ShanghaiTech University
School of Information Science and Technology

EE112 Lab Experiments

Capacitance of a PN Junction

Objective:

Investigate the AC characteristics of the PN junction diode, and find the zero-bias junction capacitance C_{j0}.

Theory - AC Analysis

The abrupt PN junction looks like a pair of parallel plates of area *A*, separation *W*, and permittivity ε. This capacitance is given by,

$$C = \frac{A\varepsilon}{W} \tag{1}$$

However, the width of the depletion (junction) region of a PN junction is not constant. *W* varies with the dc voltage across the junction as

$$W(V) = (V_0 - V)^{1/2}\left(\frac{2\varepsilon_r\varepsilon_0}{q}\right)^{1/2}\left(\frac{N_a + N_d}{N_a N_d}\right)^{1/2} \tag{2}$$

where V_0 is the built-in potential of the device (a constant). The junction capacitance then becomes:

$$C_j(V) = A\left(\frac{q\varepsilon_r\varepsilon_0}{2}\frac{N_a N_d}{N_a + N_d}\right)^{1/2}\frac{1}{|V_0 - V|^{1/2}} \tag{3}$$

where *V* is the dc applied voltage. The junction may be forward biased ($V > 0$) or reverse biased ($V < 0$) but Eq. (3) is the total capacitance only for reverse bias. If we square equation 3 and rewrite it, we have,

$$\frac{1}{C_j^{\,2}} = K(V_0 - V) \tag{4}$$

where $K = [(N_a+N_d)/(N_a*N_d)]*2/(q*\varepsilon_r*\varepsilon_0*A^2)$. A plot of $1/C_j^2$ vs. *V* as measured should be a straight line for the ideal abrupt PN junction.

In this laboratory we will design an experiment to measure the capacitance of a PN junction as a function of the dc bias voltage *V* across the device. The constraints put upon this design are that the dc voltage should be varied from -20 V to +0.0 V. Some factors should be kept in mind:

1) Typical junction capacitances are very small (about 100 pF), so we must make sure that we can measure these small capacitances
2) High frequencies must be used (you will have to justify this in your report)
3) Circuit leads (wires) may add stray capacitance to our measurements

An example of such a design is now presented, but a different design for achieving this task is also welcomed. The circuit chosen appears in Figure 1. **The diode is replaced with a parallel combination of a resistor and a capacitor for analysis (but not for measurements).** The ac and dc equivalent circuits are shown in Figure 2.

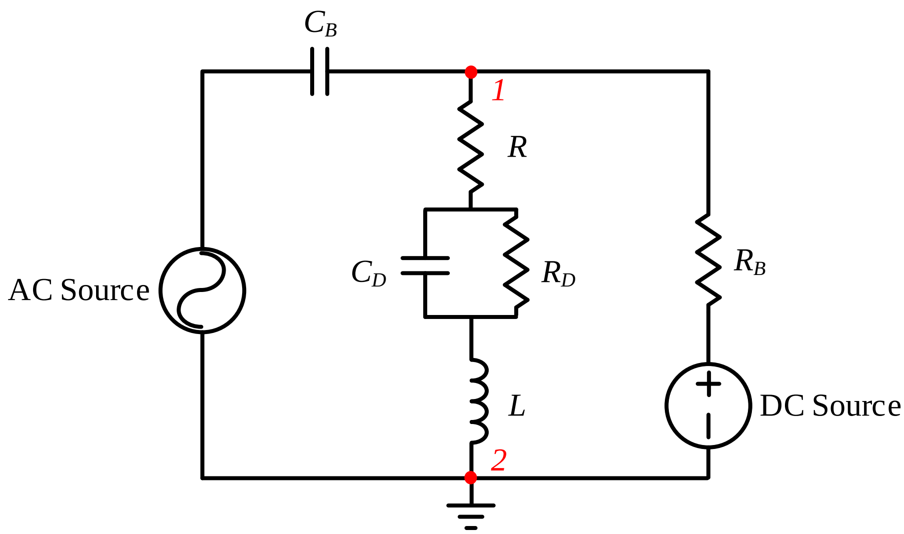

Figure 1. Experimental set-up with the diode replaced with its RC diode model

Ignoring the small R_D, If we calculate the total impedance of the RLC combination from point (1) to point (2) in Figure 1, taking into account both the real and imaginary parts, we get,

