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

$$G = 1 + \frac{52 \text{k}\Omega}{27 \text{k}\Omega} = 2.93 > 3.$$  

- What is the frequency of oscillation.
  $$\omega = (RC)^{-1} = (37 \text{k}\Omega \times 20 \text{nF})^{-1} = 1351.4 \text{ rad/s}$$
  $$f = \frac{1}{2\pi}\omega = 215.1 \text{Hz}$$

- Sketch $V_o$ when the oscillation amplitude has stabilized.
  The oscillation will be roughly sine shaped at $f = 215.1 \text{Hz}$

- Indicate the approximate voltage of oscillation on the sketch. amplitude stabilized at $\pm 0.7 \text{ V}$.
The op-amp is ideal, with $V_{CC} = 2 \text{ V}$ and $V_{EE} = -2 \text{ V}$.

![Circuit Diagram]

Initial conditions are: $V_- = 0$ and $V_o = +V_{CC}$.

- $V_o$ will switch between $\pm 2 \text{ V}$
- $V_+$ will switch between $\pm 2 \text{ V}$
- $V_+$ will exponentially rise between $\pm 1.53\text{ V}$.

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

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

where $\tau = RC = 20 \text{ kΩ} \times 37 \text{ nF} = 0.740 \text{ ms}$

For the -ve transition, $V_i = 1.53 \text{ V}$, $V_f = -1.53 \text{ V}$, and $V_\infty = -2 \text{ V}$.

\[ t = \tau \ln \left( \frac{V_f - V_\infty}{V_i - V_\infty} \right) = (0.740 \text{ ms}) \ln \left( \frac{1.53 - (-2)}{-1.53 - (-2)} \right) = 1.49 \text{ ms} \]
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

\[
\begin{align*}
i &= (V_{CC} - \frac{2}{3} V_{CC}) / 56 \text{k}\Omega = (9 \text{ V} - 6 \text{ V}) / 56 \text{k}\Omega = 3 \text{ V} / 56 \text{ k}\Omega = 53.57 \mu\text{A}.
\end{align*}
\]

Using \( i \), we calculate \( V_B = V_A - i(19 \text{k}\Omega) = 4.98 \text{ V} \).

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

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

\[
V_R = \left(\frac{2}{3} - \frac{19 \text{k}\Omega}{56 \text{k}\Omega + 19 \text{k}\Omega}\right) \left(\frac{56 \text{k}\Omega + 19 \text{k}\Omega}{56 \text{k}\Omega}\right) 9 \text{ V} = 4.98 \text{ V}
\]

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

\[
t = RC \ln \left(\frac{V_{\infty} - V_i}{V_{\infty} - V_f}\right) = (0.40)RC
\]
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:

- $t_{\text{high}} = 0.40 \times 36 \mu F \times (56 \, \text{k}\Omega + 19 \, \text{k}\Omega) = 1.08 \, \text{ms}$
- $t_{\text{low}} = 0.40 \times 36 \mu F \times (19 \, \text{k}\Omega) = 0.27 \, \text{ms}$

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).