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 $G = 1 + \frac{92\,\text{k}\Omega}{23\,\text{k}\Omega} = 5.00 > 3$.

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

\[
\omega = (RC)^{-1} = (31\,\text{k}\Omega \times 21\,\text{nF})^{-1} = 1536.1\,\text{rad/s}
\]
\[
f = \frac{1}{2\pi}\omega = 244.5\,\text{Hz}
\]

- Sketch $V_o$ when the oscillation amplitude has stabilized.
  The oscillation will be roughly sine shaped at $f = 244.5\,\text{Hz}$
- 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.

![Op-amp diagram](attachment:op_amp.png)

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 ±2 V
- $V_{+}$ will switch between ±2 V $\frac{53 \, \text{k}\Omega}{53 \, \text{k}\Omega + 32 \, \text{k}\Omega} = 1.25$ V
- $V_{+}$ will exponentially rise between ±1.25 V.

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

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

were $\tau = RC = 21 \, \text{k}\Omega \times 31 \, \text{nF} = 0.651$ ms

For the -ve transition, $V_i = 1.25$ V, $V_f = -1.25$ V, an $V_\infty = -2$ V.

$$t = \tau \ln \left( \frac{V_f - V_\infty}{V_i - V_\infty} \right) = (0.651 \, \text{ms}) \ln \left( \frac{1.25 - (-2)}{-1.25 - (-2)} \right) = 0.95$ ms
Initial conditions are that the charge on the capacitor is zero. $V_{CC} = 9$ 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

$$i = (V_{CC} - \frac{2}{3}V_{CC})/47 \text{k}\Omega = (9 \text{V} - 6 \text{V})/47 \text{k}\Omega = 3 \text{V}/47 \text{k}\Omega = 63.83 \mu\text{A}.$$  

Using $i$, we calculate $V_B = V_A - i(15 \text{k}\Omega) = 5.04 \text{V}$.

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

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

$$V_R = \left(\frac{2}{3} - \frac{15 \text{k}\Omega}{47 \text{k}\Omega + 15 \text{k}\Omega}\right)\left(\frac{47 \text{k}\Omega + 15 \text{k}\Omega}{47 \text{k}\Omega}\right)9 \text{V} = 5.04 \text{V}$$

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

$$t = RC \ln \left(\frac{V_\infty - V_i}{V_\infty - V_f}\right) = (0.42)RC$$
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:

- $t_{\text{high}} = 0.42 \times 56 \mu F \times (47 \text{k}\Omega + 15 \text{k}\Omega) = 1.46 \text{ms}$
- $t_{\text{low}} = 0.42 \times 56 \mu F \times (15 \text{k}\Omega) = 0.35 \text{ms}$

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).