

Activity: The Voltage Dependent Capacitance of the PN Junction

Doug Mercer and Antoniu Miclaus

Objective

The objective of this lab activity is to measure the voltage-dependent capacitance of a reverse-biased PN junction.

Background

PN Junction Capacitance

Increasing the reverse bias voltage, V_j , across a PN junction leads to the redistribution of charge away from the interface, leaving a depleted region or layer, W , in Figure 1. This depleted layer acts like the insulator between the two conducting plates of a capacitor. The thickness of this layer, W , is a function of the applied electric field and the doping concentration. The PN junction capacitance is divided into two components, the barrier capacitance and the diffusion capacitance. Under the conditions of reverse-bias, free carrier injection does not occur; therefore, the diffusion capacitance is equal to zero. The barrier capacitance is the dominant source of capacitance for reverse and small positive-bias voltages less than the diode turn on voltage (0.6 V for silicon). In practice, the barrier capacitance can be as small as a fraction of a picofarad to hundreds of picofarads depending on the area of the junction and the doping concentration. The dependence of the junction capacitance to the applied bias voltage called the capacitance-voltage (CV) characteristic of the junction. In this lab, you will measure and plot this characteristic for various PN junctions (diodes).

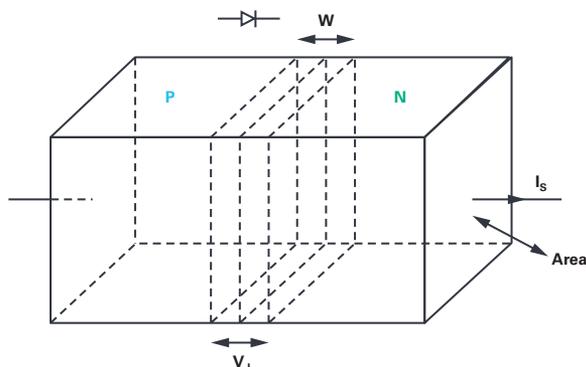


Figure 1. PN junction depletion region.

Materials

- ▶ ADALM2000 active learning module
- ▶ Solderless breadboard
- ▶ One 10 k Ω resistor
- ▶ One 39 pF capacitor
- ▶ One 1N4001 diode
- ▶ One 1N3064 diode
- ▶ One 1N914 diode
- ▶ Red, yellow, and green LEDs
- ▶ One 2N3904 NPN transistor
- ▶ One 2N3906 PNP transistor

Directions Step 1

Build the test setup as shown in Figure 2 and Figure 3 on your solderless breadboard. The first step is to measure the unknown capacitance C_m with the known C_1 we connected between the AWG output and scope input. The two scope minus inputs 1– and 2– are both grounded. The scope channel 1+ input is tied to the AWG1 output, W1, using one row on the breadboard. Scope channel 2+ is inserted into a breadboard row 8 to 10 rows away from the row that the AWG output is inserted in. The row adjacent to scope channel 2+ and toward the AWG1 row is grounded. This is to minimize any unwanted stray coupling between AWG1 and scope channel 2. Because the fly-wires are not shielded, try to keep the W1 and 1+ wires as far away from the 2+ wires as possible.

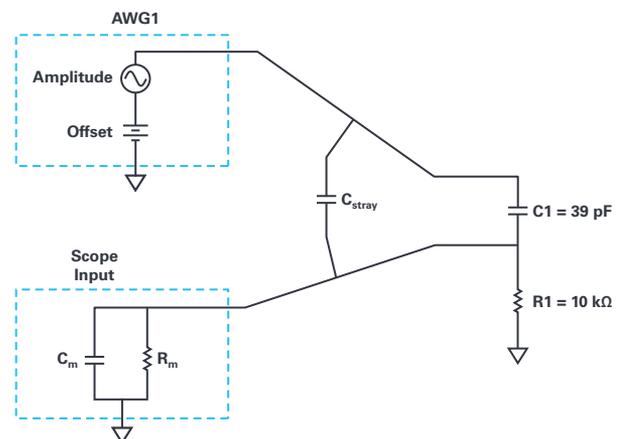


Figure 2. Step 1 setup to measure C_m .

Hardware Setup

Using the network analyzer instrument in the Scopy software obtains a gain (attenuation) vs. frequency plot from 5 kHz to 10 MHz. Scope channel 1 is the filter input and scope channel 2 is the filter output. Set AWG offset to 1 V and the amplitude to 200 mV. The offset value is not important at this point when measuring a simple real capacitor, but will be used as the reverse-bias voltage when we measure diodes in later steps. Set the vertical scale to start at +1 dB to -50 dB range. Run a single sweep and export the data to a .csv file. You should notice a high-pass characteristic that has a high attenuation at very low frequencies where the impedance of the capacitor is large compared to R1. At the very high end of the frequency sweep, there should be a relatively flat region where the impedance of the C1, C_m capacitive voltage divider is much lower than R1.

