Op-amp circuits (`EC_schmitt_2.sqproj`)

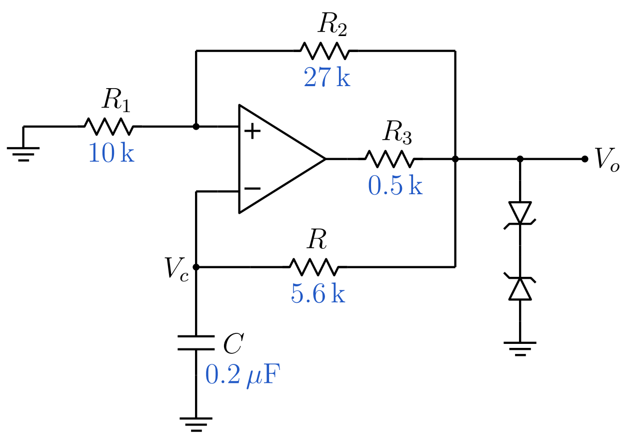

Figure 1: Oscillator circuit using a Schmitt trigger.

Question: In the oscillator circuit shown in Fig. 1, the Zener diodes have $V_Z = 9.3\,\text{V}$ and $V_{\text{on}} = 0.7\,\text{V}$. Find the period of oscillation.

Solution:

The block-diagram description of the oscillator is shown in Fig. 2, and the associated waveforms are shown in Fig. 3 (a), where V_{TH} and V_{TL} are the tripping points of the Schmitt trigger block, as shown in Fig. 3 (b).

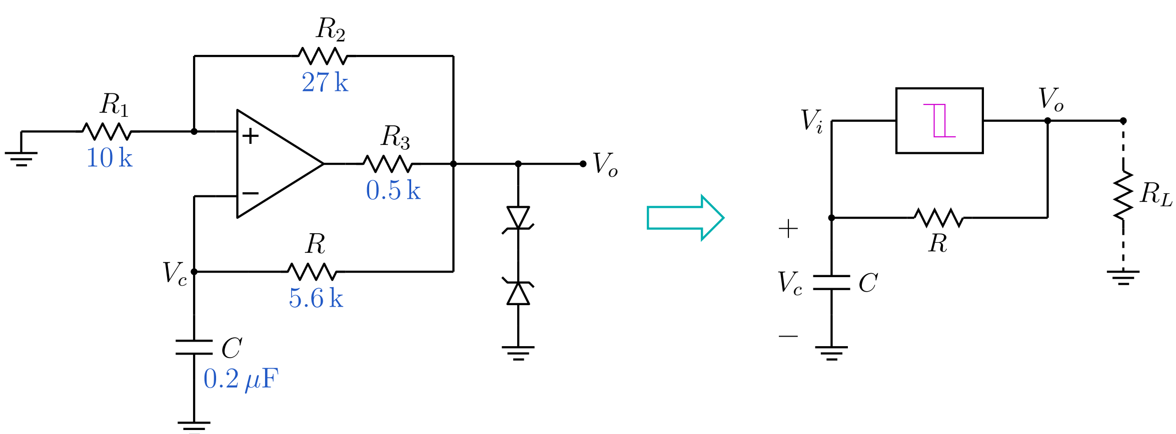

Figure 2: Oscillator circuit of Fig. 1 redrawn at the block diagram level.

The Zener pair in the oscillator circuit limits the output voltage to $\pm(V_Z + V_{\text{on}})$, and the resistor R_3 is used to limit the op-amp output current. When the output voltage is V_{max} $(= V_Z + V_{\text{on}})$, the capacitor charges toward V_{max} with a time constant $\tau = RC$. However, when V_c reaches V_{TH}, the output changes from V_{max} to V_{min} $(= -(V_Z + V_{\text{on}}))$. The capacitor now

