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
\[ G = 1 + \frac{87 \text{k} \Omega}{25 \text{k} \Omega} = 4.48 > 3. \]

• What is the frequency of oscillation.
\[ \omega = (RC)^{-1} = (21 \text{k} \Omega \times 37 \text{nF})^{-1} = 1287.0 \text{ rad/s} \]
\[ f = \frac{1}{2\pi} \omega = 204.8 \text{Hz} \]

• Sketch \( V_o \) when the oscillation amplitude has stabilized.
The oscillation will be roughly sine shaped at \( f = 204.8 \text{Hz} \)

• 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 $\pm 2\,V \cdot \frac{48\,k\Omega}{48\,k\Omega + 31\,k\Omega} = 1.22\,V$
- $V_+$ will exponentially rise between $\pm 1.22\,V$

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

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

were $\tau = RC = 37\,k\Omega \times 21\,nF = 0.777\,ms$

For the -ve transition, $V_i = 1.22\,V$, $V_f = -1.22\,V$, an $V_\infty = -2\,V$.

$$ t = \tau \ln \left( \frac{V_f - V_\infty}{V_i - V_\infty} \right) = (0.777\,ms) \ln \left( \frac{1.22 - (-2)}{-1.22 - (-2)} \right) = 1.10\,ms $$
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

$$i = (V_{CC} - \frac{2}{3}V_{CC})/32\,k\Omega = (9\,V - 6\,V)/32\,k\Omega = 3\,V/32\,k\Omega = 93.75\,\mu A.$$

Using $i$, we calculate $V_B = V_A - i(17\,k\Omega) = 4.41\,V$

Another way to see this is to think about Capacitor $C$ charging until $V_A = \frac{2}{3}V_{CC}$ (RESET) and discharging until $V_B = \frac{1}{3}V_{CC}$ (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

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

(voltage divider). Setting $V_A = \frac{2}{3}V_{CC}$ and rearranging, RESET occurs when $V_B$ reaches voltage $V_R$ given by

$$V_R = \left(\frac{2}{3} - \frac{17\,k\Omega}{32\,k\Omega + 17\,k\Omega}\right) \left(\frac{R_A + R_B}{R_A}\right) V_{CC}$$

$$V_R = \left(\frac{2}{3} - \frac{17\,k\Omega}{32\,k\Omega + 17\,k\Omega}\right) \left(\frac{32\,k\Omega + 17\,k\Omega}{32\,k\Omega}\right) 9\,V = 4.41\,V$$

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

$$t = RC \ln \left(\frac{V_\infty - V_i}{V_\infty - V_f}\right) = (0.27)RC$$
with \( V_i = \frac{V_{CC}}{3} \), \( V_f = V_R \), \( V_\infty = V_{CC} \) and \( R = R_A + R_B \) for the charge half-cycle and \( V_i = V_R \), \( V_f = \frac{V_{CC}}{3} \), \( V_\infty = 0 \) 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:

- \( t_{\text{high}} = 0.27 \times 53 \mu F \times (32 \, k\Omega + 17 \, k\Omega) = 0.70 \, ms \)
- \( t_{\text{low}} = 0.27 \times 53 \mu F \times (17 \, k\Omega) = 0.24 \, ms \)

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 \( \frac{2}{3}V_{CC} \). Meanwhile \( V_A \) rises exponentially from somewhat above \( \frac{1}{3}V_{CC} \) to \( \frac{2}{3}V_{CC} \), 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).