Lab Number 4
EEE 108L – Electronics I - Laboratory

Diode Circuits (One week)

Background

The purpose of this laboratory is to introduce what is most likely your first semiconductor device. The diode is the simplest two terminal semiconductor in common use. While there are many types of diodes, this laboratory will investigate the nonlinear characteristics of a small signal diode.

Preliminary Calculations:

1. Find the majority carrier (n) and minority carrier (p) concentration of in n-type silicon that has been doped with a donor level of $N_D = 1 \times 10^{15}\ /cm^3$.
2. Find the majority carrier (p) and minority carrier (n) concentration of p-type silicon that has been doped with an acceptor level of $N_A = 1 \times 10^{17}\ /cm^3$.
3. Assume you are making a PN diode from the p and n-type semiconductors discussed above; Calculate the built-in potential.
4. Use the exponential diode model of diode. Assume $I_s = 2 \times 10^{-14}$ A. Plot I_D vs V_D from $100mV \le V_D \le 900mV$. Take at least 50 points.
5. Calculate r_d at V_D = 0.4, 0.5, 0.6, 0.7, and 0.8V.
6. For the circuit of Figure 1, find an expression for the diode currents I_{D1} and I_{D2} in terms of V_{BIAS}, R_{BIAS} and R. You may assume that V_D = 0.7V and that the C_S prevents DC current from flowing through the function generator.
7. Find an expression for the small-signal gain V_{OUT}/V_{IN} for the circuit of Figure 1 in terms of the diode small-signal resistance (let $rd = rd_1 = rd_2$) and R. Ignore R_{BIAS} here since it is much greater than any of the other resistances in the circuit.

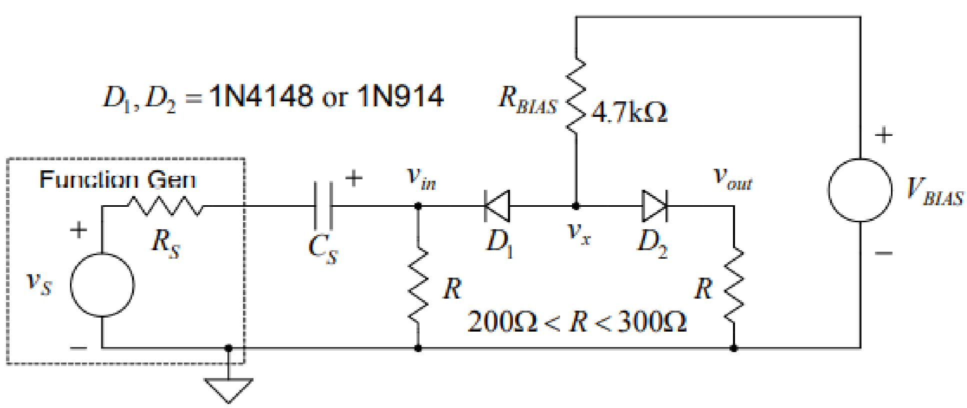

Figure 1.

SPICE Simulations:

1. Enter the circuit of Figure 1 into SPICE. Select C_S between 2 uF and 10 uF.
   Set V_{BIAS} = 6V. Set vs to zero for this step. The default value for R is 240 **Ω**. Make sure that the simulation setup enables the bias point detail.
2. Run Bias point simulation, compare the simulated diode bias current to the values calculated in preliminary calculation.
3. Now for transient, set V_{BIAS} = 6V, v_s = 50mV peak sine wave at 10kHz, and R_S=50 **Ω**, final time = $4x10^{-4}$ seconds and the maximum step size to 1×10^{-7} seconds.
4. Perform transient analysis. Display v_{in} and v_{out}.
5. Calculate the small-signal gain v_{out} (p-p) / v_{in} (p-p) (not v_{out}/v_s).

Laboratory Measurements:

1. Construct the circuit of Figure 1. Connect the +ve side of C_S to v_{in}. Set V_{BIAS} to +6V. (-V= -1V and +V=5V total 6V)
2. With no AC signal applied, verify that the DC bias voltages V_{IN} and V_{OUT} are within ±5mV of each other. This check will make sure that the diodes are well matched.
3. Verify that the currents I_{D1} and I_{D2} are reasonably close to their calculated values.
4. Set v_{in} a triangle waveform, equal to160mV_{pp} at 10 kHz.
5. Vary V_{BIAS} and observe how do the AC magnitudes at v_{in} and v_{out} change as V_{BIAS} is changed? How to the DC voltages v_{in} and v_{out} change as V_{BIAS} is changed?
6. For at least 10 values of V_{BIAS}, measure Gain = v_{out}/v_{in}. Make a table and sketch a plot of measured gain as a function of V_{BIAS}.
7. With V_{BIAS} = 4V, increase the amplitude of the input signal until v_{out} shows noticeable clipping at the top and bottom peaks.
8. For at least 10 values of V_{BIAS}, record the positive and negative clipping levels corresponding to each value of V_{BIAS}. Make a table.

SOME USEFUL EQUATIONS

Background:

The diode is a nonlinear device with defined regions of operation. For the diode, we should define at least three regions of operation

- reverse current saturation,
- forward current operation up to the "knee"
- forward current after the "knee".

The ideal diode equation is: $i_D = I_S\left(e^{\frac{v_D}{nV_T}} - 1\right)$

- I_S is the reverse saturation current up to the breakdown voltage for the diode.
- n is the ideality factor for the diode (ideal = 1, normal is $1 \le n \le 2$)
- V_T is the "thermal voltage" given by $V_T = kT/q$ = 26 mV at room temperature.

The diode large-signal model

The large-signal model relates the diode current I_D to the diode voltage V_D. A good large signal model for a diode in forward bias is given by:

$$I_D = I_S \exp\left(\frac{V_D}{nV_T}\right) \qquad \text{OR} \qquad V_D = nV_T \ln\left(\frac{I_D}{I_S}\right).$$

- Where I_S is the diode saturation current and is about 25 x 10-9A for the 1N914
- V_T is the thermal voltage (at room temperature, about 26mV and PSPICE defaults to 25.8mV),
- n = 1.836.
- if the voltage across the resistor is more than about 2 volts. V_D = 0.7V is acceptable for most purposes.

The diode small-signal model

The small-signal model relates the change in the diode current I_D to the change in the diode voltage V_D. This property can be modeled by the diode's small-signal resistance, defined as $r_d = \frac{\Delta V_D}{\Delta I_D} = \frac{v_d}{i_d}$. The small-signal conductance can be derived from the large-signal model above as follows: $g_d = \frac{dI_D}{dV_D} = \frac{I_D}{nV_T}$, hence $r_d = \frac{1}{g_d} = \frac{nV_T}{I_D}$.

The diode's small-signal resistance could be expressed as a function of V_D, but the calculations are less sensitive to error when r_d is calculated from I_D.