University of California at Berkeley
Physics 111 Laboratory
Basic Semiconductor Circuits (BSC)

Lab 4

Semiconductor Diodes

References:

Sedra & Smith	Chapter 3
Hayes & Horowitz	Pages 65–69, 71–74, 76–78
Horowitz & Hill	Chapters 1.06, 1.25–1.31, 4.15, Appendix F
Lab notes	Sections on Small Signal Input and Output Impedance in the Linear Circuit I lab

This is the first of three labs on basic semiconductor components. You will study semiconductor characteristics and some of their applications, leading up to the design and construction of a differential amplifier.

This lab studies diodes. You will find the relation between the voltage and current in a diode, and study temperature effects, rectification, nonlinear phenomena, and frequency doubling.

Before coming to class complete this list of tasks:

- Completely read the Lab Write-up
- Answer the pre-lab questions utilizing the references and the write-up
- Perform any circuit calculations or anything that can be done outside of lab.
- Plan out how to perform Lab tasks.

Pre-lab questions:

1. In a few sentences, explain what diodes are and how they are useful.
2. Show that the −1 term in Eq. (1) may be neglected for typical operating parameters ($V > 0.1$ V, $kT \approx 1/40$ eV, $I_{sat} = 10^{-9}$ A).
3. Why is there a ripple on top of the DC voltage output by the circuit in 4.8?
4. What is a load line used for? What are the relative advantages of graphical and iterative analysis?

Disclaimer: Please keep in mind that this lab is one of the most analysis & plotting intensive labs. Do not leave your analysis section to the last minute. Also, using a computer to do the analysis is much easier & quicker; so, bring a storage device to class or alternatively e-mail yourself the data files from the diode characteristic traces found by the Curve Tracer so you will have access to them both at your lab station and home. Excel is a powerful timesaver when graphing similar data sets mulitiple times. A final safety tip, Do not touch components while power is on only after they have had a chance to cool off . This is especially true if the circuit has been build wrong.

The LEDs will burn out if you hook them directly to the 5V power supplies without a current limiting resistor.

NOTE: This lab uses liquid nitrogen.

Background

Diodes and pn Junctions

Diodes and transistors are made from semiconducting materials: typically crystalline silicon. Pure silicon has few free electrons and is quite resistive. To increase its conductivity, the silicon is normally "doped"[1] with other elements. Some dopants, like phosphor, arsenic and antimony, easily give up one of their electrons to the now impure silicon.[2] As these donated electrons are free to move about the silicon, its conductivity increases dramatically.[3]

Other dopants, like boron, indium and aluminum, grab electrons from the surrounding silicon atoms, leaving positively charged silicon ions behind. In turn, these now positive silicon ions try to lessen their charge by grabbing electrons from their neighbors…the net result is that there are regions of "positiveness" floating around the crystal lattice. Such "absences of electrons" are called ***holes*****.** Amazingly, holes behave almost exactly like positively charged electrons; they move, respond to electric fields, and appear to have a mass close to the electron mass.

A doped semiconductor with more mobile electrons than holes is called an "n-type" semiconductor; conversely, a doped semiconductor with more holes than mobile electrons is called a "p-type" semiconductor.

If doping's only effect was to increase semiconductor conductivity, semiconductors would be obscure, little-used materials. The utility of semiconductors comes from the remarkable effects of placing p and n-type materials next to each other. Such juxtapositions are called "pn" junctions. An isolated pn junction makes a semiconductor diode. Other semiconductor components are made from more complicated arrangements; bipolar npn transistors, for example, are made by sandwiching a p layer in between two n layers, hence the name npn.

The current through an ideal pn junction is given by the diode equation.

$$i(V) = i_{\text{sat}}\left[\exp\left(\frac{eV}{nkT}\right) - 1\right], \qquad (1)$$

where V is the voltage drop across the junction, i_{sat} is a constant called the saturation current and depends on the temperature and the particular geometry and material of the junction, $e = 1.6 \times 10^{-19}$ C is the charge of an electron, $k = 1.38 \times 10^{-23}$ J/K is Boltzmann's constant, and T is the temperature in Kelvin.[4] The constant n varies between 1 and 2 depending on the particular diode, but is typically equal to 2 for discrete diodes. Notice that the diode's response is directional and highly nonlinear. When ***forward*** biased, (V positive) enormous currents can flow through the diode because of the exponential dependence of I on V. When ***reverse*** biased, (V negative), the current approaches $-i_{\text{sat}}$. Since i_{sat} is typically very small (picoamps are not uncommon), very little current flows.[5] Thus the diode acts like a one-way valve; current can only flow in one direction.

When forward biased, the positive end of the diode is called the anode, and the negative end is called the cathode.[6]


_The triangle side is the anode and the vertical line side or bar is the cathode.

[1] Deliberately contaminated.

[2] Of course, dopants that have given up an electron become positively charged. The net charge remains zero.

[3] Only a few dopant atoms will significantly increase silicon's conductivity. For example, one dopant atom per 100 million silicon atoms will increase pure silicon's conductivity by approximately 10^5.

[4] At room temperature, $kT/e \approx 1/40$.

[5] Junction imperfections in real diodes often cause the reverse biased current to be much bigger than $-i_{\text{sat}}$. However, Eq. (1), with the ideal value of i_{sat}, is still valid in the forward region.

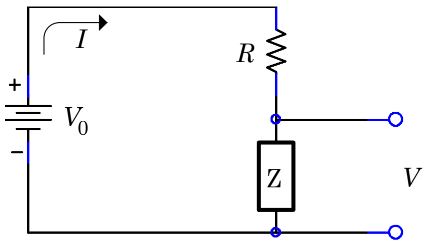
[6] The terms anode and cathode date from the days of vacuum tube diodes.

Nonlinear Circuit Equilibrium

Unlike purely linear circuits, circuits containing nonlinear elements like diodes cannot be reduced to systems of linear equations. Consequently, the equilibrium voltages and currents in nonlinear circuits are much more difficult to determine. Although these equilibrium quantities can be found using complicated computer programs like **PSpice**, quick, approximate analysis methods are often useful, particularly for simple circuits. Two quick methods will be used in this course: (I) Graphical Analysis and (II) Iterative Analysis

(I) Graphical Analysis – Load Lines

Consider the simple circuit below which contains a voltage source V_o, resistor R and a generic nonlinear component with impedance $Z(V)$, where V is the voltage across the component.

