to-tip spacing change (even 10's of microns in the mean spacing) then the apparent work function will change. With the 'Baikie Method' any changes measured are solely due to sample work function or surface potential changes. KP Technology offers the only off-null work function/surface potential measurement system with this feature.

KP TECHNOLOGY KELVIN PROBE SYSTEMS

KP Technology Ltd manufactures work function/surface potential measurement solutions for a variety of environments including Ultra-High Vacuum (UHV) and Ambient with both scanning (SKP) and non-scanning (KP) options. This manual describes in detail the UHV Kelvin Probe System.

Our systems are constructed on optical platforms allowing system upgrading, e.g, to a Scanning Kelvin Probe (SKP) system, addition of light sources (Absolute Kelvin Probe), cameras, environmental enclosures, etc.

SELECTED REFERENCES

Applications

I.D. Baikie, U. Petermann and B. Lagel, "Study of high and low work function surfaecs for hyperthermal surface ionization using an absolute Kelvin Probe", *J.Vac Sci. Technol. A*, **19**, 1460 (2001).

I.D. Baikie, U. Petermann, A. Speakman, B. Lagel, K. M. Dirscherl and P.J. Estrup,"Work Function Study of Rhenium Oxidation Using an ultra high vacuum Scanning Kelvin Probe", *J. Appl. Physics* **88**, *4371 (2000).*

I.D. Baikie, U. Petermann and B. Lagel, "UHV compatible Spectroscopic Kelvin Probe for Surface Analysis", *Surface Science* **433-435**, 249 (1999)

I.D. Baikie, U. Petermann and B. Lagel, "In-situ Work Function Study of Oxidation and Thin Film Growth on Clean Surfaces", *Surface Science* **433-435**, 770 (1999).

B. Lagel, ***I.D. Baikie*** and U. Petermann, "A Novel Detection System for defects and chemical contamination in Silicon wafers based upon DLTS/SKP", *Surface Science* **433-435**, 622 (1999).

U. Petermann, ***I.D. Baikie*** and B. Lagel, "Kelvin Probe Study of Metastable States during initial oxygen adsorption dynamics on Si(111) 7x7", *Thin Solid Films* **343-344**, 492 (1999).

E. Kopatzhi, H-G. Keck, ***I.D. Baikie***, J.A. Meyer and R.J. Behm,"Combined Work Function and STM Study on Growth, Alloying and Oxidation of Epitaxial Aluminium Films on Ru(0001)", *Surface Science* **345**, L11-L18 (1996).

Instrumentation/Technique

I.D. Baikie, M. Porterfield, P. Smith and P.J. Estrup, 'A Novel Matrix Head Scanning BioKelvin Probe', *Review Scientific Instruments* **70**, *1842 (*1999).

I.D. Baikie and P.J. Estrup, 'Low Cost PC Based Scanning Kelvin Probe', *Review of Scientific Instruments* **69**, 3902 (1998).

I.D. Baikie, S. Mackenzie, P.J.Z. Estrup and J.A. Meyer, "Noise and the Kelvin method", *Review of Scientific Instruments* **62**, 1326 (1991).

I.D. Baikie, E.Venderbosch, J.A. Meyer and P.J.Z. Estrup "Analysis of Stray Capacitance in the Kelvin method", *Review of Scientific Instruments* **62**, 725 (1991).

I.D. Baikie, K.O. van der Werf, J. Broeze and A. van Silfhout, "Automatic Kelvin Probe compatible with UltraHigh Vacuum", *Review of Scientific Instruments* **60**, 930 (1989).

SETTING UP THE KELVIN PROBE HARDWARE

After unpacking the Kelvin Probe hardware please check that all the components are there and undamaged: The Ambient Scanning Kelvin Probe Component List is listed below:

COMPONENT LIST

1. **National Instruments** high quality 6025E National Instruments Data Acquisition System (DAS) with NIDAQ 6.9.3 software on CD-ROM. The software has to be installed before mounting the card in a PCI port.
2. **KP Technology Ltd External Digital Control Unit (DCU).** This is powered by the 5/15 V mains adapter and has two 50 pin ribbon cables permitting communication with the DAS. The cable with pins numbered 1-50 is labelled DAS1, 51-100 DAS2. The front panel connections include a Lemo connector for the Head Unit Coil, a ribbon cable connecting to the tip amplifier, and 4 BNC sockets for Signal Monitor and Signal Triggering on an external oscilloscope (optional), User Input and Backing Potential (Sample connection). In addition there is a red LED that indicates communication between PC and DCU and a pot-meter that allows the user to adjust the dc-offset on the preamplifier gain stage. *Please always ensure that the Kelvin Probe power cable is connected before switching on the DCU.* The stepper motor connection cables are attached to the rear of the DCU on the 15 pin 'D' socket. Please note that the stepper motor cables *must never* be connected or disconnected when the unit is in operation, otherwise there is a risk of the induced current damaging the controller chip.
3. The Kelvin Probe **Voice Coil (VC) Driver** should be inserted into the optical mount provided. The mount includes a 25.4mm (1 inch) manual translator. The long optical post should be mounted at the appropriate point on the optical breadboard and the Kelvin probe holder inserted onto the post. The 3 Axis microstepper unit should be fastened at the mounting points provided such that the Kelvin probe tip is centrally located near the sample. The system has been shipped with a 1.83 mm dimeter tip. The LEMO power at the top of the Kelvin probe supplies probe power, the 10 pin socket near the tip permits signal acquisition via the integrated tip amplifier. *Please note that the tip is static sensitive and care should be taken not to touch the tip with bare hands.* The signal cable terminates in a 9 Pin 'D' connector located on the front panel of the DCU.
4. An optical screw should be attached to the optical breadboard at the marked point. This becomes the system ground or voltage reference point. Initially the sample can be attached to this point via the thin wire and crocodile clip provided. Note also the BNC connector with red and black crocolide clips. The back clip should be attached to the system grounding point, however the red clip (which should not be attached to ground at any time) can be used to send the backing potential to the sample rather than the tip (default mode).
5. A faraday screen is provided to provide a measure of electrical shielding, it may be required for small tip diameters, however the 1.83 mm tip should supply a sufficiently larger signal for 1-3 mV resolution in work function without the screen. A flexible wire having a crocodile clip at each end is provided to connect the faraday screen to the system earth point.

6. Summary of Cables:

- 1 National Instruments data acquisition card PCI 6025E: Two **50 pin grey ribbon connectors** between the NI Data Acquisition System in the Host PC and the DCU. Note the cable can only be inserted one way, i.e., there is a central 'tooth' or key preventing incorrect insertion. 'DAS 1' is for connector pins 1-50 and 'DAS 2' for connector pins 51-100. Note both the rear plugs on the DCU and the cables are clearly marked.
- 1 **LEMO twin axial connector cable** taking power from the extender box Voice Coil out (Coil) to the Kelvin Probe head unit.
- 1 **9 way ribbon cable** with D-type connectors connection between the DCU (KP Head) and the Kelvin Probe Tip Amplifier.
- 2 **BNC cables** (Sig Mon) and (Trigger) to take the Kelvin Probe head signal and trigger pulses to an (optional) external oscilloscope.
- 1 **Coaxial Cable** terminating with one red and one black crocodile clips. This connects the backing potential to the Sample (red or core) and the System ground (black or shielding). The DCU automatically controls the potential of the sample, the user *does not* have adjust cables if the backing potential is diverted from the tip to the sample. Please take care to ensure the Sample potential is not inadvertently grounded. **The black clip is always at ground potential** irrespective of the setting of the Backing Potential and this connector should be used to ground the chassis of the KP.
- Sample connection wire: which should be attached to the red crocolide clip of the above cable.

NB: All KP users must ensure that their system is appropriately grounded. After connecting up the system as indicated above please use an ohm-meter to determine that all metal parts (with the exception of the sample under the condition that Vb is placed on the sample) are at ground potential. Components in the vicinity of the Tip/Sample may produce electric fields that may affect WF measurements. The system local or reference ground is the outer part of the coaxial cable marked Ground which is inserted into the Sample BNC on the front panel. Please make sure the PC and DCU are *always* switched off when connecting/disconnecting the cables and that the Kelvin Probe coil power cable is attached when the unit is switched on. Note the tip is static sensitive, anti-static precautions must be taken when handling the tip. Always discharge yourself on the outer connection of any coaxial cable before approaching the tip.

SYSTEM SCHEMATIC

A schematic of the hardware arrangement is shown below. The vibrating probe assembly is constructed from a voice coil housing containing the voice coil driver. A digitally synthesised sinusoidal waveform applied to the voice coil allows computer control of the frequency of oscillation, amplitude and tip-to-sample mean spacing. A high- gain current-to-voltage converter is located at the tip and a variable gain pre-amplifier inside the Digital Control Unit (DCU) increases the signal level presented to the to the 6025E Data Acquisition System (housed in the PC). The sample and probe are connected via a voltage source termed the "backing potential" (V_b), which is controlled by a Digital to Analogue converter (DAC). The Kelvin Probe coil power cable should always be plugged into the DCU when the unit is switched on.

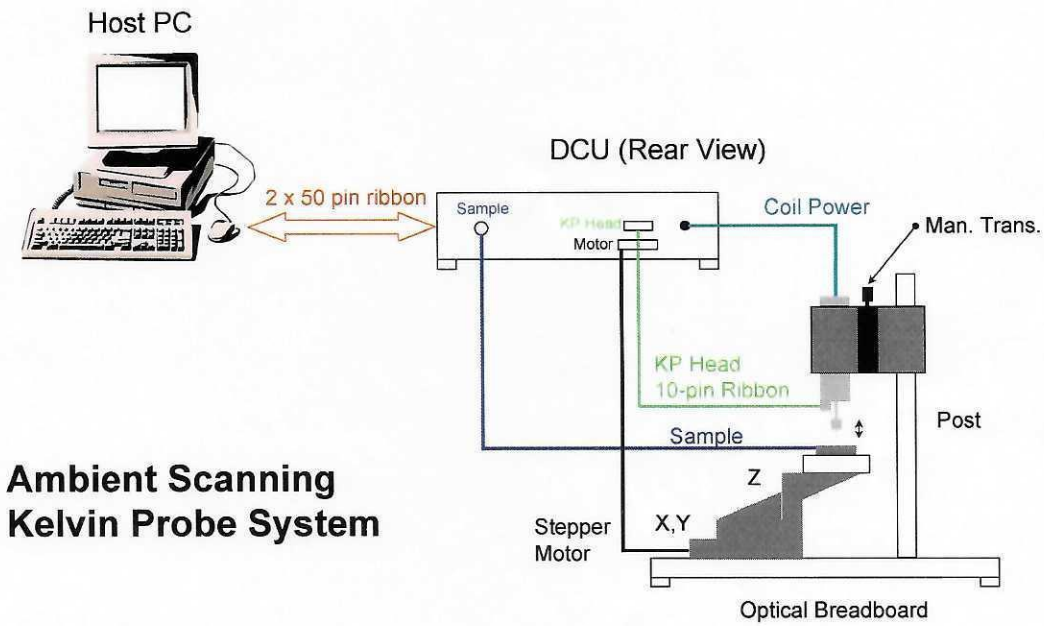


Figure 7. The KP Technology SKP Kelvin Probe System.

A 2x 50 pin ribbon cable connects the Digital Control Unit (DCU) with the Host PC. The coil power (with LEMO plugs on either end) takes the power from the DCU to energise the Kelvin Probe head unit. The Kelvin Probe tip vibrates normal to the sample surface. The Kelvin Probe itself is mounted on a 25.4 mm manual translator, which in turn is mounted on a 14 inch optical post. The sample is connected to the red core of the Sample connection cable. This allows the user to select whether the bias potential must be added to the tip (default) or sample. The 3-axis stepper motor is mounted onto the optical table as shown (X,Y) are in the palne of the surface, Z is vertical. The stepper motor cables are connected to the 'Motor' socket located at the rear of the DCU. The system ground is the outer sheath of the Sample cable which should be connected to the appropriate point on the optical breadboard.

INSTRUCTIONS FOR SYSTEM ASSEMBLY

1. First mount the 14 inch Optical Post at the position marked on the breadboard, using the long keyed tool to fasten the screw at the base of the Post.
2. Mount the Kelvin Probe Holder / Manual Translator / Rod Clamp onto the Optical Post. The Positioning Screw on the Manual translator should be positioned Upwards.
3. Mount the 3-axis stepper motor translator onto the breadboard.
4. Attach the System Grounding screw at the position indicated. This is the System Ground Point..
5. Carefully unpack the Kelvin Probe and insert from below into its holder. Be careful not to screw the nylon thread too tightly. Avoid contact with the Kelvin Probe tip and maintain anti-static precautions.
6. Insert the Lemo plug into the KP Head Coil, do this while firmly holding the Kelvin Probe Head unit so that it doesn't move in its holder.
7. Plug in the ribbon cable to the Kelvin probe tip. Attach the 10 pin ribbon cable to the KP Tip Amplifier, note the cable is keyed, i.e. it can only be inserted in one direction.
8. Position the Kelvin Probe near the top of the Optical Post.
9. Plug the LEMO (Coil) connector to the front panel of the DCU, similarly mount the 9-pin D connector to the KP Head socket.
10. Assuming that the DCU is switched off mount the Data Acquisition System cables (DAS 1 and DAS 2) to the *rear of the DCU.* All connectors are keyed, i.e., they can only be inserted on way.
11. Plug in the connection cables to each stepper motor axis, note each is individually marked.
12. Note the flexible wire from the specimen holder, attach this wire either to the system ground point (initially) or to the red core of the sample cable.
13. Position the KP Tip about 2 mm above the sample, mount the Farday screen as required.
14. Identify the DCU, ensure it is switched off, and make the connections between the Kelvin probe and tip amplifier. Remember the tip amplifier is static sensitive. Attach the optional BNC connectors marked 'Trigger' and 'Signal Monitor' to channels 1 and 2 of an optional oscilloscope.
15. Further make the connections to the stepper motor controller (rear of the DCU).
16. Attach the Sample BNC cable to the front of the DCU. Take the core to the flexible Sample connection (on the optical breadboard), attach the shielding to the System Ground Point.
17. Mount the Faraday Cage around the system at a distance of 4-6 cm. Attach the Faraday Cage to the System Ground Point.
18. Additional Croc clip cables are included to Ground other component parts as required.
19. Load the software (NIDAQ 6.9.3) for the data acquisition system (DAS). During set-up you you require only to load 'NIDAQ which is the default setting. After software installation you will be prompted to mount the Data Acquisition system PCI card into your PC. After rebooting goto 'Measurement and Automation', run this program and verify that the communication between the card and PC has been established. If this is the case the card will be identified as device number 1. Click on the device properties and ensure that the configuration is +10..-10 volts and the grounding configuration is 'non-referenced'.
20. Power down the PC again and make the connection between the DAS and the DCU. Pins 1-50 are 'DAS 1' and '51-100' DAS 2.

