Parameter analyzer - diode measurments

A parameter analyzer (HP 4155 in EE 330 lab or HP 4156 in EE 432 lab) is a fundamental tool for measuring the properties of semiconductor devices. In simple terms, the analyzer is a collection of high-precision sources and meters along with some dedicated software to control the measurents and present the measured data. The sources and meters can be configured in a number of ways to perform whatever types of measurements are needed to characterize a semiconductor device (diode, transistor, or whatever). Using the parameter analyzer is a bit like using Signal Express to automate measurements with the sources and meters on the lab bench, except that the sources and meters of the analyzer offer much higher precision. Also, since the parameter analyzer is dedicated to semiconductor device characterization, many of the more commonly used measurement routines are pre-programmed. In measuring our diodes and transistors, we will make use of these of "canned" programs.

The main components of the parameter analyzer are a set of "stimulus-measurement units" (SMUs). Each SMU is a combination of a source and meter and can be configured in one of two ways. An SMU can be set up as a voltage source, meaning that it sets as specific voltage at its terminal, and then measures the current that flows through the terminal. Or the SMU can be set up as a current source to providing a fixed current flow out of (or into) the terminal, while the corresponding voltage at the terminal is measured. Conceptually, the SMUs are not much different from voltage sources and the DMM that we use in the lab every day, but the SMUs are more flexible and work with much higher precision. (Voltage settings and readings are accurate to the microvolt level; current settings and readings are accurate to the nanoamp level.) Generally, each terminal of the device to be tested will be connected to one SMU. For example, the diode measurements described here require two SMUs. Later, when we measure bipolar junction transistors, we will need 3 SMUs. Field effect transistors will require 3 or 4 SMUs.

The 4155 and 4156 are fairly old instruments. (The models were discontinued in 2011 after a nearly 20-year run.) The sources and meters are still perfectly fine. What is somewhat out-of-date is the method for programming a measurement. However, once you understand the procedure, it becomes easy to set up a measurement. What is seriously out of date is the method for saving data. The 4155 and 4156 both have floppy disks for saving data. (Yes, floppy disks.) Of course, no one uses floppy disks anymore, so getting data out of the analyzer might be problematic. The 4156 in the EE 432 lab has been interfaced with a computer, so that extracting data is straight-forward. However, the 4155 in the EE 330 lab has not been interfaced to a computer, and the only practical way to save data is to use a camera to take a picture of the I-V curve on the display of the analyzer. Perhaps an enterprising student might take on the task of using Signal Express (or LabView) to interface the 4155 to a PC. Even better would be if a wealthy alumni took pity on the poor EE 230 students and provide the funds to buy a shiny new model.

“Programming” the analyzer is done in four basic steps:

1. Channel definition – Set up the function of each SMU (voltage source / ammeter or current source / voltmeter) and the function of each SMU (ground, fixed-value source, swept-value source).
2. Sweep setup – Define the range of voltages or currents to be used in the measurement. Also, set any limits to protect the devices being tested.
3. Display setup – Define the axes and limits of the graph that displays the measurement.
4. Graph/List – Run the measurement. The display and analyze the results.

We will illustrate the steps by describing some basic measurements for a conventional 1N4006 diode.

