University of Washington Bothell

Terminal Device Characteristics and Diode Characterization

BEE 504 Lab 1

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Activity	Name
Circuit Construction	Gwen, Ian
Data Collection	Gwen, Ian
Data Analysis	Gwen, Ian
Answers to Questions	Gwen, Ian

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I Objectives

1 Reverse Leakage Current

In this section, we use DC circuit analysis to measure the reverse leakage current of each diode. We rank the diodes based on their leakage current, with the ultimate goal of deciding which diode would be best suited to charging a capacitor and preventing it from discharging for a long period of time.

2 Forward Turn-on Voltage

In this section, we use a set of resistors to measure a diode's forward bias voltage at several different currents. From these data points, we construct an estimated I-V graph showing the exponential relationship between current and bias voltage in a diode.

3 Simulated I-V Characteristics

In this section, we use LTspice circuit simulation software to characterize the I-V response of a diode in greater detail. Our goal is to verify the results of part 2 and compare simulated diode behavior to observed behavior.

II Materials

- DC power supply
- (2x) Digital multi-meter
- Breadboard
- Solid core wire
- 1N34A Diode
- 1N4007 Diode
- 1N4148 Diode
- 1N5819 Diode
- Resistor 1.0MΩ 1%

- Resistor 100Ω
- Resistor 1.0kΩ
- Resistor 10kΩ
- Resistor 100kΩ
- Resistor 10MΩ 5%

  (Note: The lab procedure specifies a 10MΩ resistor with a 1% tolerance. Our lab kits didn't include one, so we used a 10MΩ ±5% resistor instead, and measured its exact value for our calculations).

III Procedure, Measurements and Analysis

1 Reverse Leakage Current

In this section, we use DC circuit analysis to measure the reverse leakage current of each of our four diodes. The circuit (fig 1) uses a large resistor to translate the small reverse current into a measurable voltage, measured between points A and B.

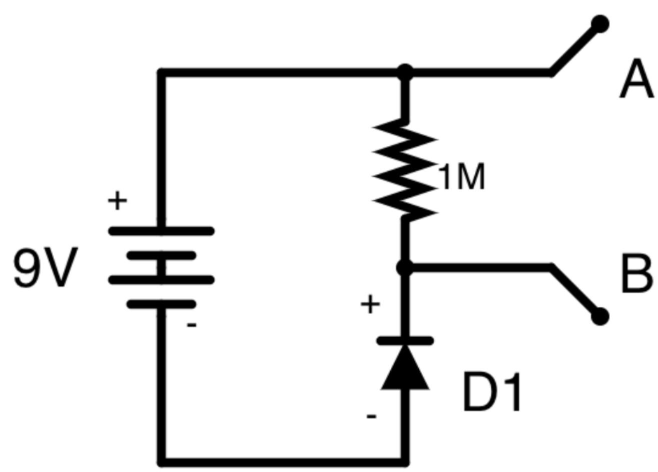
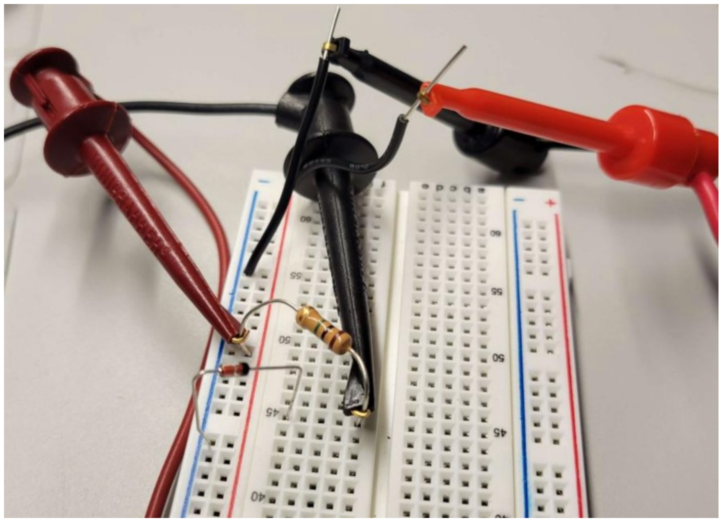


Figure 1: DC circuit used to measure reverse leakage current. Voltage is measured between points A and B, allowing us to calculate the current through the series circuit elements.

