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Use of A PC-Based Data Acquisition System For Measurement of 2-Lead Electronic Device DC Current-Voltage Relations

We have developed a simple, PC-based data acquisition system for the purpose of measuring the static, DC current-voltage (I-V) relation associated with an arbitrary 2-lead electronic device – e.g. a resistor or any type of non-linear device such as silicon and/or germanium rectifier and signal diodes, Zener diodes, Light Emitting Diodes (LEDs), varistors, etc.

The host PC used for this system interacts with a National Instruments LabPC+ general-purpose, PCI-based DAQ board, which consists of two 12-bit Digital-to-Analog Converters (DACs), eight 12-bit Analog-to-Digital Converters (ADCs), two Counter-Timers, and 24 channels of read/write programmable Transistor-Transistor Logic (TTL) Digital Input/Output (I/O) Lines. We used the National Instruments LabWindows/CVI and NI-DAQ Software to write a C-based DAQ program to carry out the DC I-V measurements, which we called IV2 (2 = 2nd version).

As shown in the figure below, we use DAC0 of the LabPC+ card to apply a voltage between –5.0 volts and +5.0 volts across the 2 leads of the electronic device we want to measure the I-V relation. A 1.0 Ohm shunt resistor is inserted in series with the 2-lead device, for the purpose of measuring the current. We use ADC0 to measure the voltage drop across the 1.0 Ohm resistor, and then use Ohm's Law ($I = V/R$) to obtain the current flowing through the 1.0 Ohm resistor, which is also the current flowing through the device, since they are in series with each other.

As mentioned previously, the LabPC+ DACs have 12 bit resolution, and a dynamic range of 10.0 volts. Thus since $2^{12} = 4096$ DAC counts, the Least Significant Bit (LSB) or least count corresponds to 10 volts/4096 DAC counts = 2.44 mV/DAC count. Now it turns out that the LabPC+ DACs are only able to source/sink current up to a maximum of ~ 14 mA, thus the maximum voltage drop across the 1.0 Ohm resistor we anticipate would be ~ 14 mV.

The LabPC+ 12-bit ADCs have programmable gain, so that the maximum dynamic range of +_5.0 Volts (10.0 Volt span) would have a LSB again of 2.44 mV/ADC count. This ADC resolution is not very useful for measuring small, ~ mV potential differences across the 1.0 Ohm resistor. However, the maximum programmable gain of 100 corresponds to a dynamic range of +_50 mV (100 mV span) which thus has a LSB of 24.4 µV/ADC count, which is much more sensitive for our needs. Hence we digitize the voltage across the 1.0 Ohm resistor with ADC0, using a programmable gain of 100 to maximize the resolution on V, and hence the current, I flowing through the circuit.
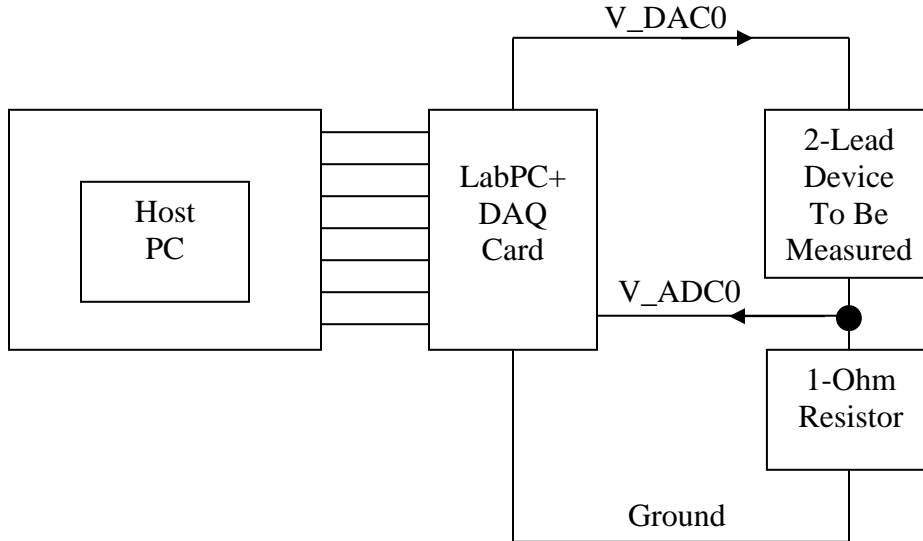
Figure 1: Hardware Setup for IV2 DAQ Experiment

We also employ the use signal-averaging techniques in the IV2 DAQ program, to minimize the effects of electrical noise fluctuations and noise pickup associated with the V_ADC0 measurement. For a given DAC0 voltage value, V = V_DAC0 we take 4000 ADC0 measurements, and obtain the average value <V_ADC0>, from which we obtain a mean value of current at this DAC0 voltage, <I(V)>.

It turns out that when we set DAC0 voltage to V_DAC0 = 0.000 volts, that we find that <V_ADC0> is NOT precisely equal to 0.000 volts, but something slightly different from zero. This slight voltage offset occurs for multiple reasons – the DACs have a slight voltage offset themselves; there also exist small contact potential differences between metals and also the ADCs will have small voltage offsets from zero potential difference. Thus, the first thing the IV2 program does before taking actual I-V data is to take 100 measurements of 4000 ADC0 samples each, for V_DAC0 = 0.000 volts. We call this the so called "pedestal", <V_PED0>, or zero-voltage offset for ADC0. We then subtract this from all subsequent measurements of V_ADC0. Thus:

$$<I> = (<V\_ADC0> - <V\_PED0>)/R$$

Now it also turns out that the R = 1.0 Ohm metal-oxide resistor we are using is not precisely R = 1.0 Ohm, but close to it. It is not trivial to accurately measure the resistance of a 1 Ohm resistor with just using e.g. a DVM. There are several ways to do this; we chose to simply calibrate our apparatus by measuring the resistance of known-value resistors, then correcting the IV2-obtained value of the 1.0 resistor in the IV2 software until the IV2 measured resistance e.g. of a 330 Ohm resistor, which we measured with a Fluke 77 DVM to be 346.1 Ohms, after subtracting the 0.1 Ohm DVM lead resistance, agreed with each other. The correction – calibration factor we needed to apply to the 1.0 Ohm resistor was less than ~ 10%.

