CALIFORNIA STATE UNIVERSITY SACRAMENTO

DEPARTMENT OF ELECTRICAL AND ELECTRONIC ENGINEERING

EEE 108L

Electronics I_ Laboratory, 1 unit

Summer_ 2022

Lab - 04 Report

Submitted to

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By

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INTRODUCTION:

In this laboratory, the student was introduced to the concept of semiconductor device and diodes. It was introduced to new information and equation. One of the new information is that diode is the simplest two-terminal semiconductor in common use. On the other hand, the student investigated the nonlinear characteristics of a small signal diode. This laboratory is divided into three parts. The firt part of the laboratory exposed the student to a hand calculation and compute for the questions with the given equations and circuit. The second part of this laboratory allows the student uses PSpice simulation to construct the given circuit, generate graphs, and record data. After, the student must evaluate the output information from the simulation. Lastly, the student must construct the circuit to the breadboard with the given laboratory kit including the main components such as diodes. Using the AD2, the student analyzed the waveform graph generated and record the data.

Part1 – Preliminary Calculations

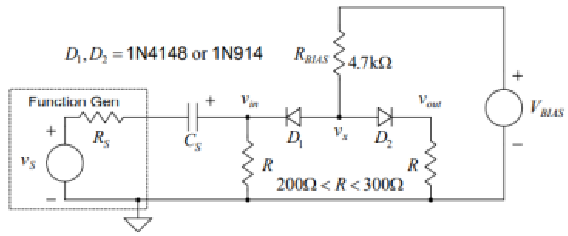


Figure 1.

1. Concentration of in n-type silicon:
   - The majority carrier (n) : $n_n = 1 \; x \; 10^{15} / \; cm^3$
   - The minority carrier (p) : $p_n = 2.25 \; x \; 10^5 / \; cm^3$
2. Concentration of in p-type silicon:
   - The majority carrier (p) : $p_p = 1 \; x \; 10^{17} / \; cm^3$
   - The minority carrier (n) : $n_p = 2.25 \; x \; 10^3 / \; cm^3$
3. The built-in potential $V_0 = 697.32 \; mV$.
4.

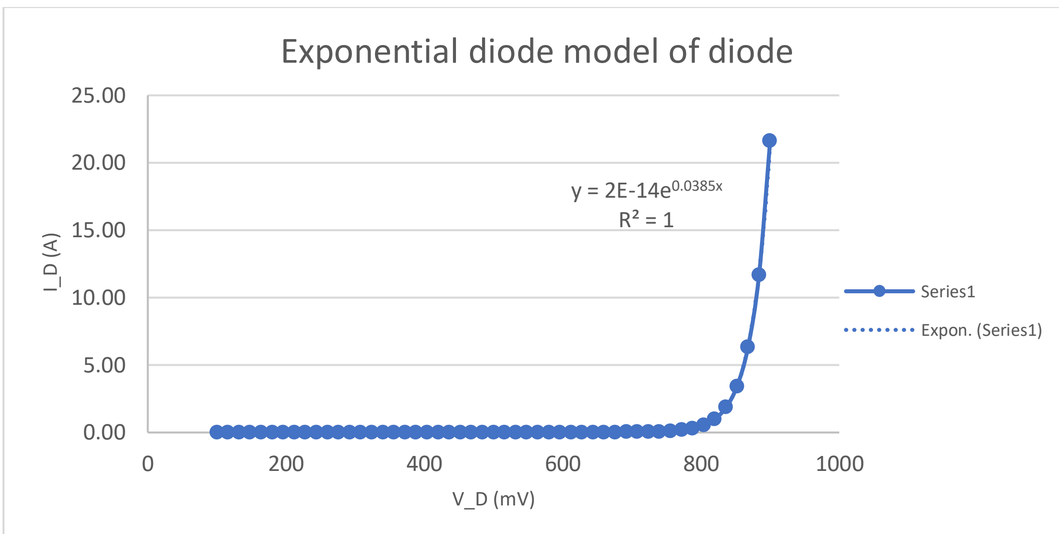


Figure 2. Exponential Diode Model: I_D vs V_D

5.