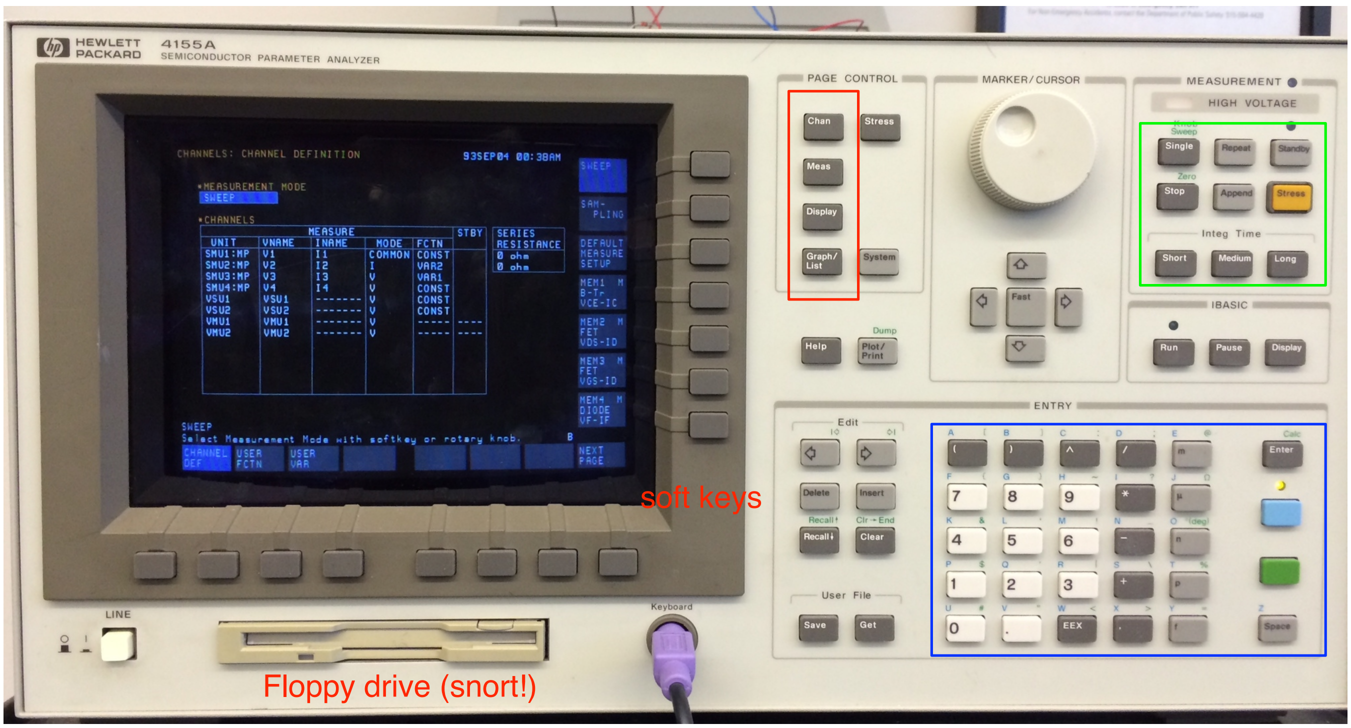

Figure 1. Front panel of 4155 parameter analyzer. (4156 front panel is identical.)

On the front panel:

1. Page control keys (inside the red box in the figure)– to jump to each of the four steps needed to set up a measurement. (Or use the “Next Page” soft key.)
2. Entry keys (inside the blue box in the figure) – to enter numbers or text when setting up measurements. Type in whatever you want and then press the “Enter” key. Note that each button is “triple-functioned” – press the blue or green keys first to change the function. When entering a voltage or current, the units are assumed to be volts or amps. If you want smaller units, use the “units” keys; m = milli-, μ = micro-, n = nano-, and p = pico-. Entering text is tedious. Use the Edit keys to fix typing mistakes.

3. Measurement (inside the green box in the figure)– start and stop measurements.
4. Soft keys – buttons along that bottom and side of the display. The function of each of these changes depending on the operating mode. (There are like the soft keys seen on the oscilloscope.)

Simple diode measurement

1. Connect a 1N4006 rectifiying diode to the analyzer. This is done using the connection box that sits on top of the analyzer. There are special connectors, but it is easy to use a breadboard for the connections. Insert the diode into two holes on the breadboard (not in the same node!) and then use the small wires to connect the anode ("wide" end) to SMU 1 and the cathode (narrow end, with the stripe) to the SMU 3. These are the SMUs that are used by the pre-set diode measurement program.