The user needs to log onto the host computer, where the IV2 DAQ program resides with the "usual" user name, password and domain name (consult with the Lab TA for this information if you don't yet know it). If the PC was in fact rebooted from a cold start – power up, then before running the IV2 program, the user will first need to run the NI-Measurement and Automation Explorer (MAX) facility in order to fully and properly initialize the LabPC+ interface card. The NI MAX explorer icon should be on the PC's desktop – double click on this and click your way through to the Devices and Interfaces, then click on/run the LabPC+ Test Panel. If there are no error messages encountered, then everything is working properly with the LabPC+ DAQ card, and you will see some kind of a green trace appear on the oscilloscope display of the LabPC+ Test Panel – you should get NO error messages. If you get no error messages, then stop running the LabPC+ Test Panel program and exit the NI MAX utility program. Everything is now set to run the IV2 DAQ program. If you get any kind of error message(s), exit the NI MAX utility program, shut down (completely) the PC (properly/gracefully), then reboot the PC from a cold-start, and then after logging in again, re-run the NI MAX utility program again and run the LabPC+ Test Panel. Everything should work fine this time. If not, please bring this problem promptly to the attention of the Lab TA!

Before running the IV2 program, one also needs to check to make certain that the green 50-pin terminal block for the IV2 experiment is in fact connected to the 50-pin ribbon cable, which connects the National Instruments LabPC+ DAQ card to the green 50-pin terminal block. It is very important to note that the 50 pin ribbon cable has a definite polarity associated with it – pin 1 of the ribbon cable is denoted by a slightly raised triangle on the light gray 50-pin connectors at both ends of this cable. We have used a red magic marker to highlight this triangle on the light gray 50-pin connectors and their mating connectors at the LabPC+ card and the 50-pin green terminal block in order to make the cable polarity more obvious to the user.

The green terminal block has two alligator clip leads connected to it. (This PC is also used for DAQ work for the Physics 303 Advanced/Modern Physics Lab Chaotic Water Drop Experiment, which has its own DAQ electronics, connected to the host PC via the same 50-pin ribbon cable…) The black alligator clip is the negative lead, which is connected to analog ground via the 1.0 Ohm shunt resistor. The red alligator clip is the positive lead, which is connected to the output of DAC0. Connect the 2-lead electronic device for which you want to measure the DC I-V relation of, to the red & black alligator leads. Note that for a diode, to forward bias the diode, connect the band end of the diode to the black (negative) lead.

To run the IV2 program, double-click on the IV2 icon on the desktop. A LabWindows/CVI project window will appear. Use the mouse to pull down on the Run menu, and click on Run Project. The IV2 main display panel will then appear. Double-click on the blue task bar at the top to expand the IV2 display panel to the full screen size. Use the mouse to click on the Initialize DAQ button to initialize the LabPC+ DAQ card's electronics. Then click on the Start button to start the IV2 program's data acquisition.

As mentioned previously, the program will first obtain the ADC0 pedestal, <V_PED0> associated with V_DAC0 = 0.000 volts. Then V_DAC0 is stepped in increments of 9.765625 mV (exactly 4 DAC counts – to avoid software V & I aliasing problems) for positive increasing DAC0 voltage, until the current exceeds +12.0 mA, or V_DAC0 exceeds +4.95 Volts, whichever comes first. As mentioned above, at each DAC0 setting, 4000 ADC0 samples are taken, and <ADC0> is computed. Then for each V_DAC0 value, we compute <I(V)> (with R = 1/0.932100 Ohms = 1.072846 Ohms) from:

$$<I(V)> = (<V\_ADC0> - <V\_PED0>)/R$$

All of this data is stored in arrays in the IV2 DAQ program. When the upper limit of +12 mA or VDAC0 = +4.95 is reached, the IV2 DAQ program sets V_DAC0 = 0.000 Volts and then begins taking data in the negative V_DAC0 direction, again in increments of 9.765625 mV (exactly 4 DAC counts) mV, until the current exceeds –12.0 mA or V_DAC0 becomes more negative than –4.95 volts, whichever comes first. The program then automatically terminates the data-taking

Note that the user can also abort the data-taking at any time simply by using the mouse to click on the STOP button of the IV2 main panel display, but then data-arrays are not properly filled. The user will have to START the DAQ again and allow it to complete normally in order for the data arrays in the program to be properly filled.

Once the IV2 data-taking is complete, the user can then use the mouse to pull down on the on-line plot menus – there are a total of nine on-line plots that can be viewed, either as linear x-y plots or as semi-log plots:

1.)   I vs. V
2.)   Static Resistance,   R = V/I   vs. V
3.)   Static Conductance, G = 1/R vs. V
4.)   Static Resistance,   R = V/I   vs. I
5.)   Static Conductance, G = 1/R   vs. I
6.)   Dynamic Resistance, $R_d = dV/dI$ vs. V
7.)   Dynamic Conductance/Transconductance, $g_m = dI/dV$ vs. V
8.)   Dynamic Resistance, $R_d = dV/dI$ vs. I
9.)   Dynamic Conductance/Transconductance, $g_m = dI/dV$ vs. V

Note also that for each of the on-line plots, one can use the mouse to click on either or both of the two (yellow & magenta) "snap-to-data" cursors. The cursor X-Y display ports for each cursor will tell you the X-Y data values of each cursor for the plot you are currently looking at. Note further that for each new on-line plot drawn, the cursor data ports update only when the user activates these cursors, each time for each plot. The user can also move the cursors along the data curves using the up/down and/or left/right arrow keys on the keyboard . Hard-copies of the on-line plots can be made by using the mouse to click on the PRINT button, just underneath the plot display on the IV2 main panel display.

The IV2 DAQ program is not without some physical limitations. As you will find, on the high-resistance side, resistances above ~ 5.0 Meg-Ohms are not reliably measured, because these correspond to measuring currents less than ~ 200 nA. This corresponds to the (total) voltage noise floor of ~ 200 nV associated with the ability of ADC0 to reliably measure the potential difference across the 1.0 Ohm shunt resistor. On the low-resistance side, low resistance measurements are limited by DAC0's ability to source/sink currents up to ~ +_12 mA.

Note that we have also made explicit efforts to reduce contributions from EM noise interference – 60 Hz AC line-voltage pickup, RFI from the host PC and other such devices in the P398EMI lab, RFI noise present in the building, etc. by shielding the 50-pin cable and also placing the 50 pin green terminal block in a grounded aluminum box, providing 4π steradians of local RFI coverage.

The V, I, R and G data just acquired using the IV2 DAQ program can also be output to a text file, using the SAVE DATA pull down menu. The user will be asked to specify the name of the output file, which is located in the C:\CVI\P398EMI\Data\IV2\ area on the host PC. Once this data is output to a file, it can then be analyzed more fully off-line at a later time, e.g. using EXCEL, Origin, Mathematica, etc.

When done with using the IV2 DAQ program, the user can exit the program by using the mouse to click on the QUIT button on the IV2 main panel display. Do the same in quitting the IV2 project window – either click on the X-square in the extreme upper right hand corner of the IV2 project window, or use the mouse to click on the File pull-down menu, and select Exit LabWindows/CVI option from the File pull-down menu.

