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 $G = 1 + \frac{71\, \text{k}\Omega}{20\, \text{k}\Omega} = 4.55 > 3$.

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

\[
\omega = (RC)^{-1} = (39\, \text{k}\Omega \times 33\, \text{nF})^{-1} = 777\, \text{rad/s}
\]
\[
f = \frac{1}{2\pi\omega} = 123.7\, \text{Hz}
\]

- Sketch $V_o$ when the oscillation amplitude has stabilized.
  The oscillation will be roughly sine shaped at $f = 123.7\, \text{Hz}$
- Indicate the approximate voltage of oscillation on the sketch.
  amplitude stabilized at $\pm0.7\, \text{V}$. 
The op-amp is ideal, with $V_{CC} = 2\,V$ and $V_{EE} = -2\,V$.

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

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

- $V_o$ will switch between $\pm 2\,V$
- $V_+$ will switch between $\pm 2\,V$\[\frac{73\,k\Omega}{73\,k\Omega + 23\,k\Omega} = 1.52\,V\]
- $V_+$ will exponentially rise between $\pm 1.52\,V$.

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

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

were $\tau = RC = 33\,k\Omega \times 39\,nF = 1.287\,ms$

For the -ve transition, $V_i = 1.52\,V$, $V_f = -1.52\,V$, an $V_\infty = -2\,V$.

$$t = \tau \ln \left( \frac{V_f - V_\infty}{V_i - V_\infty} \right) = (1.287\,ms) \ln \left( \frac{1.52 - (-2)}{-1.52 - (-2)} \right) = 2.56\,ms$$
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 $V_o = \text{high}$ 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

\[ i = \left( V_{CC} - \frac{2}{3}V_{CC} \right) / 59 \, \text{k}\Omega = (9 \, \text{V} - 6 \, \text{V}) / 59 \, \text{k}\Omega = 3 \, \text{V} / 59 \, \text{k}\Omega = 50.85 \, \mu\text{A}. \]

Using $i$, we calculate $V_B = V_A - i(12 \, \text{k}\Omega) = 5.39 \, \text{V}$.

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

\[ V_R = \left( \frac{2}{3} - \frac{12 \, \text{k}\Omega}{59 \, \text{k}\Omega + 12 \, \text{k}\Omega} \right) \left( \frac{59 \, \text{k}\Omega + 12 \, \text{k}\Omega}{59 \, \text{k}\Omega} \right) V_{CC} \]

\[ V_R = \left( \frac{2}{3} - \frac{12 \, \text{k}\Omega}{59 \, \text{k}\Omega + 12 \, \text{k}\Omega} \right) \left( \frac{59 \, \text{k}\Omega + 12 \, \text{k}\Omega}{59 \, \text{k}\Omega} \right) 9 \, \text{V} = 5.39 \, \text{V} \]

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

\[ t = RC \ln \left( \frac{V_{\infty} - V_i}{V_{\infty} - V_f} \right) = (0.51)RC \]
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:

- \( t_{\text{high}} = 0.51 \times 46 \mu \text{F} \times (59 \text{k}\Omega + 12 \text{k}\Omega) = 1.67 \text{ms} \)
- \( t_{\text{low}} = 0.51 \times 46 \mu \text{F} \times (12 \text{k}\Omega) = 0.28 \text{ms} \)

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).