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

![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

$G = 1 + \frac{59 \text{ kΩ}}{20 \text{ kΩ}} = 3.95 > 3$.

- What is the frequency of oscillation.

$\omega = (RC)^{-1} = (26 \text{ kΩ} \times 36 \text{ nF})^{-1} = 1068.4 \text{ rad/s}$

$f = \frac{1}{2\pi} \omega = 170.0 \text{ Hz}$

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

The oscillation will be roughly sine shaped at $f = 170.0 \text{ Hz}$

- Indicate the approximate voltage of oscillation on the sketch. amplitude stabilized at ±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 $\pm 2 \ V \frac{54 \ k\Omega}{54 \ k\Omega + 39 \ k\Omega} = 1.16 \ V$
- $V_+$ will exponentially rise between $\pm 1.16 \ V$.

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

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

were $\tau = RC = 36 \ k\Omega \times 26 \ nF = 0.936$ ms

For the -ve transition, $V_i = 1.16 \ V$, $V_f = -1.16 \ V$, an $V_\infty = -2$ V.

$$t = \tau \ln \left( \frac{V_f - V_\infty}{V_i - V_\infty} \right) = (0.936 \ ms) \ln \left( \frac{1.16 - (-2)}{-1.16 - (-2)} \right) = 1.24 \ ms$$
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
\[
i = \frac{(V_{CC} - \frac{2}{3}V_{CC})}{39 \, \text{k}\Omega} = \frac{9 \, \text{V} - 6 \, \text{V}}{39 \, \text{k}\Omega} = \frac{3 \, \text{V}}{39 \, \text{k}\Omega} = 76.92 \, \mu\text{A}.
\]
Using $i$, we calculate $V_B = V_A - i(12 \, \text{k}\Omega) = 5.08 \, \text{V}$.

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
\[
V_R = \left(\frac{2}{3} - \frac{R_B}{R_A + R_B}\right) \left(\frac{R_A + R_B}{R_A}\right) V_{CC}
\]
\[
V_R = \left(\frac{2}{3} - \frac{12 \, \text{k}\Omega}{39 \, \text{k}\Omega + 12 \, \text{k}\Omega}\right) \left(\frac{39 \, \text{k}\Omega + 12 \, \text{k}\Omega}{39 \, \text{k}\Omega}\right) 9 \, \text{V} = 5.08 \, \text{V}
\]
The durations of the charge and discharge half-cycles are then given by the usual formula
\[
t = RC \ln \left(\frac{V_i}{V_f} \right) = (0.43)RC
\]
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:

- $t_{high} = 0.43 \times 40 \mu F \times (39 \text{k}\Omega + 12 \text{k}\Omega) = 0.88 \text{ms}$
- $t_{low} = 0.43 \times 40 \mu F \times (12 \text{k}\Omega) = 0.21 \text{ms}$

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).