triangle_to_sine.sqproj

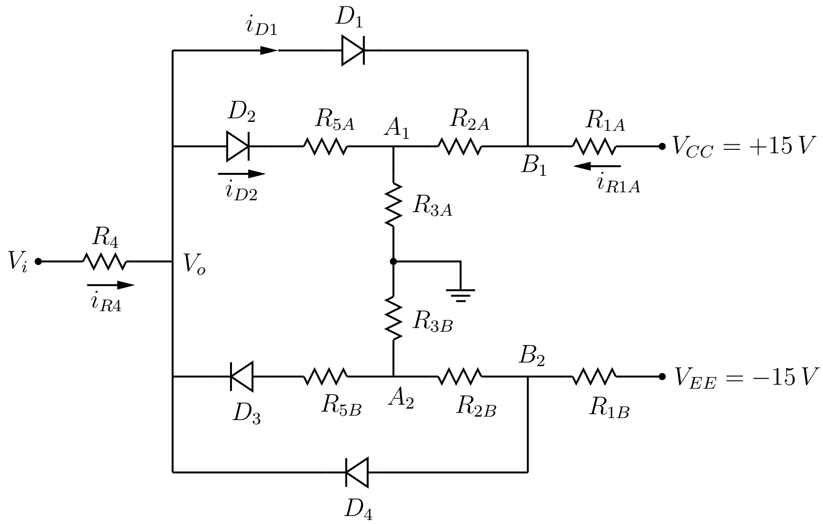

Figure 1: Circuit for triangle-to-sine conversion.

For the circuit shown in Fig. 1, $R_4 = 10\,\text{k}$, $R_{1A} = R_{1B} = 5\,\text{k}$, $R_{2A} = R_{2B} = 1.25\,\text{k}$, $R_{3A} = R_{3B} = 1.25\,\text{k}$, $R_{5A} = R_{5B} = 10\,\text{k}$. We are interested in the V_o versus V_i plot for this circuit for $-10\,V < V_i < 10\,V$.

Let us first take up the condition that all diodes are off. In this case, $i_{R1A} = \dfrac{15\,V}{R_{1A} + R_{2A} + R_{3A}} = 2\,\text{m}A$, giving $V_{A1} = 2.5\,,V$ and $V_{B1} = 5\,,V$. Similarly, $V_{A2} = -2.5\,,V$ and $V_{B2} = -5\,,V$. Since there is no current through R_4, we have $V_o = V_i$. Consider $V_o = V_i = 0\,V$ which is consistent with the condition that all diodes are off (show this). As V_i is increased from $0\,V$, $V_o = V_i$ increases. For D_1 to conduct, we need $V_i = V_{B1} + 0.7\,V = 5.7\,V$, and for D_2 to conduct, we need $V_i = V_{A1} + 0.7\,V = 3.2\,V$. Clearly, as V_i is increased, D_2 will start conducting first. Note also that a positive V_i is not favourable for D_3 or D_4 to conduct. We therefore have a range of V_i beginning at $V_i = 3.2\,V$, for which only D_2 is on (see Fig. 2 (a)).

Using Thevenin's theorem, the circuit can be simplified (see Fig. 2 (b)), with $V_{\text{Th}} = 2.5\,V$, $R_{\text{Th}} = 1.04\,\text{k}\Omega$ (show this), giving

$$V_o = V_i - R_4\, i_{R4} = 0.523\, V_i - 1.524\,, \tag{1}$$

$$V_{A1} = V_i - 0.7 - (R_4 + R_{5A})\, i_{R4} = 0.0476\, V_i + 2.35\,, \tag{2}$$

$$V_{B1} = V_{A1}\, \frac{R_{1A}}{R_{1A} + R_{2A}} + V_{CC}\, \frac{R_{2A}}{R_{1A} + R_{2A}} = 0.038\, V_i + 4.88\,. \tag{3}$$

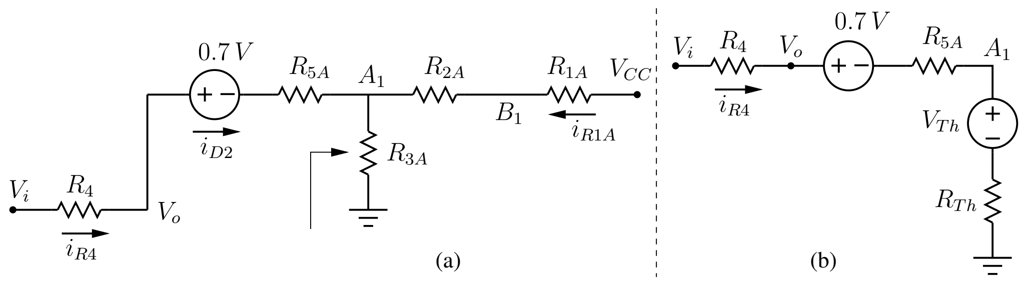

Figure 2: (a) Circuit of Fig. 1 with only D_2 conducting, (b) simplified circuit.