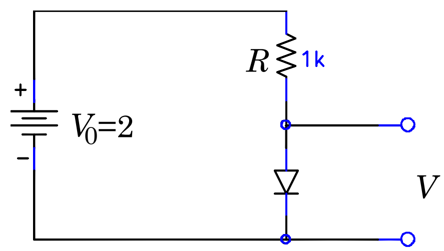


Regardless of behavior of the nonlinear component, the voltage source and resistor set certain constraints[7] on the possible equilibrium voltages and currents. For instance, the current I cannot exceed V_o/R, the current that flows when the impedance of the nonlinear component Z is zero. Under these conditions, the voltage V across the nonlinear component is zero. Alternately, V cannot exceed the voltage of the source V_o, and this maximum voltage is only obtained when the impedance Z is infinite and $I = 0$. Impedances between zero and infinity produce intermediate values of the current and voltage. The possible values fall on a curve given by the parametric equations $I = V_0/(R+Z)$ and $V = ZV_0/(R+Z)$, where Z varies between zero and infinity. Eliminating Z demonstrates that the curve is actually a straight line given by the equation

$$I(V) = (V_0 - V)/R\,. \qquad (2)$$

This equation could have been derived directly from its end points, $I = V_o/R$ at $V = 0$ and $I = 0$ at $V = V_o$, or even more simply by computing the current through a resistor as a function of V. The line determined by Eq. (2) is called the ***load line*** because it is determined solely by the load (and the power source), not by the nonlinear component.

The nonlinear component obeys its own equation, or "characteristic" curve $I_Z(V)$. Both the load line and the characteristic curve must be satisfied simultaneously. Consequently the equilibrium current and voltage for the circuit are given by the intersection of the load line (Eq. (2)) and the characteristic equation $I_Z(V)$. For example, assume that the nonlinear component is a diode ($i_{sat} = 4 \times 10^{-10}$ A) driven by a 1k resistor from a 2V battery.



[7] Assume that the nonlinear device does not contain any internal power source, hence $\mathrm{Re}(Z) \geq 0$.

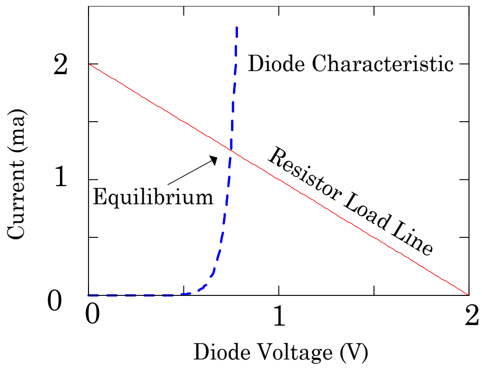


Fig. 1: Resistor Diode Equilibrium

The load line and diode, 1N4448 characteristic (Eq. 1) intersect, as shown to the left, at equilibrium voltage
$V = 0.75$ V and current $I = 1.25$ mA.

The equilibrium voltage across the diode is sometimes called the **operating point** of the circuit.

(II) Iterative Analysis

Nonlinear equilibria can also be found iteratively: by guessing an initial solution, determining the consequences of the guess, and then iteratively refining the guess. This method is best explained with an example: Using the diode circuit in Fig. 1, guess a current (say $i = 5$ ma), and then invert the diode characteristic $\left[V(i) = (nkT/e)\ln(i/i_{sat}+1)\right]$ to find the voltage across the diode that would have produced this current ($V = 0.81706$ V). Next subtract this voltage from the battery voltage to determine the voltage across the resistor ($V_o - V = 1.18294$), and divide by the resistance R to refine the current guess (1.18294 mA). Repeat and continue iterating until the numbers converge.[8] The first five iterations are given in the table below.

Iteration	Current (mA)	Diode Voltage (V)	Resistor Voltage (V)
Initial Guess	5.00000	0.81706	1.18294
1	1.18294	0.74499	1.25501
2	1.25501	0.74795	1.25205
3	1.25205	0.74783	1.25217
4	1.25217	0.74783	1.25217
5	1.25217	0.74783	1.25217

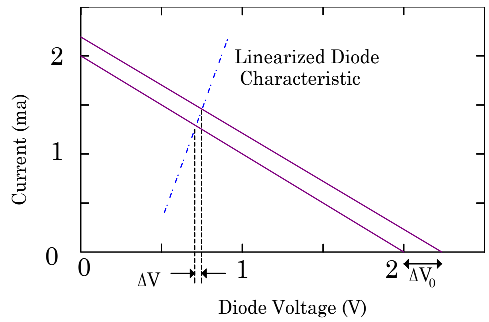
Both the load line analysis and the iterative analysis yield the same values for the equilibrium voltage and current. [Note that the diode equation [Eq. (1)] was used in both methods. With some loss in precision,[9] experimental data taken from an actual diode can be used instead.]

[8] Be careful: iterative methods do not always converge. In fact, running the described sequence backwards (guess the diode voltage, calculate the current, find the resistor voltage drop, and subtract from the battery voltage to refine the diode voltage guess) does not converge. Try it yourself! The study of the convergence of these methods is called Iterated Map Theory, and, surprisingly, is the basis for modern Chaos Theory.
An animation and a Mathcad program illustrating converging and nonconverging iterative procedures are available on the web and on the computer in the lab.

[9] Of course the apparent precision of the iterative method is deceptive as it relies on precise knowledge of i_{sat} and n. Don't worry; answers with accuracy's better than 10% are rarely required in electronics.

Perturbation Analysis

Determining a circuit's response to small changes in its parameters is as important as determining its initial equilibrium. The general subject of the response of a system to small parameter changes (perturbations) is called perturbation analysis. In the circuit of Fig. 1, for example, perturbation analysis can be used to determine the change in the diode voltage when small changes are made to the source voltage.



(i) Graphical Perturbation Analysis

By definition perturbation analysis considers only small changes to the system parameters. Consequently it is both convenient and permissible to linearize around the equilibrium conditions. Using the circuit in Fig. 1 as an example, consider a small change in the battery voltage of $\Delta V_o = +0.25$ V. This perturbation will shift the load line upwards as shown to the below,[10] and the intersection will shift concomitantly. The change in the diode voltage ΔV can then be read off the graph from the new intersection point. In this case, ΔV is much smaller than the change in the battery voltage ΔV_o.

(ii) Small Signal Impedance Perturbation Analysis

The above graphical procedure is completely equivalent to the following method: First calculate the small signal impedance Z of the nonlinear diode at its operating point. The small signal impedance is the reciprocal of the slope of the IV curve,

$$Z = \frac{\partial V}{\partial I},$$

at the operating point. Then use Z in a "linear" circuit analysis. Because the IV curve is not linear, Z must be recalculated if the voltage across the diode changes (i.e. if the operating point changes).

