• Sketch \( V_o \).

• At what times does \( V_o \) reach \( \pm 10 \) V?

• Does this circuit suffer from multiple transitions?

(Notes: voltage axis not to scale. The slope of the voltage may be approximated as 5 V/100 ms. Op amps are ideal)

This is a non-inverting amplifier with a gain of \( G = 1 + \frac{406}{1.57} = 259.6 \).

With such a large gain, it will saturate when \( V_i = \pm 10 V/G = \pm 0.039 \) V.

Times when \( |V_i| < 0.039 \) V, are

\[
T_1 = \pm \frac{0.1 - 0.039}{5 \text{V/100 ms}} = \pm 1.220 \text{ ms}.
\]

\[
T_2 = \pm \frac{0.1 + 0.039}{5 \text{V/100 ms}} = \pm 2.780 \text{ ms}.
\]

• Sketch \( V_o \).

1) From start to \(-2.780 \) ms, \( V_o = -10 \) V
2) From \(-2.780 \) ms to \(-1.220 \) ms, \( V_o = \) transitions from \(-10 \) V to \(+10 \) V
3) From \(-1.220 \) ms to \(0 \) ms, \( V_o = +10 \) V
4) From \(0 \) ms to \(+1.220 \) ms, \( V_o = -10 \) V
5) From \(+1.220 \) ms to \(+2.780 \) ms, \( V_o = \) transitions from \(-10 \) V to \(+10 \) V
6) From \(+2.780 \) ms to end, \( V_o = +10 \) V

• At what times does \( V_o \) reach \( \pm 10 \) V?

1) From start to \(-2.780 \) ms, \( V_o = -10 \) V
3) From \(-1.220 \) ms to \(0 \) ms, \( V_o = +10 \) V
4) From \(0 \) ms to \(+1.220 \) ms, \( V_o = -10 \) V
6) From \(+2.780 \) ms to end, \( V_o = +10 \) V

• Does this circuit suffer from multiple transitions?

Yes
• Sketch $V_o$.

• At what times does $V_o$ reach ±10 V?

• Does this circuit suffer from multiple transitions?

(Notes: voltage axis not to scale. The slope of the voltage may be approximated as 5 V/100 ms. Op amps are ideal)

Thresholds at $\pm \frac{1.35 \, k\Omega}{410 + 1.35 \, k\Omega} \times 10 \, V = \pm 0.033 \, V$.

Conditions:
1) If $V_i < V_+$ $\implies$ $V_o = +10 \, V$ and $V_+ = +0.033 \, V$.
2) If $V_i > V_+$ $\implies$ $V_o = -10 \, V$ and $V_+ = -0.033 \, V$.

• Sketch $V_o$.

  1) Initially, $V_o = +10$ and $V_+ = +0.033 \, V$
  2) when $V_i$ crosses $+0.033 \, V$, then $V_o = -10$ and $V_+ = -0.033 \, V$
  3) when $V_i$ crosses $-0.033 \, V$, then $V_o = +10$ and $V_+ = +0.033 \, V$
  4) when $V_i$ crosses $+0.033 \, V$, then $V_o = -10$ and $V_+ = -0.033 \, V$

• At what times does $V_o$ reach ±10 V?

  Transitions at $\pm 5 \, V/100 \, ms = \pm 1.34 \, ms$.
  1) Beginning until $-1.34 \, ms \implies V_o = +10 \, V$.
  2) $-1.34 \, ms$ until $0 \, ms \implies V_o = -10 \, V$.
  3) $0 \, ms$ until $+2.66 \, ms \implies V_o = +10 \, V$.
  4) $+2.66 \, ms$ until end $\implies V_o = -10 \, V$.

• Does this circuit suffer from multiple transitions?
  Yes
This is a low pass filter with a gain of $G = -\frac{415 \, \text{k}\Omega}{11.3 \, \text{k}\Omega} = -36.73$.

With such a large gain, it will saturate when $V_i = \pm 10 \, \text{V} / G = \pm 0.272 \, \text{V}$.

The time constant is $\tau = 415 \, \text{k}\Omega \times 471 \, \text{nF} = 195.5 \, \text{ms}$.

- At what times does $V_o$ reach $\pm 10 \, \text{V}$?
  - Transitions at $\pm \frac{0.1 + 0.272}{5 \, \text{V} / \text{100 ms}} = \pm 7.4 \, \text{ms}$.
  - Thus: 1) Beginning until $-7.4 \, \text{ms} \implies V_o = +10 \, \text{V}$.
    - 2) $+7.4 \, \text{ms}$ until end $\implies V_o = -10 \, \text{V}$.

- Sketch $V_o$ (this is difficult because of the exponential – indicate the main features of the curve)

  Begin until $-7.4 \, \text{ms} \implies V_o = +10 \, \text{V}$. Then, from $+7.4 \, \text{ms}$ until $-7.4 \, \text{ms}$ the will go from $+10$ to $-10 \, \text{V}$, following the flipped the blue line (with gain) but with a slight delay. However, it will only deviate slightly at the zigzag. The time constant $\tau$ is longer than the gap in the zigzag. Finally, from $+7.4 \, \text{ms}$ until end $\implies V_o = -10 \, \text{V}$.

- Does this circuit suffer from multiple transitions?
  - No

Explanation: In the above case, the response is linear throughout the +/-0.1V transition of the input signal. The addition of the capacitor turns the circuit into a “lossy integrator”. Its step response would be an exponential with time constant $RC = 195.5 \, \text{ms}$. We don’t have exactly a step at the input; however, if the input transitions are short compared to the time constant we can approximate the output as an exponential (perhaps with a “bump” $V_i$ briefly changes sign). Assuming the input transitions are short compared to $RC$, then $V_o$ will NOT suffer from multiple transitions.