The op-amp is ideal, with $V_{CC} = 10\,\text{V}$ and $V_{EE} = -10\,\text{V}$. The diode forward voltage, $V_D = 0.7\,\text{V}$.

This is a Wien bridge sine-wave oscillator. It oscillates because

\[
G = 1 + \frac{99\,\text{k}\Omega}{24\,\text{k}\Omega} = 5.12 > 3.
\]

- What is the frequency of oscillation.
- Sketch $V_o$ when the oscillation amplitude has stabilized.
- Indicate the approximate voltage of oscillation on the sketch.

\[
\omega = (RC)^{-1} = (37\,\text{k}\Omega \times 31\,\text{nF})^{-1} = 871.8\,\text{rad/s}
\]

\[
f = \frac{1}{2\pi} \omega = 138.8\,\text{Hz}
\]

- What is the frequency of oscillation.
- Sketch $V_o$ when the oscillation amplitude has stabilized.
  The oscillation will be roughly sine shaped at $f = 138.8\,\text{Hz}$
- Indicate the approximate voltage of oscillation on the sketch. amplitude stabilized at $\pm 0.7\,\text{V}$.
The op-amp is ideal, with $V_{CC} = 2 \text{ V}$ and $V_{EE} = -2 \text{ V}$.

Initial conditions are: $V_− = 0$ and $V_o = +V_{CC}$.

Sketch as a function of time: 1) $V_-$, 2) $V_+$, 3) $V_o$

- $V_o$ will switch between $±2 \text{ V}$
- $V_+$ will switch between $±2 \text{ V}$, $\frac{78 \text{ kΩ}}{78 \text{ kΩ} + 37 \text{ kΩ}} = 1.36 \text{ V}$
- $V_+$ will exponentially rise between $±1.36 \text{ V}$.

Timing will be symmetric between +ve and -ve pulses.

$$(V_f - V_\infty) = (V_i - V_\infty)e^{-t/\tau}$$

were $\tau = RC = 31 \text{ kΩ} \times 37 \text{ nF} = 1.147 \text{ ms}$

For the -ve transition, $V_i = 1.36 \text{ V}$, $V_f = -1.36 \text{ V}$, an $V_\infty = -2 \text{ V}$.

$$t = \tau \ln \left( \frac{V_f - V_\infty}{V_i - V_\infty} \right) = (1.147 \text{ ms}) \ln \left( \frac{1.36 - (-2)}{-1.36 - (-2)} \right) = 1.90 \text{ ms}$$
Initial conditions are that the charge on the capacitor is zero. \( V_{CC} = 9 \) V.

- Sketch \( V_o \), \( V_A \) and \( V_B \).
- What is the length of the \( V_o = \text{high} \) and \( V_o = \text{low} \) outputs?

This configuration is similar, but not the same as the configuration discussed in class. Normally \( V_+ \) of the upper comparator is connected to \( V_B \). This means that the upper transitions will not happen at \( V_B = \frac{2}{3} V_{CC} \), but instead when \( V_A = \frac{2}{3} V_{CC} \). At this time, we calculate

\[
i = \frac{(V_{CC} - \frac{2}{3} V_{CC})}{55 \text{k}\Omega} = \frac{(9 V - 6 V)}{55 \text{k}\Omega} = 3 V/55 \text{k}\Omega = 54.55 \mu\text{A}.
\]

Using \( i \), we calculate \( V_B = V_A - i(16 \text{k}\Omega) = 5.13 V \).

Another way to see this is to think about Capacitor \( C \) charging until \( V_A = \frac{2}{3} V_{CC} \) (RESET) and discharging until \( V_B = \frac{1}{3} V_{CC} \) (SET). In the usual 555 astable configuration, the trigger and threshold pins (pins 2 and 6) are both connected to the top of \( C \), so \( V_A = V_B \), however in the above circuit \( V_A \) and \( V_B \) are related by

\[
V_A = V_B + (V_{CC} - V_B) \frac{R_B}{R_A + R_B}
\]

(voltage divider). Setting \( V_A = \frac{2}{3} V_{CC} \) and rearranging, RESET occurs when \( V_B \) reaches voltage \( V_R \) given by

\[
V_R = \left( \frac{2}{3} - \frac{R_B}{R_A + R_B} \right) \left( \frac{R_A + R_B}{R_A} \right) V_{CC}
\]

\[
V_R = \left( \frac{2}{3} - \frac{16 \text{k}\Omega}{55 \text{k}\Omega + 16 \text{k}\Omega} \right) \left( \frac{55 \text{k}\Omega + 16 \text{k}\Omega}{55 \text{k}\Omega} \right) 9 V = 5.13 V
\]

The durations of the charge and discharge half-cycles are then given by the usual formula

\[
t = RC \ln \left( \frac{V_{\infty} - V_i}{V_{\infty} - V_f} \right) = (0.44)RC
\]
with $V_i = \frac{V_{CC}}{3}$, $V_f = V_R$, $V_\infty = V_{CC}$ and $R = R_A + R_B$ for the charge half-cycle and $V_i = V_R$, $V_f = \frac{V_{CC}}{3}$, $V_\infty = 0$ and $R = R_B$ for the discharge half-cycle. $V_o = V_{CC}$ during the charge period and $V_o = 0 \text{ V}$ during the discharge period. Thus:

- $t_{\text{high}} = 0.44 \times 59 \mu F \times (55 \text{ kΩ} + 16 \text{ kΩ}) = 1.84 \text{ ms}$
- $t_{\text{low}} = 0.44 \times 59 \mu F \times (16 \text{ kΩ}) = 0.42 \text{ ms}$

The shape of $V_B$ is essentially the same as that of the regular 555 astable configuration, rising and falling exponentially between the two limits - except that the upper limit is $V_R$ instead of $\frac{2}{3}V_{CC}$. Meanwhile $V_A$ rises exponentially from somewhat above $\frac{1}{3}V_{CC}$ to $\frac{2}{3}V_{CC}$, and then drops immediately to zero for the duration of the discharge half-cycle since it is connected directly to the discharge pin (pin 7).