Figure 2: Reverse-leakage circuit assembled on the solderless breadboard. Red and black leads can be seen connecting the circuit to the digital multimeter and power supply. In this image, the 2N4148 diode is being tested.



With the circuit wired as shown, any voltage measured between points A and B will correspond to a current $i = \frac{v}{R}$ flowing through the 1MΩ resistor. Assuming our digital multimeter has infinite input impedance, this current will be equal to the current flowing through the diode D1, telling us how much reverse current the diode permits when reverse-biased by $\sim$9V.

Assembly and Testing

We assembled the circuit on the solderless breadboard as shown in Figure 2. We used a desktop power supply for the 9V voltage source. Before assembly, we measured the supply's output voltage, as well as the exact value of our resistor:

$$R = 0.992\text{M}\Omega \quad V = +8.998\text{V}$$

Finally, we constructed the circuit with each of our four diode types substituted for D1, measured the voltage across the resistor, and calculated the nominal leakage current through the diode. Our measurements are given in table 1.

Diode	V_R	Leakage Current
1N34A	56 mV	56 nA
1N4007	1.03 mV	1.03 nA
1N4148	6.2 mV	6.25 nA
1N5819	1.21 V	1.22 μA

Table 1: Measured resistor voltages and calculated DC currents for each diode

The 1N4007 and 1N4148 diodes had the smallest leakage current, at least one order of magnitude less than the other two we tested. The greatest leakage current was observed through the 1N5819 diode, and was more than a thousand times greater than the leakage through the 1N4007:

1N4007	1N4148	1N34A		1N5819
Least leakage	$\longleftarrow$		$\longrightarrow$	Most leakage

Charging a Capacitor

We now return to the motivating question for this section: Which diode would be most effective for charging a capacitor and preventing it from discharging for a long period of time? Based only on this section's results, we would choose the 1N4007 diode. Since the rate at which a capacitor discharges is directly proportional to current, the amount of time for which a capacitor can be held in a "charged" state by a diode is inversely proportional to the diode's leakage current. The 1N4007 has the smallest leakage current, so it should be able to hold a capacitor in a charged state for longer than the other three diodes.

2 Forward Turn-On Voltage

In this section, we use another DC circuit and a set of resistors to measure forward-bias voltage of two diodes at many different currents. We tested the 1N4148 and 1N34A diodes, using the circuit shown in Figure 3.

Using two multimeters, we simultaneously measured the voltage across the selected resistor and across the selected diode. Using Ohm's law, we can calculate the current through the circuit from the resistor voltage; then we can graph the diode current against its directly-measured forward voltage.

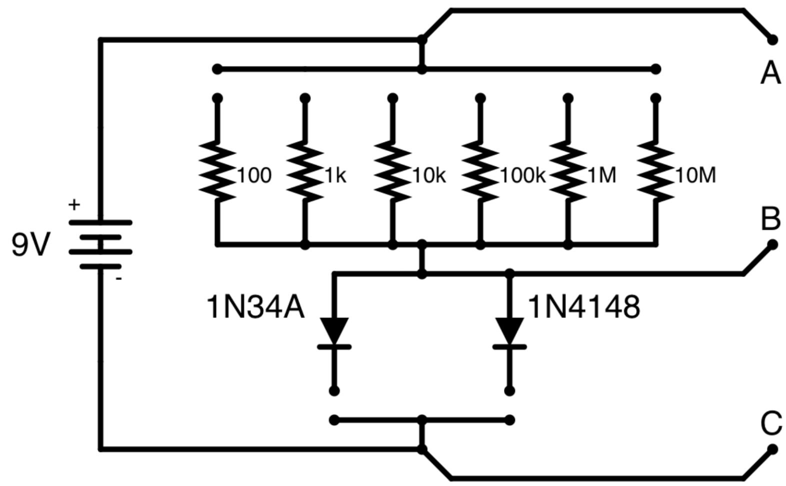


Figure 3: Forward-voltage analysis circuit. For each test, one resistor and one diode are connected in series, and voltage measurements are taken between points A and B, and points B and C.