21. Load the self install SKP software onto your hard disk.
22. Study the Software manual.
23. Ensure the DCU switch is in the Off position, plug in the 15 V PSU. Power up the DCU.
24. Power Up the PC.
25. Locate the KP Icon on the Desktop of the PC and double click to activate. The Kelvin Probe control program will run. The software section of this manual explains the program, both setting up and measuring.
26. Perform test measurements energizing the coil, etc, as explained in the next section.

SYSTEM PHOTOGRAPHS

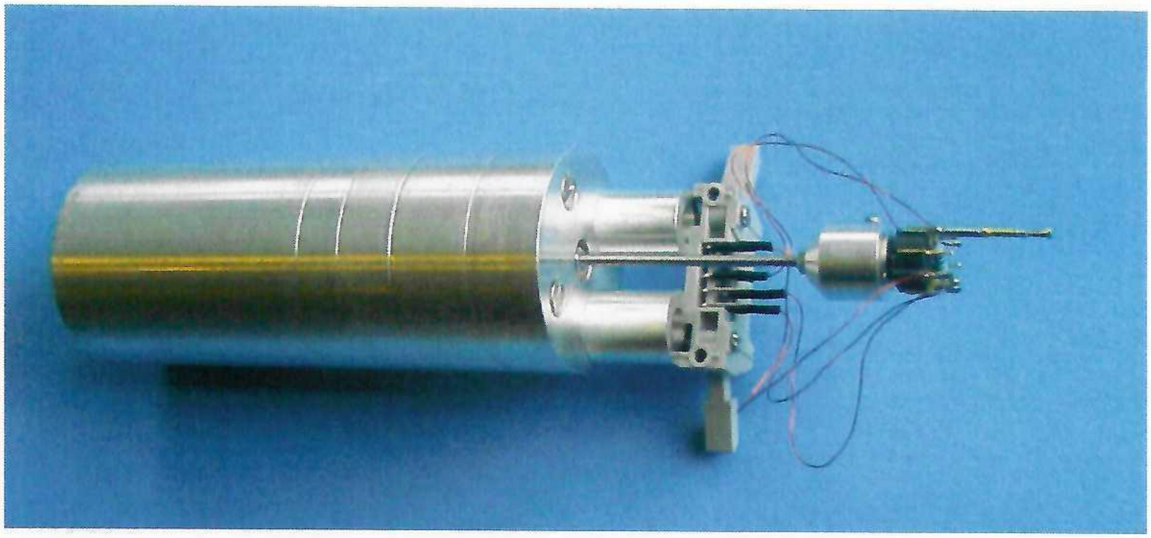


Figure 8 Ambient Kelvin Probe Head Unit with integral tip amplifier.

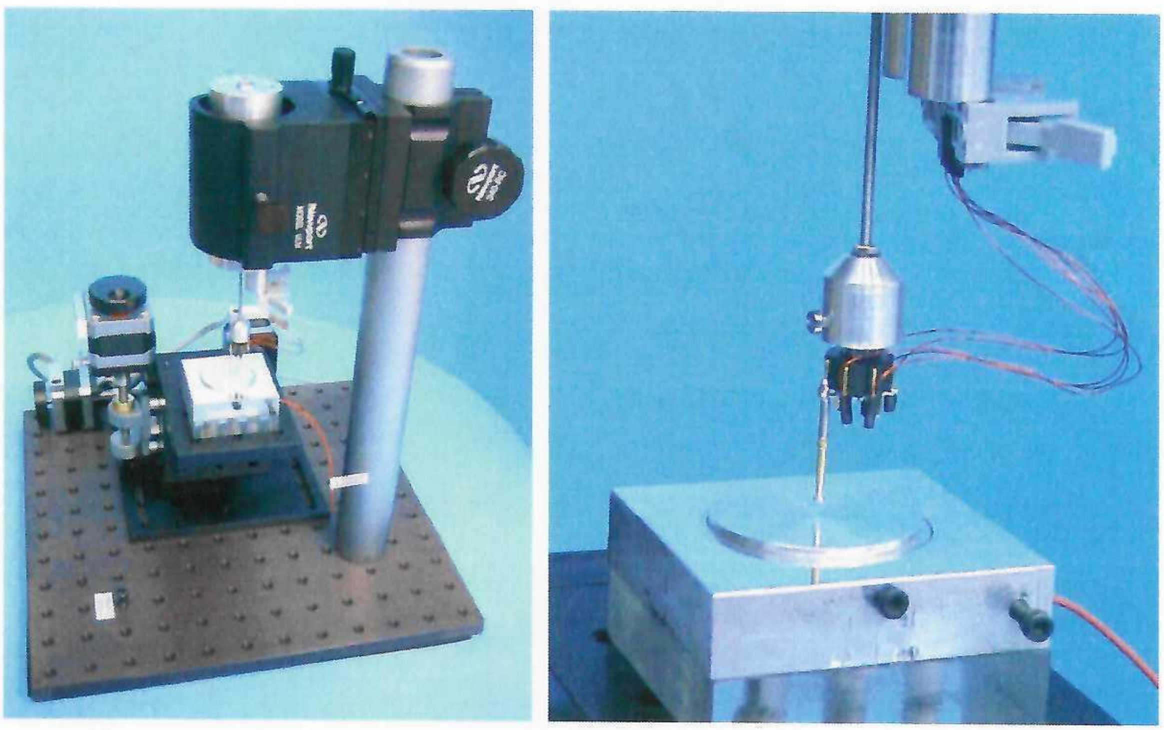


Figure 9 Ambient system showing breadboard Kelvin Probe and sample mounting geometry.

DIGITAL CONTROL UNIT (DCU)

The DCU connects all components of the Kelvin Probe together and also displays the Communication / Power Status of the system

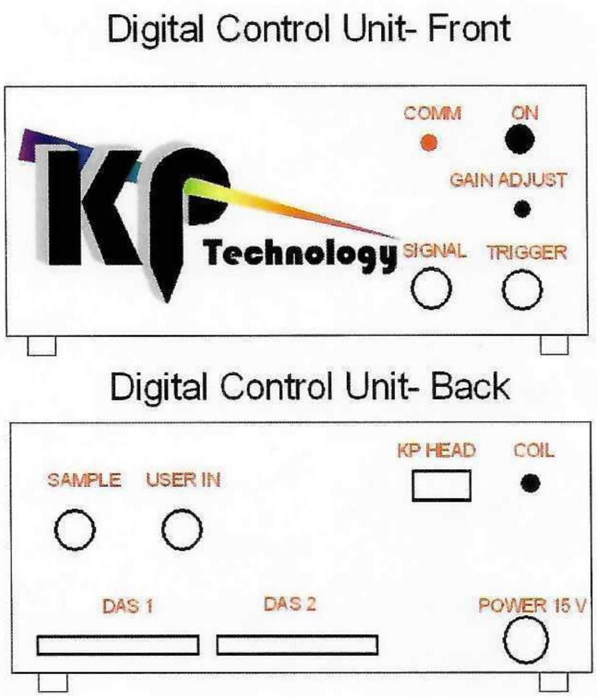


Figure 10. Schematic of the DCU front and back panels.

The following table describes the function of each connector on the DCU. The first 4 items are to be found on the rear panel.

Connector	Description
DAS 1	1-50 ribbon cable from Host PC 6025E Data Acquisition System
DAS 2	51-100 ribbon cable from Host PC 6025E Data Acquisition System
Power 15 V	Input Power (DC) to DCU via universal adapter
Motor Control	15 pin 'D' connector leading to the (x,y,z) stages on the 3-axis motorized translator
SW1 On	On/Off switch for the DCU
Signal	BNC output of the Kelvin signal; can be used e.g. to monitor the signal via an external oscilloscope
Trigger	BNC output of the Trigger signal, can be used e.g. to trigger the Kelvin signal on an external oscilloscope
User	BNC User Input (-10..10 V)
Sample	BNC connection to Sample (Centre Core) and System Ground (Outer Sheath)
KP Head	this is a 'D' 9-way ribbon connector to the tip amplifier
Coil	Power Connector to Probe Head Coil
Gain Adj	Adjusts the DC Offset on the Input Channels of the DCU Gain Stage
Comm	When lit indicates Communications 'OK' and Power 'OK' status of the DCU/DAS

SAMPLE GROUNDING AND SHIELDING

Figure 8 shows a plan view of a typical system mounting arrangement. The Optical post is located centrally and the Kelvin Probe and manual translator are mounted onto the post (not shown on the diagram below for clarity). The sample holder with sample attached is positioned directly underneath the Kelvin Probe tip. The central core of the 'Sample' cable is connected to the flexible wire attached to the sample holder. The outer part of the 'Sample' cable is connected to the Optical System Grounding Point.

The key to good Kelvin probe measurements is good extraneous noise reduction. It is relatively easy to shield the system in air using the Faraday shield provided. If you are observing noise, use and external Scope to determine the frequency which may give a guide to the noise source. If these sources cannot be eliminated, e.g., by temporary grounding, then use longer time-averaging to obtain good quality Kelvin probe waveforms.

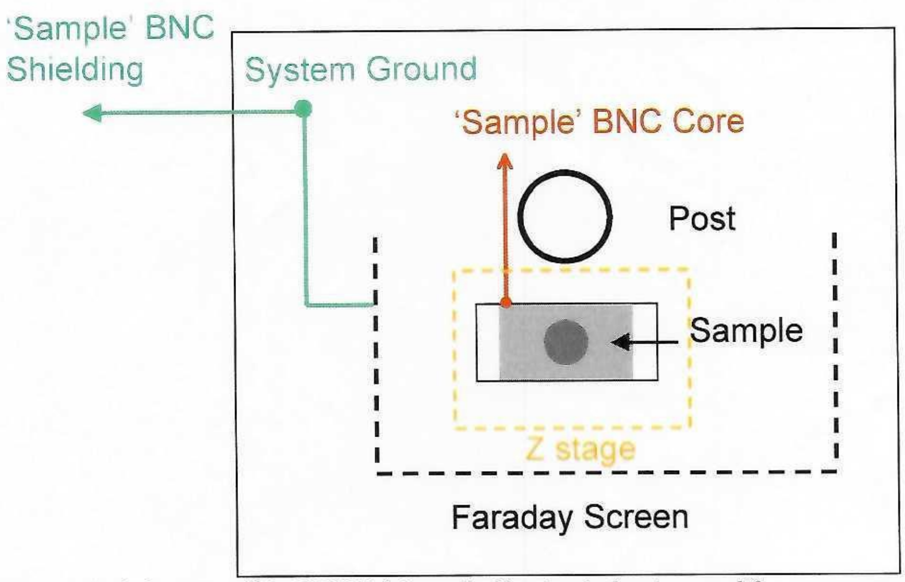


Figure 11. Schematic of the UHV Kelvin probe Head unit showing amplifier arrangements.

KELVIN PROBE TIP AND TIP AMPLIFIER

The KP Technology system is designed to permit tip and tip amplifier replacement by the user. The tips are simply plugged into the amplifier IC using the adapter provided. In this fashion tip geometry and area are easily changed. The Kelvin Probe signal amplitude is linear with tip area, so smaller tips will give higher spatial resolution, however a larger gain stage may be required to preserve work function resolution. Remember that as the gradient parameter is dependent upon the mean capacity the actual Gradient setting in the Measurement Modes are tip specific.

Likewise the tip design allows the amplifier-tip arrangement to be de-mounted, a new amplifier installed and re-mounted within a minute. The amplifier specifications and wiring arrangement is available via KP Technology support. Gold plated tip and Gold/Aluminium reference samples are available too.

SETTING UP THE KELVIN PROBE SOFTWARE

GETTING STARTED

There are two start options: either 'rapid start' or via the file commands. The system is shipped with the file commands, not the rapid start, active, in which case the following options are available:

Open Parameter File	Opens an existing file - allowing you to continue a set of measurements.
New Parameter File	Create a new file - initial parameters are those last used.
Exit	Quit the application.

To start using the Kelvin Probe application either (i) open an **existing** parameter file or (ii) create a **new** parameter file. When you create a new file you will continue working with the parameters last used until you change those parameters in the program. If, however, this is the first time you have used the probe then the factory defaults will be used and the appropriate filename is **Default.par**. The image below shows two parameter files in the working directory. In the 'rapid start' option the parameters are automatically initialised to the last saved parameters. The logical switch enabling the rapid start option is available in the Advanced / Diagnostics page.

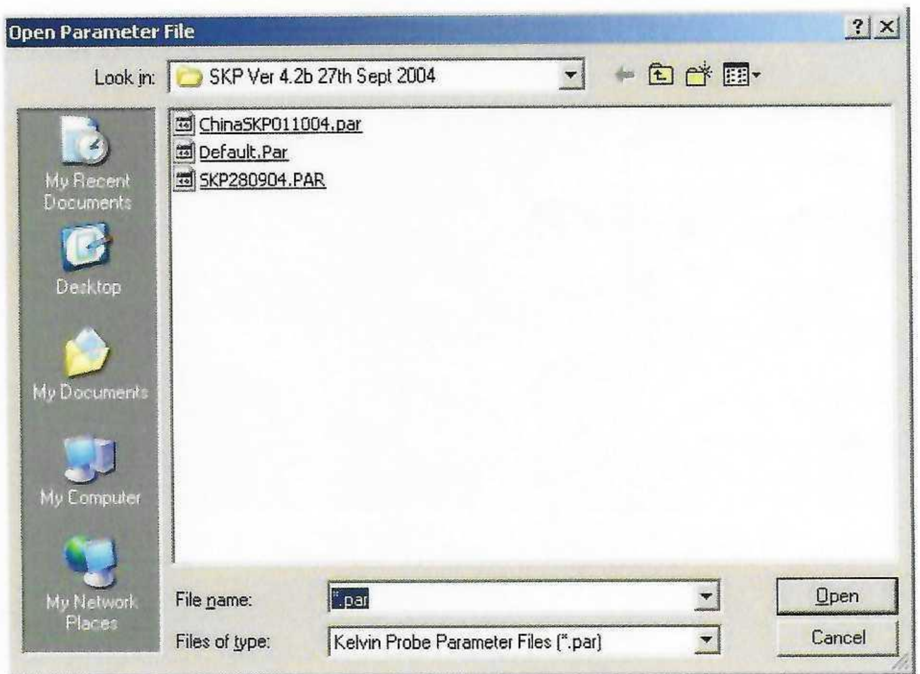


Figure 12. The Open Parameter File dialog.

