Diode-based Logical AND

Notes:

Learning Objectives

- Construct a diode-based logical "AND".

Prerequisites

- Experience building circuits from a schematic, using diodes, and using an inverter.

Logical AND Reminder:

You should be familiar with the ***truth table*** (shown in **Figure 1**) of the logical **AND** from the MOSFET based implementation of it in an earlier lab. However, there are multiple ways in which such behavior can be created with circuits. We will explore one such implementation with diodes today.

A	B	Z
0	0	0
0	1	0
1	0	0
1	1	1

Figure 1*: Desired binary value of output Z given possible binary inputs A and B for a logical AND.*

Diodes limit current such that it only flows freely in *one direction*. In the offset-ideal model (OIM) of a diode, that current flow occurs when the voltage threshold (turn-on voltage) of the diode is surpassed. In this exercise, you will analyze a single-diode circuit under that OIM model, extend that analysis to a two-diode circuit to show that it operates as a logical AND, and then investigate the operation of a physical diode circuit under realistic operating conditions. In particular, you will see that an analog circuit doesn't always give us exactly what we want, so we can condition the signals using other devices to make them more appropriate for our needs. In our case, we use inverters to force signals that are only near the power-and-ground voltages to actually take on only those two voltages.

Notes:

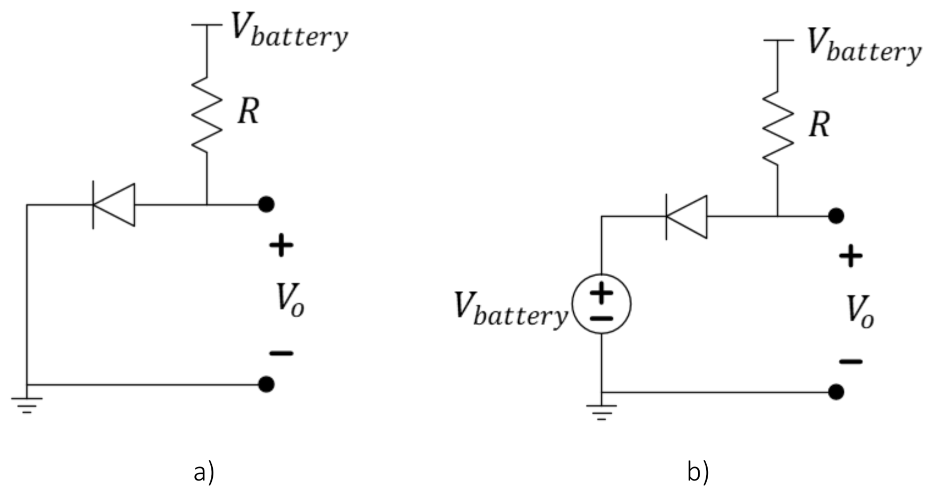

***Figure 2**: A single-loop diode circuit with (a) zero input voltage and (b) full input voltage.*

Consider the single-loop circuit shown in **Figure 2(a)** that passes from ground, through a voltage source $V_{battery}$, through the resistor, and through the diode before returning to the ground node. Although the circuit is drawn using node-voltage format, the battery is implied to be connected to ground and completes the loop. Furthermore, the terminals marking the measurement and polarity of V_D do not change the simple fact that V_D is the voltage measured across the diode.

Question 1: Complete an analysis of Figure 2(a) (do not build it yet), making the assumptions that the diode's turn-on voltage is $V_{on} = 0.7\ V$, $R = 10\ k\Omega$, and $V_{battery} = 9\ V$. What will be the value of V_o?

Now, imagine we can control the voltage at the diode, changing it between $0\ V$ (ground) and $V_{battery}$ as shown in **Figure 2(b).**

Question 2: Complete an analysis of Figure 2(b) (do not build it yet), making the assumptions that the diode's turn-on voltage is $V_{on} = 0.7\ V$, $R = 10\ k\Omega$, and $V_{battery} = 9\ V$. What will be the value of V_o?

Notes:

Next, consider a similarly designed two-diode circuit with two controllable input voltages, V_1 and V_2 as shown in Figure 3. Each voltage source can take on the value of either $0\ V$ or $V_{battery}$.