At V_D = 0.4 : $r_D = 438.30 \; \Omega$

At V_D = 0.5 : $r_D = 53.95 \; \Omega$

At V_D = 0.6 : $r_D = 6.641 \; \Omega$

At V_D = 0.7 : $r_D = 0.8174 \; \Omega$

At V_D = 0.8 : $r_D = 0.1006 \; \Omega$

6. The expression for the diod currents: $I_{D1} = I_{D2} = I_D = \frac{V_{BIAS}-0.7}{2R_{BIAS}+R}$
7. The expression for the small-signal gain: $\frac{V_{OUT}}{V_{IN}} = \frac{R}{2r_D+R}$

Part2 - Simulations Results

For this part of the laboratory, the student generated the given circuit from figure 1 into a PSpice simulation shown in figure 3. The student setup the labels such as for Cs, $\boldsymbol{V_{BIAS}}$, and R. After, the circuit runs to bias point simulation. We confirmed that the two diode bias current are the same and bias current is twice as one diode bias current value.

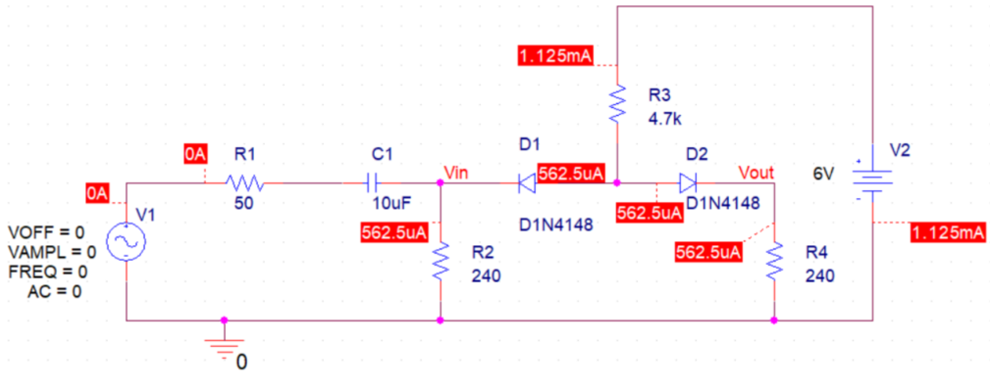


Figure 3. PSpice circuit for Bias point simulation

After the bias point simulation, the student now ran a transient simulation with the same circuit adding and changing values shown in figure 4.

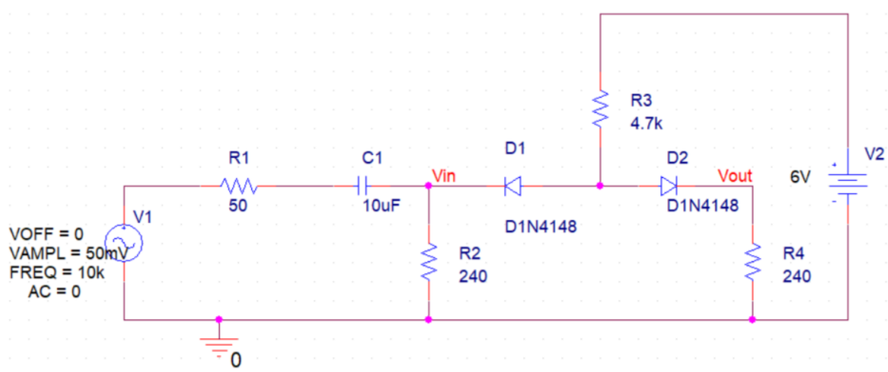
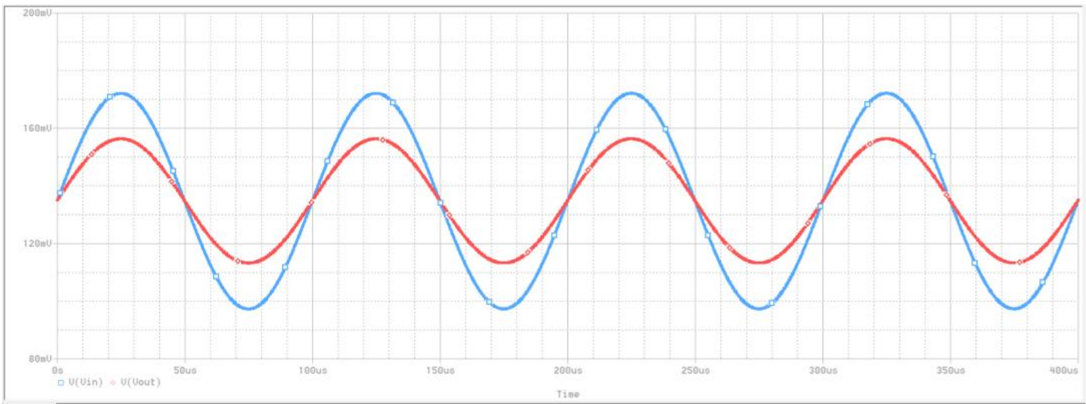