In the lab

(A) Forward and Reverse Diode Behavior

4.1 Obtain a 1N4448 diode.[11] Use a BNC cable and minigrabbers to connect the DMM to the diode. Set the DMM to the 2k-resistance scale; the diode symbol printed on this scale indicates that it is the preferred scale for diode measurements. Confirm that the diode conducts unidirectionally by measuring its resistance in both directions. The DMM is set up so that the red minigrabber lead is positively biased referenced to the black lead. Thus, for conduction, the red lead should be attached to the diode anode, and the black lead should be attached to the cathode. On the diode itself, the cathode is marked by a black band.

You should find that the diode resistance is about 650Ω in the forward direction, and off scale in the reverse direction. Since the meter attempts to provide about 1mA of current on the 2kΩ scale, 650Ω corresponds to a voltage drop across the diode of about 0.65V. This voltage drop is referred to as the "forward voltage drop" at 1mA.

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[10] For graphical clarity, the slope of the linearized diode characteristic has been decreased; otherwise ΔV would have been so small as to be unprintable.

[11] The label 1N4448 designates the type of diode. Hundreds of different types of diodes are available. Many types are made by several different manufacturers; each manufacturer certifies that their diode meets the industry-wide specifications. Parts with labels that begin with 1N are always diodes, while parts that begin with 2N are transistors, but not all diodes and transistors follow this naming convention. Specifications for the 1N4448 diode are given in Appendix I.

4.2 Obtain a plastic-stick-mounted 1N4448 diode from the laboratory staff. Repeat your measurement of the forward voltage drop using the DMM. Does this diode have exactly the same forward voltage drop as the diode you used in part 4.1? Squeeze the diode between you fingers. The forward voltage drop should change as the diode heats up to your finger temperature. What is the new value? For more dramatic results, dip the diode into liquid nitrogen, which you can obtain from the laboratory staff. What is the forward voltage drop now? Diode forward voltage drops are frequently used as temperature sensors.

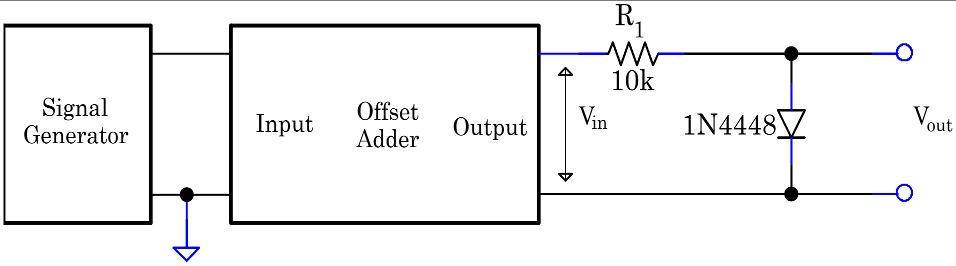
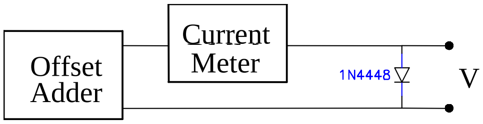


Figure 2 Diode Analysis

DMM resistance measurements are a useful crude indicator of diode performance, and are often used to determine if a diode has been burnt out. However, DMM measurements are single current measurements, and do not determine the complete forward voltage/forward current characteristic curve. The most straightforward way to obtain this curve is to measure the current while driving the diode with a variable voltage source.

4.3 Now you will examine the Offset Adder, ***which is located on the breadboard box***, to see how the Adder works. Temporarily ignore the input BNC jack. Measure the output voltage while turning the Offset Adjust knob. See how the voltage can be varied from approximately –12 to 12V? Try loading the output with several different resistor values. Prove that the circuit is a relatively stiff (low output impedance) voltage source so long as the output current is kept below approximately 24mA.

4.4 Construct the circuit below.



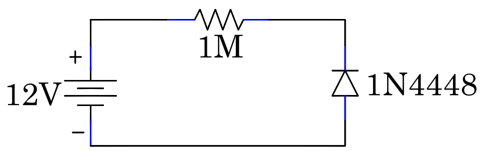
Vary the voltage across the diode with the offset adder. Record both the current and the voltage at about five points. Plot the resulting characteristic curve on linear and on log-linear paper.

Warning: Because diodes of the same type can have significantly different characteristics, use the same diode for all experiments in this lab. If you need to use your diode on another day, mark it with a piece of tape with your name and leave it on the lab bench.

Obtaining enough points to carefully characterize the diode is tedious. Moreover, the slow rate at which the data is collected allows the diode to significantly heat up at the high current points, disturbing the measurement. A ***Curve Tracer*** is an instrument that automatically and relatively quickly measures characteristic curves.

4.5 Use the Curve Tracer to find your diodes characteristic curve. Use the Curve Tracer analyze function to obtain the values of i_{sat} and the voltage coefficient. Assuming that the diode is at room temperature, calculate n. Plot the Curve-Tracer data, and add the points that you obtained in part 4.4 to the graph. (See Appendix II for operation instructions for the Curve Tracer & the meaning of the voltage coefficient.)

4.6 Measure the reverse diode current at –12V with the circuit below.



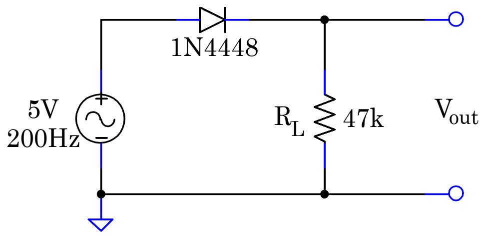
Determine the current through the diode by measuring the voltage across the resistor.

(B) Diode Rectifier

Since diodes carry current only in one direction, they can be used to ***rectify*** AC signals: to turn AC signals into DC. In fact, diodes are sometimes called rectifiers. Rectification is very important in electronics because, although almost all circuits run off of DC,[12] the electric company provides AC power.

[12] Two of the few circuits that run directly on AC power are light dimmers and some electric motor controllers.

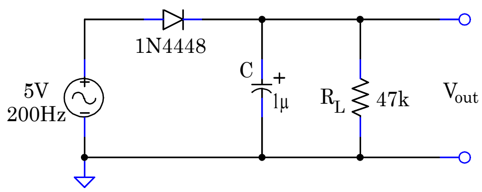
4.7 Build the half-wave rectifier circuit below.



Using both channels of the scope, look at the voltage across the AC source and the circuit output. Sketch both signals, and explain the output.

