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 $G = 1 + \frac{68\, \text{k}\Omega}{21\, \text{k}\Omega} = 4.24 > 3$.

- What is the frequency of oscillation.
  
  $\omega = (RC)^{-1} = (36\, \text{k}\Omega \times 26\, \text{nF})^{-1} = 1068.4\, \text{rad/s}$
  
  $f = \frac{1}{2\pi\omega} = 170.0\, \text{Hz}$

- Sketch $V_o$ when the oscillation amplitude has stabilized.
  
  The oscillation will be roughly sine shaped at $f = 170.0\, \text{Hz}$

- 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 $V_{o} = +V_{CC}$.

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 $\pm 2\, \text{V}$, $\frac{40\, \text{k} \Omega}{40\, \text{k} \Omega + 23\, \text{k} \Omega} = 1.27\, \text{V}$
- $V_{+}$ will exponentially rise between $\pm 1.27\, \text{V}$.

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

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

were $\tau = RC = 26\, \text{k} \Omega \times 36\, \text{nF} = 0.936\, \text{ms}$

For the -ve transition, $V_{i} = 1.27\, \text{V}$, $V_{f} = -1.27\, \text{V}$, an $V_{\infty} = -2\, \text{V}$.

$$t = \tau \ln\left(\frac{V_{f} - V_{\infty}}{V_{i} - V_{\infty}}\right) = (0.936\, \text{ms}) \ln\left(\frac{1.27 - (-2)}{-1.27 - (-2)}\right) = 1.40\, \text{ms}$$
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

\[ i = \frac{(V_{CC} - \frac{2}{3}V_{CC})}{54\, k\Omega} = \frac{(9\, V - 6\, V)}{54\, k\Omega} = 3\, V/54\, k\Omega = 55.56\, \mu A. \]

Using $i$, we calculate $V_B = V_A - i(13\, k\Omega) = 5.28\, V$.

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

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

\[ V_R = \left( \frac{2}{3} - \frac{13\, k\Omega}{54\, k\Omega + 13\, k\Omega} \right) \frac{(54\, k\Omega + 13\, k\Omega)}{54\, k\Omega} 9\, V = 5.28\, V \]

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

\[ t = RC \ln \left( \frac{V_\infty - V_i}{V_\infty - V_f} \right) = (0.48)RC \]
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:

- $t_{\text{high}} = 0.48 \times 44 \, \mu F \times (54 \, k\Omega + 13 \, k\Omega) = 1.42 \, ms$
- $t_{\text{low}} = 0.48 \times 44 \, \mu F \times (13 \, k\Omega) = 0.27 \, ms$

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).