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 $G = 1 + \frac{67\,\text{k}\Omega}{27\,\text{k}\Omega} = 3.48 > 3$.

- What is the frequency of oscillation.
  
  $\omega = (RC)^{-1} = (39\,\text{k}\Omega \times 9\,\text{nF})^{-1} = 884.2\,\text{rad/s}$
  
  $f = \frac{1}{2\pi}\omega = 140.7\,\text{Hz}$

- Sketch $V_o$ when the oscillation amplitude has stabilized.
  
  The oscillation will be roughly sine shaped at $f = 140.7\,\text{Hz}$

- 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
  
  \[ \frac{61 \text{k}\Omega}{61 \text{k}\Omega + 28 \text{k}\Omega} = 1.37 \text{ V} \]
- $V_+$ will exponentially rise between $\pm 1.37$ V.

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

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

were $\tau = RC = 29 \text{k}\Omega \times 39 \text{nF} = 1.131$ ms

For the -ve transition, $V_i = 1.37$ V, $V_f = -1.37$ V, and $V_\infty = -2$ V.

\[ t = \tau \ln \left( \frac{V_f - V_\infty}{V_i - V_\infty} \right) = (1.131 \text{ ms}) \ln \left( \frac{1.37 - (-2)}{-1.37 - (-2)} \right) = 1.90$ 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 $V_o =$ 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

\[ i = \frac{(V_{CC} - \frac{2}{3}V_{CC})}{58 \text{k} \Omega} = \frac{(9 \text{ V} - 6 \text{ V})}{58 \text{k} \Omega} = \frac{3 \text{ V}}{58 \text{k} \Omega} = 51.72 \text{ } \mu \text{A}. \]

Using $i$, we calculate $V_B = V_A - i(19 \text{k} \Omega) = 5.02 \text{ V}$.

Another way to see this is to think about Capacitor $C$ charging until $V_A = \frac{2}{3}V_{CC}$ (RESET) and discharging until $V_B = \frac{1}{3}V_{CC}$ (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 $V_A = \frac{2}{3}V_{CC}$ and rearranging, RESET occurs when $V_B$ reaches voltage $V_R$ given by

\[ V_R = \left( \frac{2}{3} - \frac{19 \text{k} \Omega}{58 \text{k} \Omega + 19 \text{k} \Omega} \right) \left( \frac{58 \text{k} \Omega + 19 \text{k} \Omega}{58 \text{k} \Omega} \right) 9 \text{ V} = 5.02 \text{ V} \]

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

\[ t = RC \ln \left( \frac{V_\infty - V_i}{V_\infty - V_f} \right) = (0.41)RC \]
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:

- \( t_{\text{high}} = 0.41 \times 43 \mu F \times (58 \text{ k}\Omega + 19 \text{ k}\Omega) = 1.36 \text{ ms} \)
- \( t_{\text{low}} = 0.41 \times 43 \mu F \times (19 \text{ k}\Omega) = 0.33 \text{ ms} \)

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).