Rectification, as provided by the previous circuit, is only the first step in converting an AC power source into a DC power supply. The gross irregularities in the signal produced by the above circuit need to be smoothed out, typically by a large filter capacitor.

4.8 Add a 1μF capacitor to your circuit. **(If you use an electrolytic capacitor, make sure you obey the polarity markings on the capacitor body.)**



Make careful sketches of the output waveform. Note the amplitude of the ripple. How does it change when you: **a)** double the input frequency; **b)** double the filter capacitor *C*; **c)** double the load resistor R_L? (See analysis question 4.15)

(C) Diode Equilibrium

4.9 Using the same diode as before, build the circuit shown in Fig 2. Study the DC response of the circuit by temporarily disconnecting the signal generator. Vary V_{in} by turning the Offset Adjust knob on the Offset Adder. What is V_{out} for V_{in} = 0.25, 0.5, 0.7, 1, and 2 VDC? Select a different resistor, say R_l = 1k. Again measure the output voltage for several input voltages. Using the graph of the diode characteristic you obtained in question 4.5, perform a graphical load line analysis for each of the resistors. Do the equilibrium points predicted by the load line analysis agree with your data? (See Appendix III for an Excel tutorial.)

(D) Small-Signal Behavior

4.10 When a signal is connected to the Offset Adder's Input BNC, the Adder's output is the sum of the input signal and the internal offset set by the Offset Adjust knob. Reconnect the signal generator to the Offset Adder, and temporarily disconnect the resistor and diode. Examine the Offset Adder's output on the scope, and play with different offsets and inputs until you understand the Offset Adder's function. (You need not record anything.)

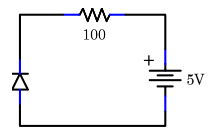
4.11 Reconnect the 10k resistor and diode to the Offset adder. (You should now be back to the circuit in Fig. 2.) Adjust the signal generator and Offset Adder to produce a 0.1 V p-p sine wave riding on a +1V DC offset. Sketch V_{out}. In contrast to the output signal produced the circuit in 4.7, the signal is not rectified, i.e. the lower half is not cut off. Explain why.

4.12 What happens to the amplitude of the AC component of the output signal as you vary the DC offset? With the values for the DC offset used in 4.9, record the amplitude of the AC component of the output signal. Plot the measured data. (See analysis question 4.16 and 4.17)

(E) Light Emitting Diodes (LEDs)

LEDs are diodes made from the semiconducting material Gallium Arsenide (GaAs) rather than from silicon. GaAs junctions have the very useful property that they emit light when forward biased.

4.13 Construct the circuit below using an LED for the diode.



The longer lead on the LED is the anode, and the flat on the side of the LED is on the cathode side. The LED should not light. Measure the voltage across the resistor to demonstrate that no current is flowing. Now swap the power supply polarity; the LED should light. Measure the voltage drop across the resistor and LED. Substitute 300Ω, 3k, 30k, and 300k resistors for the 100Ω resistor. How does the brightness of the LED change? How does the forward voltage drop change? Note: these voltage measurements can be done with either the DMM or the Scope, but you will find more accuracy and save time using the DMM.

4.14 Find the LED's characteristic curve using the Curve Tracer.

Analysis

Comment [DJO1]: Too time consuming how can we shorten this?

4.15 Derive an (approximate) expression for the (peak-to-peak) amplitude of the ripple in the rectifier built in 4.8 as a function of the input voltage and frequency, load resistor, and filter capacitor. Does your model agree with your observations?

Comment [DJO2]: Suggest a method of modeling many groups had problems with this

4.16 Perform a graphical perturbation analysis for three of the points in exercise 4.12 to predict the AC amplitude of the output. To do this, use the diode characteristic curve you obtained in 4.5 and values of the operating point from 4.9. Remember that the DC offset is the operating point voltage & the 0.1 V_{p-p} sine wave is the perturbation. Plot the predicted data on the same graph as the data you measured in 4.12.

4.17 Now make a new set of predictions for three of the points in exercise 4.12 by calculating the small signal impedance of the diode at each operating point. Use this impedance in a "linear" voltage divider analysis. Plot these predictions on the 4.12 graph. Show how the large-signal impedance would yield a voltage divider output much greater than the actual answer.

Comment [DJO3]: Again more prelab instruction on small and large signal impedance is necessary.

Supplementary Problems

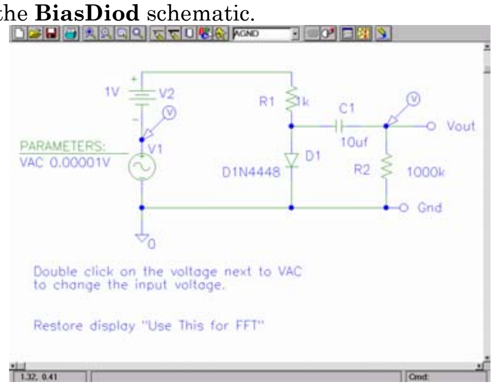
(F) Zener Diode

4.18 Circuits frequently require DC voltages less than the circuit power supply voltage. Such voltages can be obtained with voltage dividers, but dividers are not stiff and will decrease when heavily loaded. Furthermore, the divider voltage will follow any power supply voltage fluctuations. A better scheme is to use a resistor, R_S in series with a Zener diode. Use the Curve Tracer[13] to obtain the characteristic curve of a 1N5234B or the equivalent 6.2V Zener diode.[14] Design and build a circuit with the Zener that will reduce a voltage from 12V to 6.2V. The current going through R_S should be limited to 15mA. What is the smallest load resistor that will not significantly decrease the circuit output voltage?

(G) Frequency Doubling

Many nonlinear devices (including diodes) exhibit the very useful phenomenon of frequency doubling; when driven by a sufficiently high amplitude signal, they double the signal's frequency.[15]

4.19 We will study frequency doubling in a Spice diode circuit. Go to a computer running Spice, and call up the **BiasDiod** schematic.



The Spice circuit is very similar to the circuit in Fig. 2; capacitor C1 and resistor R2 are simply used to block the DC component of the signal across the diode. The parameter VAC sets the amplitude of the AC signal driving the diode, while V2 (1V) sets the DC bias. VAC can be changed by double clicking on the numeric value to its right, while V2 can be changed by double clicking on the number to its left.