In the figures below we show on-line plots from the IV2 program associated with the measured I-V behavior of a 1N5222B 2.5 Volt Zener diode.
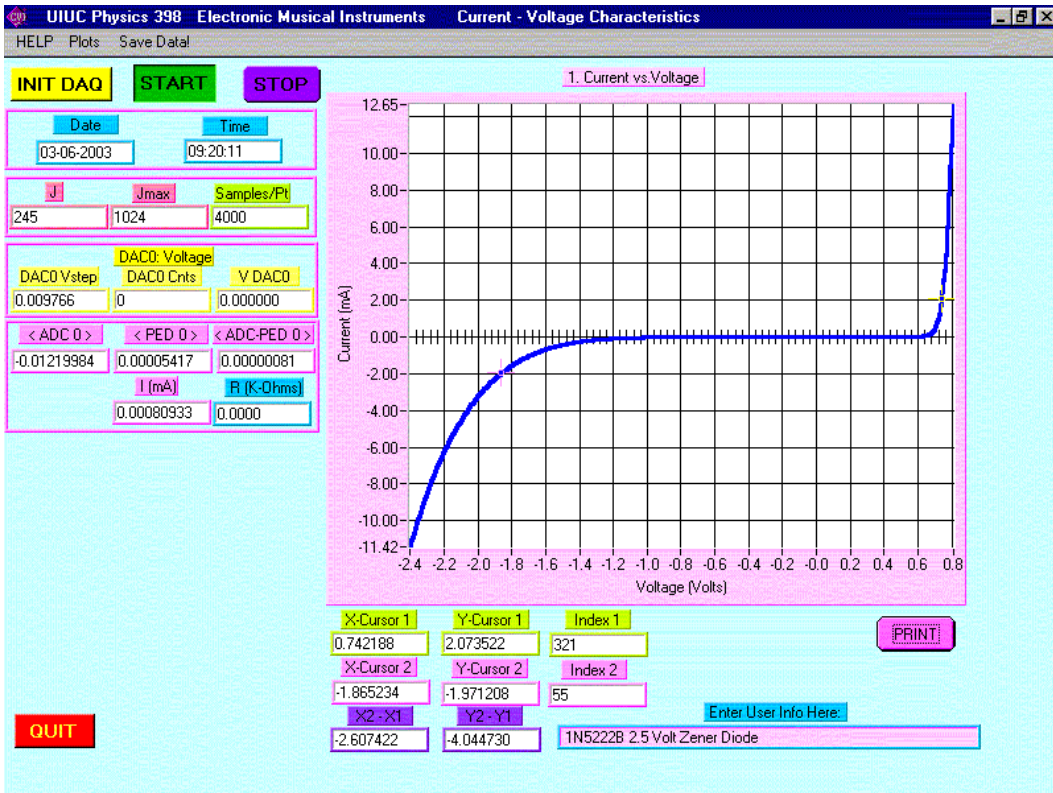
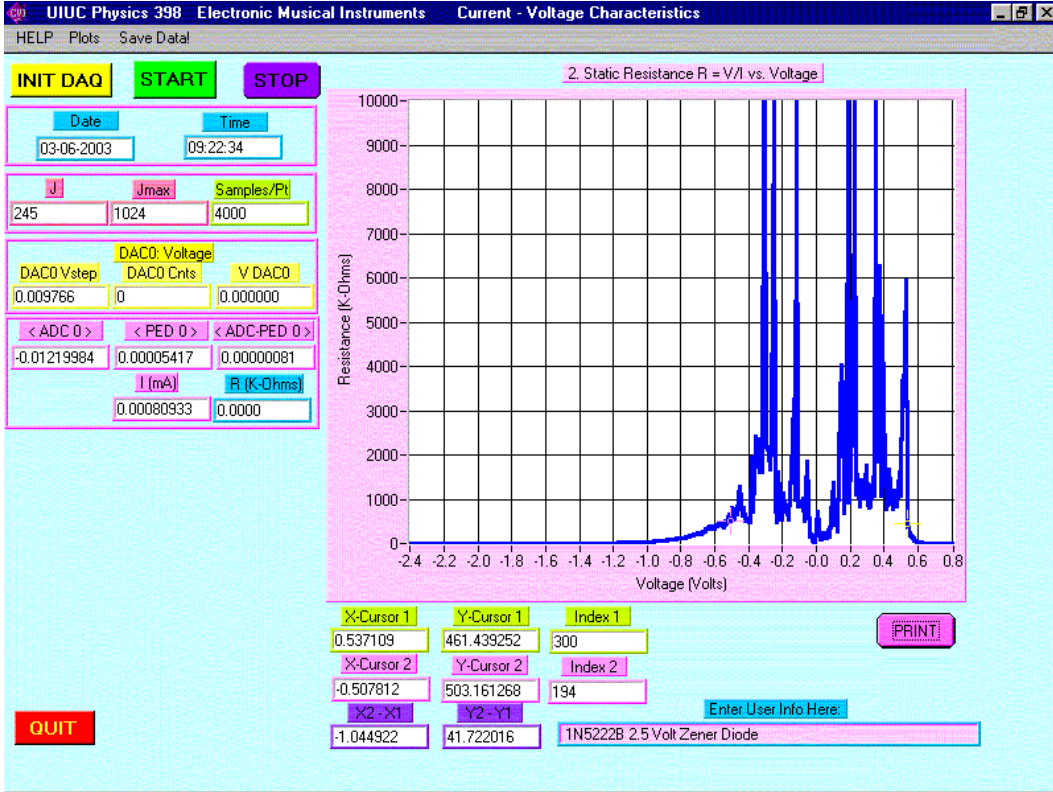Figure 2: I vs.V relation for 1N5222B 2.5 Volt Zener Diode

