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 $G = 1 + \frac{52 \text{ k}\Omega}{21 \text{ k}\Omega} = 3.48 > 3$.

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

$\omega = (RC)^{-1} = (37 \text{ k}\Omega \times 30 \text{ nF})^{-1} = 900.9 \text{ rad/s}$

$f = \frac{1}{2\pi} \omega = 143.4 \text{ Hz}$

- Sketch $V_o$ when the oscillation amplitude has stabilized.
  The oscillation will be roughly sine shaped at $f = 143.4 \text{ Hz}$
- 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 $V_{EE} = -2 \text{ V}$.

![Diagram of op-amp circuit](image)

Initial conditions are: $V_0 = 0$ 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 $\pm 2 \text{ V}$
  
  $\frac{60 \text{ k}\Omega}{60 \text{ k}\Omega + 37 \text{ k}\Omega} = 1.24 \text{ V}$

- $V_+$ will exponentially rise between $\pm 1.24 \text{ V}$.

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

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

were $\tau = RC = 30 \text{ k}\Omega \times 37 \text{ nF} = 1.110 \text{ ms}$

For the -ve transition, $V_i = 1.24 \text{ V}$, $V_f = -1.24 \text{ V}$, an $V_\infty = -2 \text{ V}$.

$$t = \tau \ln \left( \frac{V_f - V_\infty}{V_i - V_\infty} \right) = (1.110 \text{ ms}) \ln \left( \frac{1.24 - (-2)}{-1.24 - (-2)} \right) = 1.61 \text{ ms}$$
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

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

Using $i$, we calculate $V_B = V_A - i(13 \text{ k}\Omega) = 5.30 \text{ V}$.

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

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

$$V_R = \left(\frac{2}{3} - \frac{13 \text{ k}\Omega}{56 \text{ k}\Omega + 13 \text{ k}\Omega}\right) \left(\frac{56 \text{ k}\Omega + 13 \text{ k}\Omega}{56 \text{ k}\Omega}\right) 9 \text{ V} = 5.30 \text{ V}$$

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 $V_i = VCC/3$, $V_f = V_R$, $V_\infty = VCC$ and $R = R_A + R_B$ for the charge half-cycle and $V_i = V_R$, $V_f = VCC/3$, $V_\infty = 0$ and $R = R_B$ for the discharge half-cycle. $V_o = VCC$ during the charge period and $V_o = 0$ V during the discharge period. Thus:

- $t_{\text{high}} = 0.48 \times 36 \mu F \times (56 \text{k}\Omega + 13 \text{k}\Omega) = 1.19 \text{ms}$
- $t_{\text{low}} = 0.48 \times 36 \mu F \times (13 \text{k}\Omega) = 0.22 \text{ms}$

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 $2/3VCC$. Meanwhile $V_A$ rises exponentially from somewhat above $1/3VCC$ to $2/3VCC$, 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).