Set VAC to 0.00001. Here nonlinear effects are negligible. Run Spice, and look at the output. The graphics program (Probe) will pop up with a display of the input signal (at the amplitude 0.00001V) and the smaller output signal. As both waveforms look like perfect sine waves, it is difficult to determine the purity of the waves directly from these plots. The best way to determine their spectral content is to find their Fourier representation. Use Window→Display Control to examine the Save/Restore Menu, and Restore the "Use this for FFT" display. The display will change to graphs of the Input and Output harmonic content. Both waves are nearly pure sine waves (Note the log verti-

[13] Make sure you switch from the Diode Tracer window to the Zener Diode Tracer window.

[14] The Zener diode spec sheet is posted on the web.

[15] Frequency doubling is frequently employed to produce short-wavelength coherent light. Few lasers laze in blue or shorter wavelengths. Powerful red lasers, however, are easy to build. The output from such red lasers can be fed into a frequency doubling crystal…and blue light will come out. This blue light can then be fed into another crystal, yielding ultraviolet light. Although the process is lossy, frequency doubling is the most effective way of making intense, short-wavelength laser pulses.

cal scale.) The input sine wave does have some low level, white noise[16] background that results from the numerics used in the Spice algorithm. The output waveform has some components near zero frequency; these components are numeric artifacts that result from the finite time that the simulation is run.

Now go back to the schematic and adjust VAC to 1V. Rerun the simulation, and note the gross distortion of the output wave. Look at the FFT display: in addition to the double frequency component, there is now a whole series of slowly decreasing higher harmonics.

Play with VAC. What is the lowest amplitude input signal required for significant frequency doubling? Are the harmonics ever stronger than the fundamental? Why do you think the frequency doubling occurs?

[16] Noise that is evenly distributed over all frequencies is called white noise. Examples of white noise include the steady drone from a distant highway or waterfall.

Physics 111 ~ BSC *Student Evaluation of Lab Write-Up*

Now that you have completed this lab, we would appreciate your comments. Please take a few moments to answer the questions below, and feel free to add any other comments. Since you have just finished the lab it is *your* critique that will be the most helpful. Your thoughts and suggestions will help to change the lab and improve the experiments.

Please be specific, use references, include corrections when possible, using both sides of this paper as needed, and *turn this in with your lab report*. Thank you!

Lab Number: ________ Lab Title: ____________________________________ Date: ______________

Which text(s) did you use?

How was the write-up for this lab? How could it be improved?

How easily did you get started with the lab? What sources of information were most/least helpful in getting started? Did the pre-lab questions help? Did you need to go outside the course materials for assistance? What additional materials could you have used?

What did you like and/or dislike about this lab?

What advice would you give to a friend just starting this lab?

The course materials are available over the internet. Do you (a) have access to them and (b) prefer to use them this way? What additional materials would you like to see on the web?

Appendix I Diode Specifications

Philips Semiconductors **Product specification**

High-speed diodes 1N4148; 1N4446; 1N4448

FEATURES

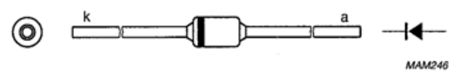
- Hermetically sealed leaded glass SOD27 (DO-35) package
- High switching speed: max. 4 ns
- General application
- Continuous reverse voltage: max. 75 V
- Repetitive peak reverse voltage: max. 75 V
- Repetitive peak forward current: max. 450 mA
- Forward voltage: max. 1 V.

APPLICATIONS

- High-speed switching.

DESCRIPTION

The 1N4148, 1N4446, 1N4448 are high-speed switching diodes fabricated in planar technology, and encapsulated in hermetically sealed leaded glass SOD27 (DO-35) packages.



The diodes are type branded.

Fig.1 Simplified outline (SOD27; DO-35) and symbol.

LIMITING VALUES

In accordance with the Absolute Maximum Rating System (IEC 134).

SYMBOL	PARAMETER	CONDITIONS	MIN.	MAX.	UNIT
V_{RRM}	repetitive peak reverse voltage		–	75	V
V_R	continuous reverse voltage		–	75	V
I_F	continuous forward current	see Fig.2; note 1	–	200	mA
I_{FRM}	repetitive peak forward current		–	450	mA
I_{FSM}	non-repetitive peak forward current	square wave; T_j = 25 °C prior to surge; see Fig.4			
		t = 1 μs	–	4	A
		t = 1 ms	–	1	A
		t = 1 s	–	0.5	A
P_{tot}	total power dissipation	T_{amb} = 25 °C; note 1	–	500	mW
T_{stg}	storage temperature		–65	+200	°C
T_j	junction temperature		–	200	°C

Note

1. Device mounted on an FR4 printed circuit-board; lead length 10 mm.

Philips Semiconductors Product specification

High-speed diodes 1N4148; 1N4446; 1N4448

ELECTRICAL CHARACTERISTICS

T_j = 25 °C; unless otherwise specified.

SYMBOL	PARAMETER	CONDITIONS	MIN.	MAX.	UNIT
V_F	forward voltage	see Fig.3			
	1N4148	I_F = 10 mA	–	1.0	V
	1N4446	I_F = 20 mA	–	1.0	V
	1N4448	I_F = 5 mA	0.62	0.72	V
		I_F = 100 mA	–	1.0	V
I_R	reverse current	V_R = 20 V; see Fig.5		25	nA
		V_R = 20 V; T_j = 150 °C; see Fig.5	–	50	μA
I_R	reverse current; 1N4448	V_R = 20 V; T_j = 100 °C; see Fig.5	–	3	μA
C_d	diode capacitance	f = 1 MHz; V_R = 0; see Fig.6		4	pF
t_{rr}	reverse recovery time	when switched from I_F = 10 mA to I_R = 60 mA; R_L = 100 Ω; measured at I_R = 1 mA; see Fig.7		4	ns
V_{fr}	forward recovery voltage	when switched from I_F = 50 mA; t_r = 20 ns; see Fig.8	–	2.5	V

THERMAL CHARACTERISTICS

SYMBOL	PARAMETER	CONDITIONS	VALUE	UNIT
$R_{th\ j\text{-}tp}$	thermal resistance from junction to tie-point	lead length 10 mm	240	K/W
$R_{th\ j\text{-}a}$	thermal resistance from junction to ambient	lead length 10 mm; note 1	350	K/W