Figure 4. PSpice circuit for transient simulation

With this modification, the student performed a transient analysis and generated a graph displaying V_{in} and V_{out} shown in figure 5. The graph shows a blue sinewave which incorporated to V_{in} and the red sinewave incorporated to V_{out}.



Trace Color	Trace Name	Y1	Y2	Y1 - Y2
	X Values	25.682u	74.773u	-49.091u
CURSOR 1,2	V(Vin)	172.084m	97.328m	74.756m
	V(Vout)	156.314m	113.263m	43.051m

Figure 5. V_{in} and V_{out} sinewave graph

With the simulation, the student was able to record the peak to peak V_{in} and V_{out} shown in figure 5. And calculate the small gain which is equal to 0.575.

Part3 – Laboratory Measurements

In this part of the laboratory, the student constructed the circuit from figure 1 into the breadboard using the laboratory kit given shown in figure 6.

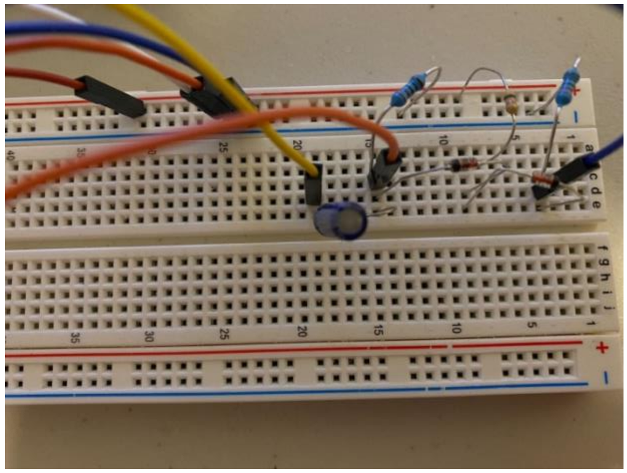


Figure 6. Actual circuit in breadboard

With this, the student verified in that DC bias voltage V_{in} and V_{out} are within ± 5 mV of each other without AC signal applied which confirms that the diodes are well matched shown in figure 7.

	Channel 1	Channel 2
DC	136 mV	138 mV
True RMS	136 mṼ	138 mṼ
AC RMS	2 mṼ	2 mṼ

Figure 7. Data for V_{in} and V_{out} DC bias voltage

After, the student set V_{in} a triangle waveform and generate the graph shown in figure 7.