$$Z_{eq} = R + \frac{1}{j\omega C_D} + j\omega L \tag{5}$$

Rearranging and combining the real and imaginary terms,

$$Z_{eq} = R + j\left(\omega L - \frac{1}{\omega C_D}\right) \tag{6}$$

From this we can clearly see that resonance will occur for,

$$C_D = \frac{1}{(2\pi f)^2 L} \tag{7}$$

This is derived from the fact that the magnitude of a complex number has a minimum value when its imaginary component is equal to zero. Since the value of the inductance *L* is fixed, the only variable is frequency which is a convenient controlling parameter.

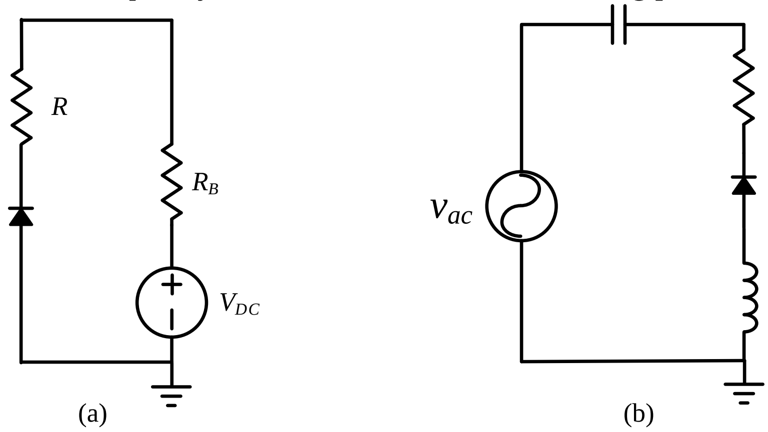

Figure 2. (a) DC equivalent circuit; (b) AC equivalent circuit.

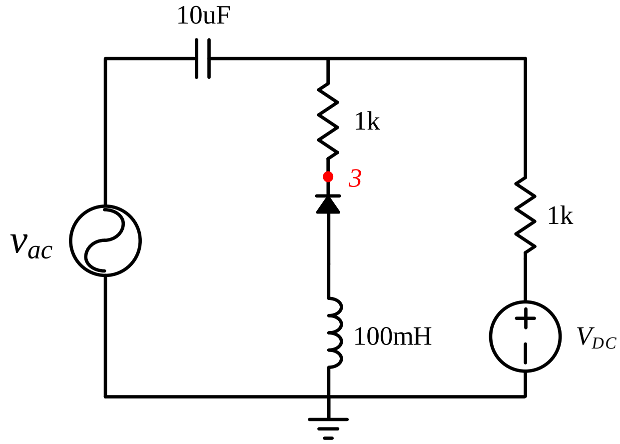

Figure 3. Circuit for capacitance measurement

PreLab - AC Analysis

Before performing the following experiments, decide on

1) Format for table of resonance data (voltage drop, frequency, capacitance, etc.). Be sure to note the voltage across *L* and diode.
2) Method for determining C_{j0}, the junction capacitance at zero dc bias.

Procedure - AC Analysis

1. Using an estimate of 1 pF for the diode capacitance C_j, calculate the expected resonant

frequency ($\omega^2 = 1/ LC$). Use this value to choose a starting point for the frequency of your AC source.

2. Set up the circuit in Fig. 3.
3. Obtain desired voltage drop across the diode V_d by adjusting the DC power supply from 20 V to ~0.0 V in 5V steps.
4. For each V_d, observe v_{out} (the voltage of point (3) to the ground). Vary the frequency of the AC source until the LCR circuit reaches resonance (as indicated by a minimum p-p v_{out}). Record the resonant frequency f at this V_d. Tabulate these values and plot results for C_j vs. V_d and $1 /C_j^2$ vs. V_d.
5. **In simulation, the frequency response can be observed by the AC sweep function in Multisim. While in experiments, the Bode analyzer in Elvis II can be used.**

Reference

[1] Drexel University, ECE-E302, Electronic Devices.