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 $G = 1 + \frac{49\, \text{k}\Omega}{22\, \text{k}\Omega} = 3.23 > 3$.

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

\[ \omega = (RC)^{-1} = (34\, \text{k}\Omega \times 22\, \text{nF})^{-1} = 1336.9\, \text{rad/s} \]
\[ f = \frac{1}{2\pi\omega} = 212.8\, \text{Hz} \]

- Sketch $V_o$ when the oscillation amplitude has stabilized.
  The oscillation will be roughly sine shaped at $f = 212.8\, \text{Hz}$
- Indicate the approximate voltage of oscillation on the sketch. amplitude stabilized at $\pm 0.7\, \text{V}$.
The op-amp is ideal, with \(V_{CC} = 2\) V and \(V_{EE} = -2\) 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 V
- \(V_+\) will switch between ±2 V \(\frac{53\ \text{k}\Omega}{53\ \text{k}\Omega + 30\ \text{k}\Omega} = 1.28\) V
- \(V_+\) will exponentially rise between ±1.28 V.

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

\[
(V_f - V_\infty) = (V_i - V_\infty)e^{-t/\tau},
\]
where \(\tau = RC = 22\ \text{k}\Omega \times 34\ \text{nF} = 0.748\) ms

For the -ve transition, \(V_i = 1.28\) V, \(V_f = -1.28\) V, and \(V_\infty = -2\) V.

\[
t = \tau \ln \left( \frac{V_f - V_\infty}{V_i - V_\infty} \right) = (0.748\ \text{ms}) \ln \left( \frac{1.28 - (-2)}{-1.28 - (-2)} \right) = 1.13\ \text{ms}
\]
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 $V_A = \frac{1}{3}V_{CC}$. At this time, we calculate

$$i = (V_{CC} - \frac{2}{3}V_{CC})/51 \text{k}\Omega = (9V - 6V)/51 \text{k}\Omega = 3V/51 \text{k}\Omega = 58.82 \mu A.$$  

Using $i$, we calculate $V_B = V_A - i(14 \text{k}\Omega) = 5.18 V$.

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

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

$$V_R = \left(\frac{2}{3} - \frac{14 \text{k}\Omega}{51 \text{k}\Omega + 14 \text{k}\Omega}\right)\left(\frac{51 \text{k}\Omega + 14 \text{k}\Omega}{51 \text{k}\Omega}\right)9V = 5.18 V$$

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

$$t = RC \ln \left(\frac{V_i}{V_f} \frac{V_f}{V_i}\right) = (0.45)RC$$
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:

- $t_{\text{high}} = 0.45 \times 34 \, \mu\text{F} \times (51 \, \text{k}\Omega + 14 \, \text{k}\Omega) = 0.99 \, \text{ms}$
- $t_{\text{low}} = 0.45 \times 34 \, \mu\text{F} \times (14 \, \text{k}\Omega) = 0.21 \, \text{ms}$

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).