Figure 3: R (= V/I) vs.V relation for 1N5222B 2.5 Volt Zener Diode
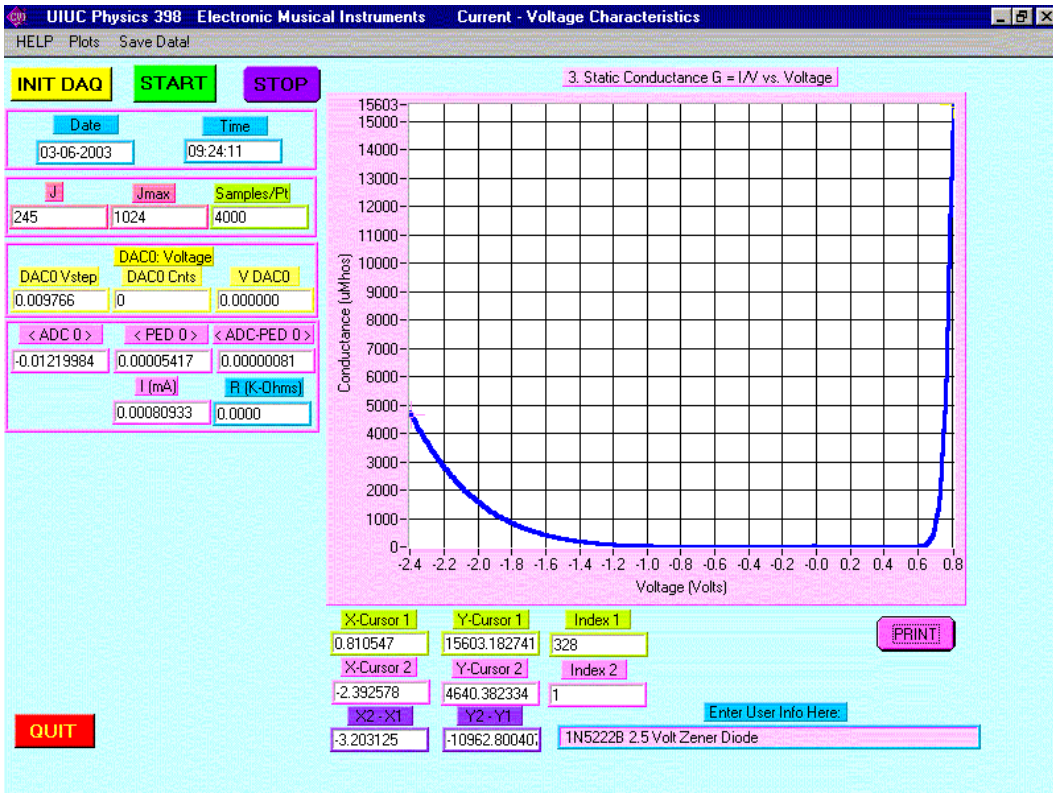
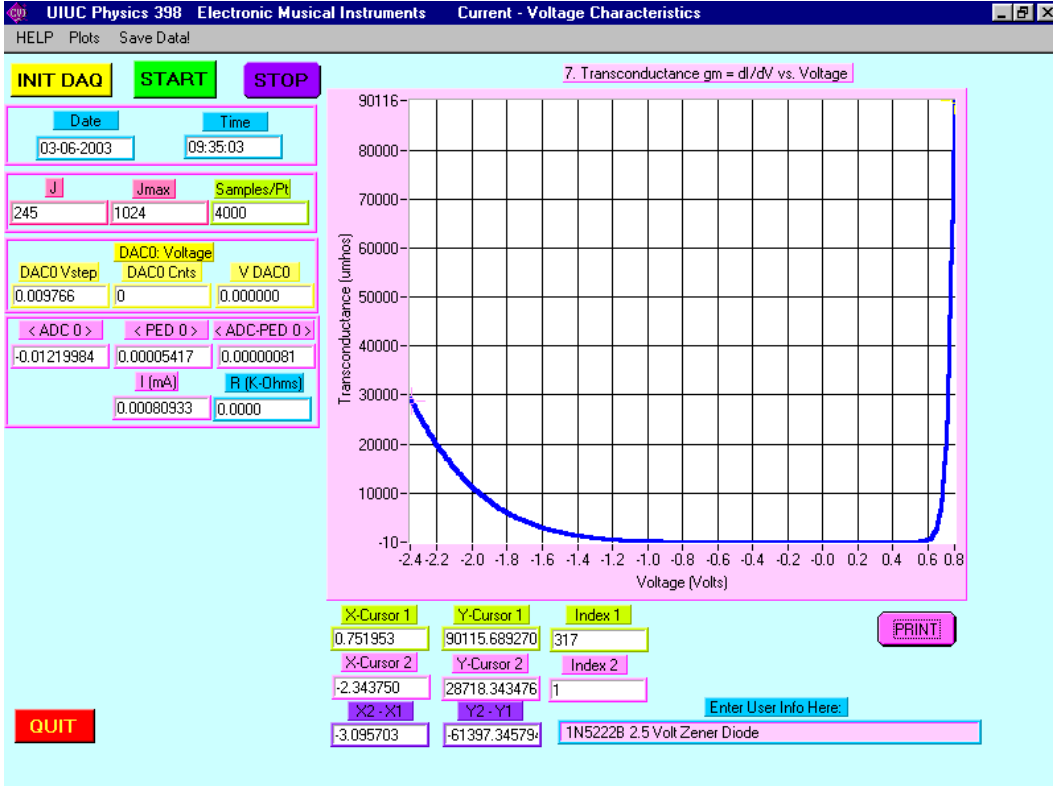Figure 4: G (= 1/R = I/V) vs.V relation for 1N5222B 2.5 Volt Zener Diode