As V_i is increased, $V_{D1} = V_o - V_{B1}$ increases (see Eqs. 1 and 3). When V_{D1} becomes equal to $0.7\,V$, D_1 begins to conduct. The corresponding value of V_i is obtained by using the condition, $V_o - V_{B1} = 0.7\,V$, and solving for V_i using Eqs. 1 and 3. This gives $V_i \approx 8.4\,V$. When D_1 starts conducting (in addition to D_2), the slope of the V_o versus V_i plot changes. To find this slope, we redraw the circuit (see Fig. 3 (a)) and find R_{Th}, the Thevenin resistance as seen from PQ. For this purpose, we deactivate the voltage sources (see Fig. 3 (b)) and get

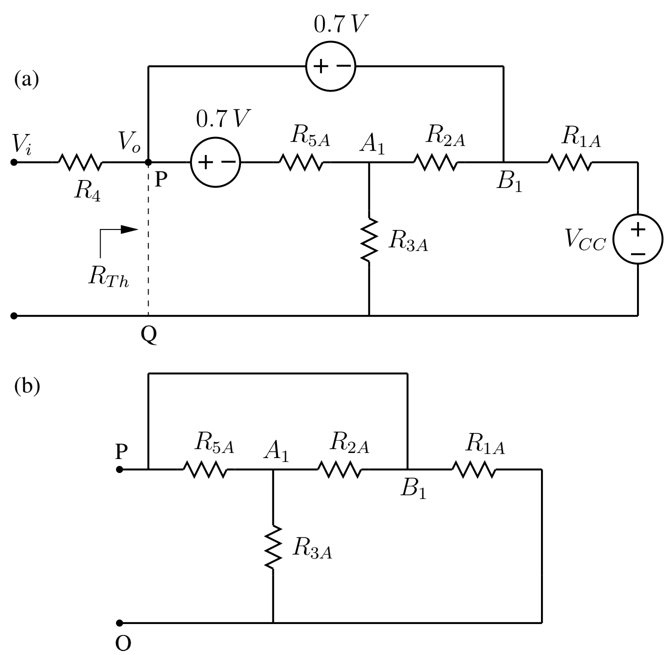

Figure 3: (a) Circuit of Fig. 1 with D_1 and D_2 conducting, (b) Computation of R_{Th}.

$R_{\text{Th}} = [(R_{5A} \parallel R_{2A}) + R_{3A}] \parallel R_{1A} = 1.6\,\text{k}$. The slope $\dfrac{dV_o}{dV_i}$ is then given by,

$$\frac{dV_o}{dV_i} = \frac{R_{\text{Th}}}{R_{\text{Th}} + R_4} = 0.138 \text{ (Show this.)} \tag{4}$$

Combining the above three cases, viz., (a) all diodes off, (b) only D_2 on, (c) D_1 and D_2 on, and using symmetry between the upper and lower parts of the circuit (see Fig. 1), we get the V_o versus V_i curve shown in Fig. 4 (a). If a triangular input $V_i(t)$ is applied, the output $V_o(t)$ is almost sinusoidal (see Fig. 4 (b)). For this reason, this circuit is called triangle-to-sine converter.

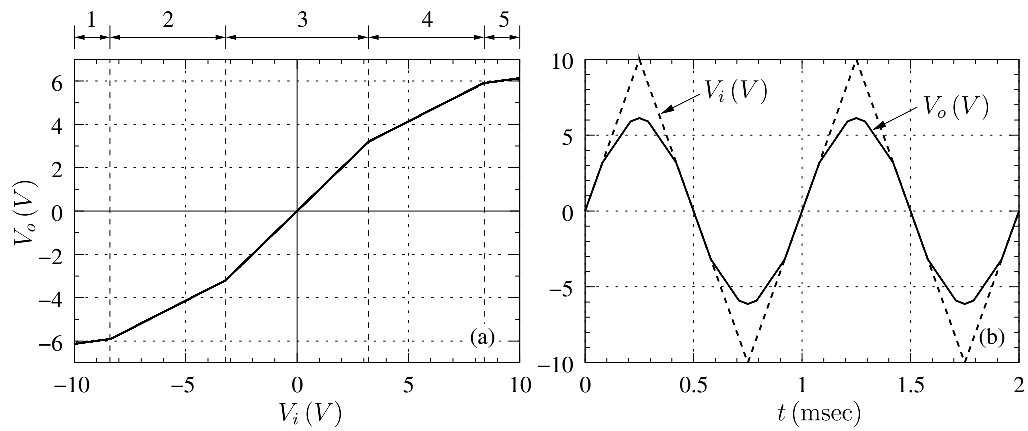

Figure 4: (a) V_o versus V_i for the circuit of Fig. 1. Region 1: D_3 and D_4 on, Region 2: D_3 on, Region 3: all diodes off, Region 4: D_2 on, Region 5: D_1 and D_2 on, (b) $V_o(t)$ for a triangular input $V_i(t)$.

Exercise Set

(a) Simulate the circuit. Plot i_{D1}, i_{D2}, i_{D3}, i_{D4} versus V_i, and verify that the diodes start conducting at the V_i values expected from the above analysis.

(b) How do you expect the node voltages V_{A1}, V_{B1} to vary with V_i? Verify with simulation.