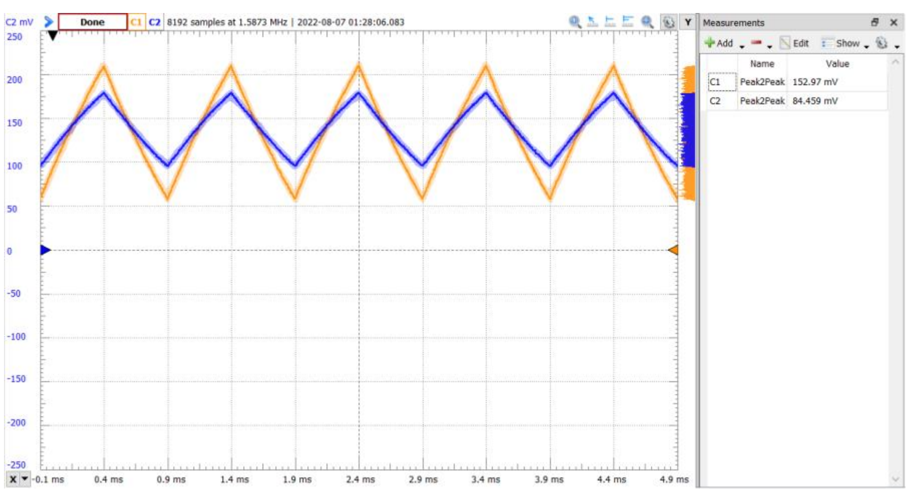


Figure 8. Graph for V_{in} and V_{out}

From the graph, the student labeled V_{in} as C1 showed orange-colored trace which the peak-to-peak value is 152.97 mV and V_{out} as C2 showed indigo-colored trace which the peak-to-peak value is 84.459 mV. When we vary V_{BIAS}, the AC V_{in} decreases and the V_{out} stays the same. While in DC, the V_{in} increase and the V_{out} decreases.

On the other hand the student recorded data for atleast 10 values V_{BIAS} and measure Gain in each shown in table 1 and generated a graph shown in figure 8.

Table 1. Data for V_{BIAS} and Gain

V_{BIAS}	Gain
2	0.94
2.5	0.96
3	0.96
4	0.97
5	0.97
6	0.98
7	0.98
8	0.99
9	0.99
10	0.99

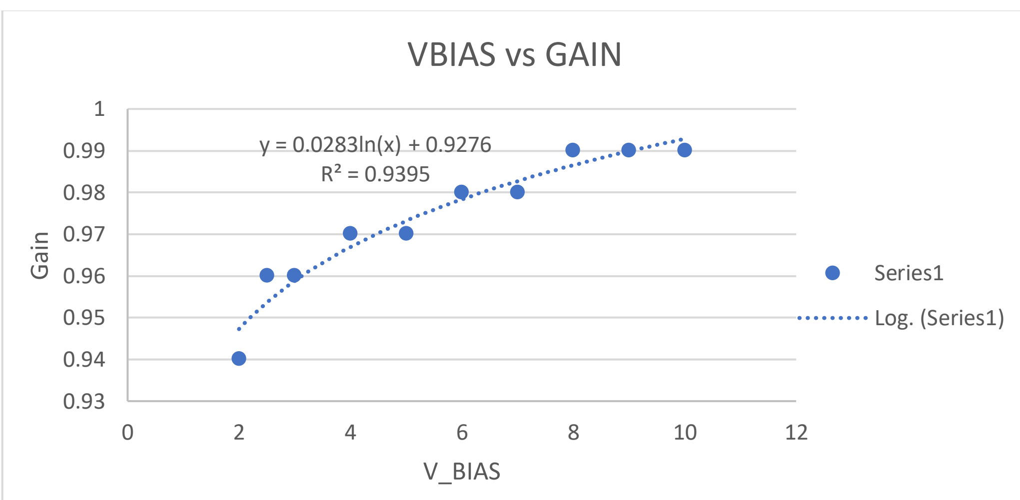


Figure 8. Graph for V_{BIAS} and Gain

With the V_{BIAS} = 4V, the student increased the amplitude of the input signal and shows the noticeable clipping when amplitude is at 500 mV shown in figure 9.

