• 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 $G = 1 + \frac{327}{110} = 298.3$. With such a large gain, it will saturate when $V_i = \pm 10 V / G = \pm 0.034 V$.

Times when $|V_i| < 0.034$, V, are

$T_1 = \pm \frac{0.1 - 0.034}{5V/100\text{ms}} = \pm 1.320 \text{ ms}$.

$T_2 = \pm \frac{0.1 + 0.034}{5V/100\text{ms}} = \pm 2.680 \text{ ms}$.

• Sketch $V_o$.

1) From start to $-2.680 \text{ ms}$, $V_o = -10 \text{ V}$
2) From $-2.680 \text{ ms}$ to $-1.320 \text{ ms}$, $V_o = \text{transitions from} -10 \text{ V to} +10 \text{ V}$
3) From $-1.320 \text{ ms}$ to $0 \text{ ms}$, $V_o = +10 \text{ V}$
4) From $0 \text{ ms}$ to $+1.320 \text{ ms}$, $V_o = -10 \text{ V}$
5) From $+1.320 \text{ ms}$ to $+2.680 \text{ ms}$, $V_o = \text{transitions from} -10 \text{ V to} +10 \text{ V}$
6) From $+2.680 \text{ ms}$ to end, $V_o = +10 \text{ V}$

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

1) From start to $-2.680 \text{ ms}$, $V_o = -10 \text{ V}$
2) From $-1.320 \text{ ms}$ to $0 \text{ ms}$, $V_o = +10 \text{ V}$
3) From $0 \text{ ms}$ to $+1.320 \text{ ms}$, $V_o = -10 \text{ V}$
4) From $+1.320 \text{ ms}$ to $+2.680 \text{ ms}$, $V_o = +10 \text{ V}$

• 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 $\pm \frac{1.09 \text{k}\Omega}{318+1.09 \text{k}\Omega} \times 10 \text{V} = \pm 0.034 \text{V}$.

Conditions:
1) If $V_i < V_+$ then $V_o = +10 \text{ V}$ and $V_+ = +0.034 \text{ V}$.
2) If $V_i > V_+$ then $V_o = -10 \text{ V}$ and $V_+ = -0.034 \text{ V}$.

• Sketch $V_o$.
  1) Initially, $V_o = +10$ and $V_+ = +0.034$ V
  2) when $V_i$ crosses $+0.034$ V, then $V_o = -10$ and $V_+ = -0.034$ V
  3) when $V_i$ crosses $-0.034$ V, then $V_o = +10$ and $V_+ = +0.034$ V
  4) when $V_i$ crosses $+0.034$ V, then $V_o = -10$ and $V_+ = -0.034$ V

• At what times does $V_o$ reach ±10 V?
  Transitions at $\pm \frac{0.1-0.034}{5\text{V}/100\text{ms}} = \pm 1.32 \text{ ms}$.
  1) Beginning until $-1.32 \text{ ms}$ then $V_o = +10 \text{ V}$.
  2) $-1.32 \text{ ms}$ until $0 \text{ ms}$ then $V_o = -10 \text{ V}$.
  3) $0 \text{ ms}$ until $+2.68 \text{ ms}$ then $V_o = +10 \text{ V}$.
  4) $+2.68 \text{ ms}$ until end then $V_o = -10 \text{ V}$.

• Does this circuit suffer from multiple transitions? Yes
This is a low pass filter with a gain of \( G = \frac{-407 \, \text{k}\Omega}{12.2 \, \text{k}\Omega} = -33.36 \).
With such a large gain, it will saturate when \( V_i = \pm 10 \, \text{V} \) \( / \) \( G = \pm 0.300 \, \text{V} \).
The time constant is \( \tau = 407 \, \text{k}\Omega \times 330 \, \text{nF} = 134.3 \, \text{ms} \).

- At what times does \( V_o \) reach \( \pm 10 \, \text{V} \)?
  
  Transitions at \( \pm 0.1 + 0.300 \, \text{V} / \text{100 ms} = \pm 8.0 \, \text{ms} \).
  
  Thus: 1) Beginning until \(-8.0 \, \text{ms} \implies V_o = +10 \, \text{V} \).
  
  2) \(+8.0 \, \text{ms} \) 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)
  Begining until \(-8.0 \, \text{ms} \implies V_o = +10 \, \text{V} \). Then, from \(+8.0 \, \text{ms} \) until \(-8.0 \, \text{ms} \) 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 \(+8.0 \, \text{ms} \) 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 \( RC = 134.3 \, \text{ms} \). 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.