



Experiment 1: I-V Characteristic of Semiconductor Diodes

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Purpose:

To measure current vs voltage for a pn-junction diode, and to present it in graphical form that permits extraction of diode parameters.

Method:

The voltage across a series resistor-diode circuit will be increased in steps; at each step the diode voltage and the current will be measured. Two plots will be produced: a linear plot of current vs voltage and a plot of log current vs voltage. The slope of the latter will give the ideality factor η , and its y-intercept will give the scale current I_s . These follow from the ideal diode equation

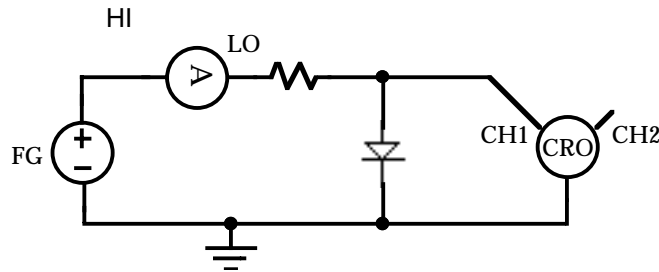
$$i_D = I_s \left(e^{\frac{v_D}{\eta V_T}} - 1 \right) \approx I_s e^{\frac{v_D}{\eta V_T}} \text{ in forward bias,} \tag{1-1}$$

and $\ln i_D = 2.303 \log 10 i_D \approx \frac{v_D}{\eta V_T} + 2.303 \log 10 I_s.$ (1-2)

Therefore, on a graph of $\log i_D$ vs v_D the slope is $\frac{1}{2.303 \eta V_T}$, and $i_D = I_s$ at $v_D = 0.$ (1-3)

Hardware Setup:

Build this circuit, with a resistor of about 1 k Ω and a 1N4006 or 1N4007 silicon pn-junction diode.



Remember that the outer sheaths of the coaxial connectors of the function generator and the oscilloscope are permanently connected to system ground. The multimeter and triple power supply, on the other hand, can be operated with all terminals floating, and can therefore be connected anywhere in the circuit, as shown in this schematic. The triple power supply does have a terminal connected to system ground, which can be used if desired.

**Software Setup:**

After placing **Panel Driver** objects for the function generator, multimeter, and oscilloscope on the screen, reset each instrument panel object before establishing its default configuration. After resetting, set the following parameters:

Function generator: Function = DC; Units = V peak-peak; Load = Infinity

Multimeter: Function = DC Amps; Auto Range = on

Oscilloscope: Channel 1 sens = 5 V/div; Probe = 10

Place **component drivers** for the three instruments on the screen. Double click them to open them, and add an **OFFSET** input data terminal to the function generator driver, a **READINGS** output data terminal to the multimeter driver, and a **MEAS_V_AVRG** output data terminal to the scope driver. This can be done in either of two ways: place the mouse over the object near the left edge and execute **ctrl a** to add an input terminal, or near the right edge and execute **ctrl a** to add an output terminal; or select the appropriate **add terminal** command from the object menu. The two procedures for deleting a terminal are similar, except that the first method uses **ctrl d** instead of **ctrl a**.

In this experiment, the oscilloscope acts as a dc voltmeter at each step of input voltage. The reason for recording its average value is to minimize the effect of random voltage fluctuations during each interval.

Connect wires from the sequence output pin of the function generator object to the sequence input pins of the multimeter and oscilloscope drivers. These connections tell the two measuring instruments to take a reading after each new input voltage value is received by the function generator. You can observe this sequence by using the debugging procedure described in the introduction to this manual. **These connections are essential; you will use them in most of the experiments in this manual.**

The input voltage values will be set by a **For Range** object (**Flow --> Repeat --> For Range**), whose output goes to the **offset** input of the function generator driver. After placing the For Range object, edit the boxes to set the initial value, final value, and increment of the voltage. A good choice for a 1N4007 pn-junction diode is -0.2 V to +3.5 V in 0.1-V steps. Connect a wire from the For Range output pin to the Function Generator input pin. When numbers are entered in objects such as this, the units (volts, amps, etc.) are never included. The only allowable non-numeric symbols are **n**, **u**, **m**, **k**, and **M** for **nano**, **micro**, **milli**, **kilo**, and **mega**, respectively; leave no spaces. For example, 0.2 may be written 200m.

The i-v plots will be displayed on **XY Plot** objects (**Display --> X vs Y Plot**). It is recommended that you place markers on the plot, which will display coordinates and intervals on the plot. This is done in the **Properties Box** of the XY plot. Right click over the object then select **Properties**, in the **Markers** group, select **Delta**, or Double click the header and in the **Markers** group select **Delta**. To produce the linear plot, connect the output of the oscilloscope driver to the x-axis pin and the output of the multimeter to the y-axis pin of one of the XY plots. It is a good idea to give meaningful names to the pins and the axis legends of the XY plot, and to the titles of all the objects that you use.

To produce the semilogarithmic plot, create a **Formula** object, open it, and enter the expression **log10(mag(a))**. The symbol **a** is the name of the default input terminal. The magnitude is used because some of the very small current values in reverse bias may appear to be negative because of random fluctuations; they would cause overflow. You might wish to change the symbol **a** to **i**, since you are measuring current. Connect the input terminal of this object to the multimeter driver output, and the output of the object to the y-axis terminal of the second X vs Y plot object. Connect the x-axis terminal of the second XY plot to the oscilloscope driver output.