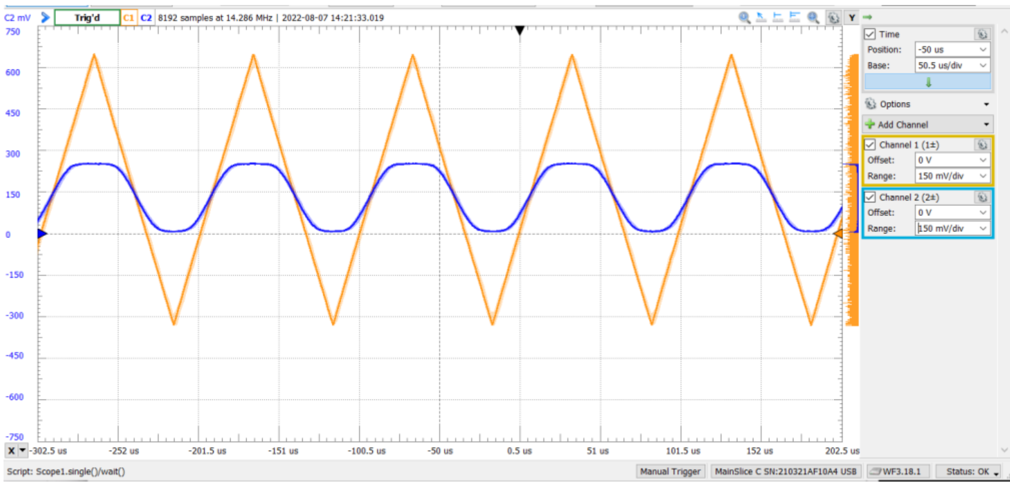


Figure 9. Graph at amplitude 500 mV showing the clipping

After this analysis, the student recorded data for atleast 10 values of V_{BIAS} with the corresponding positive and negative clipping levels shown in table 2.

Table 2. Recorded data for V_{BIAS}, positive and negative clipping levels

V_{BIAS}	Positive Clipping Levels	Negative Clipping Levels
2	68.385 mV	-0.992 mV
2.5	139.10 mV	-1.327 mV
3	120.33 mV	-1.997 mV
4	160.55 mV	1.6892 mV
5	206.13 mV	3.7001 mV
6	252.05 mV	5.0407 mV
7	297.30 mV	5.3759 mV
8	341.87 mV	5.7110 mV
9	387.12 mV	6.0462 mV
10	431.36 mV	7.0516 mV

CONCLUSION:

This laboratory helps the student be introduced and understand semiconductor and diodes as they apply in most of our devices nowadays. This laboratory elaborates more by performing three different tasks. For the first part, the student was introduced to the conceptual information using the given equation and understanding the circuit by finding the looking expressions, specifically for the diode current and the gain. The second part let the student apply the circuit to the PSpice simulation and analyze graphs and record data. Lastly, the third part of the laboratory lets the student construct the circuit to a breadboard with the given laboratory kit and use AD2 to analyze the circuit. This part of the laboratory gaves a lot of subtasks and recorded a lot of data which we are able to analyze the clipping of V_{BIAS} . With the three parts, the student was able to compare the diode current and gain shown in table 3.

Table 3. The comparison for three parts of the laboratory

	Hand Calculation	Simulation Results	Laboratory Measurements
I_D	549.79 μA	562.5 μA	559.2 μA
Gain	0.5802	0.5759	0.552

APPENDIX

HAND CALCULATION:

QUESTION 01:

$$n_n = N_D = 1\times10^{15}/cm^3$$

$$p_n = \frac{n_i^2}{N_D} = \frac{(1.5\times10^{10})^2}{1\times10^{15}} = 2.25\times10^{5}/cm^3$$