Figure 5: g_m (= dI/dV) vs. V relation for 1N5222B 2.5 Volt Zener Diode
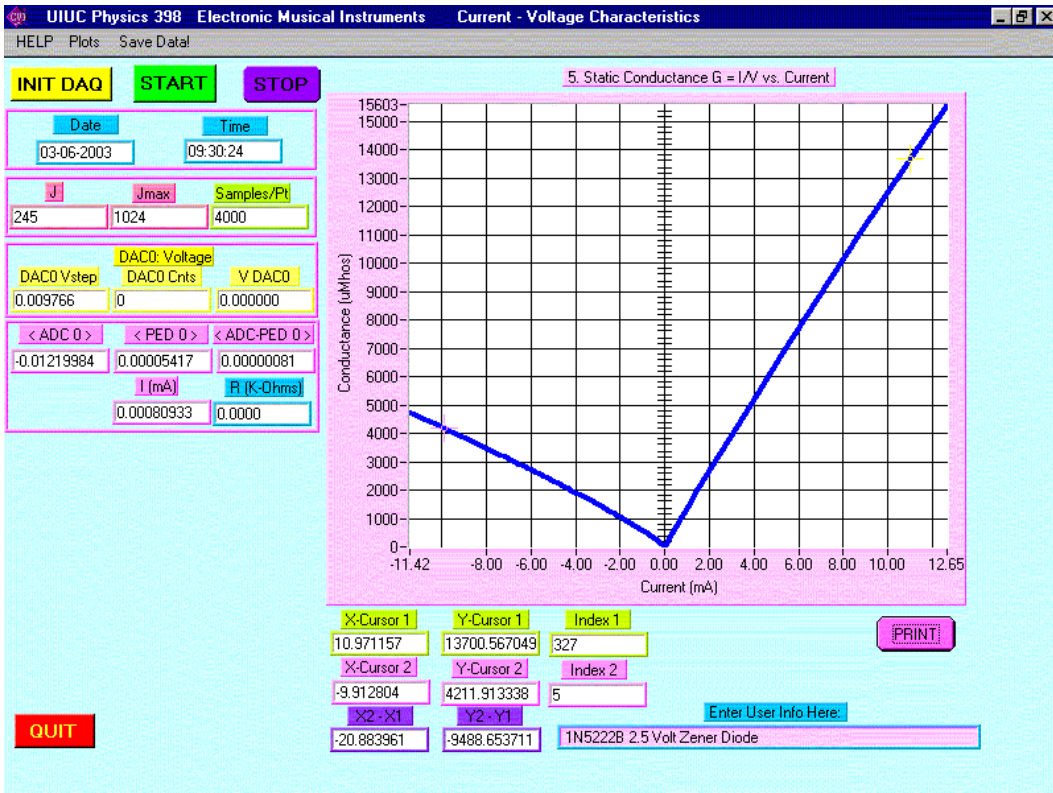
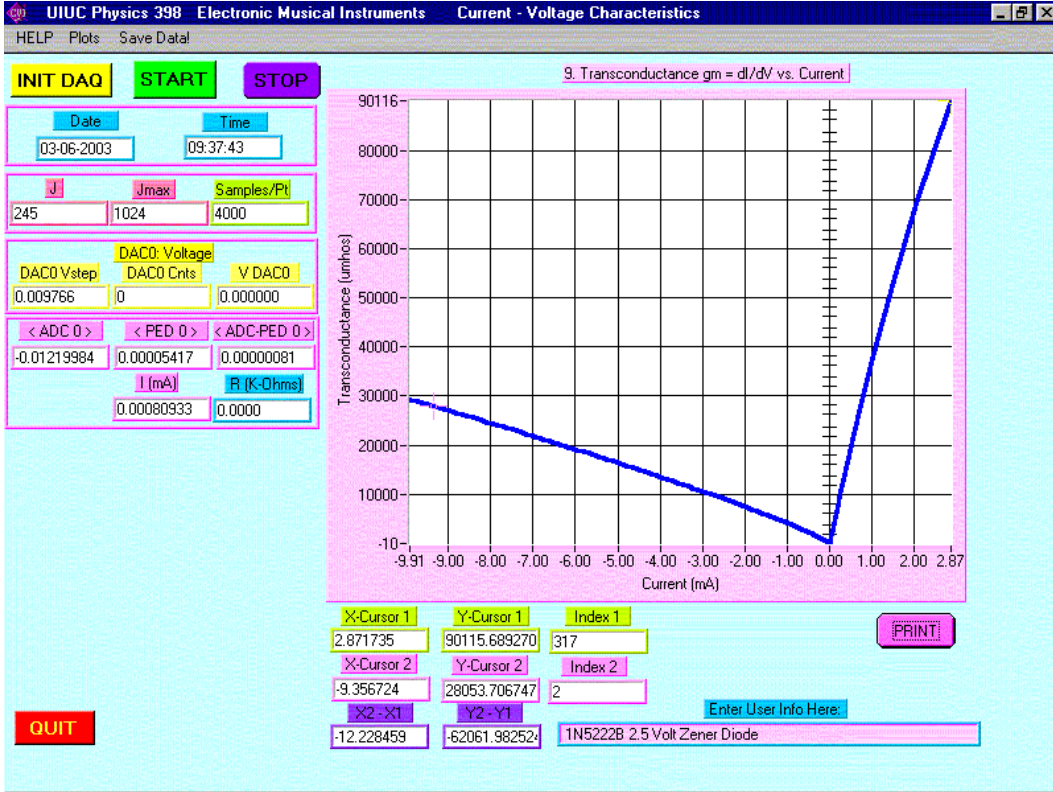Figure 6: G (= 1/R = I/V) vs. I relation for 1N5222B 2.5 Volt Zener Diode