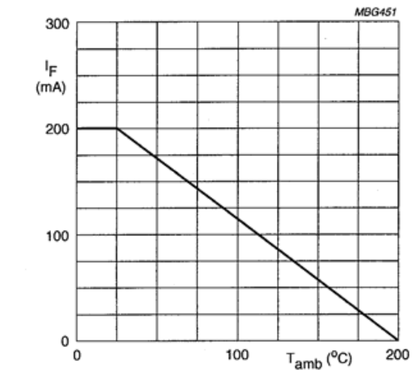
Note

1. Device mounted on a printed circuit-board without metallization pad.

Philips Semiconductors Product specification

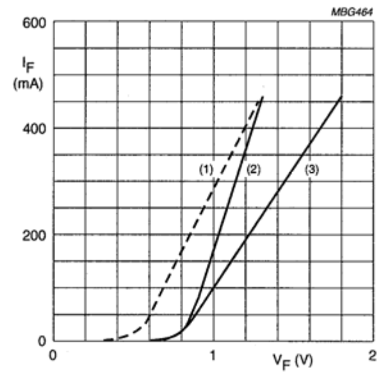
High-speed diodes 1N4148; 1N4446; 1N4448

GRAPHICAL DATA



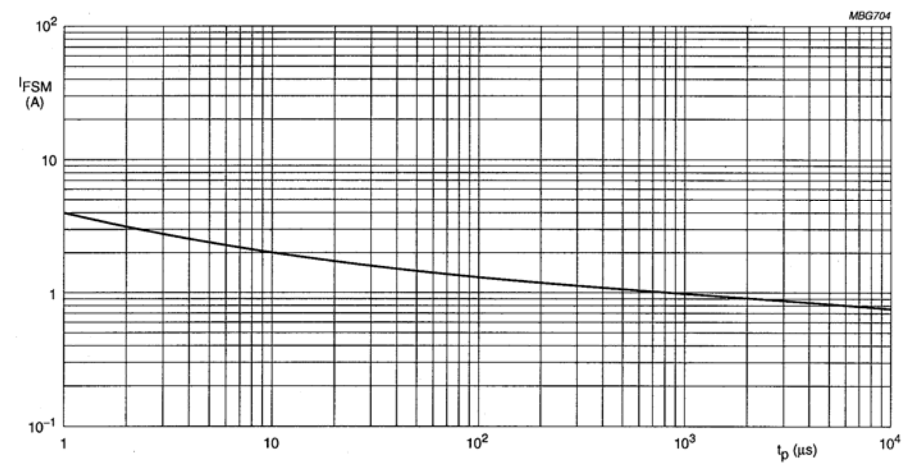
Device mounted on an FR4 printed-circuit board; lead length 10 mm.

Fig.2 Maximum permissible continuous forward current as a function of ambient temperature.



(1) T_j = 175 °C; typical values.
(2) T_j = 25 °C; typical values.
(3) T_j = 25 °C; maximum values.

Fig.3 Forward current as a function of forward voltage.

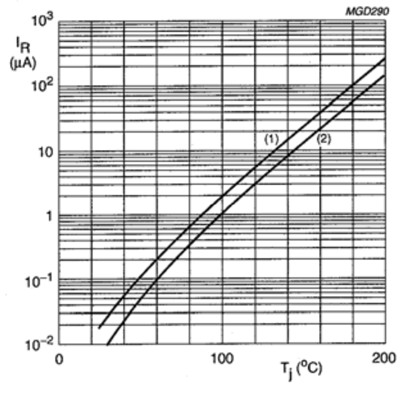


Based on square wave currents.
T_j = 25 °C prior to surge.

Fig.4 Maximum permissible non-repetitive peak forward current as a function of pulse duration.

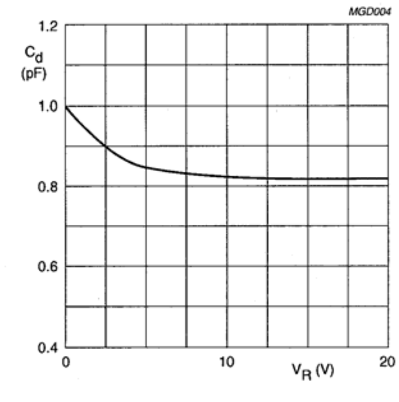
Philips Semiconductors Product specification

High-speed diodes 1N4148; 1N4446; 1N4448



(1) V_R = 75 V; typical values.
(2) V_R = 20 V; typical values.

Fig.5 Reverse current as a function of junction temperature.



f = 1 MHz; T_j = 25 °C.

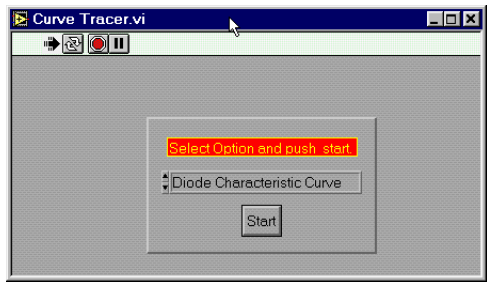
Fig.6 Diode capacitance as a function of reverse voltage; typical values.

Appendix II Curve Tracer Operation

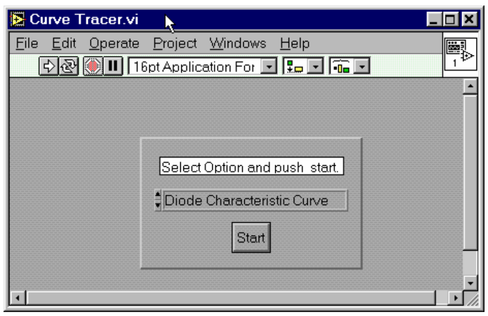
Curve tracers are versatile instruments that characterize a wide variety of electronic components. Commercial curve tracers cost upwards of $30,000. We will use a homemade, computer-based curve tracer that has a few advantages over commercial units.[17] The Curve Tracer consists of a circuit that provides appropriate biases to the device leads and measures the currents into the leads, an analog to digital computer converter card, and a LabVIEW virtual instrument program that controls the biasing hardware and collects the resulting data. LabVIEW is an unusual programming environment that is superb for computerized data acquisition tasks.

Note that help for many of the controls can be obtained by typing ^H.

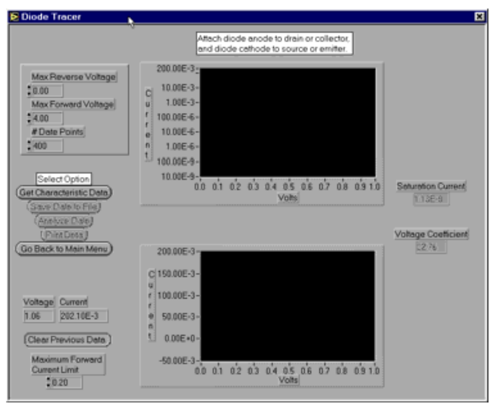
If the Curve Tracer is not already running, start it by double clicking on the Curve Tracer icon. The main selection window will appear, as shown to the right, from which you pick the device type to be analyzed.