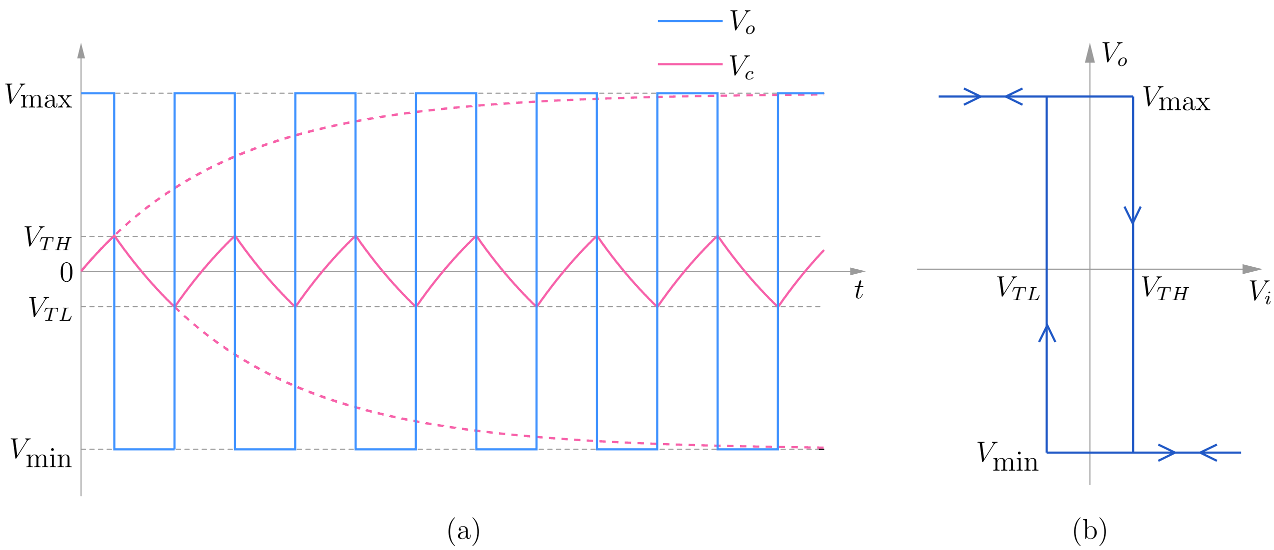

Figure 3: (a) V_c and V_o waveforms, (b) V_o versus V_i relationship for the Schmitt trigger block.

starts discharging toward $V_{\min}$. When V_c reaches V_{TL}, the output changes from $V_{\min}$ to $V_{\max}$, and the cycle repeats.

To find the period of oscillation, we need to find the V_{TL} and V_{TH} values for the Schmitt trigger circuit (see Fig. 4). When $V_o = V_{\max} = (V_Z + V_{\text{on}})$, we have $V_+ = V_{\max} \times \dfrac{R_1}{R_1 + R_2}$. When V_-, which is the same as V_i,crosses this value (see Fig. 3 (b)), the output flips from $V_{\max}$ to $V_{\min}$. In other words $V_{TH} = V_{\max} \times \dfrac{R_1}{R_1 + R_2}$. Similarly, we can show that
$V_{TL} = V_{\min} \times \dfrac{R_1}{R_1 + R_2}$.

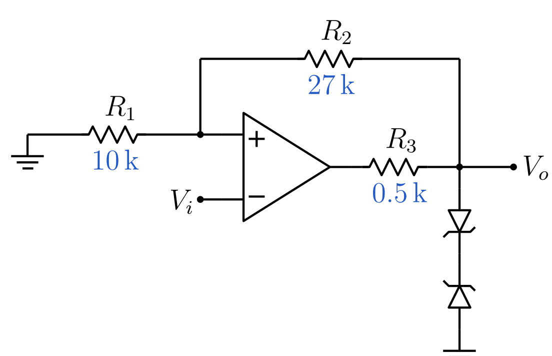

Figure 4: Schmitt trigger part of the oscillator circuit of Fig. 1.

We are now in a position to obtain the period of oscillation. With reference to the V_c and V_o waveforms shown in Fig. 5, we find the charging and discharging intervals as follows.

(a) Charging (from 0 to t_1): Let $V_c(t) = A_1 e^{-t/\tau} + B_1$ in this interval, with $\tau = RC$. Using