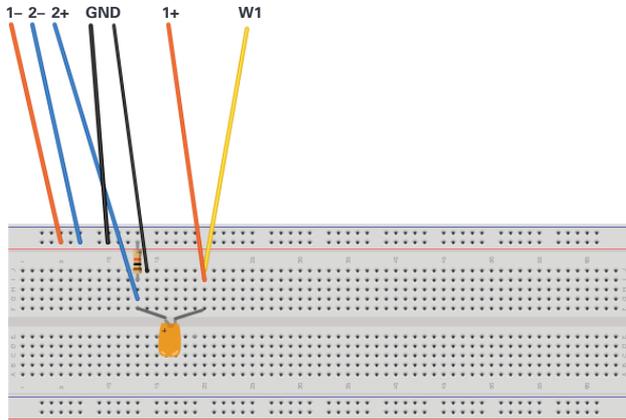


Figure 3. Step 1 setup to measure C_m.

Procedure Step 1

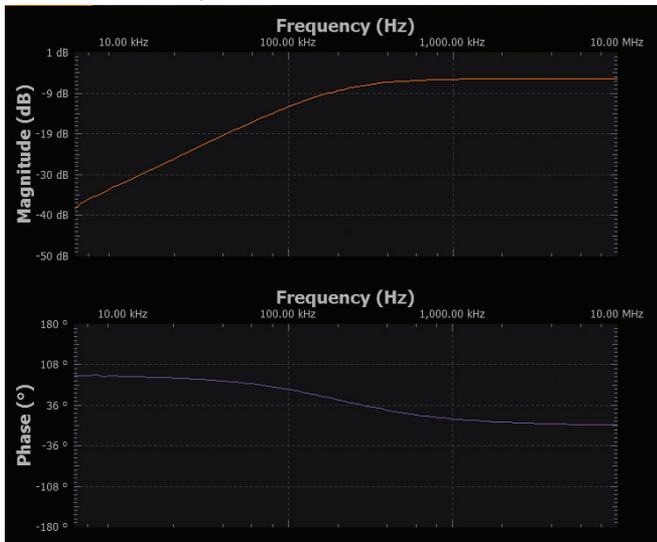


Figure 4. Scopy screenshot.

We chose C1 to be sufficiently larger than C_{stray} such that we can ignore C_{stray} in our calculations but still have a similar value to our unknown C_m.

Open the saved data file in a spreadsheet program and scroll to near the end of the data at high frequencies (>1 MHz) where the attenuation level is essentially flat. Write down the magnitude; this is G_{HF1} (in dB). Since we now know G_{HF1} and C1, we can use the following equation to calculate C_m. Write down your C_m value which we will need when we move to the next step and measure the capacitance of various diode PN junctions.

$$G_{HF1} = 20 \log \times \frac{C1}{(C_m + C1)} \quad (1)$$

Directions Step 2

Now we will measure the capacitance of the various diodes from the ADALM2000 analog parts kit under a range of reverse bias conditions. Build the test setup as shown in Figure 4 and Figure 5 on your solderless bread board. Simply replace C1 with D1, a 1N4001. Be sure to insert the diode with the correct polarity such that a positive offset in AWG1 will reverse bias the diode.

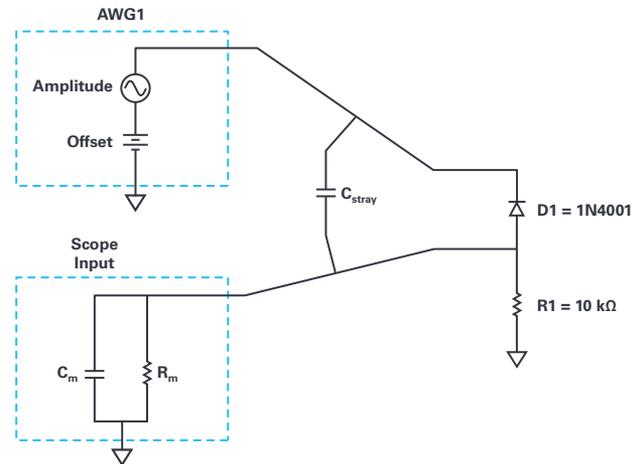


Figure 5. Step 2 setup to measure diode capacitance.

