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 $G = 1 + \frac{66 \text{k}\Omega}{25 \text{k}\Omega} = 3.64 > 3$.

- What is the frequency of oscillation.
  
  $\omega = (RC)^{-1} = (35 \text{k}\Omega \times 29 \text{nF})^{-1} = 985.2 \text{ rad/s}$
  
  $f = \frac{1}{2\pi} \omega = 156.8 \text{Hz}$

- Sketch $V_o$ when the oscillation amplitude has stabilized.
  
  The oscillation will be roughly sine shaped at $f = 156.8 \text{Hz}$

- 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 \( \pm 2 \text{ V} \frac{50 \text{k}\Omega}{50 \text{k}\Omega + 21 \text{k}\Omega} = 1.41 \text{ V} \)
- \( V_+ \) will exponentially rise between \( \pm 1.41 \text{ V} \).

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

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

where \( \tau = RC = 29 \text{k}\Omega \times 35 \text{nF} = 1.015 \text{ ms} \)

For the -ve transition, \( V_i = 1.41 \text{ V}, \ V_f = -1.41 \text{ V}, \text{ an } V_\infty = -2 \text{ V} \).

\[
t = \tau \ln \left( \frac{V_f - V_\infty}{V_i - V_\infty} \right) = (1.015 \text{ ms}) \ln \left( \frac{1.41 - (-2)}{-1.41 - (-2)} \right) = 1.78 \text{ ms}
\]
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 $V_o =$ 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

$$i = (V_{CC} - \frac{2}{3}V_{CC})/53 \, \text{k}\Omega = (9 \, \text{V} - 6 \, \text{V})/53 \, \text{k}\Omega = 3 \, \text{V}/53 \, \text{k}\Omega = 56.60 \, \mu\text{A}.$$  

Using $i$, we calculate $V_B = V_A - i(17 \, \text{k}\Omega) = 5.04 \, \text{V}$.

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

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

$$V_R = \left(\frac{2}{3} - \frac{17 \, \text{k}\Omega}{53 \, \text{k}\Omega + 17 \, \text{k}\Omega}\right) \left(\frac{53 \, \text{k}\Omega + 17 \, \text{k}\Omega}{53 \, \text{k}\Omega}\right) 9 \, \text{V} = 5.04 \, \text{V}$$

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

$$t = RC \ln \left(\frac{V_\infty - V_i}{V_\infty - V_f}\right) = (0.42)RC$$
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:

- $t_{\text{high}} = 0.42 \times 43 \, \mu F \times (53 \, k\Omega + 17 \, k\Omega) = 1.26 \, ms$
- $t_{\text{low}} = 0.42 \times 43 \, \mu F \times (17 \, k\Omega) = 0.31 \, ms$

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).