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

$$G = 1 + \frac{57\, \text{k}\Omega}{25\, \text{k}\Omega} = 3.28 > 3.$$  

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

\[ \omega = (RC)^{-1} = (32\, \text{k}\Omega \times 36\, \text{nF})^{-1} = 868.1\, \text{rad/s} \]

\[ f = \frac{1}{2\pi \omega} = 138.2\, \text{Hz} \]

The oscillation will be roughly sine shaped at $f = 138.2\, \text{Hz}$

- Sketch $V_o$ when the oscillation amplitude has stabilized.
- 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 $V_{EE} = -2\, \text{V}$.

![Circuit Diagram](image)

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 $\pm 2\, \text{V}$
- $V_+$ will switch between $\pm 2\, \text{V}$, $V_+ = \frac{78\, \text{k}\Omega}{78\, \text{k}\Omega + 36\, \text{k}\Omega}$ = 1.37 V
- $V_+$ will exponentially rise between $\pm 1.37\, \text{V}$.

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

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

were $\tau = RC = 36\, \text{k}\Omega \times 32\, \text{nF} = 1.152\, \text{ms}$

For the -ve transition, $V_i = 1.37\, \text{V}$, $V_f = -1.37\, \text{V}$, an $V_\infty = -2\, \text{V}$.

$$t = \tau \ln \left( \frac{V_f - V_\infty}{V_i - V_\infty} \right) = (1.152\, \text{ms}) \ln \left( \frac{1.37 - (-2)}{-1.37 - (-2)} \right) = 1.93\, \text{ms}$$
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 $V_A = \frac{2}{3}V_{CC}$. At this time, we calculate

$$i = (V_{CC} - \frac{2}{3}V_{CC})/48\,\text{k}\Omega = (9\,\text{V} - 6\,\text{V})/48\,\text{k}\Omega = 3\,\text{V}/48\,\text{k}\Omega = 62.50\,\mu\text{A}.$$

Using $i$, we calculate $V_B = V_A - i(17\,\text{k}\Omega) = 4.94$ 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

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

$$V_R = \left(\frac{2}{3} - \frac{17\,\text{k}\Omega}{48\,\text{k}\Omega + 17\,\text{k}\Omega}\right) \left(\frac{48\,\text{k}\Omega + 17\,\text{k}\Omega}{48\,\text{k}\Omega}\right) 9\,\text{V} = 4.94\,\text{V}$$

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

$$t = RC \ln \left(\frac{V_\infty - V_i}{V_\infty - V_f}\right) = (0.39)RC$$
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:

- $t_{\text{high}} = 0.39 \times 39 \mu F \times (48 \, \text{kΩ} + 17 \, \text{kΩ}) = 0.99 \, \text{ms}$
- $t_{\text{low}} = 0.39 \times 39 \mu F \times (17 \, \text{kΩ}) = 0.26 \, \text{ms}$

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).