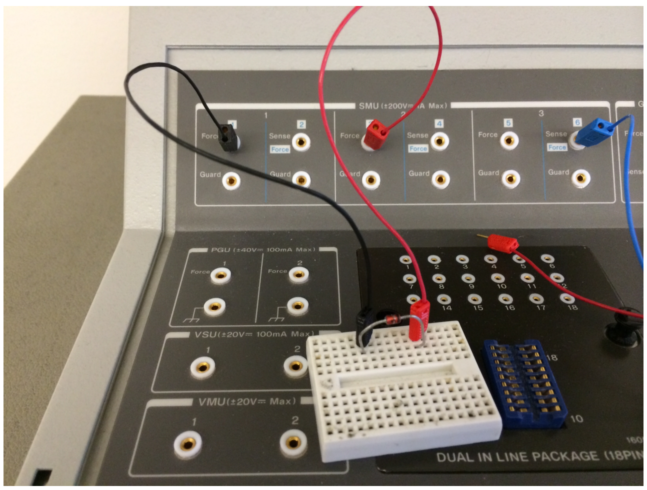

Figure 2. Diode connections. SMU1 = anode, SMU3 = cathode.

2. Press the “Chan” button to go to the first page of the set-up routine.

Figure 3. Initial view of Channel definition page.

3. Press the soft-key labeled “MEM4 DIODE VF-IF”. This enters the pre-programmed SMU set up for the diode. Note the SMU 1 is in voltage mode. Its function is listed as VAR1, meaning that the voltage of SMU 1 will be varied over some range (defined on the next page). The voltage and current are given names “VF” and “IF”. The names have no special significance – they are using in making the *I*-*V* plot. You can change them if you want, but it is not necessary. SMU 3 is defined as “COMMON”, meaning that it is the ground connection. Its function is CONST, because its value will not be changed during the measurement.

Figure 4. Channel definition page with the SMUs set up for a diode measurement.

4. Press the “Meas” key to go to the Sweep Setup page. (Or use the NEXT PAGE soft key, *twice*. Pressing the NEXT PAGE key once takes us to an intermediate page that we don’t need right now.)

On the Sweep Setup page, we define the range of voltages that will be applied to the diode. There are entries in only the VAR1 column. On the previous page, we had declared that the voltage of SMU 1 would be VAR1, so that it is entered here already. The values below in the column are default values, and generally we will want to change some of these. Use the arrow keys below the rotary knob to jump from one line to the next.

The SWEEP MODE can be left at "SINGLE". (Take only one sweep of the data.)

The LIN/LOG can left at LINEAR. (Use a linear spacing of the data points.)

Use the Entry keys to change the START voltage to -10 V. (Type in -10 and hit the Enter key. The analyzer assumes that you mean "volts".)

Change the STOP voltage to 2 V.

Change the step size to 50 mV. (Type in 50 and hit the "m" key for milli- and press Enter or type in .05 and press Enter.) Once you enter the step size, the number of steps is calculated and displayed. A smaller step size means more data points and a longer measurement time.

Change the COMPLIANCE to 50 mA. The compliance is the maximum current that will be allowed to flowed through the SMU. The purpose of setting a compliance is to protect your device. Many electronic devices are very sensitive to the large currents, and more than a few devices have been burned out while testing. Setting a low compliance helps protect against accidental frying of components. The diodes being used here will easily handle 50 mA or even 100 mA. Note that the maximum compliance allowed by the analyzer is 100 mA. There is also a POWER COMP (power compliance = maximum power dissipation allowed), but we typically do not use that.

Use the arrow keys to move over the *SWEEP box that say "STOP AT ANY". Use the soft key to change this to "CONTINUE AT ANY". This change prevents the analyzer from stopping the measurement prematurely if it thinks that some sort of error has occurred.

