• 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 $G = 1 + \frac{422}{1.31} = 323.1$.
With such a large gain, it will saturate when $V_i = \pm 10$ V/$G = \pm 0.031$ V.

Times when $|V_i| < 0.031$, $V_i$ are
$T_1 = \pm \frac{0.1 - 0.031}{5\text{V/100ms}} = \pm 1.380$ ms.
$T_2 = \pm \frac{0.1 + 0.031}{5\text{V/100ms}} = \pm 2.620$ ms.

• Sketch $V_o$.
  1) From start to $-2.620$ ms, $V_o = -10$ V
  2) From $-2.620$ ms to $-1.380$ ms, $V_o$ = transitions from $-10$ V to $+10$ V
  3) From $-1.380$ ms to $0$ ms, $V_o = +10$ V
  4) From $0$ ms to $+1.380$ ms, $V_o = -10$ V
  5) From $+1.380$ ms to $+2.620$ ms, $V_o$ = transitions from $-10$ V to $+10$ V
  6) From $+2.620$ ms to end, $V_o = +10$ V

• At what times does $V_o$ reach $\pm 10$ V?
  1) From start to $-2.620$ ms, $V_o = -10$ V
  3) From $-1.380$ ms to $0$ ms, $V_o = +10$ V
  4) From $0$ ms to $+1.380$ ms, $V_o = -10$ V
  6) From $+2.620$ 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 $\pm 10 \text{ V}$?

• 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 $\pm \frac{1.41 \text{ k} \Omega}{451 + 1.41 \text{ k} \Omega} \times 10 \text{ V} = \pm 0.031 \text{ V}$.

Conditions:
1) If $V_i < V_+ \implies V_o = +10 \text{ V}$ and $V_+ = +0.031 \text{ V}$.
2) If $V_i > V_+ \implies V_o = -10 \text{ V}$ and $V_+ = -0.031 \text{ V}$.

• Sketch $V_o$.
  1) Initially, $V_o = +10$ and $V_+ = +0.031 \text{ V}$
  2) when $V_i$ crosses $+0.031 \text{ V}$, then $V_o = -10$ and $V_+ = -0.031 \text{ V}$
  3) when $V_i$ crosses $-0.031 \text{ V}$, then $V_o = +10$ and $V_+ = +0.031 \text{ V}$
  4) when $V_i$ crosses $+0.031 \text{ V}$, then $V_o = -10$ and $V_+ = -0.031 \text{ V}$

• At what times does $V_o$ reach $\pm 10 \text{ V}$?
  Transitions at $\pm \frac{0.1 - 0.031}{5 \text{ V}/100 \text{ ms}} = \pm 1.38 \text{ ms}$.
  1) Beginning until $-1.38 \text{ ms} \implies V_o = +10 \text{ V}.$
  2) $-1.38 \text{ ms}$ until $0 \text{ ms} \implies V_o = -10 \text{ V}.$
  3) $0 \text{ ms}$ until $+2.62 \text{ ms} \implies V_o = +10 \text{ V}.$
  4) $+2.62 \text{ ms}$ until end $\implies V_o = -10 \text{ V}.$

• Does this circuit suffer from multiple transitions?
  Yes
This is a low pass filter with a gain of \( G = -\frac{477 \text{k}\Omega}{19.1 \text{k}\Omega} = -24.97. \)
With such a large gain, it will saturate when \( V_i = \pm 10 \text{ V} / G = \pm 0.400 \text{ V}. \)
The time constant is \( \tau = 477 \text{k}\Omega \times 394 \text{nF} = 187.9 \text{ ms}. \)

- At what times does \( V_o \) reach \( \pm 10 \text{ V} \)?
  
  Transitions at \( \pm 0.1 + 0.400 \text{V/100 ms} = \pm 10.0 \text{ ms}. \)
  
  Thus: 1) Beginning until \( -10.0 \text{ ms} \implies V_o = +10 \text{ V}. \)
  
  2) +10.0 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 \( -10.0 \text{ ms} \implies V_o = +10 \text{ V}. \) Then, from +10.0 ms until \( -10.0 \text{ ms} \) 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 +10.0 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 \( RC = 187.9 \text{ ms}. \) 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.