SETUP PROBE AND DATA ACQUISITION

Once a parameter file has been opened a window similar to the one below will be displayed. There are three tabs: one for the 'Setup Probe and Data Acquisition' discussed below, a second tab for the 'Work Function Measurement' routines and a third for 'Advance Parameter Setting and System Diagnostics'. Note that some of the measurement parameters on the 'Work Function Measurement' page are used when measurements are performed in the Setup page: these are all in the Measurement Group, i.e., Vb+, Vb-, Steps and WF Aver. We advise that these parameters be set to 5000, -5000, 1 and 1 respectively during the initial stages of operation where the user is unfamiliar with system.

The Setup page contains groups for setting-up the probe, data acquisition system, tip translation and measurement options. In addition there are buttons to enable the probe (switch power to the voice-coil), start a measurement and save the measurement parameters. The ‘Source’ group allows the user to switch between various measurement channels and the 'Show' group features different acquisition modes explained below.

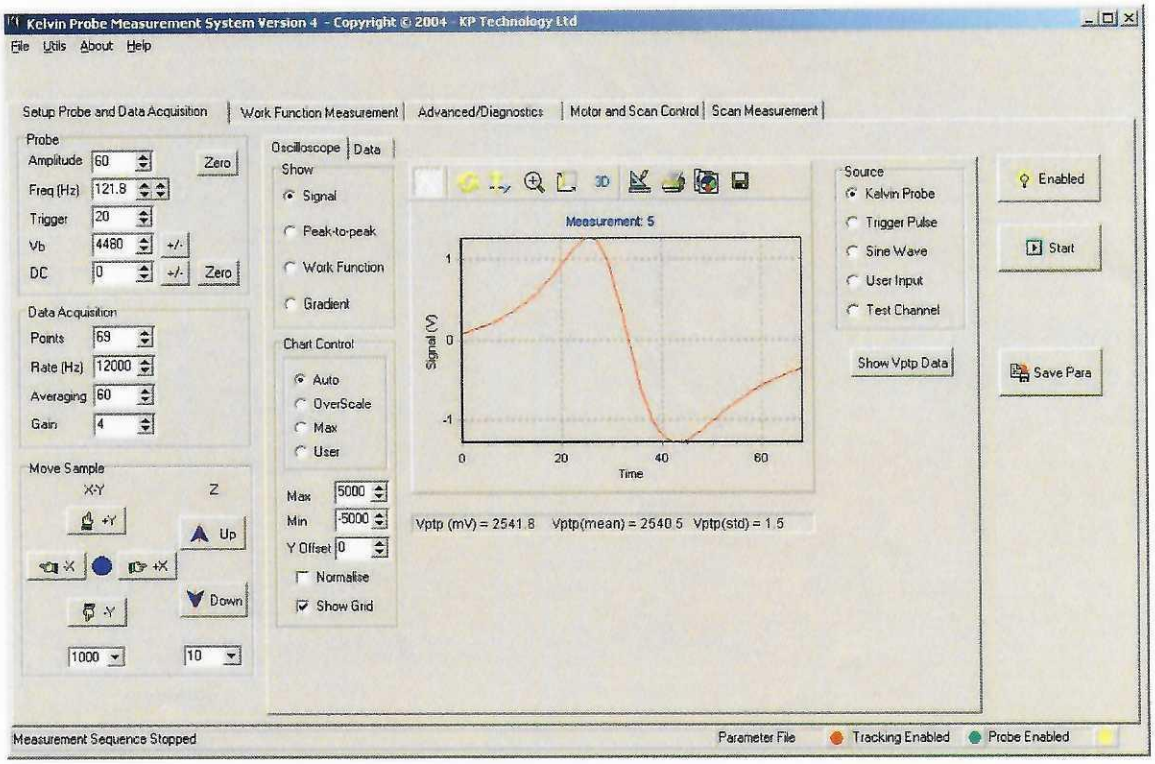
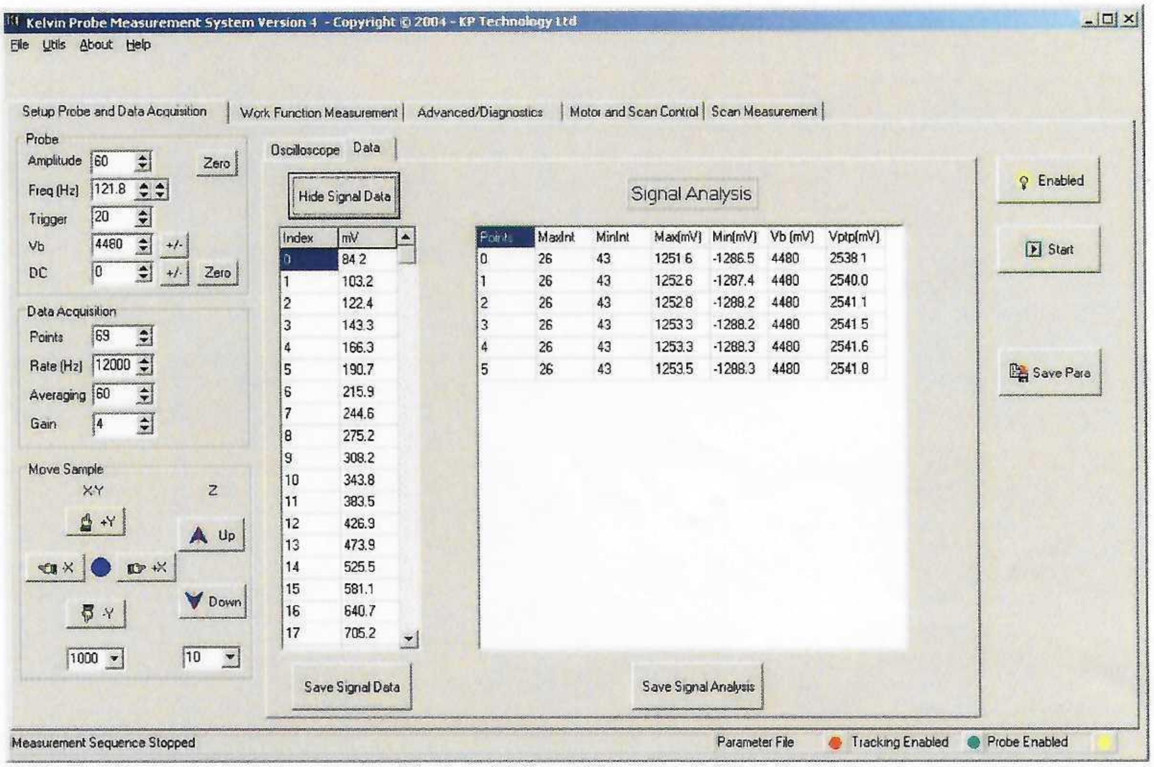


Figure 13. Initial setup featuring the Oscilloscope tab.

You will regularly use this page to verify correct probe operation and to optimise the parameter set for high precision measurements. All the parameters have ‘Hints’ i.e., clues of what the function of the component or valid range of values are. These hints appear when you place the cursor over the parameter and have ‘Hints’ enabled in the Diagnostics page. We recommend that you use ‘Hints’ to help you in the initial stages!

In the centre of the Setup Probe and Data Acquisition page is a Signal Display and Analysis monitor with two tabs: 'Oscilloscope' and 'Data'. In the Oscilloscope mode the user can select which Kelvin Probe data set to display, either the (averaged) signal output from the probe, the signal peak-to-peak height, the calculated work function (WF) or the gradient (Grad) of the V_{ptp} versus V_b line (see

Figure 6). Alternatively the user can select to monitor the user input channel, or various sub-systems of the DCU, such as the digital sine wave generator, the logical trigger circuit, etc. There are various chart control options (some of which are only for viewing the Kelvin Probe Signal) and similarly there are several data output options including storing the signal waveform, the peak-to-peak data, and derived work function and gradient data.



Index	mV
0	84.2
1	103.2
2	122.4
3	143.3
4	166.3
5	190.7
6	215.9
7	244.6
8	275.2
9	308.2
10	343.8
11	383.5
12	426.9
13	473.9
14	525.5
15	581.1
16	640.7
17	705.2

Points	MaxInt	MinInt	Max(mV)	Min(mV)	Vb (mV)	Vptp(mV)
0	26	43	1251.6	-1286.5	4480	2538.1
1	26	43	1252.6	-1287.4	4480	2540.0
2	26	43	1252.8	-1288.2	4480	2541.1
3	26	43	1253.3	-1288.2	4480	2541.5
4	26	43	1253.3	-1288.3	4480	2541.6
5	26	43	1253.5	-1288.3	4480	2541.8

Figure 14. The Data output tab in Setup Probe and Data Acquisition

When the KP program is started the system first performs a communications and power supply status check on the DCU. If these tests are passed the front panel LED on the DCU will flash. If not the user is prompted to check the DAS connections and verify that the DCU is switched on.

PROBE PARAMETERS GROUP

Amplitude Sets the amplitude of oscillation of the Kelvin Probe. Legal values range from 0 to 300. The actual amplitude of the probe will depend upon the frequency setting and tip loading. In general use 60 to get started and find a visible oscillation. More advanced users will use smaller values, ie.10-30, and move the tip closer to generate adequate signal heights.

Freq [Hz] Sets the Probe oscillation frequency in hertz. Legal values range from 10.0 to 300 Hz. Each probe is shipped with the parameter optimised. Usual probe resonant frequencies are 50-80 Hz.

Trigger This parameter is used to shift the position of the first data element in the measurement array with respect to the trigger signal. This has the effect of moving the phase of the signal on the screen. Allowed values are 0 through to 200.

Vb This is the backing potential, ie. the voltage difference between the probe tip and the surface being scanned. Legal values range from +10000 mV to -10000 mV.

DC The DC offset parameter adds an offset voltage to the output of the oscillator. This allows the probe tip to be displaced in well-defined amounts. Legal values range from -600 to +600. We would advise users to avoid operating the probe coil at large DC offsets for extended periods.

DATA AQUISITION PARAMETERS GROUP

Points This is the number of times the signal is sampled. Legal values range from 2 points to 400 points, usually 60-100 points in the measurement array are sufficient. In general larger data arrays take longer to process and this slows measurements down. Conversely if the data array is too small then the position of the single maximum and minimum per measurement will not be accurately reported leading to wf / surface potential errors.

Rate [Hz] This is the rate at which the Data Acquisition Card samples the data. For example if the sample rate is 12000Hz, then 12000 points per second are measured by the card. The legal values for this parameter are card specific. However, a sample rate of 10 - 20 kHz is suitable for most occasions.

Averaging This is the number of times the Signal is re-sampled for an average signal to be calculated. Legal values range from 1 loop (no averaging) to 1000 loops. Keep this parameter low, i.e., 5-10 in the initial stages of setup and increase it to 30-50 when the measurement parameters are optimised.

Gain There are 8 stages of digital gain allowed, corresponding to actual gains of 30..4000. The nominal gain settings are {26, 53, 105, 211, 511, 1022, 2044, 4088}. In practice one gain setting is used for a particular tip. The Gain Adjust pot-meter on the front panel allows the DC offset of the gain stage to be minimised.

MOVE PROBE GROUP

Out/In Press the In and Out buttons to move the probe in the direction perpendicular to its vibration, either 'In' (towards the sample) or 'Out' (away from the sample). The number of steps displaced is indicated in the box below. The default value is 10. When you use this control you will note the value of the DC parameter in the Probe Group box changing too. The bar located at the bottom of this Group graphically indicates the current state of the DC offset in relation to maximum travel and direction with respect to the sample.

Reverse Reverses the direction of the above translation.

OTHER BUTTONS

Enable Pressing the 'Enable' button sends power to the Kelvin Probe coil. Pressing it again cuts power. When the KP program is closed power is automatically cut off.

Start Commences a measurement with the current parameters. The caption on the button changes to 'Stop', if pressed again the measurement sequence will terminate. Note when proceeding to the 'Work Function Measurement' page be sure to stop any measurement in progress in 'Setup Probe and Data Acquisition' first.

Save Para Saves the current measurement parameter set to disk. User will be prompted for a file name.

Source Selects the current input channel, e.g., Kelvin Probe, Trigger Channel, Sine Channel, User Input Channel or a Test Channel. The User Input is accessed via the appropriate BNC connector on the front panel of the DCU.

Show V_{ptp} Shows the user the value of Vb and associated V_{ptp} when performing Work Function or Gradient measurements.

SHOW PARAMETER GROUP

Signal Allows the user to monitor the signal at each input channel. Note the appropriate value of 'points' will depend upon the nature of the incoming data stream. Adjust the Probe and DAS setting to achieve an optimum signal (see next section).

Peak-to-peak Allows the user to monitor the peak to peak value (V_{ptp}) of the Kelvin Probe signal as a function of time.

Work Function Allows the user to perform Work Function measurements and determine the effect on the peak to peak value of the Kelvin Probe signal as a function of time. Note that this measurement sequence utilises measurement parameters such as Vb+, Vb- and WF Aver contained in the Work Function Measurement page.

Gradient Allows the user to monitor the Gradient (GD) which is proportional to the fractional change in capacity, as a function of time. If the user now alters the mean spacing by using the 'Move Probe' controls the increase or decrease in GD can be monitored.