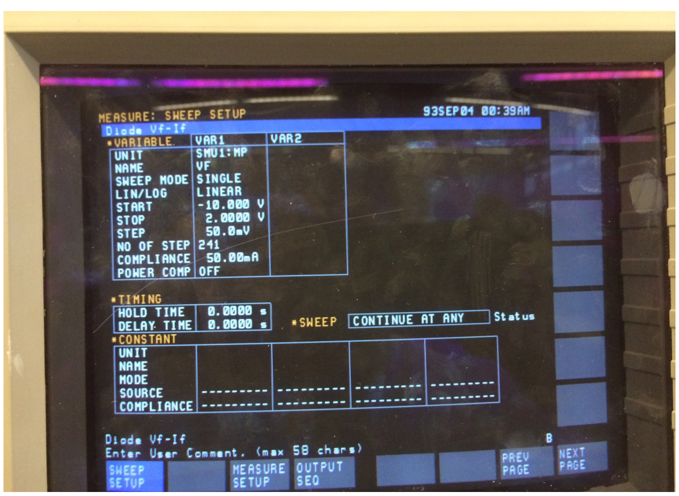

Figure 5. Sweep Setup page after all entries have been changed.

5. Press the “Display” key to move the the Display Setup page. (Or use the “NEXT PAGE” soft key.) On this page, we set up the axes and scales for the graph that will be created during the measurement.

   We want to the X-axis to be the diode voltage, VF. The SCALE should be linear. The MIN and MAX can be set to whatever you like, but it probably makes sense to use the values defined in the Sweep Setup. So change the MIN to -10 V and the MAX to 2 V.

   We want the Y1-axis to be the diode current. The scale can be linear. We don’t know what the current will be until we have actually done the measurement. You can make a guess at this point or just leave the values at the defaults. We will re-scale the graph after we have run the measurement. For this measurement there is no second variable to be plotted, so we can leave the Y2-axis column empty.

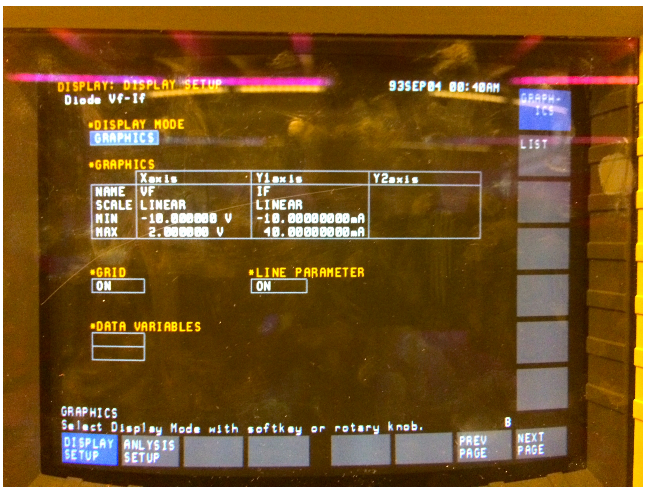

Figure 6. Entries on the Display set up page.

6. Press the Graph/List button to move to the Graph/List page. You will see an empty graph with axes that were defined on the previous page. We are finally ready to take a measurement!

Figure 7. Graph/List page just prior to taking a measurement.

7. Press the “Single” button in the Measurement section of the front panel. The analyzer begins to sweep through the range of voltages that we had defined previously, measuring the current at each voltage point. The results are plotted on the graph. While the sweep is underway, a red LED in the Measurement section of the front panel is lit. It goes out when the measurement is done.

8. Very often the data does not fit well on the default values of the axis. It may too big – extending out the top of the graph. Or too small – not even showing up on the graph. If the scaling is off, we might go back to the Display Setup page and change the vertical axis limits. However, there is a simpler method. The analyzer has an autoscaling feature that will automatically adjust the axes scales to match the measured data. To autoscale, push the SCALING soft key along the bottom of the screen and then push the Autoscale soft key along the upper right edge of the screen.

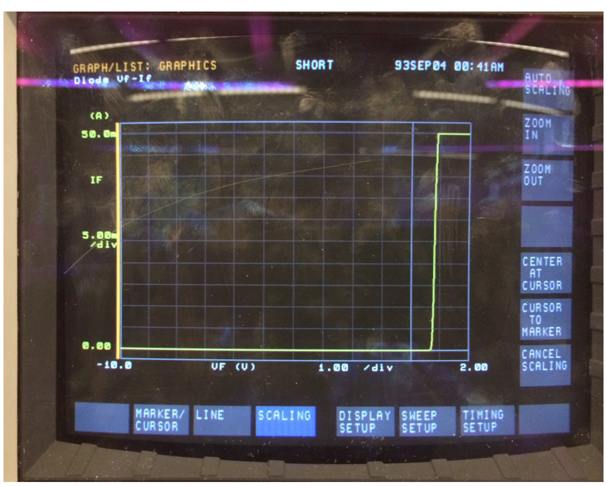

Figure 8. Diode curve after auto-scaling. It is classic. Note that the forward characteristic flattens off at 50 mA. This is due to the current compliance limit that was set on the Sweep Setup page.

