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

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

This is a Wien bridge sine-wave oscillator. It oscillates because $G = 1 + \frac{60\,\text{k}\Omega}{26\,\text{k}\Omega} = 3.31 > 3$.

- What is the frequency of oscillation.
  $\omega = (RC)^{-1} = (38\,\text{k}\Omega \times 37\,\text{nF})^{-1} = 711.2\,\text{rad/s}$
  $f = \frac{1}{2\pi \omega} = 113.2\,\text{Hz}$
- Sketch $V_o$ when the oscillation amplitude has stabilized.
  The oscillation will be roughly sine shaped at $f = 113.2\,\text{Hz}$
- 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 $\pm 2\text{ V}$
- $V_+$ will switch between $\pm 2\text{ V}$
  \[ \frac{55\text{ k}\Omega}{55\text{ k}\Omega + 24\text{ k}\Omega} = 1.39 \text{ V} \]
- $V_+$ will exponentially rise between $\pm 1.39 \text{ V}$.

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

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

were $\tau = RC = 37 \text{ k}\Omega \times 38 \text{ nF} = 1.406 \text{ ms}$

For the -ve transition, $V_i = 1.39 \text{ V}$, $V_f = -1.39 \text{ V}$, an $V_\infty = -2 \text{ V}$.

\[ t = \tau \ln \left( \frac{V_f - V_\infty}{V_i - V_\infty} \right) = (1.406 \text{ ms}) \ln \left( \frac{1.39 - (-2)}{-1.39 - (-2)} \right) = 2.41 \text{ ms} \]
Initial conditions are that the charge on the capacitor is zero. \( V_{CC} = 9 \text{ V} \).

- Sketch \( V_o \), \( V_A \) and \( V_B \).
- What is the length of the \( V_o \) = high and \( V_o \) = 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

\[
i = (V_{CC} - \frac{2}{3} V_{CC})/57 \text{kΩ} = (9 \text{ V} - 6 \text{ V})/57 \text{kΩ} = 3 \text{ V}/57 \text{kΩ} = 52.63 \mu \text{A}.
\]

Using \( i \), we calculate \( V_B = V_A - i(18 \text{kΩ}) = 5.05 \text{ V} \).

Another way to see this is to think about Capacitor \( C \) charging until \( V_A = 2/3 V_{CC} \) (RESET) and discharging until \( V_B = 1/3 V_{CC} \) (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 \( V_A = 2/3 V_{CC} \) and rearranging, RESET occurs when \( V_B \) reaches voltage \( V_R \) given by

\[
V_R = \left( \frac{2}{3} - \frac{18 \text{kΩ}}{57 \text{kΩ} + 18 \text{kΩ}} \right) \left( \frac{57 \text{kΩ} + 18 \text{kΩ}}{57 \text{kΩ}} \right) 9 \text{ V} = 5.05 \text{ V}
\]

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

\[
t = RC \ln \left( \frac{V_\infty - V_i}{V_\infty - V_f} \right) = (0.42)RC
\]
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 $V_o = 0$ V during the discharge period. Thus:

- $t_{\text{high}} = 0.42 \times 40 \, \mu F \times (57 \, k\Omega + 18 \, k\Omega) = 1.26 \, ms$
- $t_{\text{low}} = 0.42 \times 40 \, \mu F \times (18 \, k\Omega) = 0.30 \, ms$

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 $2/3V_{CC}$. Meanwhile $V_A$ rises exponentially from somewhat above $1/3V_{CC}$ to $2/3V_{CC}$, 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).