The current, average and standard deviation of the V_{ptp}, WF and GD parameters are reported underneath the Oscilloscope signal. The standard deviation is reported after the third measurement and is set to zero for the first two.

CHART CONTROL GROUP

Auto The charting procedure automatically controls the Y axis.

Overscale The charting procedure automatically controls the Y axis, however the scaling allows the signal to be smaller than the maximum/minimum of the Y Axis by a percentage defined in the Advanced / Diagnostics Page.

Max The Y axis is set to the maximum and minimum allowed, e.g., +/-10,000 mV.

User The user can set the maximum and minimum of the Y axis values using the appropriate edit boxes below.

Y Offset This is used to make the signal plot symmetrical on the screen if required. It does not affect any calculated values such as WF or GD.

Normalise Normalises the data array before plotting. The absolute value of the data is reported in the dialog underneath the chart.

Show Grid Turns the chart grid on and off.

VIEWING DATA ON THE OSCILLOSCOPE PAGE

1. Ensure that all parameters are within legal range: for instance the backing potential should not be zero; rather a value of ±5000. Also the (initial) probe amplitude should be around 60 as a greater

2. Enable the Probe by selecting the 'Enable' button. The application always disables the probe upon start-up to prevent damage to the probe tip. To disable the probe after enabling it, press the 'Enable' button again. The status of the probe will be shown in the small status window at the bottom right of the page.
3. Select the Source Kelvin Probe and press the 'Start' button to initiate the acquisition of the signal. The Oscilloscope will now continuously be updated with a snapshot of the data.
4. Choose the parameters you want to view in the 'Show' options, e.g., Signal.
   You can edit the parameters, and see how this effects the data. Use the edit or spin control buttons to change parameters. The parameters are saved when either the 'Save Para' button is pressed or via the File Menu Option. The Para File prompt at the bottom of the screen will turn red if any of the current parameter set is changed and green when the new file is saved to disk. Please be careful not to type in an inappropriate number, e.g., rate 0. **Adjust the parameters so that Kelvin Probe signal shows one minimum and one maximum,** similar to the signal you see in Figure 13 above.
   Figure 15 shows an example of an incorrect set-up because there are more than one maxima or minima displayed on the screen. This would lead to an erroneous calculation of signal phase and incorrect WF and Grad data. **It is imperative that the signal setup is accomplished correctly before proceeding to utilise the Tracking feature in the Measurement page.**

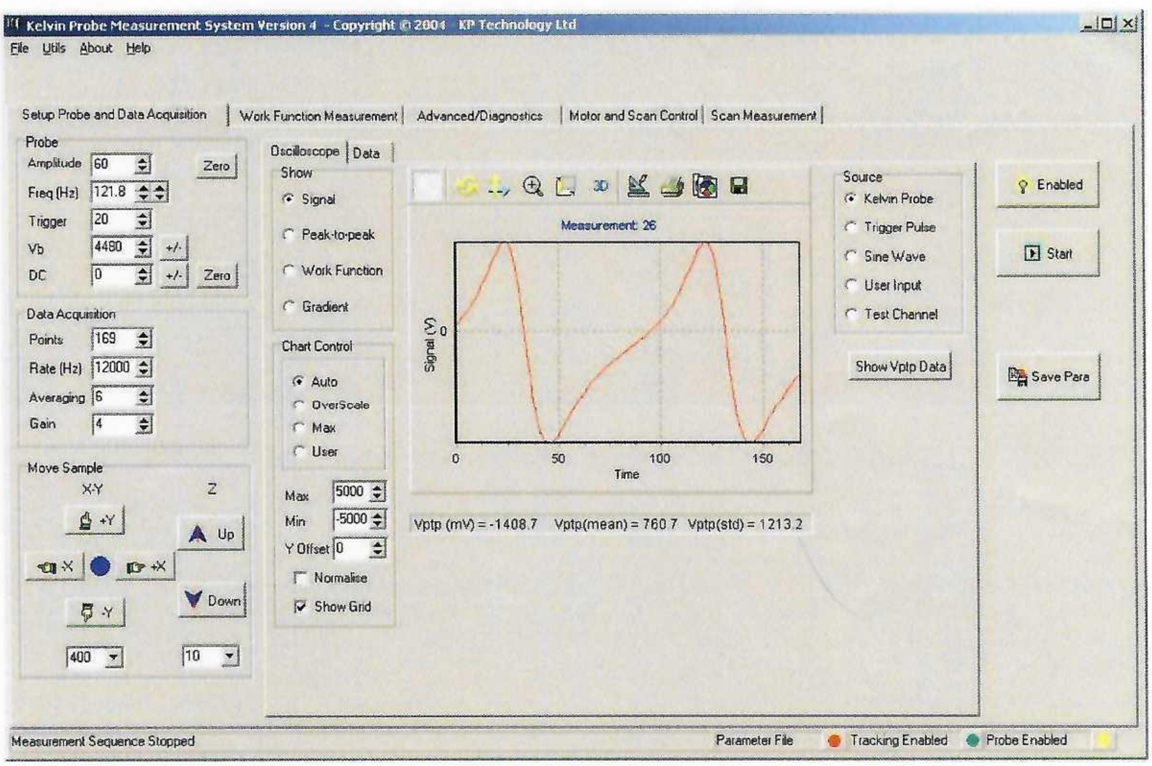


*Figure 15. Example of **incorrect** set-up for WF and Grad calculation as there are two maxima and two minima displayed. The calculation software will only function correctly if part of one period is displayed with a single clear peak and a single clear trough such as that shown in Figure 13.*

5. Suggestion: if the snap-shots are taking too long, decrease the averaging loops. Press the 'Stop' button to exit the signal acquisition mode first.
6. Use the three options Auto, Overscale, Max or User in the Scale Y box to set the Y scale as desired.
7. To alter the phase of the initial point in the data array use Probe:Trigger. Figure 16 when compared with Figure 13, illustrates the effect of changing the Trigger point from 80 to 93.

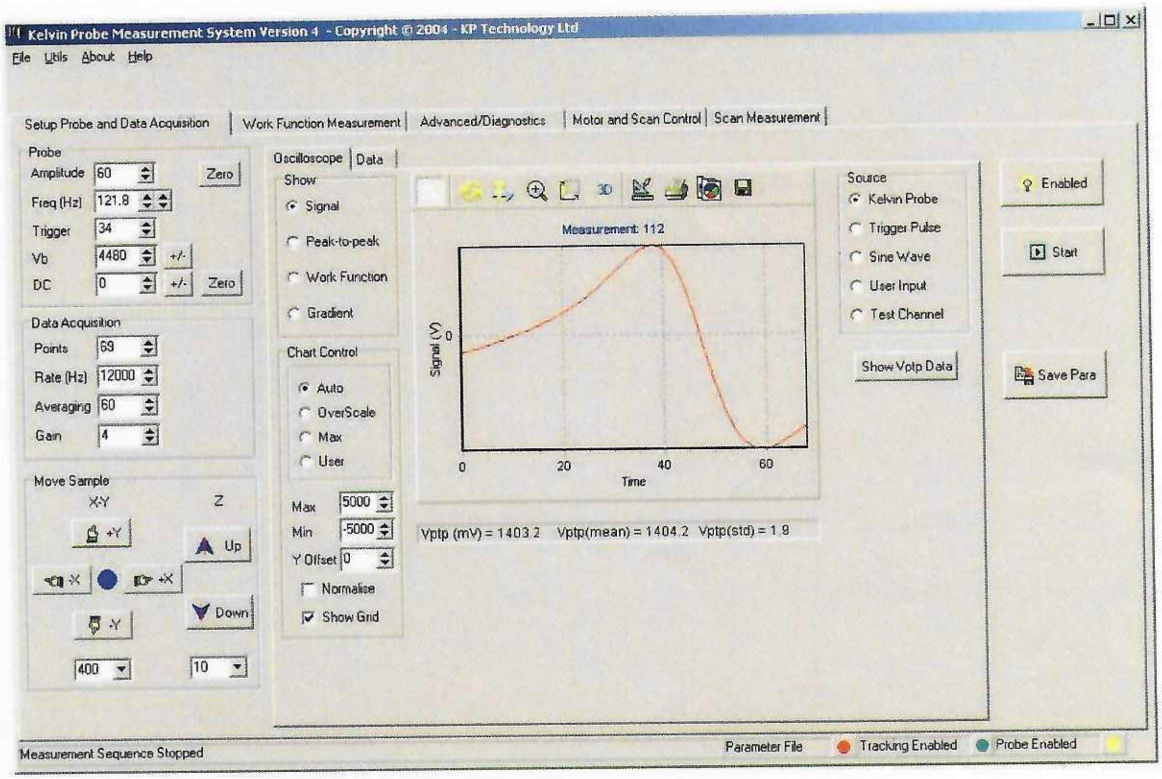


Figure 16 Effect of changing the Trigger parameter from 20 to 34. The end of the data array is now very close to the signal minimum. This is a dangerous position as the automatic peak detection software is now very sensitive to any noise near the location of the trough.

8. For a given probe oscillation frequency determine the best combination of Probe: Amplitude, Trigger, Rate and Points to register a single clear maximum and minimum in 60-100 signal points. Ensure the maxima and minima are not too close to the ends of the signal data array.
9. If the backing potential V_b is changed from +5000 mV to –5000 mV then the signal phase should shift through 180^0, see Figure 17. Note that the peak-to-peak heights of the associated signals will not necessarily be the same. When automatic WF measurements are performed such well developed low-noise measurements at $+V_b$ and $–V_b$ are a prerequisite of high quality data.
10. The 'Save Signal Data' and 'Save Signal Analysis' buttons (on the Data tab) can be used to store the information in the measurement log and actual signal waveform data respectively. The user will be prompted to assign filenames to these data sets. Note that the data display provides the user with information on the current measurement point, the value of the maximum and

minimum in each signal and the positions in the signal array the maximum and minimum occurred, see Figure 14.

11. Remember to 'STOP' any current measurements in the Setup Page before commencing Scan measurements
12. The delay parameter visible in the Advanced / Diagnostic Parameters Page provides the user with the options of changing the Backing Potential Settling time. Until the user is familiar with the measurement program the defaults settings should be used.

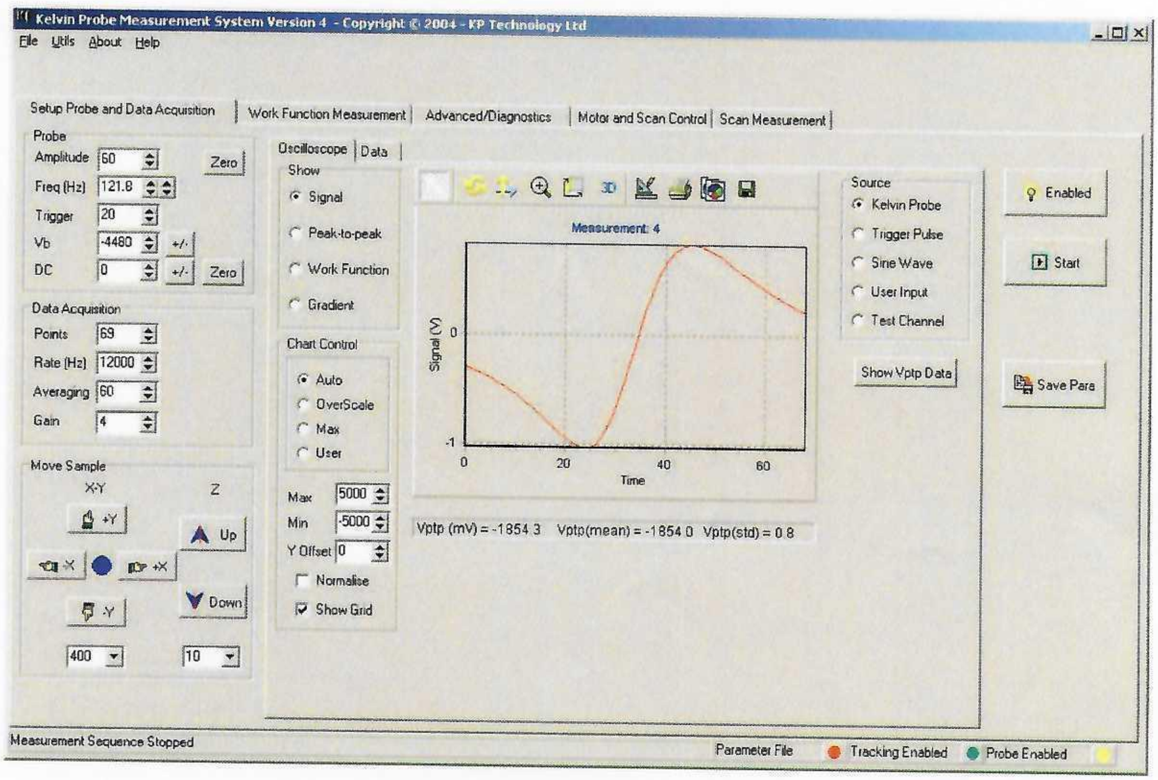
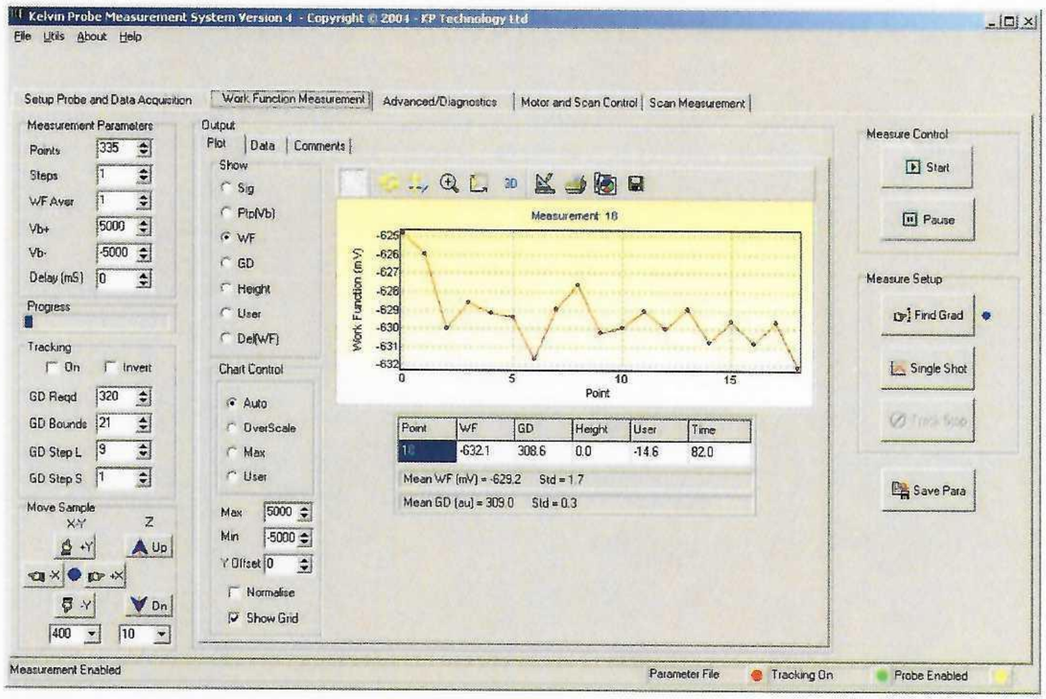


Figure 17. Effect of changing V_b from 4480 mV to –4480 mV. The phase of the signal has changed approximately 180^0

THE MEASURE PAGE

Once you have set up the probe as required, select the 'Work Function Measurement' page. This is where high resolution work function measurements are performed.



