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 \( G = 1 + \frac{80 \text{k} \Omega}{25 \text{k} \Omega} = 4.20 > 3 \).

- What is the frequency of oscillation.
  \[
  \omega = (RC)^{-1} = (31 \text{k} \Omega \times 34 \text{nF})^{-1} = 948.8 \text{ rad/s}
  \]
  \[
  f = \frac{1}{2\pi} \omega = 151.0 \text{ Hz}
  \]
- Sketch \( V_o \) when the oscillation amplitude has stabilized.
  The oscillation will be roughly sine shaped at \( f = 151.0 \text{ Hz} \).
- 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 \( V_{EE} = -2 \text{ V} \).

![Circuit Diagram](image)

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 \( \pm 2 \text{ V} \)
- \( V_+ \) will switch between \( \pm 2 \text{ V} \) \( \frac{73 \text{k}\Omega}{73 \text{k}\Omega + 39 \text{k}\Omega} = 1.30 \text{ V} \)
- \( V_+ \) will exponentially rise between \( \pm 1.30 \text{ V} \).

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

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

where \( \tau = RC = 34 \text{k}\Omega \times 31 \text{nF} = 1.054 \text{ ms} \)

For the -ve transition, \( V_i = 1.30 \text{ V}, V_f = -1.30 \text{ V}, \) and \( V_\infty = -2 \text{ V} \).

\[ t = \tau \ln \left( \frac{V_f - V_\infty}{V_i - V_\infty} \right) = (1.054 \text{ ms}) \ln \left( \frac{1.30 - (-2)}{-1.30 - (-2)} \right) = 1.63 \text{ ms} \]
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

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

Using $i$, we calculate $V_B = V_A - i(17 \text{k}\Omega) = 4.89 \text{ V}$.

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

\[
V_R = \left(\frac{2}{3} - \frac{17 \text{k}\Omega}{46 \text{k}\Omega + 17 \text{k}\Omega}\right) \left(\frac{46 \text{k}\Omega + 17 \text{k}\Omega}{46 \text{k}\Omega}\right) V_{CC}
\]

\[
V_R = \left(\frac{2}{3} - \frac{17 \text{k}\Omega}{46 \text{k}\Omega + 17 \text{k}\Omega}\right) (46 \text{k}\Omega + 17 \text{k}\Omega) 9 \text{ V} = 4.89 \text{ V}
\]

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

\[
t = RC \ln \left(\frac{V_\infty - V_i}{V_\infty - V_f}\right) = (0.38)RC
\]
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:

- \( t_{\text{high}} = 0.38 \times 50 \, \mu F \times (46 \, k\Omega + 17 \, k\Omega) = 1.20 \, \text{ms} \)
- \( t_{\text{low}} = 0.38 \times 50 \, \mu F \times (17 \, k\Omega) = 0.32 \, \text{ms} \)

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).