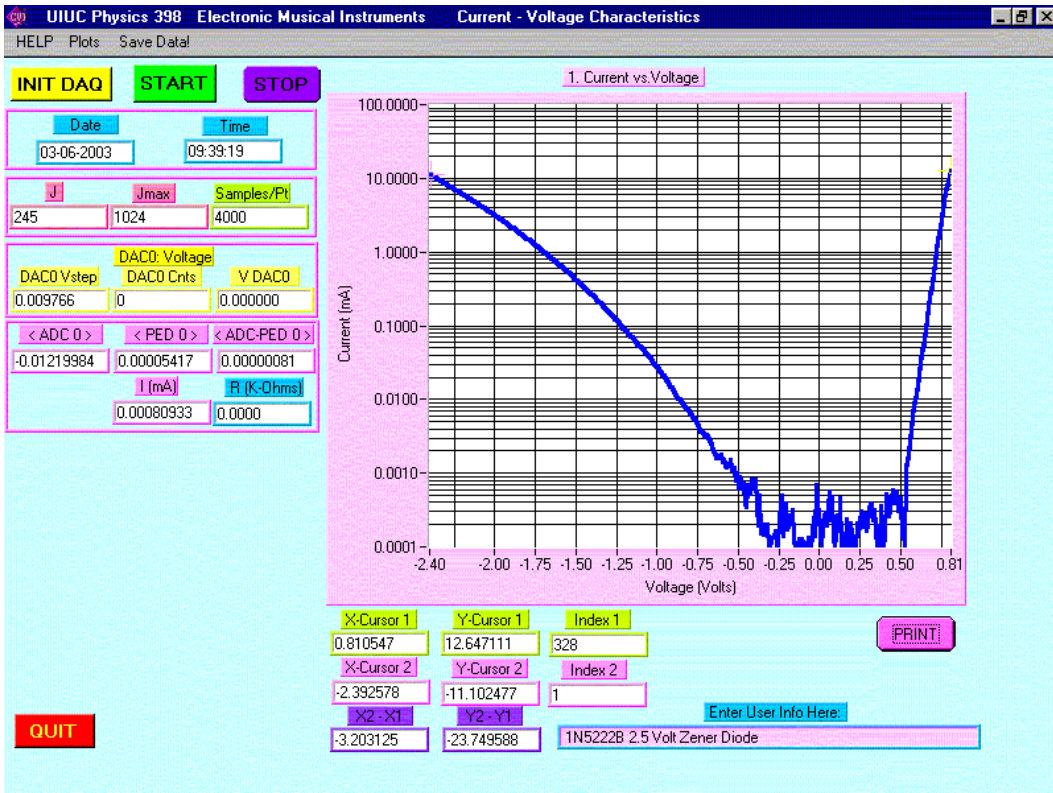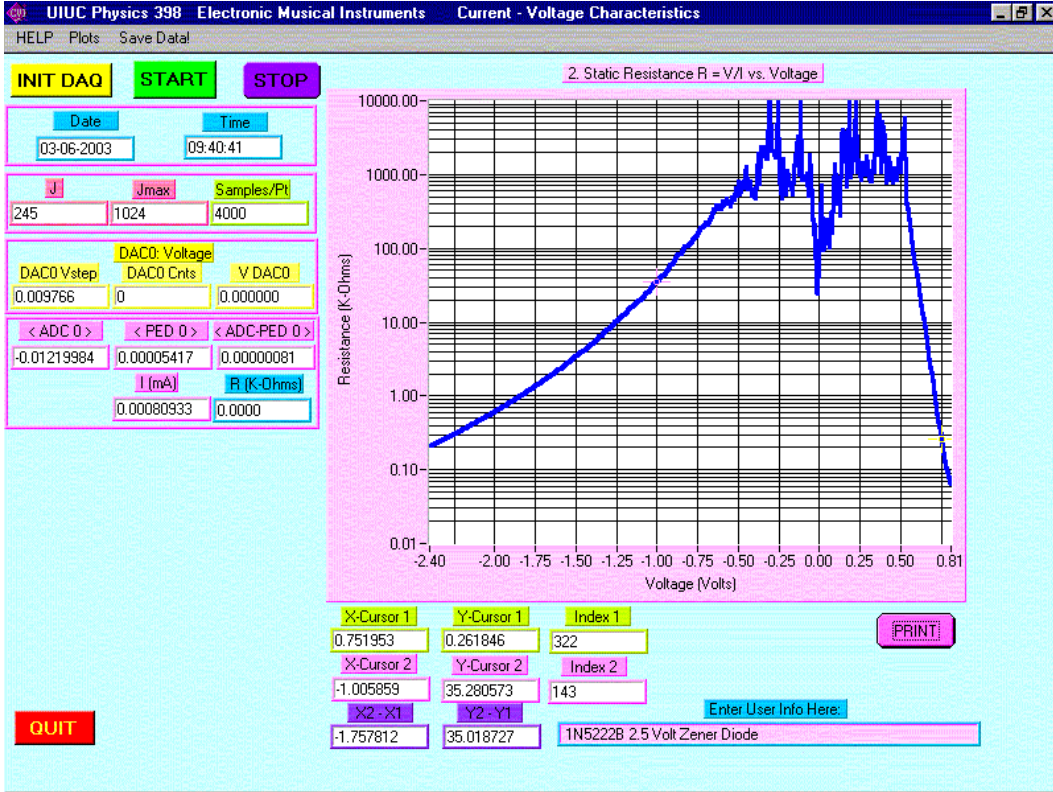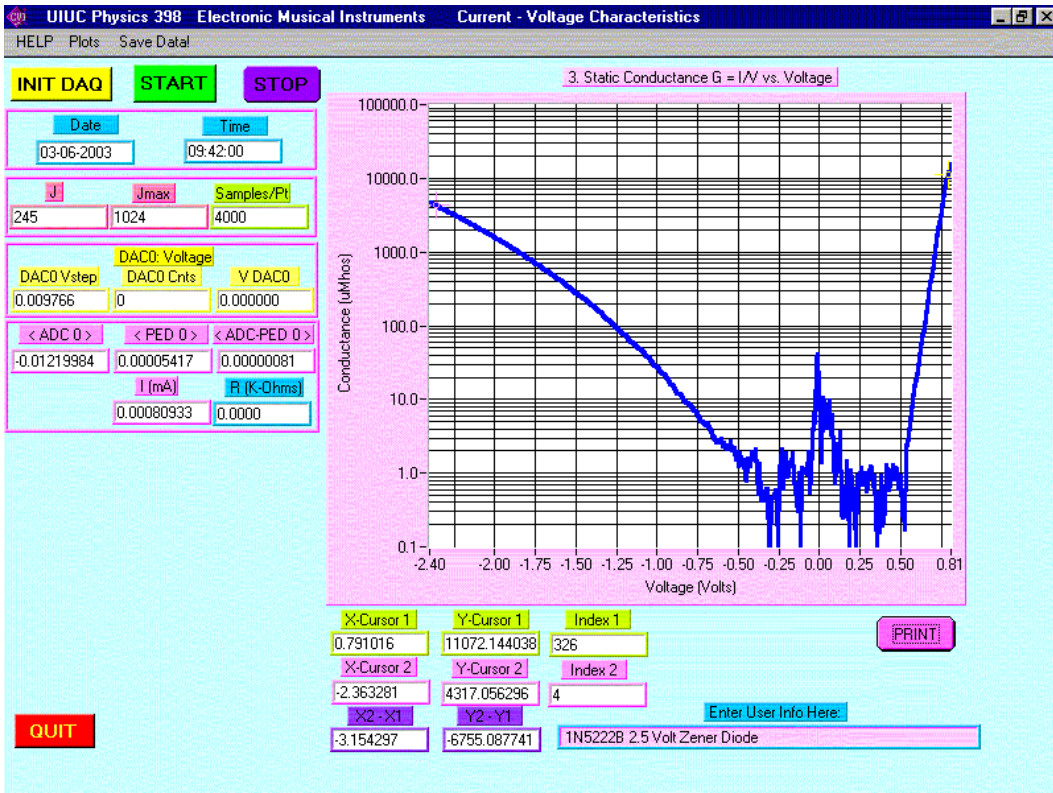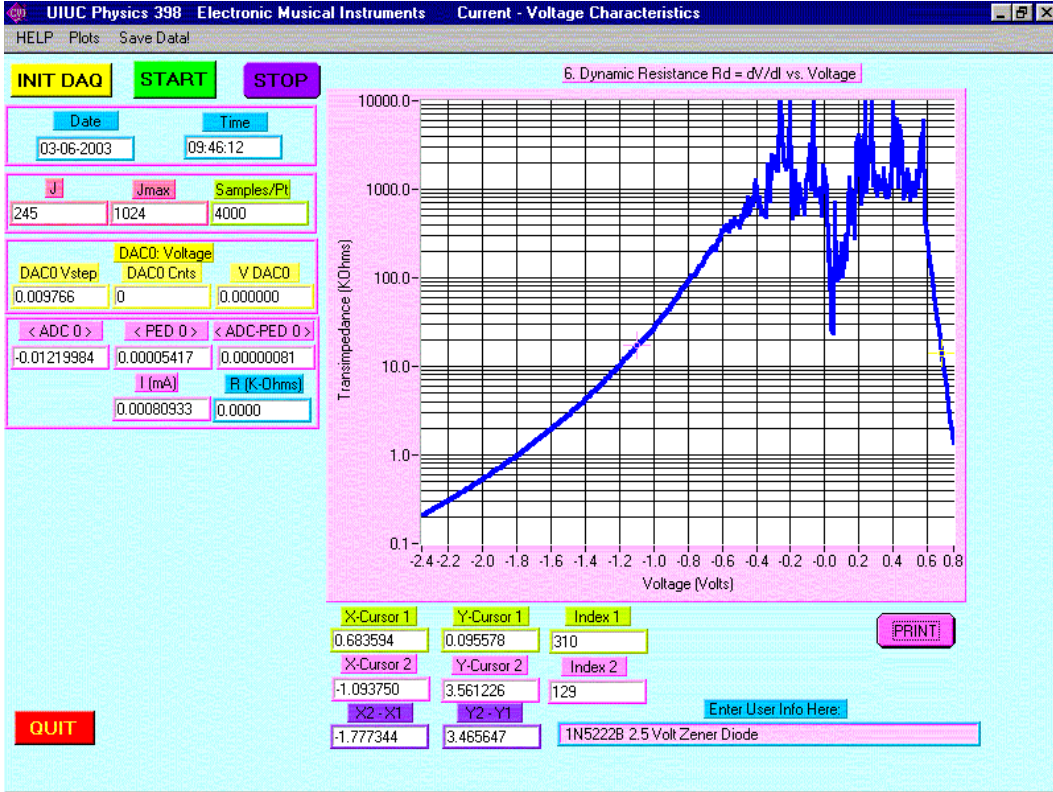Figure 7: g$_m$ (= dI/dV) vs. I relation for 1N5222B 2.5 Volt Zener Diode

