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 $G = 1 + \frac{99 \, k\Omega}{19 \, k\Omega} = 6.21 > 3$.

- What is the frequency of oscillation.
  
  $\omega = (RC)^{-1} = (31 \, k\Omega \times 36 \, nF)^{-1} = 896.1 \, \text{rad/s}$
  
  $f = \frac{1}{2\pi} \omega = 142.6 \, \text{Hz}$

- Sketch $V_o$ when the oscillation amplitude has stabilized.
  
  The oscillation will be roughly sine shaped at $f = 142.6 \, \text{Hz}$

- Indicate the approximate voltage of oscillation on the sketch.
  
  amplitude stabilized at $\pm 0.7 \, \text{V}$. 

The op-amp is ideal, with $V_{CC} = 2$ V and $V_{EE} = -2$ 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 $\pm 2$ V
- $V_+$ will switch between $\pm 2V \frac{62 \, k\Omega}{62 \, k\Omega + 23 \, k\Omega} = 1.46$ V
- $V_+$ will exponentially rise between $\pm 1.46$ V.

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

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

were $\tau = RC = 36 \, k\Omega \times 31 \, nF = 1.116$ ms

For the -ve transition, $V_i = 1.46$ V, $V_f = -1.46$ V, an $V_\infty = -2$ V.

$$t = \tau \ln \left( \frac{V_f - V_\infty}{V_i - V_\infty} \right) = (1.116 \, ms) \ln \left( \frac{1.46 - (-2)}{-1.46 - (-2)} \right) = 2.07$ 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

$$i = \left( V_{CC} - \frac{2}{3} V_{CC} \right) / 46 \text{k}\Omega = (9 \text{ V} - 6 \text{ V}) / 46 \text{k}\Omega = 3 \text{ V} / 46 \text{k}\Omega = 65.22 \mu\text{A}.$$  

Using $i$, we calculate $V_B = V_A - i(11 \text{k}\Omega) = 5.28 \text{ V}$

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

$$V_A = V_B + (V_{CC} - V_B) \frac{R_B}{R_A + R_B} \tag{voltage divider}$$

Setting $V_A = 2/3 V_{CC}$ and rearranging, RESET occurs when $V_B$ reaches voltage $V_R$ given by

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

$$V_R = \left( \frac{2}{3} - \frac{11 \text{k}\Omega}{46 \text{k}\Omega + 11 \text{k}\Omega} \right) \left( \frac{46 \text{k}\Omega + 11 \text{k}\Omega}{46 \text{k}\Omega} \right) 9 \text{ V} = 5.28 \text{ V}$$

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

$$t = RC \ln \left( \frac{V_{\infty} - V_i}{V_{\infty} - V_f} \right) = (0.48) RC$$
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:

- $t_{\text{high}} = 0.48 \times 59 \mu F \times (46 \text{k}\Omega + 11 \text{k}\Omega) = 1.61 \text{ms}$
- $t_{\text{low}} = 0.48 \times 59 \mu F \times (11 \text{k}\Omega) = 0.31 \text{ms}$

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).