If the main selection window is visible, but not running, it will look like this:



Restart it by pushing the go arrow:  Once the main selection window is running, select and start the Diode Tracer. The Diode Tracer window will appear as shown below.



Attach your diode to the input connections (the program will tell you how to connect the diode – **anode to drain/collector and diode to source/emitter**), and press the **Get Characteristic Data** button. The Curve Tracer will acquire and plot the diode characteristic. The saturation current and voltage coefficient in Eq. 1 can be obtained by pressing the **Analyze Data** button. When the **Analyze Data** button is pushed, LabVIEW fits an exponential of the form Ae^{Bx} to the data using least squares method. Calculated A & B correspond to i_{sat} & the voltage coefficient, respectively. The data can also be saved to a file and printed by pressing the appropriate buttons.

[17] Our curve tracer is simpler to use and more accurate at lower currents than most commercial units, and can also calculate parameters like the saturation current automatically. Its major disadvantage is that it takes data relatively slowly.

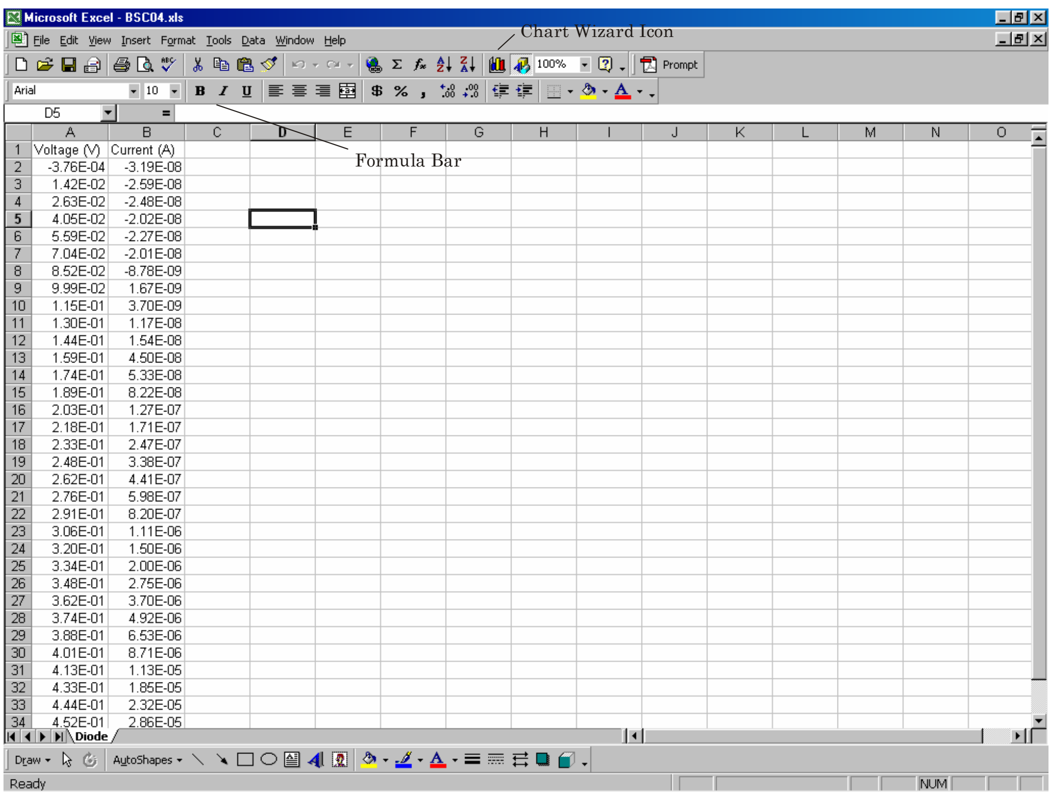
Toggling the **Clear Previous Data** button to **Keep Previous Data** will overlay additional characteristic traces over the initial trace. This option can be used to compare the curves for different devices.

Some additional information about the Curve Tracer is available on the BSC Web Site.

Appendix III Excel Tutorial

Although this tutorial is meant to be a general introduction on how to use Excel to plot your data, we will use the load line analysis in Lab 4 (Diodes) as a specific example and go through the procedure step by step. In this document, an expression such as "Menu"→"Command" implies click on the menu item on the top (such as File, Edit, View, etc.) and select a command from the submenu (such as Open, Copy, Paste, etc.).

First let's talk about how to get the data into Excel. You will notice that Labview saves your diode characteristic curve in .dat format. This file is a standard text file (ASCII) that you can open with any text editor such as Notepad. Excel is also capable of importing ascii files. In Excel, go to File→Open. This will bring up the Open File dialog box. Go to the directory your file is in and click on the .dat file (we'll call the file diode.dat from now on). You may not be able to find diode.dat unless "Files of type" is not set to "All Files". This may or may not bring up the "Text Import Wizard" depending on the version of Excel you are using. If it does, follow the directions of the wizard, but most likely clicking "Finish" will import the data correctly. If the data has been imported correctly, you will see two columns of numbers with the first row of each column reading "Voltage (V)" and "Current (A)". (See figure below.)