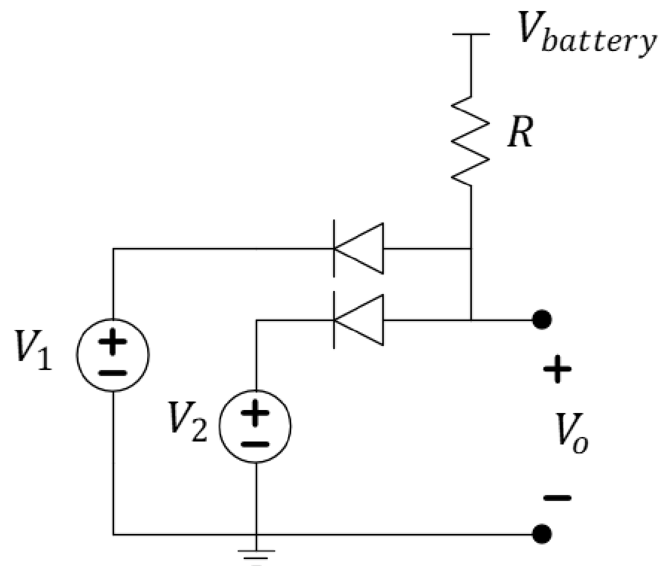

***Figure 3**: Diode-based logical AND.*

Question 3: Complete an analysis of Figure 3 (do not build it yet), making the assumptions that the diode's turn-on voltage is $V_{on} = 0.7\ V$, $R = 10\ k\Omega$, and $V_{battery} = 9\ V$. What will be the value of V_o for each of the four scenarios? Place your answer in table form with one row for each combination of V_1 and V_2 and a separate column for the output, V_o. The table entries should be voltages and ***not*** binary values.

Notes:

The output V_o is less than ideal if it is intended to be a "binary" signal driving a logical circuit. This can be corrected through the use of an inverter which will convert an analog (continuous-voltage) signal like V_o into a thresh-hold limited binary signal that takes on purely one of two values, $0\ V$ or $V_{battery}$. Figure 4 demonstrates this idea suggesting that the output V_o of Figure 4(a) could become the input V_3 of a Schmitt-trigger inverter shown in Figure 4(b). Although the inverter will "flip" the logic we are trying to achieve, that can be later undone by another inverter.

Question 4: Build the circuit of Figure 4(a), using two silicon diodes from your kit, $R = 10\ k\Omega$, and $V_{battery} \approx 9\ V$. Report your actual value of R and $V_{battery}$ using your multimeter to measure them. Remember that you cannot accurately measure your resistor while it is embedded in the circuit. Remove it first.

Question 5: Now, **duplicate the table of Question 3**, but using measurements directly from your circuit. To set V_1 or V_2 to $0\ V$, use a wire to connect it to your ground rail. To set V_1 or V_2 to $V_{battery}$, use a wire to connect it to your power rail. Also, **comment** on what you perceive to be the "real" turn-on voltages of your diodes.

Notes:

