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

![Wien bridge sine-wave oscillator circuit diagram]

- 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 $G = 1 + \frac{97 \text{k} \Omega}{28 \text{k} \Omega} = 4.46 > 3$.

- What is the frequency of oscillation.
  
  $\omega = (RC)^{-1} = (22 \text{k} \Omega \times 21 \text{nF})^{-1} = 2164.5 \text{ rad/s}$
  
  $f = \frac{1}{2\pi} \omega = 344.5 \text{ Hz}$

- Sketch $V_o$ when the oscillation amplitude has stabilized.
  
  The oscillation will be roughly sine shaped at $f = 344.5 \text{ Hz}$

- Indicate the approximate voltage of oscillation on the sketch.
  
  amplitude stabilized at $\pm 0.7$ V.
The op-amp is ideal, with $V_{CC} = 2$ V and $V_{EE} = -2$ 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 $\pm 2$ V
- $V_+$ will switch between $\pm 2$ V $\frac{44 \, \text{k}\Omega}{44 \, \text{k}\Omega + 22 \, \text{k}\Omega} = 1.33$ V
- $V_+$ will exponentially rise between $\pm 1.33$ V.

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

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

were $\tau = RC = 21 \, \text{k}\Omega \times 22 \, \text{nF} = 0.462$ ms

For the -ve transition, $V_i = 1.33$ V, $V_f = -1.33$ V, and $V_\infty = -2$ V.

$$t = \tau \ln \left( \frac{V_f - V_\infty}{V_i - V_\infty} \right) = (0.462 \, \text{ms}) \ln \left( \frac{1.33 - (-2)}{-1.33 - (-2)} \right) = 0.74$ \text{ms}$$
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

\[
i = (V_{CC} - \frac{2}{3}V_{CC})/33\,\text{k}\Omega = (9\,\text{V} - 6\,\text{V})/33\,\text{k}\Omega = 3\,\text{V}/33\,\text{k}\Omega = 90.91\,\mu\text{A}.
\]

Using $i$, we calculate $V_B = V_A - i(20\,\text{k}\Omega) = 4.18\,\text{V}$.

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

\[
V_R = \left(\frac{2}{3} - \frac{20\,\text{k}\Omega}{33\,\text{k}\Omega + 20\,\text{k}\Omega}\right)\left(\frac{33\,\text{k}\Omega + 20\,\text{k}\Omega}{33\,\text{k}\Omega}\right)V_{CC}
\]

\[
V_R = \left(\frac{2}{3} - \frac{20\,\text{k}\Omega}{33\,\text{k}\Omega + 20\,\text{k}\Omega}\right)9\,\text{V} = 4.18\,\text{V}
\]

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

\[
t = RC\ln\left(\frac{V_{\infty} - V_i}{V_{\infty} - V_f}\right) = (0.22)RC
\]
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 $V_o = 0 \text{ V}$ during the discharge period. Thus:

- $t_{\text{high}} = 0.22 \times 59 \, \mu\text{F} \times (33 \, \text{k}\Omega + 20 \, \text{k}\Omega) = 0.69 \, \text{ms}$
- $t_{\text{low}} = 0.22 \times 59 \, \mu\text{F} \times (20 \, \text{k}\Omega) = 0.26 \, \text{ms}$

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).