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 $G = 1 + \frac{94\, \text{k}\Omega}{25\, \text{k}\Omega} = 4.76 > 3$.

- What is the frequency of oscillation.
  
  $\omega = (RC)^{-1} = (31\, \text{k}\Omega \times 38\, \text{nF})^{-1} = 848.9\, \text{rad/s}$
  
  $f = \frac{1}{2\pi}\omega = 135.1\, \text{Hz}$

- Sketch $V_o$ when the oscillation amplitude has stabilized.
  
  The oscillation will be roughly sine shaped at $f = 135.1\, \text{Hz}$

- 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.

![Circuit Diagram]

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 $\pm 2$ V
- $V_+$ will switch between $\pm 2$ V $\frac{75 \text{k}\Omega}{75 \text{k}\Omega + 28 \text{k}\Omega} = 1.46$ V
- $V_+$ will exponentially rise between $\pm 1.46$ V.

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

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

were $\tau = RC = 38 \text{k}\Omega \times 31 \text{nF} = 1.178$ ms

For the -ve transition, $V_i = 1.46$ V, $V_f = -1.46$ V, an $V_{\infty} = -2$ V.

$$t = \tau \ln \left( \frac{V_f - V_{\infty}}{V_i - V_{\infty}} \right) = (1.178 \text{ ms}) \ln \left( \frac{1.46 - (-2)}{-1.46 - (-2)} \right) = 2.19 \text{ ms}$$
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

\[ i = \frac{(V_{CC} - \frac{2}{3}V_CC)}{47\text{k}\Omega} = \frac{(9\text{ V} - 6\text{ V})}{47\text{k}\Omega} = 3\text{ V}/47\text{k}\Omega = 63.83\mu\text{A}. \]

Using $i$, we calculate $V_B = V_A - i(17\text{k}\Omega) = 4.91\text{ V}$.

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

\[ V_R = \frac{2}{3} - \frac{17\text{k}\Omega}{47\text{k}\Omega + 17\text{k}\Omega} \left( \frac{47\text{k}\Omega + 17\text{k}\Omega}{47\text{k}\Omega} \right) 9\text{ V} = 4.91\text{ V} \]

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

\[ t = RC\ln\left(\frac{V_\infty - V_i}{V_\infty - V_f}\right) = (0.38)RC \]
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:

- $t_{\text{high}} = 0.38 \times 57 \mu\text{F} \times (47 \, \text{k}\Omega + 17 \, \text{k}\Omega) = 1.39 \text{ ms}$
- $t_{\text{low}} = 0.38 \times 57 \mu\text{F} \times (17 \, \text{k}\Omega) = 0.37 \text{ ms}$

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).