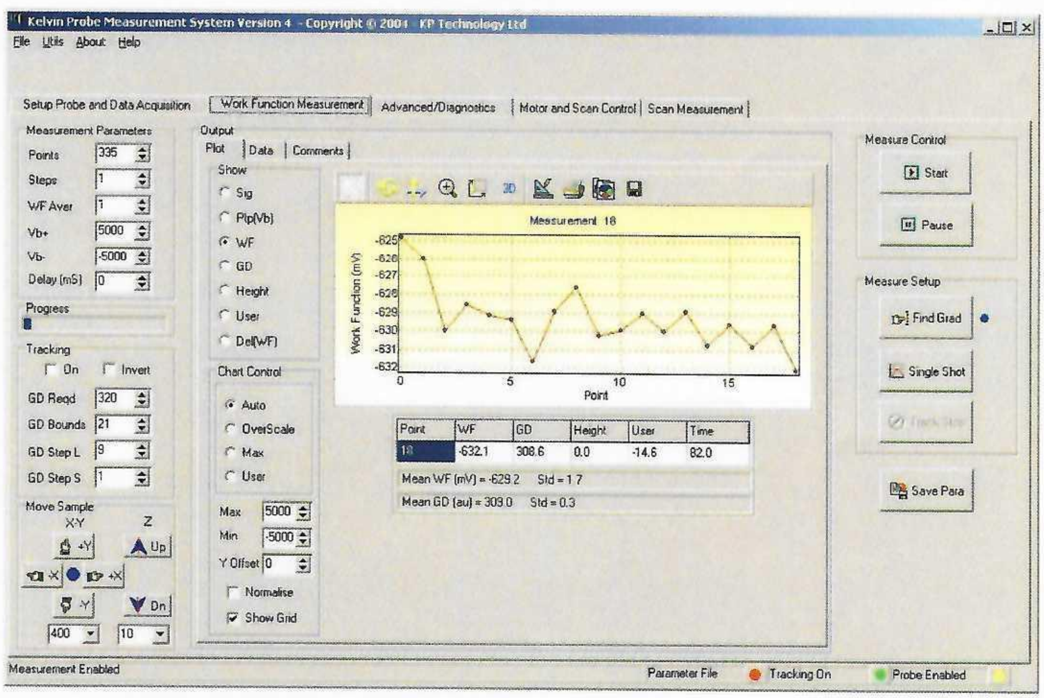


Figure 18. The Measurement Page showing the WF Chart (top) and associated GD data (bottom).

MEASURE PARAMETERS GROUP

Vb+ Upper level of Backing Potential, valid range 10000 to –10000 mV.

Vb- Lower level of Backing Potential, , valid range 10000 to –10000 mV.

Steps The number of steps the backing potential (Vb) will be set to between Vb+ and Vb-. For example if steps is 1 then a two point measurement will result. Legal values range from 1 to 30.

Aver Number of times the work function measurement will be performed for each value reported in the plot.

Points Number of required measurement points (maximum array size is 3000).

Delay (ms) Required Delay time in milliseconds between measurements (default is 0).

TRACKING GROUP

On When enabled this selects the automatic tip tracking control.

Invert This Parameter will invert the sign of the step size in the automatic tracking control mode. The default value is 'off'.

GD Reqd Sets the required Gradient, usually this in the range 100 – 3000.

GD Bounds Sets the allowed error in the required gradient, i.e., the acceptable gradient will lie between (GD Reqd + GD Bounds) and (GD Reqd - GD Bounds). Note in tracking the absolute value of the gradient is used- the sign of the gradient is irrelevant.

GD StepL Sets the base size of each step that will be use in the gradient feedback loop. A large value of GDstep will get to the required gradient region earlier but may overshoot.

GD StepS Sets the smallest step in gradient tracking which is enabled once the gradient is close to the required value. This (small) step is used to prevent the probe continually trying to find the requested gradient but being moved either just too close or too far away.

SHOW GROUP

Sig Charts the incoming signal from the tip.

PTP(Vb) Charts the data set V_{ptp} versus Vb.

WF Charts the WF data with time.

GD Charts the GD data with time.

DC Offset Charts the DC Offset applied to the coil. Only applicable if tracking is enabled.

User Charts the voltage on the User input Channel if requested. This function is enabled in the Advanced/Diagnostics page.

Delta WF Charts the change in WF, commencing from the beginning of the measurement series.

MOVE PROBE GROUP

X-Y Press each button to move the probe in the direction perpendicular to its vibration. The number of units indicated in the box below. 1000 (half-step) units corresponds to 0.4 mm. Remember the stepper motors must be energized (see the Motor Scan and Control section below) first. Initially try for small probe displacements as it is not possible to cancel your command after a Move command. Remember to verify visually that the steppers are not near the end of their displacement otherwise you may damage the translation mechanism.

Z Press the Z Up and Z Dn buttons to move the probe Down (closer to the sample) or Up (away from the sample) the number of steps indicated in the box below. In general the steps made here are quite small, e.g., 20 steps corresponds to 8 microns.

Further motor options including motor testing, reverse action and axis re-assignment are available via the Motor Motor Scan and Control Page.

ANALYSIS BELOW MEASUREMENT CHART

WF The current and std deviation work function values in mV.

Grad The current and std deviation gradient values.

DATA TAB AND COMMENTS TAB

The Data tab provides a summary of all measured data, including point number, time (in seconds, WF, Grad and steps performed in spatial tracking).

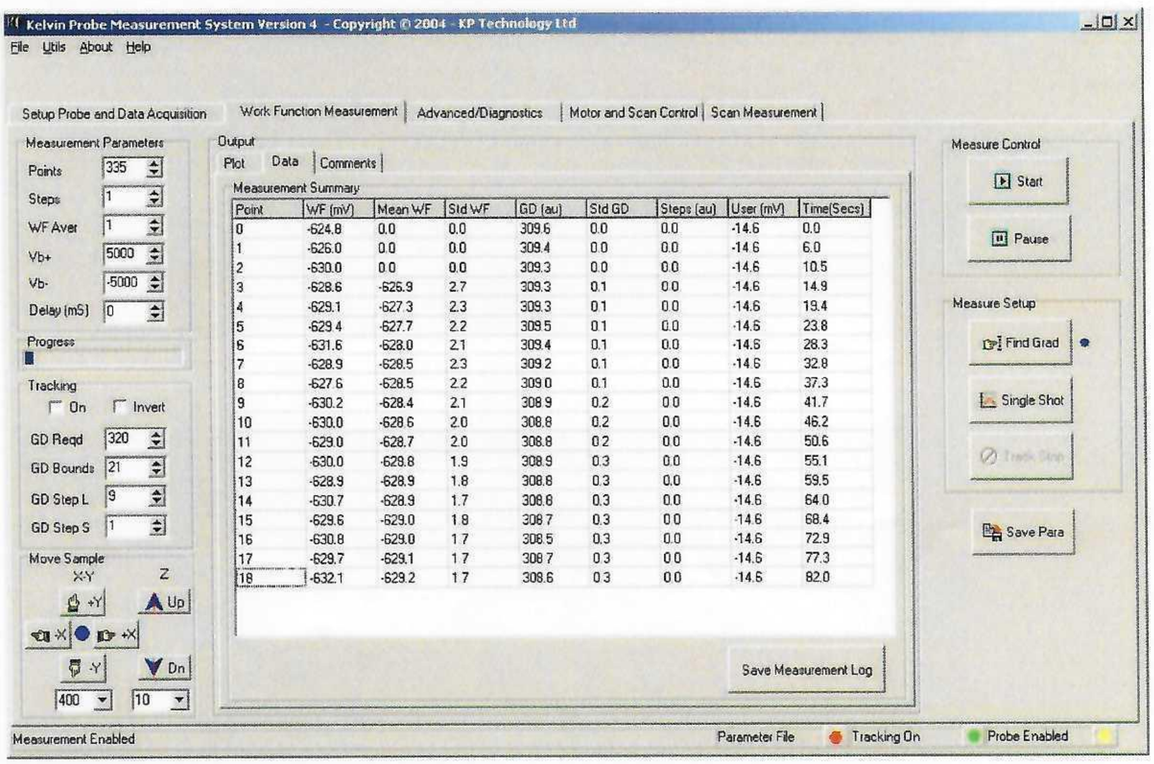


Figure 19. Example of the Measurement Data tab

The Comments tab allows the user to add experimental details, experiment date and time and relevant program parameters. These values will be appended to the saved data file. The user can stop the measurement at any time and a export file dialog will appear.

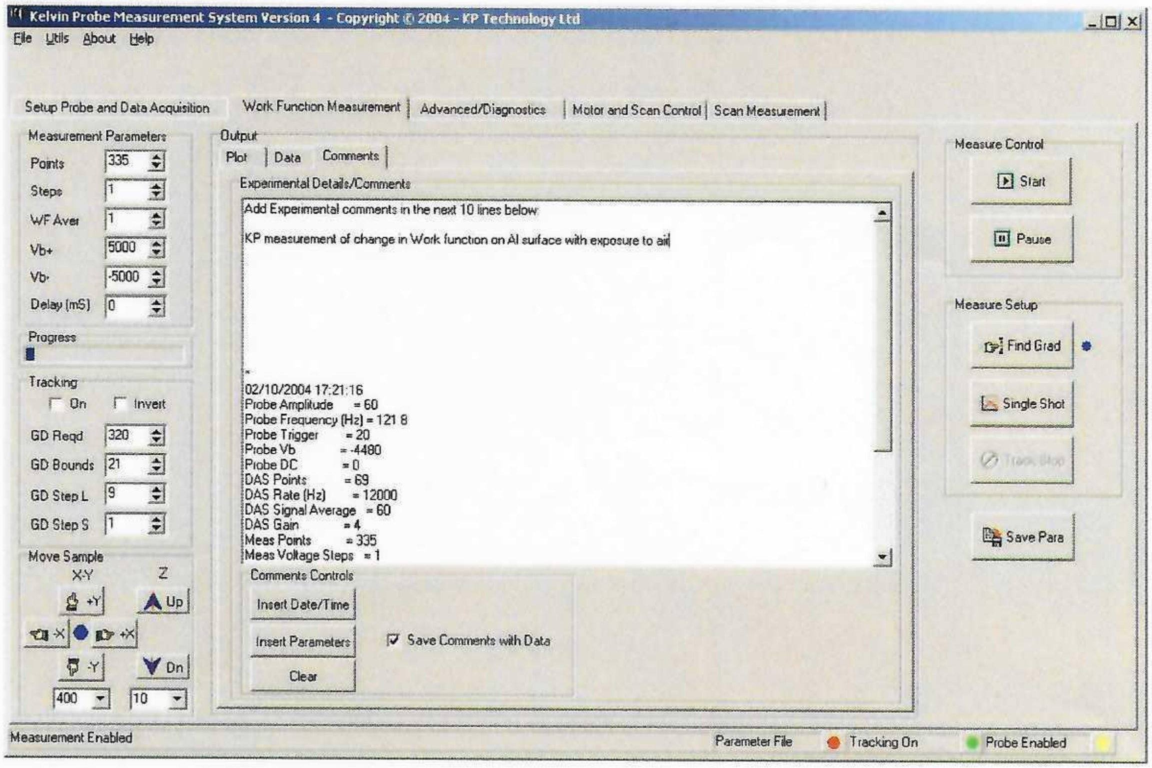


Figure 20. Example of the Measurement Comments Screen.

MEASURE SETUP BUTTONS

This group gives the current status of the tip tracking procedure, it is only active if either 'tracking' has been switched on or the 'Find Grad' button has been pressed. The following parameters are used to indicate tracking status (see Figure 24): 'delGD' is the value of the difference between the current gradient (*GD*) and the gradient required (GD Reqd), 'WF' is the current work function and 'Steps' is the number of DC offset steps taken in the current tracking loop. 'DC' is the actual DC offset setting. The tracking progress gauge gives an overview of the tracking procedure: it is red if the current gradient is out of the requested gradient bounds and turns blue if the requested gradient has been found. 'Track Stop' halts the gradient tracking loop at any point.

Find Grad Upon pressing the button the measurement program will attempt to position the tip to achieve the pre-selected gradient entered in the Tracking Group, within the stated error bounds. After twenty attempts to find this gradient this routine will automatically terminate. The associated 'Tracking Monitor' Group appears to illustrate the operation of the feedback loop using a coloured bar to indicate tracking in progress (red) and within tracking bounds (blue). This operation should be used in advance of a scan in order to get the probe tip close to the sample.

Single Shot Performs one measurement allowing for the user to quickly confirm probe status, i.e., Work Function and Gradient values and, for example, compare these to the current settings of the tracking loop.

TrackStop Cancels the current tracking routine.

MEASURE CONTROL BUTTONS

Start Commences the Measurement cycle and changes to 'Stop', when pressed again measurement stops.