Figure 8: Log(|I|) vs. V relation for 1N5222B 2.5 Volt Zener Diode

Figure 9: Log(R) vs. V relation for 1N5222B 2.5 Volt Zener Diode

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Figure 10: Log(G) vs. V relation for 1N5222B 2.5 Volt Zener Diode

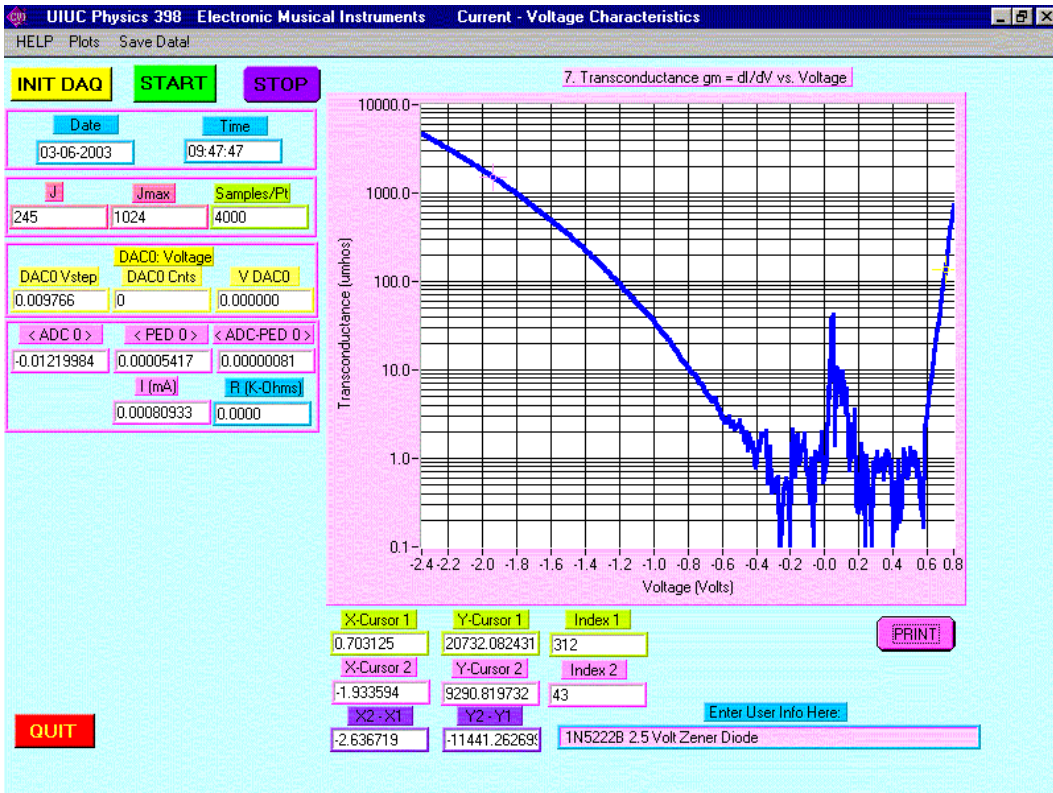Figure 11: Log(R_d) vs. V relation for 1N5222B 2.5 Volt Zener Diode

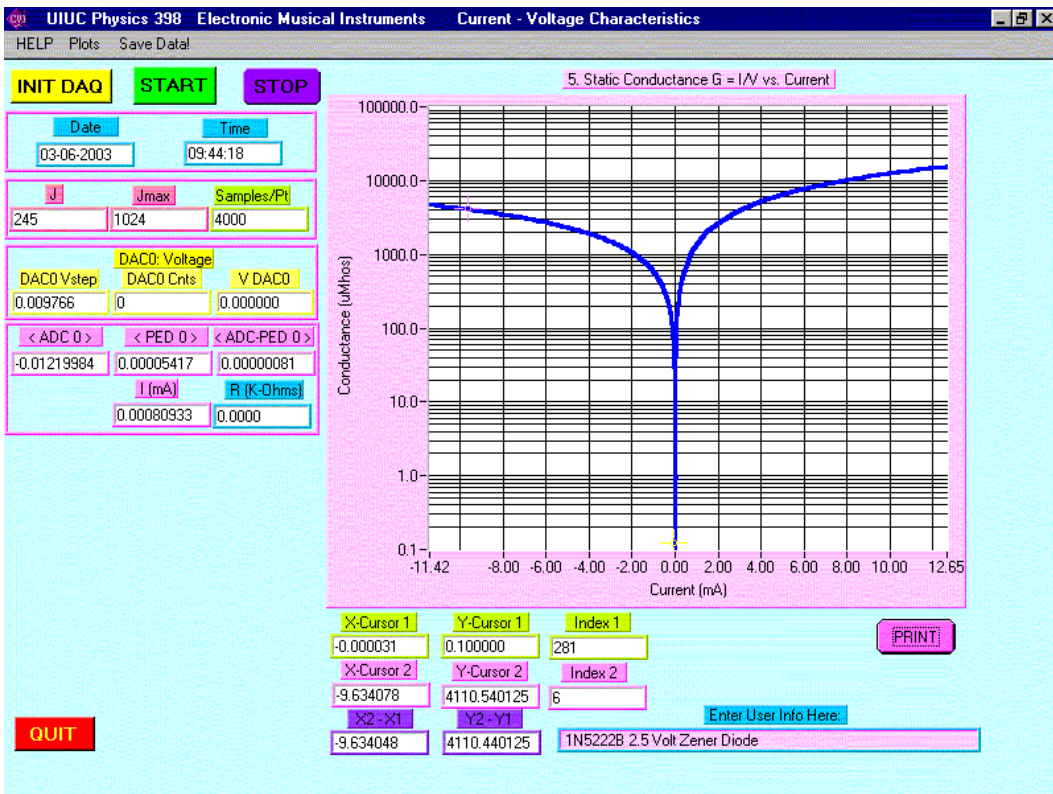Figure 12: Log(g$_m$) vs. V relation for 1N5222B 2.5 Volt Zener Diode