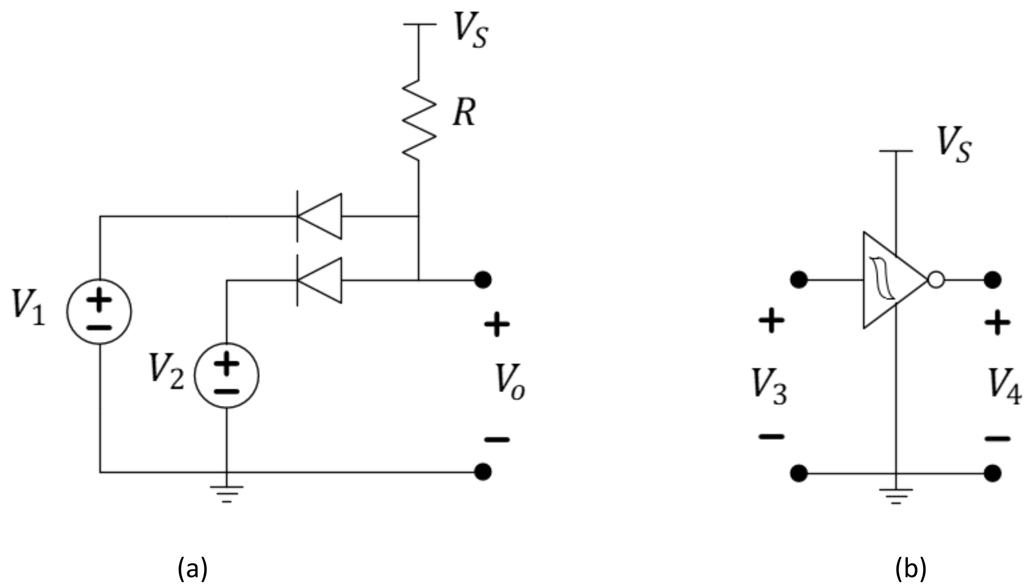

Figure 4: Proposed clean-up of the diode-based AND output signal.

Build the circuit of Figure 4(b). Use a $10\ k\Omega$ potentiometer in a voltage-divider configuration to control voltage V_3.

Question 6: Starting with V_3 near $0.3\ V$, increase the voltage while monitoring V_4. Record the voltage value of V_3 at which the voltage V_4 drops to $0\ V$. Call this voltage v_p.

Question 7: With the output V_o now low at $0\ V$, turn the potentiometer in the opposite direction until V_4 again rises near the battery voltage. Call this voltage v_n.

Remember that a potentiometer can be damaged by tuning the resistance between the wiper and an end terminal to a very low resistance. You will be okay if you start with your potentiometer near the middle of its mechanical limits, then monitor the voltage as you reduce it to $0.3\ V$.

Notes:

Question 8: Discussion: Does the range of V_o determined in Question 5 appear sufficient to create a logical NAND (NOT of AND) operator when both portions of Figure 4 are connected so that $V_3 = V_o$?

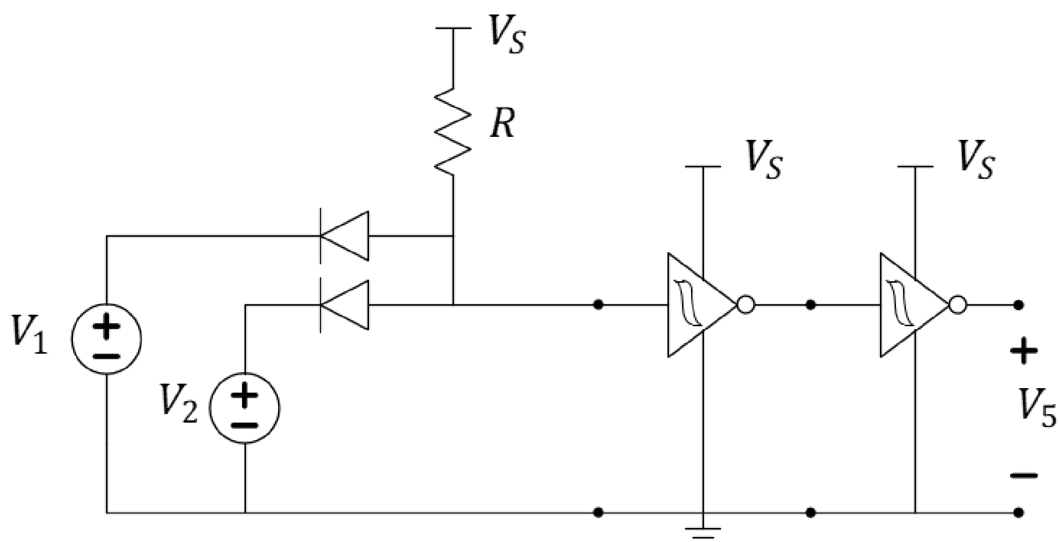

***Figure 5**: Circuit schematic of a two-input PULL-DOWN diode-based logical AND*

Notes:

Question 9: With the lower supply voltage, v_p and v_n will have changed value. Find these new values under the 5-volt source condition and call them $v_p^{(5v)}$ and $v_n^{(5v)}$. Note that this measurement again requires the use of a potentiometer and a Schmitt-trigger.

Build the complete circuit of Figure 5.

Question 10: Verify that the circuit behaves as a logical AND by again completing a table of measurements comparing the different input signal options to the output voltage. Present them in table form. Be sure to use only input voltages of $0\ V$ and $5\ V$.