Pause Pauses the Measurement cycle, press again to 'Re-Start' the measurement.

PROGRESS GAUGE

This gauge indicates how far through the current measurement the program currently is. It acts as a simple visual indication of experiment completion.

SAVING MEASURED DATA

At the end of the measurement cycle a file dialog box, as in Figure 22 will appear prompting the user to save the data. The default file name is DEFMeas.Dat. The user can change this filename as required.

SETTING UP A MESUREMENT

1. First ensure the sample is grounded and that the system ground is the outer shield Signal cable. Using a gain setting of 5 to 6 use the Oscilloscope page to obtain a waveform having a peak to peak height of 1-3 V, ensure that the phase of the waveform changes by 180 degrees when Vb changes from +5000 mV to –5000 mV. Perform a WF and Gradient measurement and use the signal averaging parameter to reduce the std. Devn. of WF to <=10 mV.
2. Use the Save Parameters Button to store the new parameters in a file.
3. Switching to the Measurement page perform a Single point measurement, with WF Averaging and Steps parameters both set to 1. The WF and Gradient Data will appear in the analysis box and the data table underneath the plot, see Figure 18 (top).
4. Initially set the WF points parameter to 40 and ***do not*** activate the tracking. Press 'Start' to perform a 40 point measurement. You will observe the current measurement data changing in the table underneath the plot. This data represents: measurement point, WF, Gradient, DC Offset, User (as required), and delta WF.
5. If you forgot to 'Enable' the probe before starting the measurement a warning box appears, see Figure 21. The button 'Start' initiates the measurement sequenc, the button label changes to 'Stop', pressing the button a second time will halt the measurement set after the current measurement.
6. You can review the measured data sets either during or at the end of the measurement, using the 'Show' control.

Figure 21. Example of the Warning displayed when the Probe is not 'Enabled' before measurement.

7. Pressing upon the data tab, displays a review of the measurement, together with mean and std. devn. of selected data, see Figure 19.

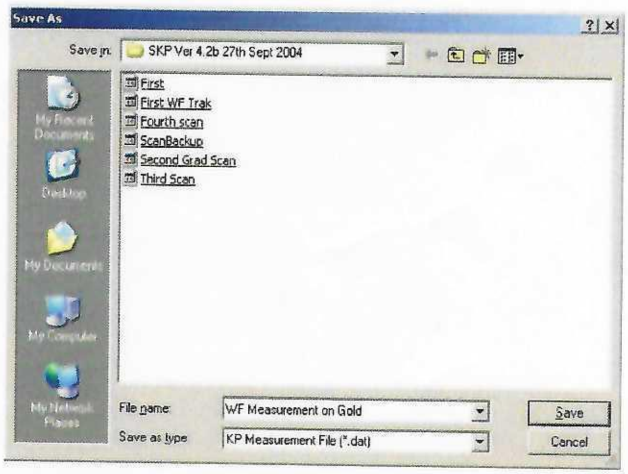


Figure 22. The Save Data Dialog.

8. At the completion of the measurement (or a discontinued measurement) the 'Save As' dialog appears. The user should select an appropriate filename and save the measured data. The data sets can also be directly ported into Excel using the Chart controls. The user can now vary the parameters such as 'Steps', 'WF Aver', etc. in order to evaluate the effect upon the measured data. A user defined measurement delay is available to pause in-between each measurement.
9. If the 'Move Probe' control is used to move the tip in and out, it will be noted that the apparent work function changes as described above. To avoid this effect and to allow comparisons of data sets measured at different times, we utilise the tracking feature, see Figure 23.
10. Initially set 'Steps' and 'WF Aver' to 1 and make the tracking active. Set the required gradient to 400, error of 10 and large and small increment to 6 and 1 respectively.
11. Press the Clear Data button to erase previously measured data and press 'Single Shot' to measure the current gradient and WF data.

12. Press the 'Find-Grad' button, the plot mode switches to display the DC offset tracking steps and a tracking box appears which shows tracking progress. The progress bar turns from red to blue when the correct gradient has been determined.

13. The user is free to change tracking and other parameters during the measurement and tracking procedures and to press on 'STOP' to discontinue the measurement. Note that, if the probe is currently in a tracking procedure, it may take some time to respond to the operator input. Therefore **only press the 'Stop' button once** or else another measurement will be actuated.

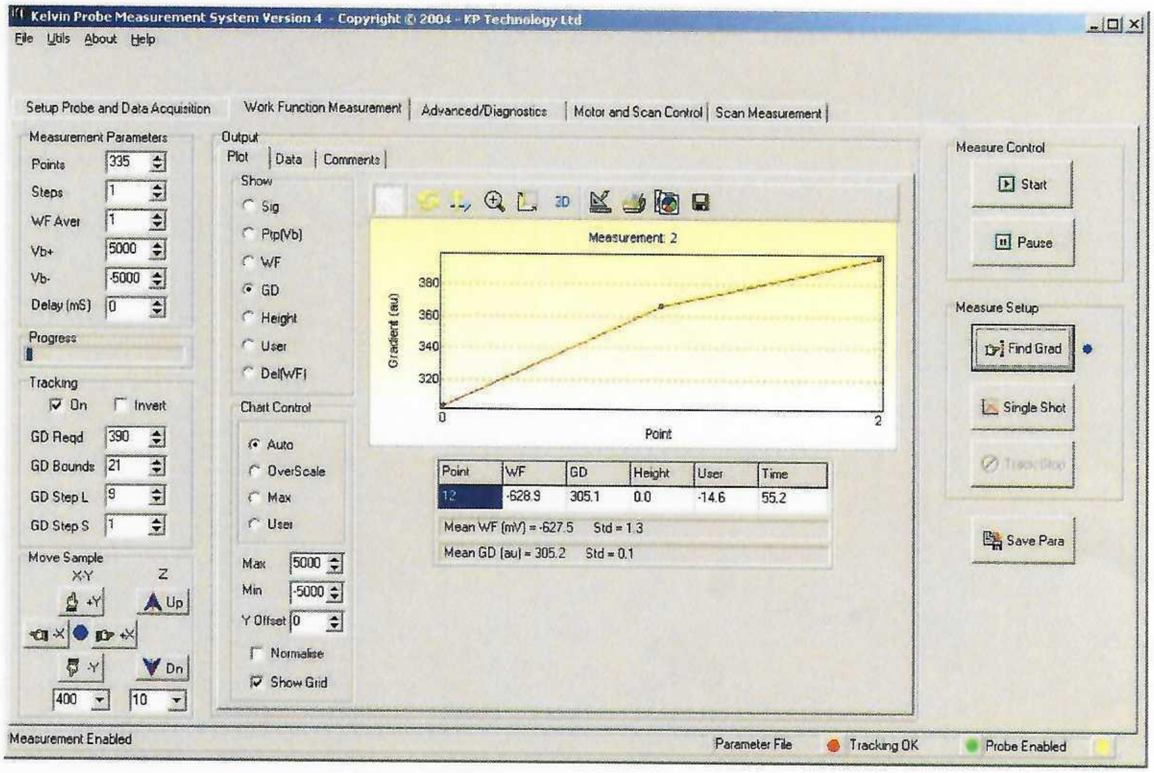


Figure 23. Example of 'Find-Gradient': the plot displays the gradient changing as theZ stepper motor is adjusted to find the requested gradient within the required bounds

14. The 'Find Grad' button will, irrespective of the Tracking switch position, attempt to set the required gradient using the current gradient tracking parameters. The status of the tracking control can be monitored via the 'Tracking' Group. At any time the tracking loop can be stopped by pressing on the 'Track Stop' button. Note that the gradient tracking loop utilises a maximum of 20 steps to find the gradient. The first time the operator uses this control the value of the 'delGD' parameter should be closely inspected. If 'delGD' is increasing the position of the 'Invert' switch should be changed. After this action the 'delGD' parameter should decrease. If the Kelvin Probe physical parameters are such that even after 20 tracking steps the required gradient has not been found the operator can press 'Find Grad' again.

15. If the current data indicate that the gradient error is increasing then use the 'Invert' control to reverse the direction of the tracking loop.

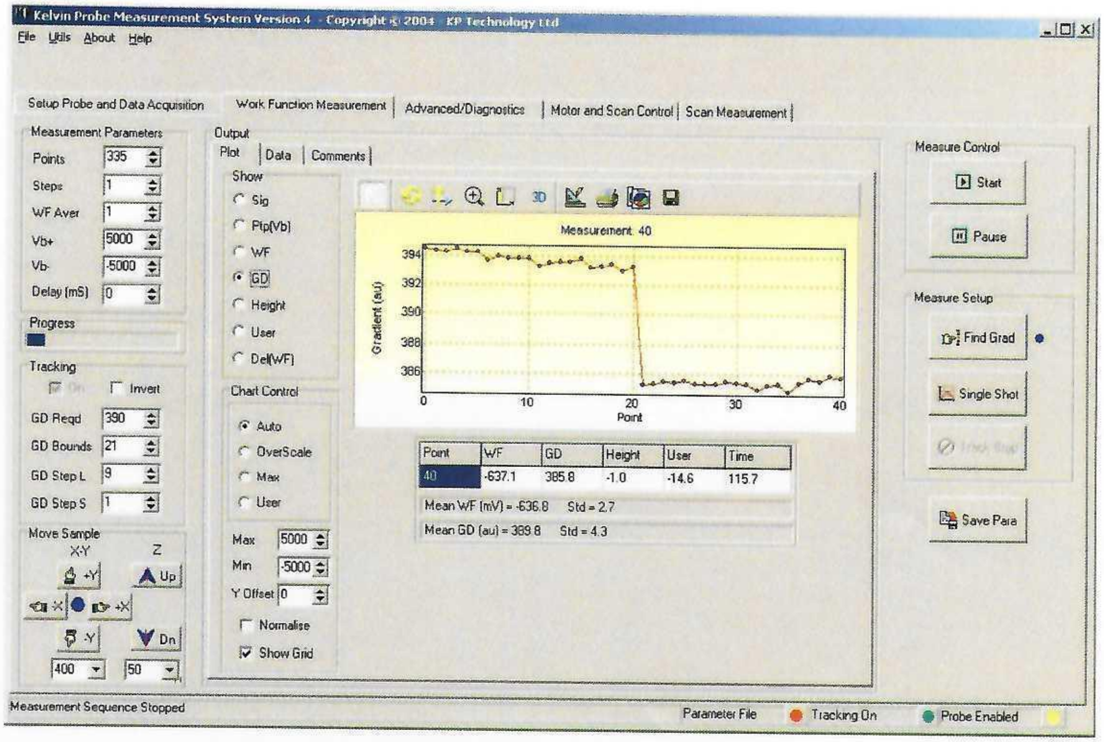


Figure 24. Example of the tracking loop when the sample is suddenly moved back 0.5 mm.

16. After the requested gradient has been found the user can now proceed to a WF measurement, in this case the 'Show DC' data represent the number of steps require to maintain a constant spacing. Figure 24 shows the effect of a deliberate change in spacing during a measurement due to a sudden translation of the sample away from the tip. We observe that the probe is pushed forward to maintain spacing and the WF data remain relatively unaffected, see Figure 25

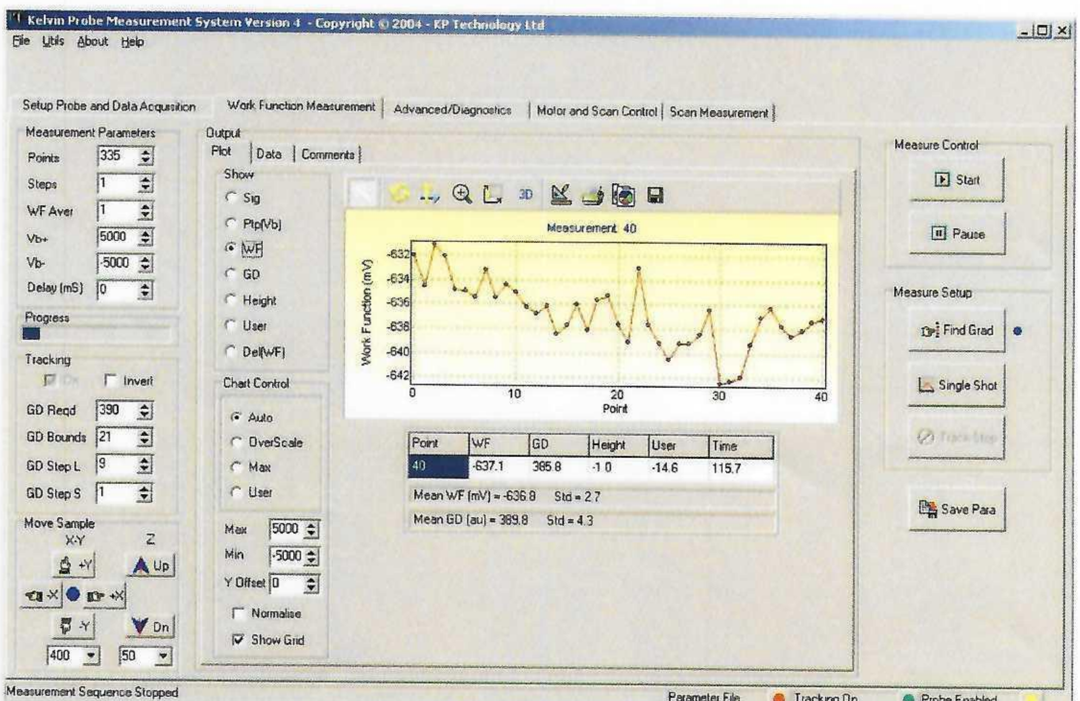


Figure 25 Associated WF change during tracking, i.e., the mechanical disturbance has little effect.

ADVANCED/DIAGNOSTICS

The 'Advanced / Diagnostics' page, see below, contains several enhanced features to allow the user to control the Kelvin Probe System.