QUESTION 02:

$$n_p = \frac{n_i^2}{N_D} = \frac{(1.5\times10^{10})^2}{1\times10^{17}} = 2.25\times10^{3}/cm^3$$

$$p_n = N_D = 1\times10^{17}/cm^3$$

QUESTION 03:

$$V_o = V_T \ln\left[\frac{N_A N_D}{n_i^2}\right] \qquad V_T \approx 26\,mV \text{ at } 300°k$$

$$V_o = (26\,mV)\ln\left[\frac{(1\times10^{17}/cm^3)(1\times10^{15}/cm^3)}{(1.5\times10^{10}/cm^3)^2}\right]$$

$$V_o = 697.32\,mV$$

QUESTION 04:

when $V_D = 100mV$;

$$I_D = I_s(e^{V_D/V_T} - 1)$$

$$I_D = (2\times10^{-14}A)[e^{(100/26)} - 1]$$
$$= 9.16\times10^{-13}\,A$$

when $V_D = 900mV$

$$I_D = (2\times10^{-14}A)[e^{(900/26)} - 1]$$
$$= 21.59\,A$$

QUESTION 05:

$$r_d = \frac{nV_T}{I_D} \qquad I_D = I_s e^{V_D/nV_T}$$

$$r_d = \frac{nV_T}{I_s e^{V_D/nV_T}} \qquad n = 1.836 \qquad I_s = 25\times10^{-9}A$$

$$V_T = 26\,mV$$

At $V_D = 0.4$: $r_d = 438.30\,\Omega$

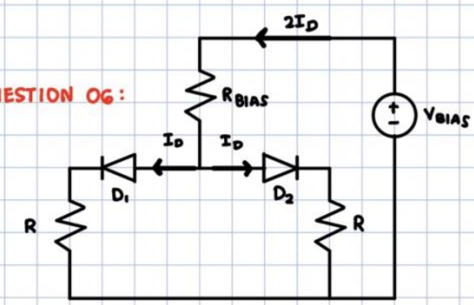
At $V_D = 0.5$: $r_d = 53.95\,\Omega$

At $V_D = 0.6$: $r_d = 6.641\,\Omega$

At $V_D = 0.7$: $r_d = 0.8174\,\Omega$

At $V_D = 0.8$: $r_d = 0.1006\,\Omega$

QUESTION 06:



since symmetrical,

$$I_{D1} = I_{D2} = I_D$$

since $I_D = \frac{V_s - V_D}{R} = \frac{V_s - 0.7}{R}$,

$$V_s = I_D R + 0.7$$

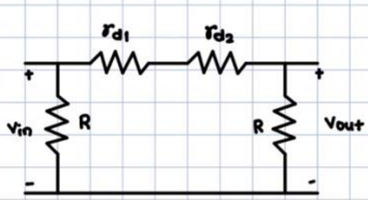
then $2I_D = \frac{V_{BIAS} - V_s}{R_{BIAS}}$

$$2I_D R_{BIAS} = V_{BIAS} - (I_D R + 0.7)$$

$$I_D(2R_{BIAS} + R) = V_{BIAS} - 0.7$$

$$I_{D1} = I_{D2} = \frac{V_{BIAS} - 0.7}{2R_{BIAS} + R}$$

QUESTION 07:



$$V_{out} = V_{in}\left[\frac{R}{r_{d1} + r_{d2} + R}\right]$$

$$\frac{V_{out}}{V_{in}} = \frac{R}{2r_d + R} \qquad r_{d1} = r_{d2} = r_d$$

CONCLUSION:

• HAND CALCULATION

$V_{BIAS} = 6V$ $R = 240\Omega$

$R_{BIAS} = 4.7K\Omega$

$$I_D = \frac{V_{BIAS} - 0.7}{2R_{BIAS} + R} = 549.79\,\mu A$$

$$Gain = \frac{R}{2r_D + R} \qquad r_D = \frac{nV_T}{I_D} = \frac{(1.836)(26\times10^{-3})}{549.79\times10^{-6}} = 86.83\Omega$$

$$= 0.5802$$

• SIMULATION RESULTS

$I_D = 562.5\,\mu A$ (reading from the circuit)

$$Gain = \frac{V_{out}}{V_{in}} = \frac{43.051\,mV}{74.756\,mV} = 0.5759$$

• LABORATORY MEASUREMENTS

$I_D = 559.2\,\mu A$

$$Gain = \frac{V_{out}}{V_{in}} = \frac{84.459\,mV}{152.97\,mV} = 0.552$$