We assembled this circuit on the solderless breadboard as shown, once again using a desktop power supply as our voltage source. We conducted twelve tests, covering every possible resistor-diode pair. For each, we recorded the voltage across the resistor and across the diode, and calculated the current through the circuit. Our results are given in table 2.

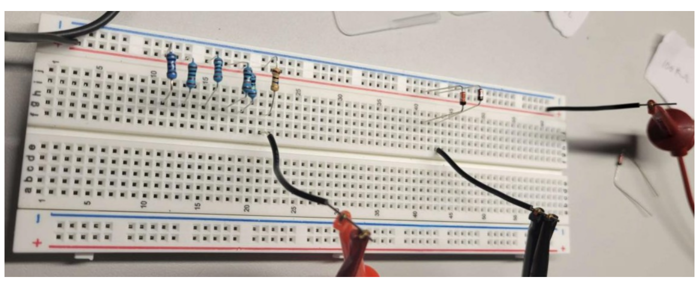


Figure 4: Forward voltage test rig assembled on the solderless breadboard. During a test, only one resistor and one diode are connected to the power source.

Diode	Resistor	Resistor Voltage	Current	Diode Voltage
1N34A	100 Ω	8.11 V	81.1 mA	0.86 V
1N34A	1 kΩ	8.48 V	08.5 mA	0.49 V
1N34A	10 kΩ	8.67 V	867 μA	0.30 V
1N34A	100 kΩ	8.75 V	87.5 μA	0.22V
1N34A	1 MΩ	8.81 V	8.8 μA	0.16 V
1N34A	9.5 MΩ	8.86 V	930 nA	0.11 V
1N4148	100 Ω	8.05 V	81 mA	0.90 V
1N4148	1 kΩ	8.25 V	8.3 mA	0.73 V
1N4148	10 kΩ	8.37 V	840 μA	0.60 V
1N4148	100 kΩ	8.48 V	85 μA	0.50 V
1N4148	1 MΩ	8.58 V	8.6 μA	0.39 V
1N4148	9.5 MΩ	8.67 V	910 nA	0.30 V

Table 2: Measured values for each diode-resistor pair. Voltages across the resistors and diodes were measured directly, and the series current was calculated using Ohm's law.

(a) I-V Plot

We expect to see a logarithmic relationship between forward voltage and diode current; we plotted the data from our tests on a semi-logarithmic graph, shown in Figure 5.

(b) Voltage Response

On this plot, our diodes' voltage responses do not appear to be perfectly logarithmic for currents above 10 mA. This might be because currents above 10 mA, in this circuit, correspond to diode forward-bias voltages between 0.5 V and 0.7 V, near the nominal cutoff voltage of most silicon junction diodes. For this section, we're interested in the logarithmic region of the diodes' response curves, so we'll restrict our analysis to the four lowest-current trails for each diode.

The 1N34A diode exhibits a forward-voltage increase of 0.19 V over just under three decades of current increase. Approximating from the graph and our data, we find:

$$v(i)_{\text{1N34A}} \approx 0.063 \log i + 0.5\text{V}$$

Meanwhile, the 1N4148 diode exhibits a forward-voltage increase of 0.3 V over just under three decades of voltage increase. Approximating,

$$v(i)_{1N4148} \approx 0.1 \log i + 0.9\text{V}$$

...Of course, these formulae are only valid for a narrow voltage range. Current won't flow through the diode when no voltage is applied across it, so our model breaks down at low voltages, and our data show that the diodes' behavior deviates from our model at high voltages.