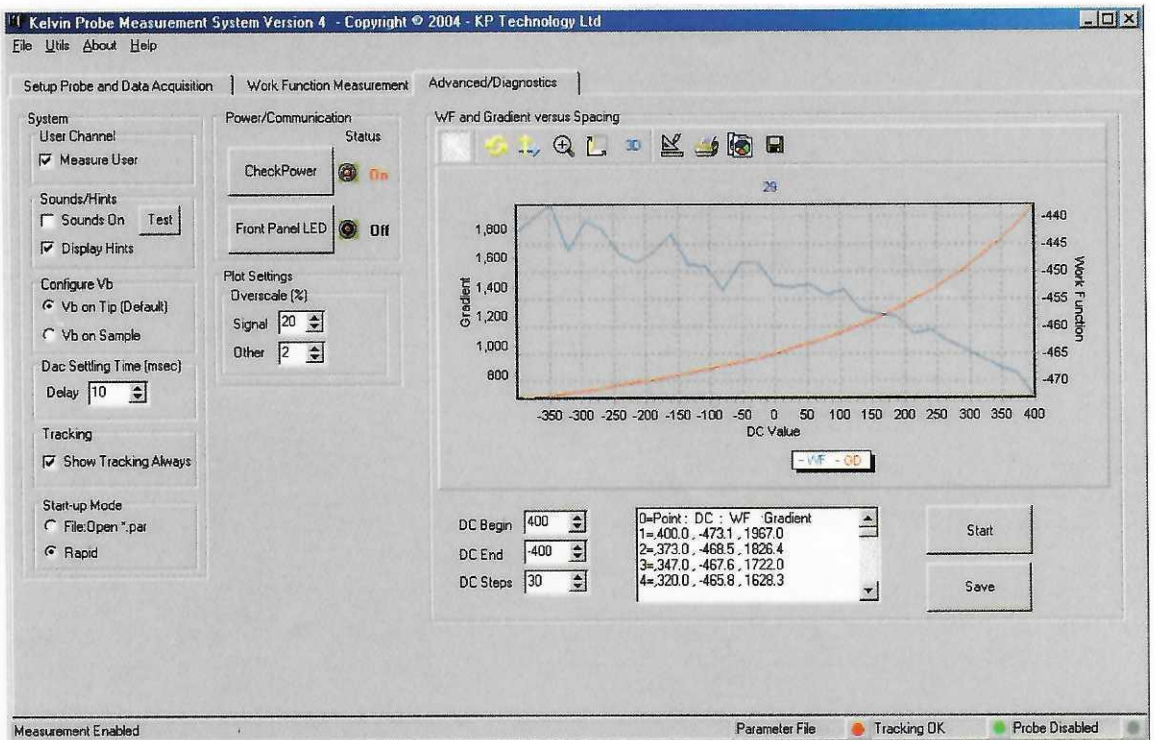


Figure 26 The Advanced / Diagnostics page (nb figure from SKP ver 4.1)

User Channel If active then the voltage on the User Input on the Front Panel is recorded as a function of time during Kelvin Probe measurements.

Sounds On Turns On the System sounds.

Hints On Turns On the Hints: placing the cursor over a parameter will explain its function and allowed range.

Configure Vb Logical switch which sets the Backing Potential either on the Tip or Sample.

DAC Settling Time Time in milliseconds that the system pauses after setting the Backing Potential. The default value is between 100-150 milliseconds.

Show tracking Always The data showing the status of the tracking loop are displayed continuously during WF measurements.

Start-up Mode Either through File - Open Parameter file or Rapid start-up with the last saved parameter set.

Check Power Turns LED on if Power Suppliers in the DCU are OK.

Front Panel LED Switches the Front Panel LED on the DCU on and off.

Plot Settings Used to control the Overscale feature during charting of Kelvin Probe Signal and Work Function Data.

Work Function and Gradient Versus Spacing Allows the user to program a DC offset 'scan' and measure the WF and GD at each point. Useful for determining the change in WF with spacing and to establish a optimum value for the Gradient in the Tracking Loop.

The 'Motor and Scan Control Page', see below, contains features to allow the user to test and control the 3 axis translator. There are 3 principal groups: 'Move control' which allows the user to individually test each stepper motor; 'Axis reassignment which allows the user to change the logical axis representation; 'Holding Torque' which allows the user to turn on and off the prower to all the stepper motors, allowing free rotation by hand. The other options are described in the 'Scan' section below.

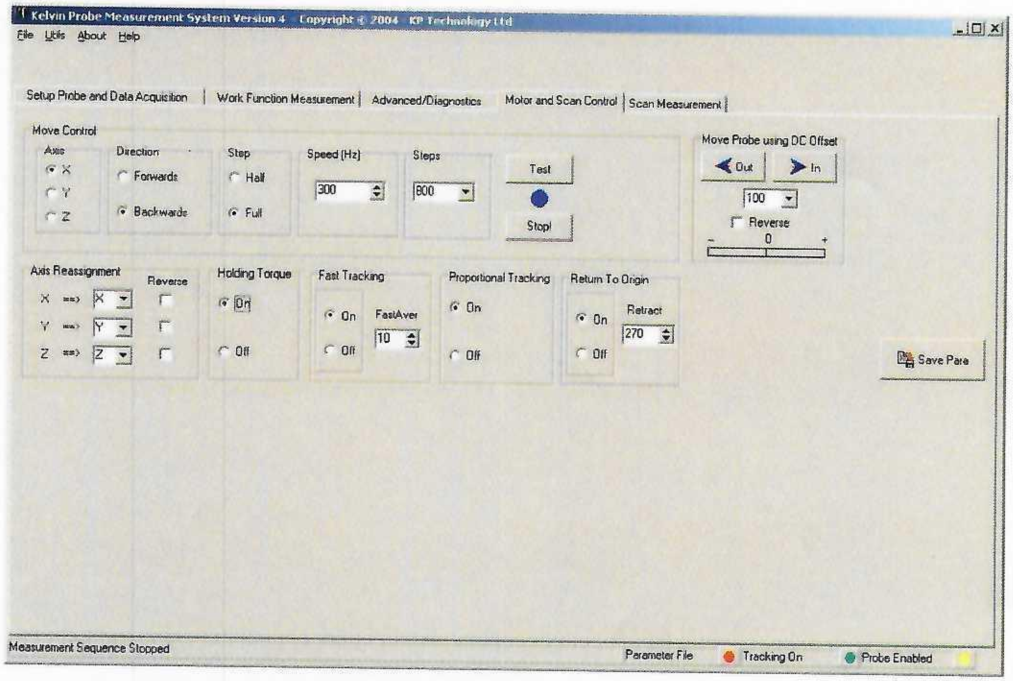


Figure xy the Motor and Scan Control dialog.

Move Control This group allows the selection of each motor (X,Y,Z) which are logically assigned to each asis via the 'Axis Reassignment' box. In the default mode motor 1 is the X axis, Motor 2 the Y axis and Motor 3 the Z axis. Each motor will move the number of steps indicated in the 'Steps' box. Changing the 'Delay' parameter will either speed up or show down the rotation. The default value for 'Holding Torque' is 'On'. Press 'Test' to actuate the translator.

Reverse Changes the direction of stepper motor rotation in the setup and measurement modes.

Speed This is the speed in Hertz that pulses are sent to each stepper motor. We suggest that the user leaves the pre-set value alone initially.

Holding Torque Switches power to all 3 stepper motors. If switched off then the motors can be turned by hand.

Step Used to switch between hald and full step modes, corresponding to 200 or 400 stepsper rotation.

Steps The number of steps the motor should travel.

Axis Stepper motor selector eith X or Y or Z axis.

Direction Forwards or Backwards rotation.

THE SCAN PAGE

Once you have set up the probe as required, select the "Scan" page. This is where scanning work function measurements are performed.

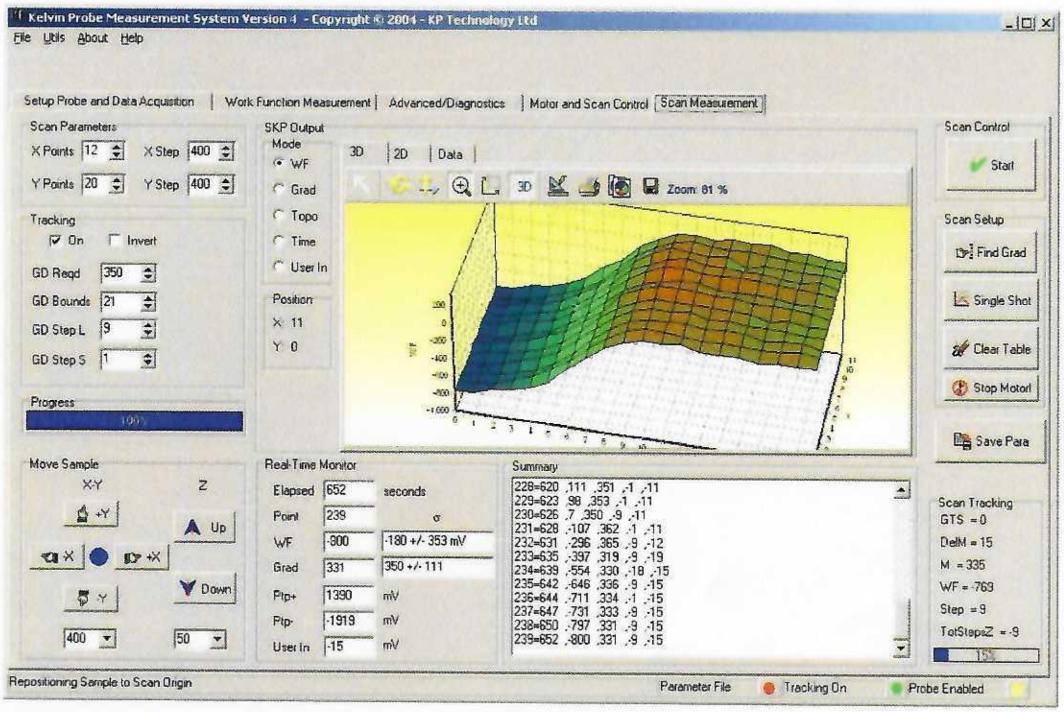


Figure 27 The Scan Page with measured data displayed in a 3D graph.

SCAN PARAMETERS GROUP

XPoints Number of measurement points in the X direction, valid range is 1 through 100.

YPoints Number of measurement points in the Y direction, valid range is 1 through 100.

XStep Sets the size of the X step in units (each unit is 400 nm).
Legal values range from 0 to2000.

YStep Sets the size of the Y step in units (each unit is 400 nm).
Legal values range from 0 to2000.

TRACKING GROUP

On When enabled this selects the automatic tip tracking control.

Invert This Parameter will invert the sign of the step size in the automatic tracking control mode. The default value is 'off'.

GDreqd Sets the required Gradient, usually this in the range 100 – 1000.

GDbds Sets the allowed error in the required gradient, i.e., the acceptable gradient will lie between Gdreqd+Gdbds and Gdreqd-Gdbds. Note in tracking the absolute value of the gradient is used- the sign of the gradient is irrelevant.

GDstepL Sets the base size of each step that will be use in the gradient feedback loop. A large value of GDstep will get to the required gradient region earlier but may overshoot.

GDstepS: Sets the smallest step in gradient tracking which is enabled once the gradient is close to the required value. This (small) step is used to prevent the probe continually trying to find the requested gradient but being moved either just too close to too far away.

MEASURE GROUP (located in the 'Work Function Measurement Page)

Vb+ Upper level of Backing Potential, valid range 5000 to –5000 mV

Vb- Lower level of Backing Potential, , valid range 5000 to –5000 mV

Aver Number of times the measurement will be performed at each probe location.

MOVE SAMPLE GROUP

X-Y Press each button to move the probe in the direction perpendicular to its vibration. The number of units indicated in the box below. 1000 units corresponds to 0.4 mm.

Z Press the Z Up and Z Dn buttons to move the probe Down (closer to the sample) or Up (away from the sample) the number of steps indicated in the box below. In general the steps made here are quite smale, e.g., 20 steps corresponds to 8 microns.

REAL TIME MONITOR GROUP

Elapsed The time in seconds from initiating measurement.

Point The current measurement point.

WF The current and std deviation (σ) work function values in mV.

Grad The current and std deviation (σ) gradient values.

Ptp+ The signal waveform Ptp height in mV for Vb+.

Ptp- The signal waveform Ptp height in mV for Vb-.

User The current voltage of the selected User channel .

SUMMARY GROUP

Provides a summary of all measured data, including point number, time (in seconds), WF, Grad, steps performed in topographic tracking and, if, selected, user channel data.

PROGRESS GAUGE

This gauge indicates how far through the current data set the program current is. It acts as a simple visual indicator of experiment completion.

SKP OUTPUT GROUP

MODE Selects the measurement data to display, either work function (WF), gradient data (Grad), topographic height data (Topo), Time data (Time), or User Channel data (Url/2). The array of numbers to the right of Mode Select are the measured data. Default setting is work function. Note that the mode can be changed during measurement to review the current data set.

Position

X Current X Point (during scan).

Y Current Y Point (during scan).

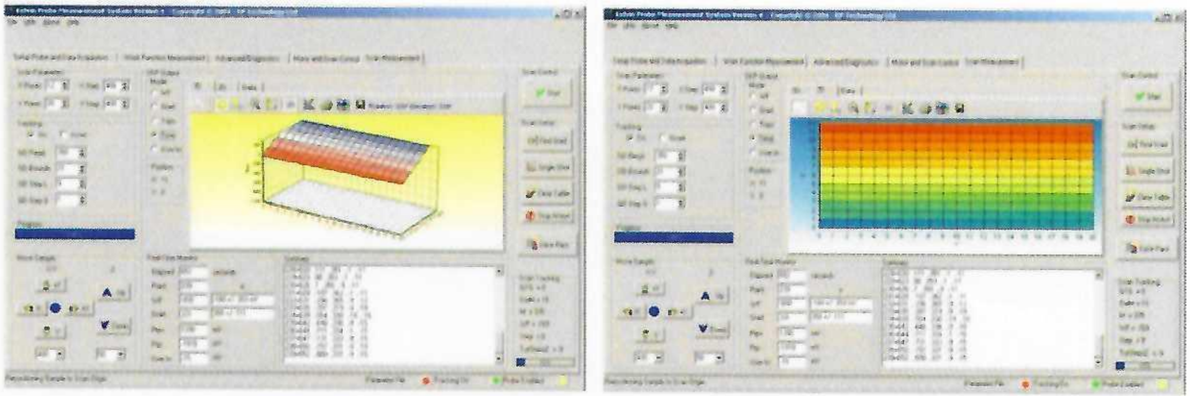


Figure 28 The Scan Page with measured topography data in 2D and 3D formats, demonstrating operation of the tracking function during the scan.