One more object that is useful, but not necessary, is a **Start** button (**Flow --> Start**) connected to the sequence input pin of the For Range object. The program can be run by clicking on this or by using the **Run** command on the menu bar.

Finally, arrange your objects neatly and execute **Edit --> Clean up Lines** to make the screen more readable. Figure 1-1 shows a screen layout for this experiment. You should sketch your arrangement in your notebook.

**Procedure:**

Double click on the XY displays to open them; then run the program, observing the panel displays of the benchtop function generator and multimeter. You should see the input voltage and current values change with time on the instruments. The arrow in the menu bar will be green while the program is running.

You will also see the plots of current vs voltage being drawn on the XY displays. If a plot begins to go off scale, click the **Auto Scale** button. After the program stops, you can choose the axis limits by entering values in the appropriate boxes. You can also move the two markers to any desired positions with the mouse. Their coordinates and the differences between the coordinates are displayed at the bottom. Remember that the y-axis values on the semilog plot are the logarithms of the current.

Calculate the slope of the logarithmic plot from the expression

$$\text{slope} = m = \frac{\log 10 i_{D2} - \log 10 i_{D1}}{V_{D2} - V_{D1}} \quad (1-4)$$

Since $i_D = I_s$ at $v_D = 0$, we have

$$m = \frac{\log 10 i_{D2} - \log 10 I_s}{V_{D2}}$$

So

$$\log 10 I_s = \log 10 i_{D2} - m V_{D2}, \quad (1-5)$$

and

$$m = \frac{1}{2.303 \eta V_T} \quad (1-6)$$

Knowing that $V_T = 0.026$ V at room temperature, obtain the values for η and I_s for your diode from (1-5) and (1-6). Inspect the linear i-v plot and estimate V_f , the "turn-on" voltage of the diode. Change the y-axis limit to 100 μ A. What is your estimate of V_f now? What do you conclude about the significance of V_f from these estimates? Label and save this diode for use in later experiments.

Rerun the experiment using a 1N4733 zener diode, for which $V_{zk} = 5.1$ V. Choose voltage scan limits of ± 10 V. Do you expect the η and I_s values in forward bias to be different for the zener diode? Does the zener diode behave as expected in reverse bias? Record the value of V_{zk} , then label and save this zener diode for use in later experiments.

Repeat the experiment, using a light-emitting diode (LED), and determine η and I_s . How can you tell that the LED is not made of silicon?

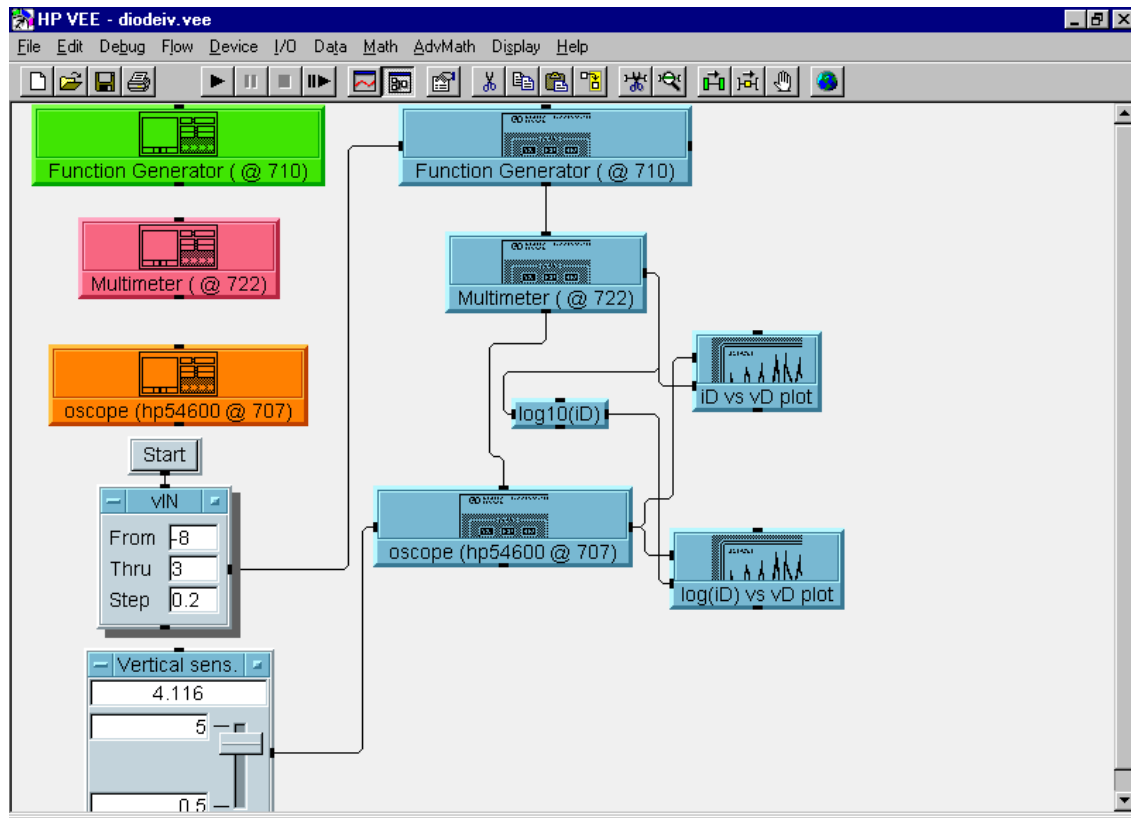


Fig. 1-1 Agilent VEE Setup for Measurement of the Diode i-v Characteristic