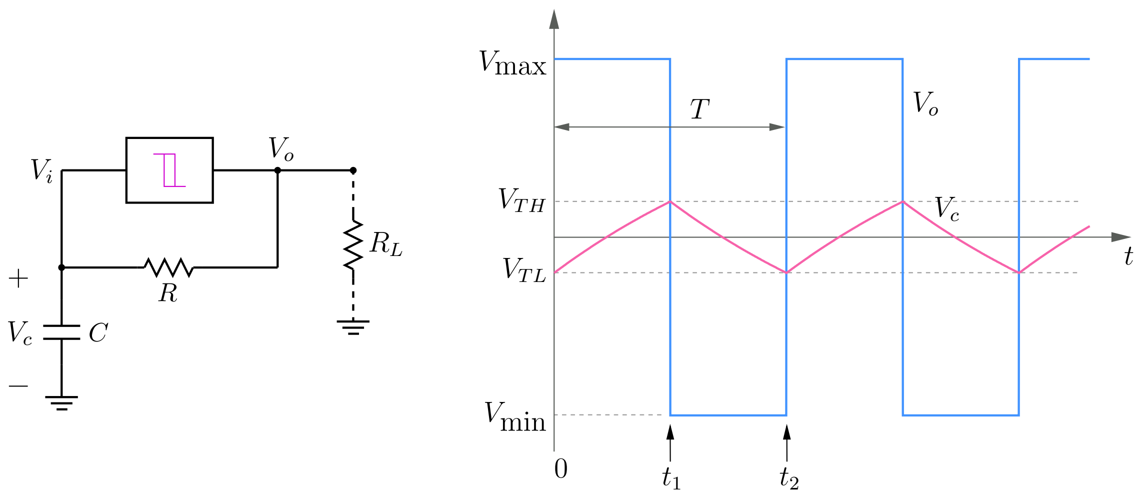

Figure 5: V_c and V_o waveforms showing charging and discharging times.

the conditions, $V_c(0) = V_{TL}$, $V_c(\infty) = V_{\max}$, we find A_1 and B_1 to be $B_1 = V_{\max}$, $A_1 = V_{TL} - V_{\max}$, giving

$$V_c(t) = (V_{TL} - V_{\max})e^{-t/\tau} + V_{\max}. \tag{1}$$

At $t = t_1$, $V_c = V_{TH}$, i.e.,

$$V_{TH} = (V_{TL} - V_{\max})e^{-t_1/\tau} + V_{\max}. \tag{2}$$

$$\rightarrow t_1 = \tau \ln\left(\frac{V_{\max} - V_{TL}}{V_{\max} - V_{TH}}\right). \tag{3}$$

(b) Charging (from t_1 to t_2): Let $V_c(t) = A_2 e^{-(t-t_1)/\tau} + B_2$ in this interval. Using the conditions, $V_c(t_1) = V_{TH}$, $V_c(\infty) = V_{\min}$, we find A_2 and B_2 to be $B_2 = V_{\min}$, $A_2 = V_{TH} - V_{\min}$, giving

$$V_c(t) = (V_{TH} - V_{\min})e^{-(t-t_1)/\tau} + V_{\min}. \tag{4}$$

At $t = t_2$, $V_c = V_{TL}$, i.e.,

$$V_{TL} = (V_{TH} - V_{\min})e^{-(t_2-t_1)/\tau} + V_{\min}. \tag{5}$$

$$\rightarrow (t_2 - t_1) = \tau \ln\left(\frac{V_{TH} - V_{\min}}{V_{TL} - V_{\min}}\right). \tag{6}$$

For the conditions $V_{\max} = -V_{\min}$, and $V_{TH} = -V_{TL}$, which are valid for the oscillator of Fig. 1, the charging and discharging intervals are equal. The period of oscillation T, which is the same as t_2 in Fig. 5, is from the above equations,

$$(t_2 - t_1) + t_1 = \tau \left[\ln \left(\frac{V_{TH} - V_{\min}}{V_{TL} - V_{\min}} \right) + \ln \left(\frac{V_{\max} - V_{TL}}{V_{\max} - V_{TH}} \right) \right]. \quad (7)$$

After substituting the numerical values, we find $V_{\min} = -10\,\text{V}$, $V_{\max} = 10\,\text{V}$, $V_{TL} = -2.7\,\text{V}$, $V_{TH} = 2.7\,\text{V}$, and $T = 1.24\,\text{msec}$.

SequelApp Exercises:

1. Find the period of oscillation in the following cases, with other parameter values the same as in Fig. 1.

   (a) R_1 is changed from 27 k to 15 k.

   (b) R is changed from 5.6 k to 10 k.

   (c) V_Z of the Zener diodes is changed from 9.3 V to 7.3 V.

2. Find R_1 in order to obtain an oscillation frequency of 500 Hz, with other parameter values the same as in Fig. 1.

Verify your answers using SequelApp.