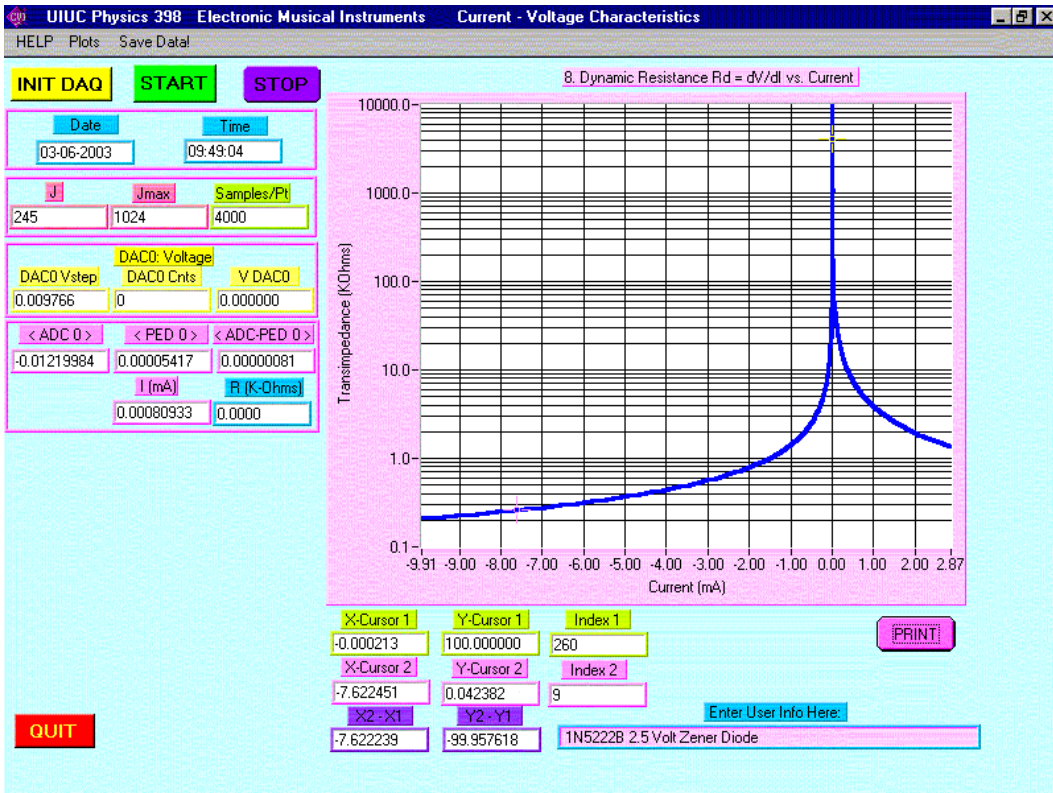Figure 13: Log(G) vs. I relation for 1N5222B 2.5 Volt Zener Diode

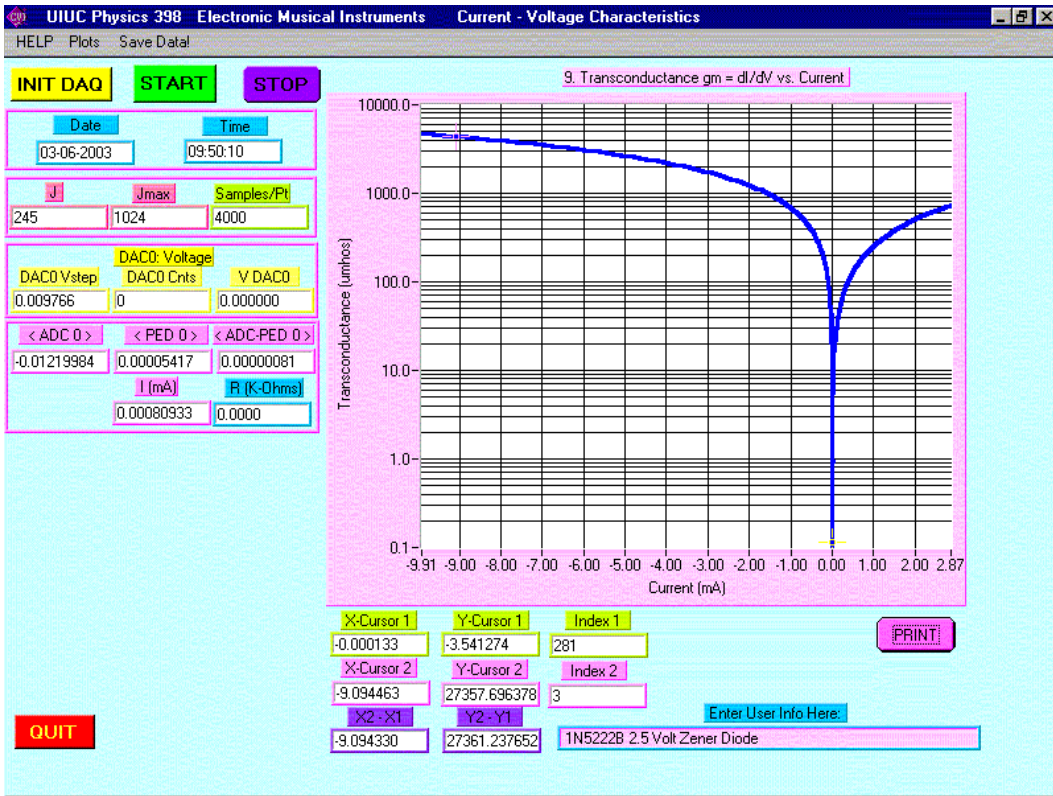Figure 14: Log(R_d) vs. I relation for 1N5222B 2.5 Volt Zener Diode

Figure 15: Log(g_m) vs. I relation for 1N5222B 2.5 Volt Zener Diode