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

- 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

$G = 1 + \frac{91\, k\Omega}{27\, k\Omega} = 4.37 > 3$.

- What is the frequency of oscillation.

$$\omega = (RC)^{-1} = (39\, k\Omega \times 21\, nF)^{-1} = 1221.0\, \text{rad/s}$$

$$f = \frac{1}{2\pi}\omega = 194.3\, \text{Hz}$$

- Sketch $V_o$ when the oscillation amplitude has stabilized.

The oscillation will be roughly sine shaped at $f = 194.3\, \text{Hz}$

- Indicate the approximate voltage of oscillation on the sketch.

amplitude stabilized at $\pm 0.7\, V$. 

\[\text{ Circuit Diagram with Wien Bridge oscillator structure}\]
The op-amp is ideal, with $V_{CC} = 2 \text{V}$ and $V_{EE} = -2 \text{V}$.

\[
\begin{align*}
\text{Initial conditions are: } V_- &= 0 \text{ and } V_o = +V_{CC}.
\end{align*}
\]

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 $\pm 2 \text{V}$ $V_+ = \frac{5.4k\Omega}{54k\Omega+38k\Omega} = 1.17 \text{V}$
- $V_+$ will exponentially rise between $\pm 1.17 \text{V}$.

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

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

were $\tau = RC = 21 \text{k}\Omega \times 39 \text{nF} = 0.819 \text{ms}$

For the -ve transition, $V_i = 1.17 \text{V}$, $V_f = -1.17 \text{V}$, and $V_\infty = -2 \text{V}$.

\[
t = \tau \ln \left( \frac{V_f - V_\infty}{V_i - V_\infty} \right) = (0.819 \text{ms}) \ln \left( \frac{1.17 - (-2)}{-1.17 - (-2)} \right) = 1.10 \text{ms}
\]
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

\[
i = (V_{CC} - \frac{2}{3} V_{CC})/59 \text{k} \Omega = (9 \text{ V} - 6 \text{ V})/59 \text{k} \Omega = 3 \text{ V}/59 \text{k} \Omega = 50.85 \mu\text{A}.
\]

Using \( i \), we calculate \( V_B = V_A - i(19 \text{k} \Omega) = 5.03 \text{ V} \).

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

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

\[
V_R = \left(\frac{2}{3} - \frac{19 \text{k} \Omega}{59 \text{k} \Omega + 19 \text{k} \Omega}\right) \left(\frac{59 \text{k} \Omega + 19 \text{k} \Omega}{59 \text{k} \Omega}\right) 9 \text{ V} = 5.03 \text{ V}
\]

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 $V_i = V_{CC}/3$, $V_f = V_R$, $V_\infty = V_{CC}$ 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:

- $t_{\text{high}} = 0.41 \times 55 \mu F \times (59 \, k\Omega + 19 \, k\Omega) = 1.76 \, ms$
- $t_{\text{low}} = 0.41 \times 55 \mu F \times (19 \, k\Omega) = 0.43 \, ms$

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).