Other measurements

Obtaining the simple diode curve might be sufficient. However, now that we have the basic measurement setup, we can easily look at some other features. In class, it was pointed out that it is sometimes more useful to look at just the forward characteristic, plotted using a logarithmic vertical axis. On a log scale, the exponential forward characteristic will appear as a (nearly) straight line.

As a first step, let's plot just the forward portion of the diode curve on linear scales. Go back to the Sweep Setup page and change the limits so that the voltage sweeps from 0 to 2 V, i.e. only forward bias. We can also increase the compliance to 100 mA – the 1N4006 and 1N740 diodes can both handle that amount of current. On the Display Setup page, change the MIN value of the X-axis to 0 V.

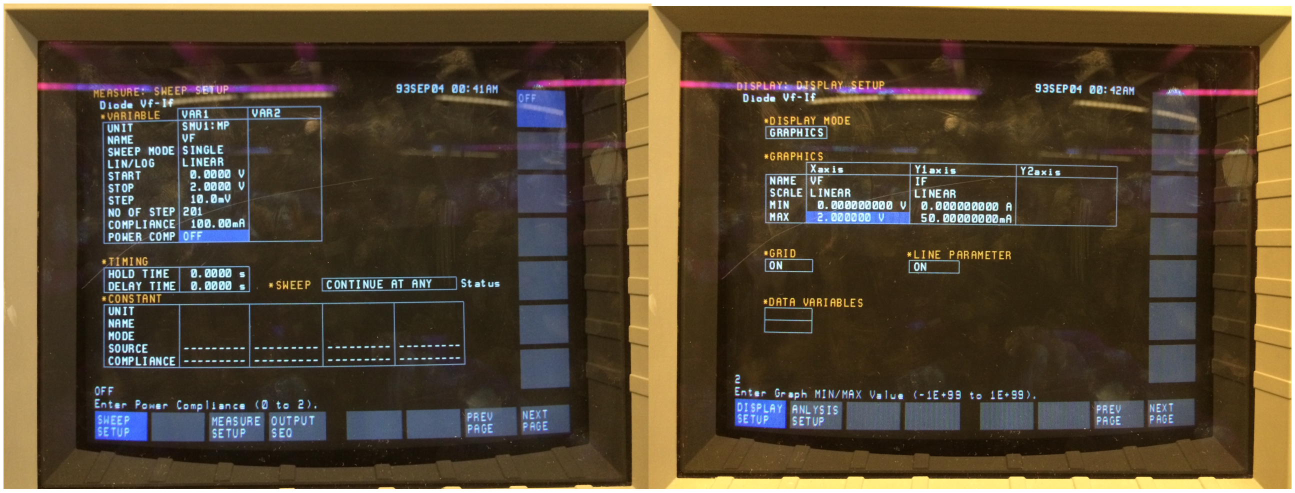

Figure 9. Sweep Setup and Display set up pages for a measurement of just the forward characteristic of the diode.

Once everything is set up, we can go back to the Graph/List page and initiate another Single sweep measurement. Then autoscale the graph to see the forward characteristic, as shown in Fig. 10.

Figure 10. Forward characteristic of the diode on linear scales. Once again, note how the compliance limit has flattened the top of the measurement.

To change the plot to have a logarithmic vertical scale, go back to the Display Setup page and change the scale of the Y1-axis to LOG. Then go back to the Graph/List page. The data will automatically be replotted on the log scale. However, there is nothing wrong with doing another measurement sweep and auto-scaling the graph.