Hardware Setup

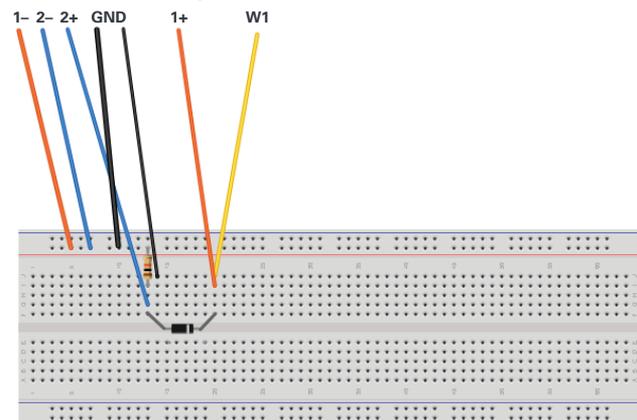


Figure 6. Step 2 setup to measure diode capacitance.

Using the network analyzer instrument in the Scopy software obtain a gain (attenuation) vs. frequency plot from 5 kHz to 10 MHz for each AWG 1 DC offset value in Table 1. Export the data for each sweep to a different .csv file.

Procedure

Fill in the rest of Table 1 with the G_{HF} value for each offset voltage value and using the value for C_m and the equation from Step 1, calculate the value for C_{diode}.

Table 1. Capacitance vs. Voltage Data

Offset Voltage	G _{HF}	C _{diode}
0 V		
1 V		
2 V		
3 V		
4 V		

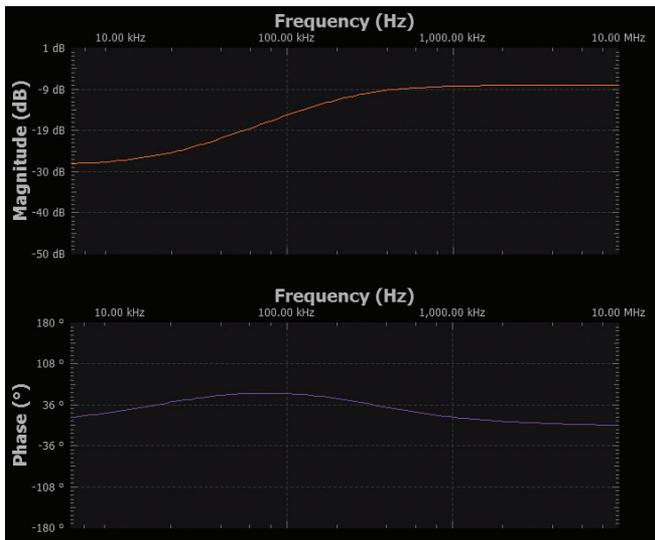


Figure 7. Scope shot with offset at 0 V.

Replace the 1N4001 diode with the 1N3064 diode from the ADALM2000 kit and repeat the same set of sweeps you just did for the first diode. Fill out another table with your measured data and calculated C_{diode} values. How do the 1N3064 values compare to those for the 1N4001 diode? You should include a plot of the diode capacitance vs. reverse bias voltage for each diode you measure.



About the Author

Doug Mercer received his B.S.E.E. degree from Rensselaer Polytechnic Institute (RPI) in 1977. Since joining Analog Devices in 1977, he has contributed directly or indirectly to more than 30 data converter products and he holds 13 patents. He was appointed to the position of ADI Fellow in 1995. In 2009, he transitioned from full-time work and has continued consulting at ADI as a Fellow Emeritus contributing to the Active Learning Program. In 2016 he was named Engineer in Residence within the ECSE department at RPI. He can be reached at doug.mercer@analog.com.



About the Author

Antoniu Miclaus is a system applications engineer at Analog Devices, where he works on ADI academic programs, as well as embedded software for Circuits from the Lab[®], QA automation and process management. He started working at Analog Devices in February 2017 in Cluj-Napoca, Romania. He is currently an M.Sc. student in the Software Engineering master's program at Babes-Bolyai University and he has a B.Eng. in Electronics and Telecommunications from Technical University of Cluj-Napoca. He can be reached at antoniu.miclaus@analog.com.

Next replace the 1N3064 diode with one of the 1N914 diodes from the ADALM2000 kit. Again repeat the same set of sweeps you just did for the other diodes. Fill out another table with your measured data and calculated C_{diode} values. How do the 1N914 values compare to those for the 1N4001 and 1N3064 diodes?

The capacitance you measure for the 1N914 diode should be much smaller than the other two diodes. It might be small enough to be comparable in size to C_{stray} .

Extra Credit Measurements

Light emitting diodes or LEDs are also PN junctions. They are fabricated from materials other than silicon so their turn-on voltage is much different from normal diodes. However, they still have a depletion layer and capacitance. For extra credit, measure the red, yellow, and green LEDs supplied in the ADALM2000 analog parts kits as you did the normal diodes. Be sure to insert the LEDs into the test setup with the proper polarity for reverse bias. If you did it wrong, you will probably see the LED light up at some point.

Questions

Using the formula given at Step 1, the value of C_1 , and the plot presented in Figure 4, compute scope input capacitance C_m .

You can find the answers at the [StudentZone blog](#).