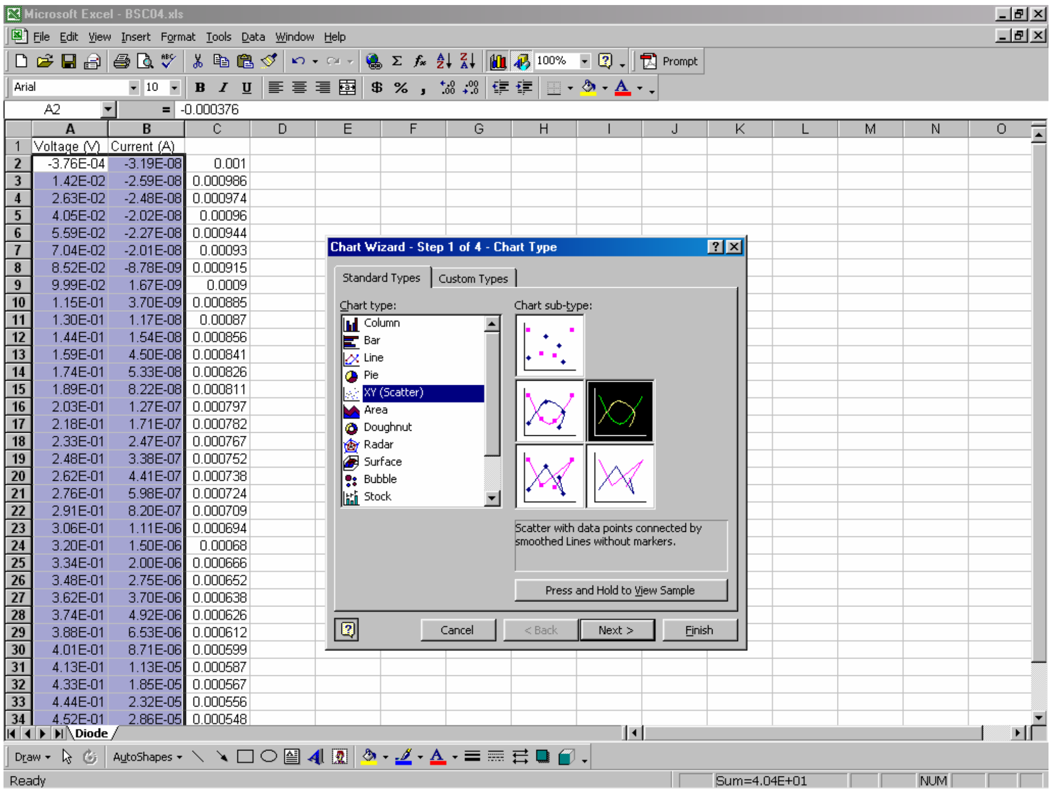
We now have the diode characteristic curve. What we need to do next is to generate the data for the load line: we want to create a new column of currents where $I(V) = (V_o - V)/R$ (remember that V_o is the offset adder voltage and R is the resistor value in Ohms). As an example, let's assume that the offset adder voltage is 1V and R = 1k. Click on the cell located at Column3, Row 2 (C2). Type the following into the formula bar (you must type the = sign):

=(1–[click on Column1, Row2])/1000

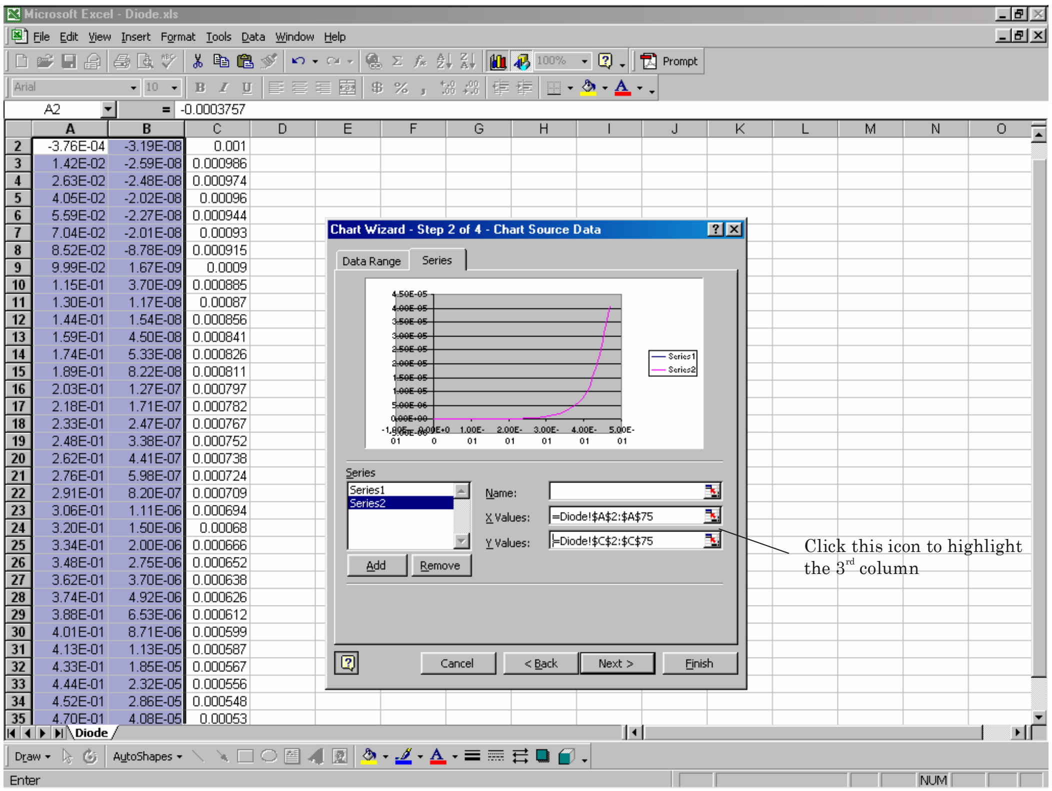
If your columns are labeled by A, B, C, etc., then the expression should look like:

=(1–A2)/1000

When you press enter, a numerical value will appear in the cell at C2. There is an easy way to generate the rest of the currents for the load line. Notice that when you click on C2, the cell is surrounded by a box with a little square on the lower right hand corner. Click, hold, and drag the square to the row where the data ends (probably around row 70). This will automatically generate all the I values for the given V values in the first column.



Now that we have the data, we want to plot both the diode curve and the load line on the same plot to find the intersection. Highlight the first two columns from Row2 to the end of the data (i.e. do not highlight the title of each column) and click on the "Chart Wizard" Icon, or alternatively, Insert→Chart. This will bring up the Chart Wizard. Select "XY (Scatter)" from the "standard Types" and select "Chart sub-type" that has the data points connected without markers. (See figure above.) Click "Next" which brings you to the Chart Source Data dialog box. Click on the "Series" tab. You will see that there is only one series called "Series 1" corresponding to the diode curve. Add a new series by clicking "Add". The x values should be the same so, click on "Series 1" and highlight its "X Values" and Edit→Copy. Click on "X Values" of "Series 2" and Edit→Paste. The "Y Values" should be the data in column 3. You can mimic the style and just type it in (notice that it designates the range by $the initial row $the initial column: $the final row $the final column) or by clicking on the up red arrow icon on the right side of the "Y Values" box which minimizes the chart wizard box allowing you to highlight Column3 from Row2 to ending row. Once you have highlighted it, click on the down red arrow to maximize the Chart Wizard where the proper range should be entered in to the "Y Values" box. You will notice that a second line with a different color is added to the plot. Now, you can either click "Finish to exit the Chart Wizard or continue clicking "Next" to embellish your plot with titles, etc. However, once you are done, you'll see that a plot of the data is embedded into your worksheet.



You might have to rescale the plot to find the intersection point. To rescale the y-axis, for example, double click on any of the y values which will bring up the "Format Axis" dialog box. Go to the "Scale" tab and play around with the maximum value plotted, etc. to rescale. You can use this method to plot multiple load lines by adding additional series.