- 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 $G = 1 + \frac{406}{143} = 284.9$.
With such a large gain, it will saturate when $V_i = \pm 10$ V/$G = + \pm 0.035$ V.

Times when $|V_i| < 0.035$, $V_o$ are:

$T_1 = \pm \frac{0.1-0.035}{5\text{V}/100\text{ms}} = \pm 1.300$ ms.
$T_2 = \pm \frac{0.1+0.035}{5\text{V}/100\text{ms}} = \pm 2.700$ ms.

- Sketch $V_o$.
  1) From start to $-2.700$ ms, $V_o = -10$ V
  2) From $-2.700$ ms to $-1.300$ ms, $V_o$ = transitions from $-10$ V to $+10$ V
  3) From $-1.300$ ms to $0$ ms, $V_o = +10$ V
  4) From $0$ ms to $+1.300$ ms, $V_o = -10$ V
  5) From $+1.300$ ms to $+2.700$ ms, $V_o$ = transitions from $-10$ V to $+10$ V
  6) From $+2.700$ ms to end, $V_o = +10$ V

- At what times does $V_o$ reach $\pm 10$ V?
  1) From start to $-2.700$ ms, $V_o = -10$ V
  3) From $-1.300$ ms to $0$ ms, $V_o = +10$ V
  4) From $0$ ms to $+1.300$ ms, $V_o = -10$ V
  6) From $+2.700$ 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 $\pm 10$ 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 $\pm \frac{1.35 \text{k}\Omega}{476+1.35 \text{k}\Omega} \times 10 \text{V} = \pm 0.028 \text{V}$.

Conditions:
1) If $V_i < V_+ \implies V_o = +10 \text{V}$ and $V_+ = +0.028 \text{V}$.
2) If $V_i > V_+ \implies V_o = -10 \text{V}$ and $V_+ = -0.028 \text{V}$.

• Sketch $V_o$.
  1) Initially, $V_o = +10$ and $V_+ = +0.028$ V
  2) when $V_i$ crosses +0.028 V, then $V_o = -10$ and $V_+ = -0.028$ V
  3) when $V_i$ crosses −0.028 V, then $V_o = +10$ and $V_+ = +0.028$ V
  4) when $V_i$ crosses +0.028 V, then $V_o = -10$ and $V_+ = -0.028$ V

• At what times does $V_o$ reach $\pm 10$ V?
  Transitions at $\pm \frac{5 \text{V/100ms}}{0.1-0.028} = \pm 1.44 \text{ms}$.
  1) Beginning until $-1.44 \text{ms} \implies V_o = +10 \text{V}$.
  2) $-1.44 \text{ms}$ until $0 \text{ms} \implies V_o = -10 \text{V}$.
  3) $0 \text{ms}$ until $+2.56 \text{ms} \implies V_o = +10 \text{V}$.
  4) $+2.56 \text{ms}$ 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 $G = -\frac{443\,k\Omega}{14.8\,k\Omega} = -29.93$.
With such a large gain, it will saturate when $V_i = \pm 10\,V / G = \pm 0.334\,V$.
The time constant is $\tau = 443\,k\Omega \times 428\,nF = 189.6\,ms$.

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

  Transitions at $\pm \frac{0.334}{5\,V/100\,ms} = \pm 8.7\,ms$.
  Thus: 1) Beginning until $-8.7\,ms \implies V_o = +10\,V$.
  2) $+8.7\,ms$ until end $\implies V_o = -10\,V$.

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

  Begining until $-8.7\,ms \implies V_o = +10\,V$. Then, from $+8.7\,ms$ until $-8.7\,ms$ the will go from $+10$ to $-10\,V$, 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 $+8.7\,ms$ until end $\implies V_o = -10\,V$.

- 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 $RC = 189.6\,ms$. 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.