Diode circuits-1 (`EC_diode_1.sqproj`)

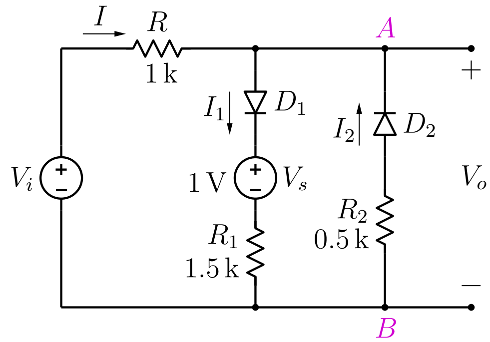

Figure 1: Diode circuit example.

Question: For the diode circuit shown in Fig. 1, plot V_o versus V_i for $-5\,\text{V} < V_i < 5\,\text{V}$. Assume the turn-on voltage of the diodes to be $V_{\text{on}} = 0.7\,\text{V}$.

Solution:

First, we note that the currents I_1 and I_2 can only be zero or positive. When D_1 conducts, $V_{AB} = V_{\text{on}}^{D1} + 1\,\text{V} + R_1 I_1 \geq 1.7\,\text{V}$. When D_2 conducts, $V_{BA} = V_{\text{on}}^{D2} + R_2 I_2 \geq 0.7\,\text{V}$. This gives the following conditions for conduction of D_1 and D_2.

D_1 on $\rightarrow V_{AB} \geq 1.7\,\text{V}$.

D_2 on $\rightarrow V_{AB} \leq -0.7\,\text{V}$.

Clearly, D_1 and D_2 cannot be on at the same time. We therefore have the following three cases.

1. Both D_1 and D_2 off

   This requires $-0.7\,\text{V} < V_{AB} < 1.7\,\text{V}$, and since there is no voltage drop across R in this case, $V_i = V_{AB} = V_o$.

2. D_1 on, D_2 off

   This requires $V_{AB} \geq 1.7\,\text{V}$. Since $I_1 > 0\,\text{A}$, we have $I > 0\,\text{A}$, and $V_i = V_{AB} + R\,I \geq 1.7\,\text{V}$.

3. D_1 off, D_2 on

   This requires $V_{AB} \leq -0.7\,\text{V}$. Since $I_2 > 0\,\text{A}$, we have $I < 0\,\text{A}$, and $V_i = V_{AB} + R\,I \leq -0.7\,\text{V}$.

To calculate the slope of the V_o versus V_i curve, i.e., $\frac{dV_o}{dV_i}$, we can write a KVL equation relating V_i and V_o and then obtain $\frac{dV_o}{dV_i}$ by differentiation. For example, when D_2 is conducting, we can write the loop equation,

$$V_i + R_2 I_2 + V_{\text{on}}^{D2} + I_2 R = 0 \rightarrow I_2 = \frac{-V_i - V_{\text{on}}^{D2}}{R_2 + R}. \tag{1}$$

V_o is then obtained as

$$V_o = -(R_2 I_2 + V_{\text{on}}^{D2}) = -V_{\text{on}}^{D2} - R_2 \times \frac{-V_i - V_{\text{on}}^{D2}}{R_2 + R}, \tag{2}$$

giving

$$\frac{dV_o}{dV_i} = \frac{R_2}{R_2 + R}. \tag{3}$$

There is a simpler way to arrive at the same result. When D_2 is conducting, it acts as a voltage source[1], and we now have two voltage source in the circuit, viz., V_i and V_{on}^{D2}. We have a linear circuit with two sources, and we can make use of superposition to obtain V_o, i.e., we can find the individual contributions due to V_i and V_{on}^{D2}, and then add the two to get the net V_o. Since we are only interested in how V_o changes with V_i, we replace V_{on}^{D2} with $0\,\text{V}$ (a short circuit). We then have the circuit shown in Fig. 2 for which

$$V_o = \frac{R_2}{R_2 + R} V_i \rightarrow \frac{dV_o}{dV_i} = \frac{R_2}{R_2 + R}, \tag{4}$$

as before.

In a similar manner, it can be shown that, when D_1 is conducting, $\frac{dV_o}{dV_i} = \frac{R_1}{R_1 + R}$.

