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 $G = 1 + \frac{49 \text{k}\Omega}{19 \text{k}\Omega} = 3.58 > 3$.

- What is the frequency of oscillation.
  $\omega = (RC)^{-1} = (24 \text{k}\Omega \times 36 \text{nF})^{-1} = 1157.4 \text{ rad/s}$
  $f = \frac{1}{2\pi\omega} = 184.2 \text{ Hz}$
- Sketch $V_o$ when the oscillation amplitude has stabilized.
  The oscillation will be roughly sine shaped at $f = 184.2 \text{ Hz}$
- Indicate the approximate voltage of oscillation on the sketch.
  amplitude stabilized at $\pm 0.7 \text{ V}$.
The op-amp is ideal, with $V_{CC} = 2\, V$ and $V_{EE} = -2\, V$.

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 $±2\, V$
- $V_+$ will switch between $±2\, V\frac{42\, kΩ}{42\, kΩ+33\, kΩ} = 1.12\, V$
- $V_+$ will exponentially rise between $±1.12\, V$.

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

$$(V_f - V_∞) = (V_i - V_∞)e^{-t/τ},$$

were $τ = RC = 36\, kΩ \times 24\, nF = 0.864\, ms$

For the -ve transition, $V_i = 1.12\, V$, $V_f = -1.12\, V$, an $V_∞ = -2\, V$.

$$t = τ\ln\left(\frac{V_f - V_∞}{V_i - V_∞}\right) = (0.864\, ms)\ln\left(\frac{1.12 - (-2)}{-1.12 - (-2)}\right) = 1.09\, ms$$
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

\[
    i = \left( V_{CC} - \frac{2}{3} V_{CC} \right) / 36 \text{k}\Omega = \frac{(9 \text{ V} - 6 \text{ V})}{36 \text{k}\Omega} = 3 \text{ V/36 k}\Omega = 83.33 \mu\text{A}.
\]

Using \( i \), we calculate \( V_B = V_A - i(11 \text{k}\Omega) = 5.08 \text{ V} \).

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

\[
    V_R = \left( \frac{2}{3} - \frac{11 \text{k}\Omega}{36 \text{k}\Omega + 11 \text{k}\Omega} \right) \left( \frac{36 \text{k}\Omega + 11 \text{k}\Omega}{36 \text{k}\Omega} \right) V_{CC} = 5.08 \text{ V}
\]

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

\[
    t = RC \ln \left( \frac{V_{\infty} - V_i}{V_{\infty} - V_f} \right) = (0.43)RC
\]
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 \( V_o = 0 \text{ V} \) during the discharge period. Thus:

- \( t_{\text{high}} = 0.43 \times 35 \mu\text{F} \times (36 \text{ k}\Omega + 11 \text{ k}\Omega) = 0.71 \text{ ms} \)
- \( t_{\text{low}} = 0.43 \times 35 \mu\text{F} \times (11 \text{ k}\Omega) = 0.17 \text{ ms} \)

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).