3D/2D and DATA

Use this control to flip between 3D 2D images and numerical data.

Data Measured data are displayed in a numerical matrix.

3D/2D Measured data are displated in plot, use the plot controls to adjust the display.

MEASURE CONTROL

Start Commences Scan, press again to stop at any point.

MEASURE SETUP

Find Grad Upon pressing the button the measurement program will attempt to position the tip to achieve the pre-selected gradient entered in the Tracking Group, within the stated error bounds. After twenty attempts to find this gradient this routine will automatically terminate. The associated '*Tracking Monitor*' Group appears to illustrate the operation of the feedback loop using a colored bar to indicate (tracking in progress (red) and within tracking bounds (blue). This operation should be used in advance of a scan in order to get the probe tip close to the sample.

Single Shot Performs one measurement allowing for the user to quickly confirm probe status, i.e., *WF* and *Grad* values and, for example, compare these to the currently settings of the tracking loop.

Clear Table Deletes the values in the data array (from the previous measurement).

Stop Motor Immediately stops the stepper motor (when in operation).

Save Para Saves the current measurement parameter set to disk under the current parameter filename. To change the parameter filename select File: Save Parameter As…

SETTING UP A SCAN

1. First select a small scan area, such as 2 x 4 or 2 x 10 points. Keep the step size small, e.g., 500 units (0.2 mm). The Scan program will use the current measurement parameter in the SETUP page to perform the measurement. Press the 'Clear' button to reset the array display and Real Time Monitor.
2. Use Move Probe to position the probe over the sample and initially switch tracking off. Use 'Single shot' to determine the approximate gradient and work function values then use 'Find Grad' to position the probe more accurately.
3. Perform a simple scan without tracking and then with tracking. At the end of each scan you will be prompted to save the measurement data. It is most useful to scan the calibration Gold Aluminium interface (supplied) as it produces a large contrast in work function and a useful visual reference of where the tip is with respect to the interface. The work function difference of a freshly prepared calibration interface will produce a work function difference of approximately 1 Volt, thus even small probe displacements in the vicinity of the interface will be visible as changes in work function. The probe scans in the 'Y' direction and increments in the 'X' direction, where the 'Y' direction is in and out (for an operator facing the probe head unit). The 'X' is then from left to right.
4. The user is free to change tracking and other parameters during the scan and to press on 'STOP' to discontinue the measurement. Note that, if the probe is currently in a tracking procedure, it may take some time to respond to the operator input. Therefore only press the 'Stop' button once or else another measurement will be actuated. If you forgot to 'Enable' the probe before starting a measurement a warning box appears, see **Error! Reference source not found.**

5. At the end of the Scan the following dialog appears (Figure 29), the user should select and appropriate filename and save the measured data. In tracking mode there are 4 data sets: WF, Grad, Topo and Time. Scanning without tracking produces WF, Grad and Time. Note the topographic data are the steps (in 0.4 micron units) that the probe was moved up or down to maintain a constant mean spacing.

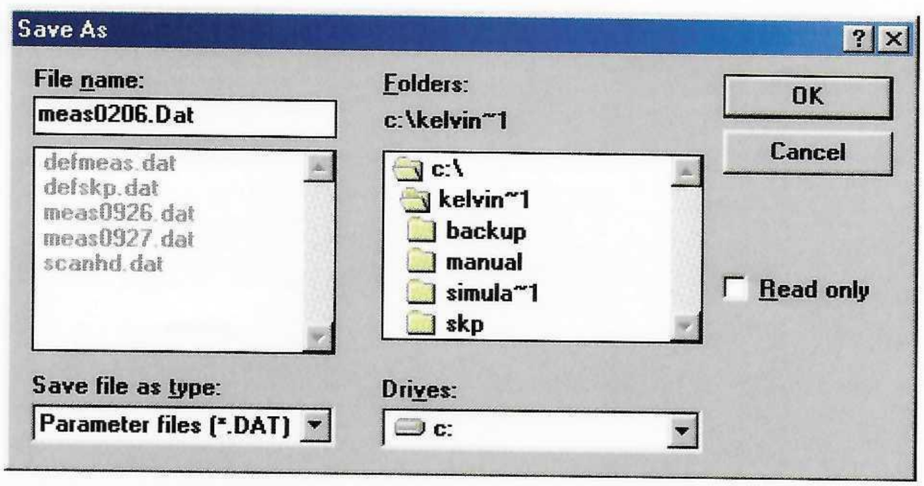


Figure 29 Example of the Scan Save Data Screen.

TRACKING MODE

If the 'Move Sample' control is used to move the tip in and out, it will be noted that the apparent work function changes as described above. To avoid this effect and to allow comparisons of data sets measured at different times, we utilise the tracking feature:

1. Initially set 'WF Aver' to 1 and make the tracking active. Set the required gradient to 400, error of 10 and large and small increment of 5 and 1 respectively.
2. Press the Clear Data button to erase previously measured data and press 'Single Shot' to measure the current gradient and WF data.
3. Press the 'Find-Grad' button, the plot mode switches to display the translator tracking steps and a tracking box appear which shows tracking progress. The tracking bar turns from red to blue when the correct gradient has been determined.
4. The user is free to change tracking and other parameters during the measurement and tracking procedures and to press on 'STOP' to discontinue the measurement. Note that, if the probe is currently in a tracking procedure, it may take some time to respond to the operator input. Therefore only press the 'Stop' button once or else another measurement will be actuated
5. The '*Find Grad*' button will, irrespective of the Tracking switch position, attempt to set the required gradient using the current gradient tracking parameters. The status of the tracking control can be monitored via the 'Tracking' Group. At any time the tracking loop can be stopped by pressing on the '*Track Stop*' button. Note the gradient tracking loop utilised a maximum of 20 steps of to find the gradient. The first time the operator uses this control the value of the '*delGD*' parameter should be closed inspected. If '*delGD*' is increasing the position of the '*Invert*' switch should be changed. After this action the '*delGD*' parameter should decrease. If the Kelvin probe physical parameters are such that even after 20 tracking steps the required gradient has not been found the operator can press '*Find Grad*' again.
6. If the current data indicate that the gradient error is increasing then use the 'Invert' control to reverse the direction of the tracking loop. The default setting is unchecked.
7. After the requested gradient has been found the User can now proceed to a WF measurement, in this case the 'Topo' data represent the number of steps required to maintain a constant spacing.

ADDITIONAL SCAN OPTIONS

The main menu screen contains three additional scan options: 'Return to Origin', 'Proportional Tracking' and 'Fast Tracking' These parameters are found on the 'Motor and Scan Options' page and are described in detail below.

Return to Origin If switched on the sample first be translated away from the tip, then motored to the original start position. Please note the Y index must be an even number 2,4,6,8,10 etc for this function.

Fast Tracking If enabled the measurement system attempts to find the correct gradient using a small amount of measuring loops. This makes it faster at finding the corrent height. After the correct position is found the actual measurement is performed at the number of averaging loops indicated in the Signal Menu.

Proportional Tracking During tracking operations the feeback is proportional to the difference between the actual gradient and the required gradient.

To process the data mesured by the Kelvin Probe use Excel. Open the saved KP data file *.DAT in Excel. The Text Import Wizard will start, in the second step of the Wizard tick on 'comma' and '=' in the 'Other' box (see below).

Figure 30. Measured data in Excel's Text Import Wizard.

The last step in the Wizard allows you to delete the line number in the measurement file.

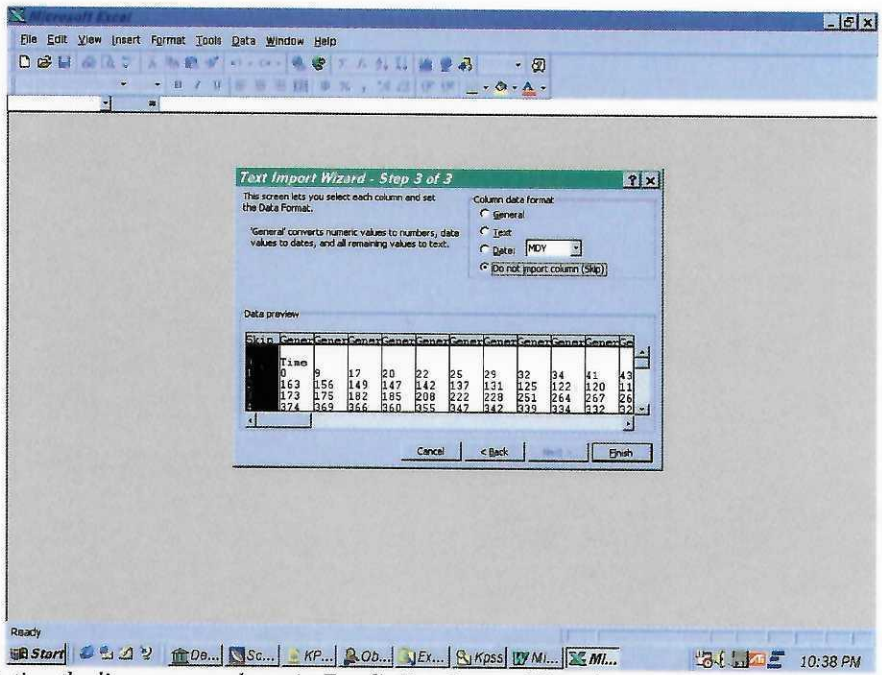
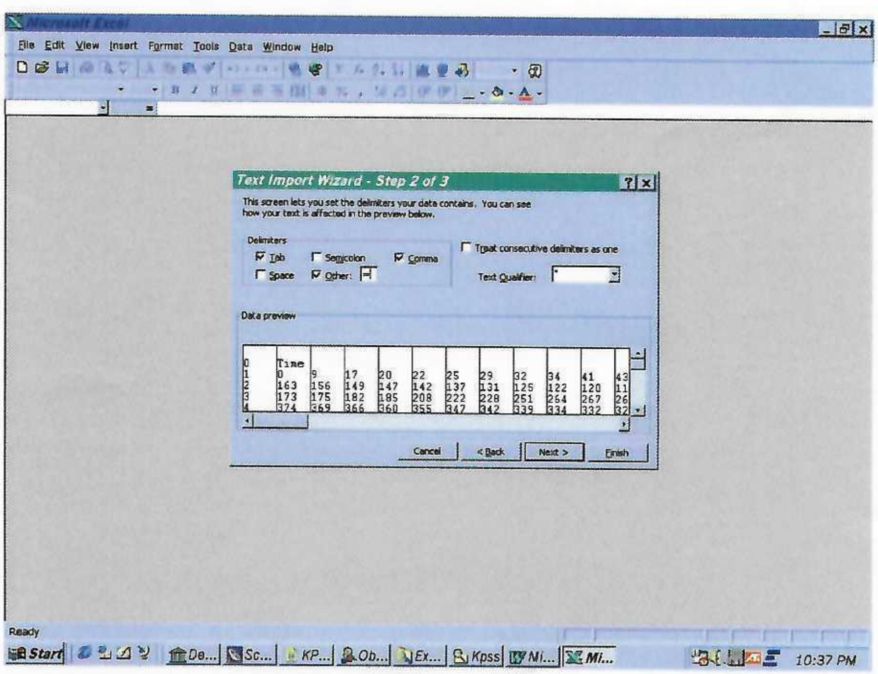


Figure 31. Deleting the line numer column in Excel's Text Import Wizard.

After importing data to Excel, select the relevant data set, e.g., work function and run the plotting wizard:



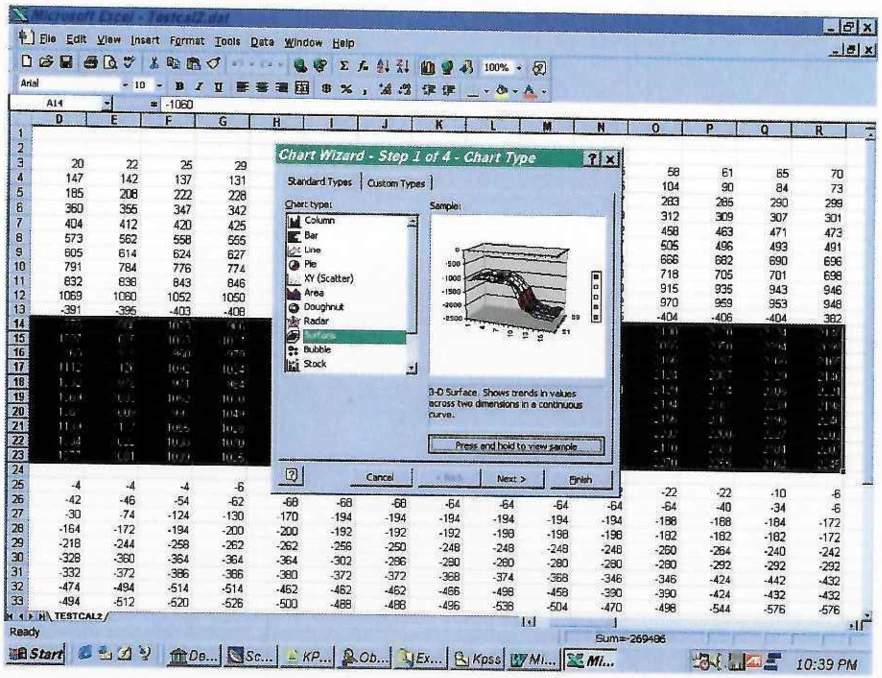


Figure 32. Plotting data using Excel's Chart Wizard.

Then type in the axes and graph labels and view the data, such as the Al/Au interface above. Note this is raw data and the above *relative* values have to be corrected to obtain approximate *absolute* data. For example in the above data the gold film (red section) is approximately 5.1eV.

The KP is capable of 1-3 mV resolution however there is an error of at least 50 mV in converting to absolute WF data. This is because real surfaces are not homogeneous and the WF varies in the order 50 -100 mV across the surface.