Putting these observations together, we get the V_o-V_i plot shown in Fig. 3.

[1]Note that the voltage source which represents a diode can only absorb power. However, for the purpose of circuit analysis, we can treat it like any other voltage source.

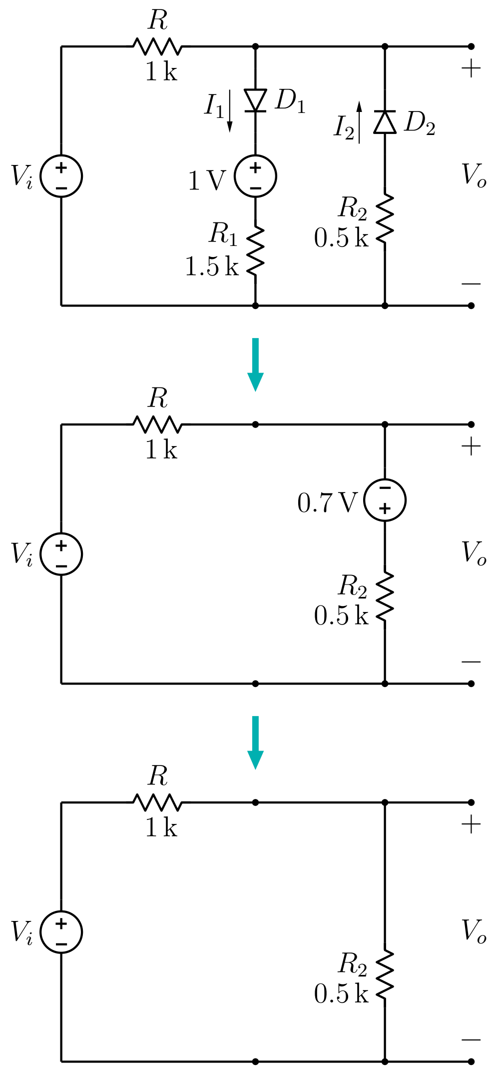

Figure 2: Calculation of $\dfrac{dV_o}{dV_i}$ for the diode circuit of Fig. 1 when D_1 is off and D_2 is conducting.

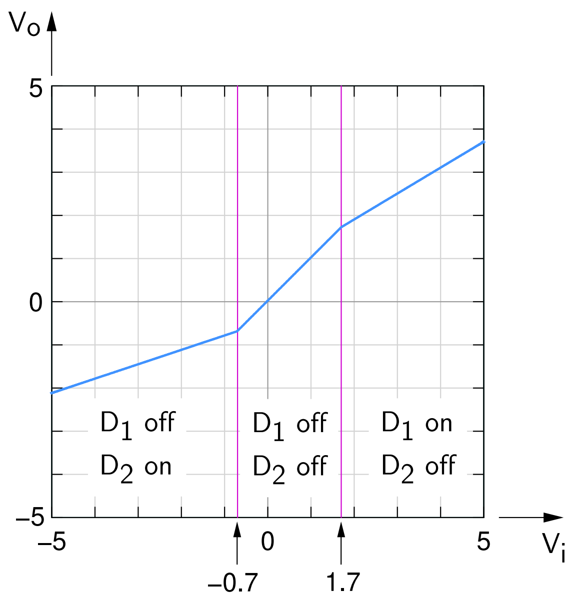

Figure 3: V_o versus V_i plot for the diode circuit of Fig. 1.

SequelApp Exercises: Answer the following, and verify using SequelApp.

1. How will the V_o versus V_i curve be affected with the following changes (keeping all other component values the same as in Fig. 1)?

   (i) R is changed from 1 k to 2 k.

   (ii) R_1 is changed from 1.5 k to 0.5 k.

   (iii) R_2 is changed from 0.5 k to 1 k.

   (iv) V_s is changed to 2 V.

   (v) V_s is changed to −1 V.

2. If $V_i(t) = V_m \sin \omega t$, with $V_m = 3$ V, find the minimum and maximum values of $V_o(t)$.

3. Let $V_i = 5$ V.

   (i) What value of R_1 is required to obtain $V_o = 3$ V (with all other component values the same as in Fig. 1)?

   (ii) What value of V_s is required to obtain $V_o = 4.1$ V (with all other component values the same as in Fig. 1)?