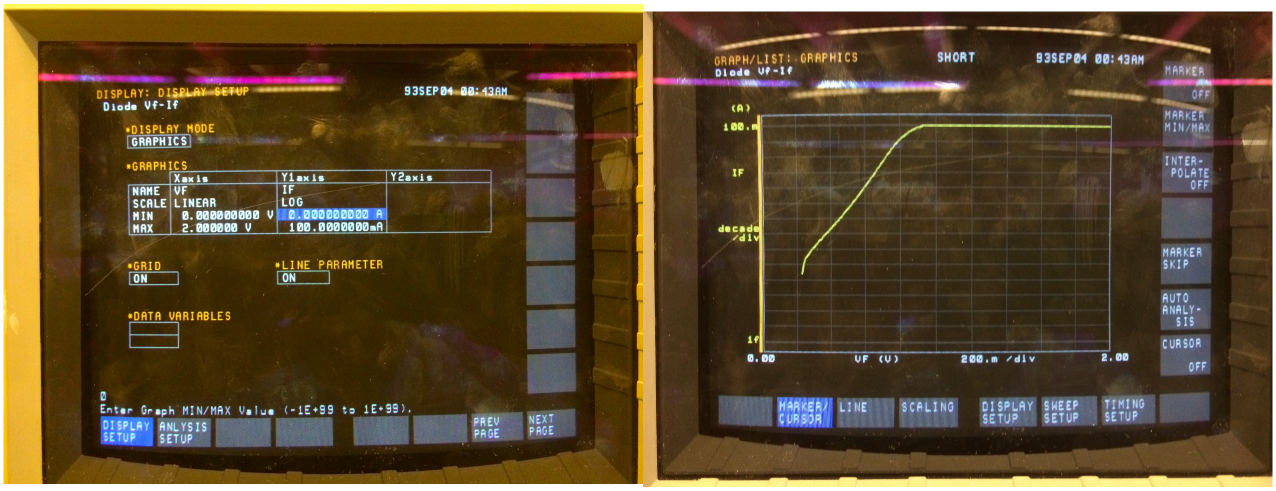

Figure 11. The Display Setup page showing the log vertical axis and Graph/List page after the voltage sweep and auto-scaling. On the log scale, the forward characteristic is (approximately) a straight line. (Real diodes are never ideal.) Much of the forward curve is compliance limited again. If we limited the voltage to a smaller range (say 0 V to 1 V) we would see less compliance limit and more of the “linear” portion.

Finally, if we are measuring a Zener diode, we might like to see the reverse breakdown characteristic.

Replace the 1N4006 diode with a 1N740 diode. Set up the measurement to sweep from -12 V to 2 V, with linear scales for voltage and current. Run a single sweep and auto-scale to get the plot shown in Fig. 12.

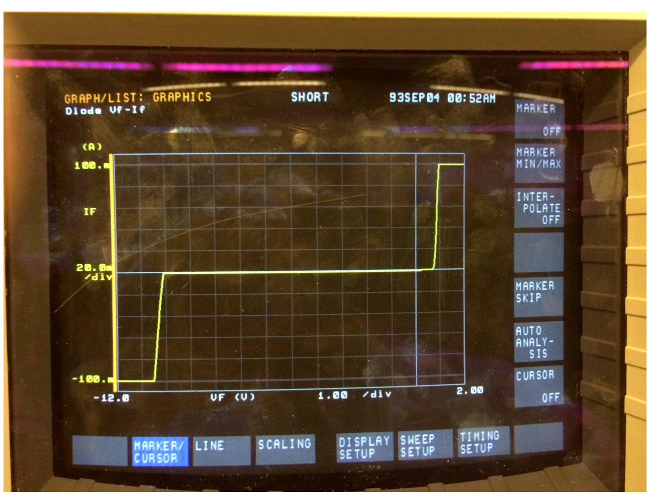

Figure 12. Forward and reverse characteristic of a 1N740 Zener diode. The reverse breakdown at –10 V is quite clear. Note that the current hits the compliance limit in both directions now.