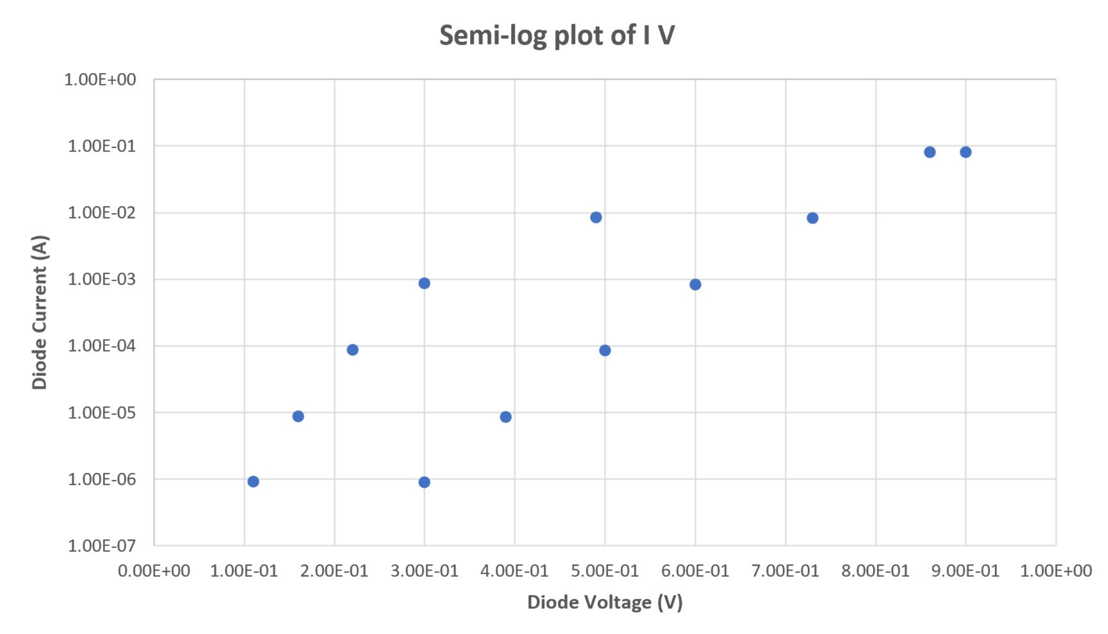


Figure 5: Measurement of diode forward turn on voltage. For each decade increase of current, the data point on the left represents the 1N34A diode, and the point on the left represents the 1N4148 diode.

(c) Diode Comparison

The forward turn-on voltage of the 1N34A diode is consistently less than the turn-on voltage of the 1N4148 diode. For comparison purposes, however, it might be more useful to say that for a given voltage the 1N34A diode will tend to admit more current than the 1N4148.

This was also true in our reverse-leakage test: the 1N34A diode tended to leak more current than the 1N4148. In both the forward and reverse directions, the 1N34A diode passes current more easily.

