The op-amp is ideal, with $V_{CC} = 10\, \text{V}$ and $V_{EE} = -10\, \text{V}$. The diode forward voltage, $V_D = 0.7\, \text{V}$.

This is a Wien bridge sine-wave oscillator. It oscillates because $G = 1 + \frac{93\, \text{k}\Omega}{20\, \text{k}\Omega} = 5.65 > 3$.

- What is the frequency of oscillation.
- Sketch $V_o$ when the oscillation amplitude has stabilized.
- Indicate the approximate voltage of oscillation on the sketch.

\[ \omega = (RC)^{-1} = (37\, \text{k}\Omega \times 23\, \text{nF})^{-1} = 1175.1\, \text{rad/s} \]
\[ f = \frac{1}{2\pi}\omega = 187.0\, \text{Hz} \]

- Sketch $V_o$ when the oscillation amplitude has stabilized.
  The oscillation will be roughly sine shaped at $f = 187.0\, \text{Hz}$
- 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 $V_{EE} = -2 \, \text{V}$.

![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 $\pm 2 \, \text{V}$
- $V_+$ will switch between $\pm 2 \, \text{V}$ $\frac{56 \, \text{k}\Omega}{56 \, \text{k}\Omega + 21 \, \text{k}\Omega} = 1.45 \, \text{V}$
- $V_+$ will exponentially rise between $\pm 1.45 \, \text{V}$.

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

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

were $\tau = RC = 23 \, \text{k}\Omega \times 37 \, \text{nF} = 0.851 \, \text{ms}$

For the -ve transition, $V_i = 1.45 \, \text{V}$, $V_f = -1.45 \, \text{V}$, an $V_\infty = -2 \, \text{V}$.

$$t = \tau \ln \left( \frac{V_f - V_\infty}{V_i - V_\infty} \right) = (0.851 \, \text{ms}) \ln \left( \frac{1.45 - (-2)}{-1.45 - (-2)} \right) = 1.56 \, \text{ms}$$
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

$$i = (V_{CC} - \frac{2}{3}V_{CC})/56 \text{ k}\Omega = (9 \text{ V} - 6 \text{ V})/56 \text{ k}\Omega = 3 \text{ V}/56 \text{ k}\Omega = 53.57 \mu\text{A}.$$  

Using $i$, we calculate $V_B = V_A - i(12 \text{ k}\Omega) = 5.36 \text{ V}$.

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

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

$$V_R = \left(\frac{2}{3} - \frac{12 \text{ k}\Omega}{56 \text{ k}\Omega + 12 \text{ k}\Omega}\right) \left(\frac{56 \text{ k}\Omega + 12 \text{ k}\Omega}{56 \text{ k}\Omega}\right) 9 \text{ V} = 5.36 \text{ V}$$

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

$$t = RC \ln \left(\frac{V_\infty - V_i}{V_\infty - V_f}\right) = (0.50)RC$$
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:

- \( t_{\text{high}} = 0.50 \times 57 \mu F \times (56 \, k\Omega + 12 \, k\Omega) = 1.94 \, ms \)
- \( t_{\text{low}} = 0.50 \times 57 \mu F \times (12 \, k\Omega) = 0.34 \, ms \)

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).