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 $G = 1 + \frac{56\,\text{k}\Omega}{19\,\text{k}\Omega} = 3.95 > 3$.

• What is the frequency of oscillation.

$\omega = (RC)^{-1} = (38\,\text{k}\Omega \times 24\,\text{nF})^{-1} = 1096.5\,\text{rad/s}$

$f = \frac{1}{2\pi} \omega = 174.5\,\text{Hz}$

• Sketch $V_o$ when the oscillation amplitude has stabilized.

The oscillation will be roughly sine shaped at $f = 174.5\,\text{Hz}$

• 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 \( V_{EE} = -2 \text{ V} \).

Initial conditions are: \( V_- = 0 \) and \( V_0 = +V_{CC} \).

Sketch as a function of time: 1) \( V_- \), 2) \( V_+ \), 3) \( V_0 \)

- \( V_0 \) will switch between \( \pm 2 \text{ V} \)
- \( V_+ \) will switch between \( \pm 2 \text{ V} \)
  \[ \frac{74 \text{ k}\Omega}{74 \text{ k}\Omega + 38 \text{ k}\Omega} = 1.32 \text{ V} \]
- \( V_+ \) will exponentially rise between \( \pm 1.32 \text{ V} \).

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

\[
(V_f - V_\infty) = (V_i - V_\infty)e^{-t/\tau},
\]
where \( \tau = RC = 24 \text{ k}\Omega \times 38 \text{ nF} = 0.912 \text{ ms} \)

For the -ve transition, \( V_i = 1.32 \text{ V} \), \( V_f = -1.32 \text{ V} \), an \( V_\infty = -2 \text{ V} \).

\[
t = \tau \ln \left( \frac{V_f - V_\infty}{V_i - V_\infty} \right) = (0.912 \text{ ms}) \ln \left( \frac{1.32 - (-2)}{-1.32 - (-2)} \right) = 1.45 \text{ ms}
\]
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

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

Using \( i \), we calculate \( V_B = V_A - i(11 \text{k}\Omega) = 5.42 \text{ V} \).

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

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

\[
V_R = \left(\frac{2}{3} - \frac{11 \text{k}\Omega}{57 \text{k}\Omega + 11 \text{k}\Omega}\right) \left(\frac{57 \text{k}\Omega + 11 \text{k}\Omega}{57 \text{k}\Omega}\right) 9 \text{ V} = 5.42 \text{ V}
\]

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

\[
t = RC \ln \left(\frac{V_\infty - V_i}{V_\infty - V_f}\right) = (0.52)RC
\]
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:

- \( t_{\text{high}} = 0.52 \times 38 \, \mu F \times (57 \, \text{k}\Omega + 11 \, \text{k}\Omega) = 1.34 \, \text{ms} \)
- \( t_{\text{low}} = 0.52 \times 38 \, \mu F \times (11 \, \text{k}\Omega) = 0.22 \, \text{ms} \)

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 \( 2/3V_{CC} \). 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).