3 Simulation of Diode I-V Characteristics

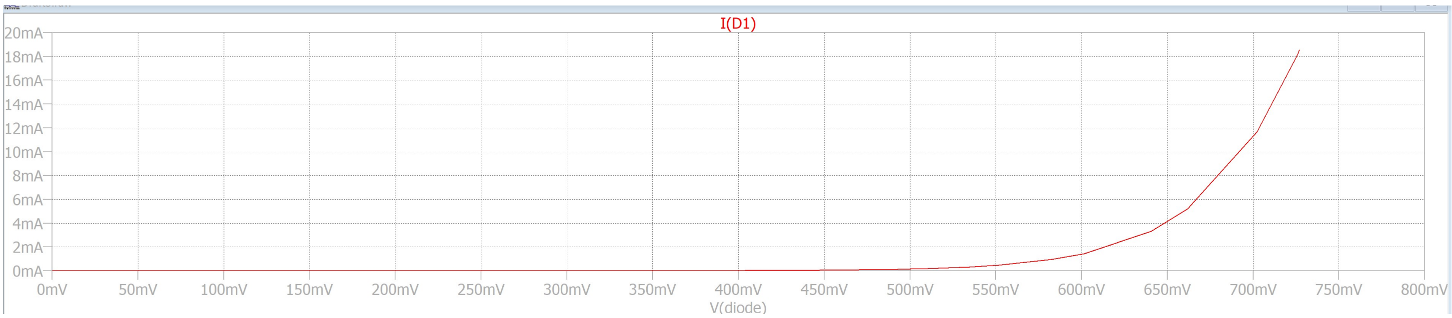


Figure 6: Trace of 1N4148 diode current in LTspice

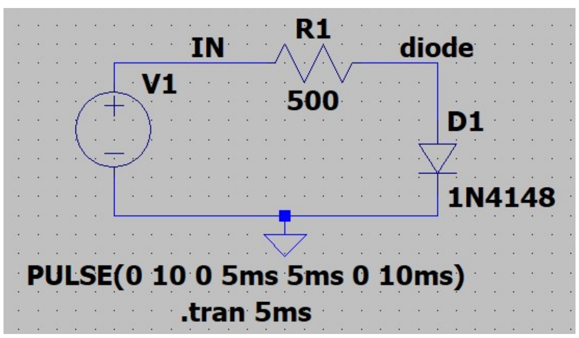


Figure 7: LTspice schematic of 1N4148 diode connected to voltage source and 500Ω resistor

The 1N4148 diode was connected in series with a voltage source and resistor in LTspice. The diode was forward biased. We enabled pulse, set the values shown in Figure 7, then ran a simulation to test the I-V characteristics of the diode. The I-V characteristic of the 1N4148 diode is shown in Figure 6.

IV Conclusion

In this lab, we measured the reverse-leakage characteristics of four diodes, went on to measure the forward voltage-vs-current characteristics of two of those diodes, and simulated one of them using LTspice to explore its logarithmic behavior. We found that our four diodes span a wide range of reverse leakage parameters, with the "leakiest" diode, the 1N5819, admitting more than a thousand times more backwards current than the 1N4007. Of the two diodes we used in section 2, the diode with the higher reverse leakage, the 1N4148, also admitted more forward current for a given bias voltage. We speculated that forward current admittance may be proportional to reverse current leakage, although with our sample size of two diodes it would be irresponsible to speculate too far.

The forward-biased behavior of the 1N34A and 1N4148 diodes didn't match the smooth logarithmic response we expected. There was also a discrepancy between our 1N4148 and its simulated counterpart, which we explore below. We believe both discrepancies are due to the input impedance of our digital multimeter, which we did not measure or factor into our calculations. Further exploration of this lab might start with a reproduction of the forward-bias portion, this time correcting for the effect of the multimeter on the circuit's series resistance.

The 1N4148: Expectation vs. Reality

Several factors may have contributed to the discrepancy between the LTspice simulation of the 1N4148 diode and our observations. LTspice's model is an approximation based on nominal component values, and so may not perfectly represent the real-world behavior of imperfect components in imperfect settings. We, meanwhile, only tested one 1N4148 diode, and so our sample is also unlikely to be representative.

Our calculations also assume that our multimeters are perfect, possessing infinite input impedance. In reality, most digital multimeters have input impedance in the megaohms. This means that, when measuring voltages across large resistors, the multimeter wired in parallel with the resistor may substantially decrease its series resistance. In our case, if our circuits were actually "seeing" less resistance than we recorded, the actual current flowing through our diodes may have been greater than what we calculated, with the discrepancy becoming much more dramatic at high resistances. This alone could explain the non-logarithmic behavior of our data, and the discrepancy between our observations and the simulated behavior of the 1N4148.