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 $G = 1 + \frac{54 \text{k}\Omega}{24 \text{k}\Omega} = 3.25 > 3$.

- What is the frequency of oscillation.
  \[
  \omega = (RC)^{-1} = (26 \text{k}\Omega \times 31 \text{nF})^{-1} = 1240.7 \text{ rad/s}
  \]
  \[
  f = \frac{1}{2\pi} \omega = 197.5 \text{Hz}
  \]
- Sketch $V_o$ when the oscillation amplitude has stabilized.
  The oscillation will be roughly sine shaped at $f = 197.5 \text{Hz}$
- 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 $V_{EE} = -2\, \text{V}$.

$$\begin{array}{c}
\begin{array}{c}
\hline
\text{79 kΩ} \\
\hline
\text{33 kΩ} \\
\hline
\text{26 nF} \\
\hline
\text{31 kΩ}
\end{array}
\end{array}$$

Initial conditions are: $V_0 = 0$ 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 $\pm 2\, \text{V}$: $\frac{79\, \text{kΩ}}{79\, \text{kΩ} + 33\, \text{kΩ}} = 1.41\, \text{V}$
- $V_+$ will exponentially rise between $\pm 1.41\, \text{V}$.

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

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

were $\tau = RC = 31\, \text{kΩ} \times 26\, \text{nF} = 0.806\, \text{ms}$

For the -ve transition, $V_i = 1.41\, \text{V}$, $V_f = -1.41\, \text{V}$, an $V_\infty = -2\, \text{V}$.

$$t = \tau \ln \left( \frac{V_f - V_\infty}{V_i - V_\infty} \right) = (0.806\, \text{ms}) \ln \left( \frac{1.41 - (-2)}{-1.41 - (-2)} \right) = 1.41\, \text{ms}$$
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 $V_o = \text{high}$ 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

$$i = (V_{CC} - \frac{2}{3}V_{CC})/39\, \text{k}\Omega = (9\, \text{V} - 6\, \text{V})/39\, \text{k}\Omega = 3\, \text{V}/39\, \text{k}\Omega = 76.92\, \mu\text{A}.$$  

Using $i$, we calculate $V_B = V_A - i(16\, \text{k}\Omega) = 4.77\, \text{V}$.

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

$$V_R = \left(\frac{2}{3} - \frac{R_B}{R_A + R_B}\right)\left(\frac{R_A + R_B}{R_A}\right)\frac{V_{CC}}{39\, \text{k}\Omega + 16\, \text{k}\Omega}$$

$$V_R = \left(\frac{2}{3} - \frac{16\, \text{k}\Omega}{39\, \text{k}\Omega + 16\, \text{k}\Omega}\right)\left(\frac{39\, \text{k}\Omega + 16\, \text{k}\Omega}{39\, \text{k}\Omega}\right)9\, \text{V} = 4.77\, \text{V}$$

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

$$t = RC \ln \left(\frac{V_{\infty} - V_f}{V_{\infty} - V_i}\right) = (0.35)RC$$
with $V_i = V_{CC}/3$, $V_f = V_R$, $V_\infty = V_{CC}$ and $R = R_A + R_B$ for the charge half-cycle and $V_i = V_R$, $V_f = V_{CC}/3$, $V_\infty = 0$ 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:

- $t_{\text{high}} = 0.35 \times 37 \, \mu F \times (39 \, k\Omega + 16 \, k\Omega) = 0.71 \, ms$
- $t_{\text{low}} = 0.35 \times 37 \, \mu F \times (16 \, k\Omega) = 0.21 \, ms$

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).