• 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 $G = 1 + \frac{326}{1.47} = 222.8$. With such a large gain, it will saturate when $V_i = \pm 10$ V$/G = \pm \pm 0.045$ V.

Times when $|V_i| < 0.045$, V, are

$T_1 = \pm \frac{0.1-0.045}{5 \text{V/100ms}} = \pm 1.100$ ms.

$T_2 = \pm \frac{0.1+0.045}{5 \text{V/100ms}} = \pm 2.900$ ms.

• Sketch $V_o$.
  1) From start to $−2.900$ ms, $V_o = −10$ V
  2) From $−2.900$ ms to $−1.100$ ms, $V_o =$ transitions from $−10$ V to $+10$ V
  3) From $−1.100$ ms to 0 ms, $V_o = +10$ V
  4) From 0 ms to $+1.100$ ms, $V_o = −10$ V
  5) From $+1.100$ ms to $+2.900$ ms, $V_o =$ transitions from $−10$ V to $+10$ V
  6) From $+2.900$ ms to end, $V_o = +10$ V

• At what times does $V_o$ reach $\pm 10$ V?
  1) From start to $−2.900$ ms, $V_o = −10$ V
  3) From $−1.100$ ms to 0 ms, $V_o = +10$ V
  4) From 0 ms to $+1.100$ ms, $V_o = −10$ V
  6) From $+2.900$ 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 $\pm \frac{1.09 \text{k}\Omega}{305+1.09 \text{k}\Omega} \times 10 \text{ V} = \pm 0.036 \text{ V}.$

Conditions:
1) If $V_i < V_+ \implies V_o = +10 \text{ V}$ and $V_+ = +0.036 \text{ V}$.
2) If $V_i > V_+ \implies V_o = -10 \text{ V}$ and $V_+ = -0.036 \text{ V}$.

• Sketch $V_o$.
  1) Initially, $V_o = +10$ and $V_+ = +0.036 \text{ V}$
  2) when $V_i$ crosses +0.036 V, then $V_o = -10$ and $V_+ = -0.036 \text{ V}$
  3) when $V_i$ crosses -0.036 V, then $V_o = +10$ and $V_+ = +0.036 \text{ V}$
  4) when $V_i$ crosses +0.036 V, then $V_o = -10$ and $V_+ = -0.036 \text{ V}$

• At what times does $V_o$ reach ±10 V?
  Transitions at $\pm \frac{0.1-0.036}{5 \text{ V}/100 \text{ ms}} = \pm 1.28 \text{ ms}$.
  1) Beginning until -1.28 ms $\implies V_o = +10 \text{ V}$.
  2) -1.28 ms until 0 ms $\implies V_o = -10 \text{ V}$.
  3) 0 ms until +2.72 ms $\implies V_o = +10 \text{ V}$.
  4) +2.72 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 $G = \frac{-400 \text{k}\Omega}{14.9 \text{k}\Omega} = -26.85$.
With such a large gain, it will saturate when $V_i = \pm 10 \text{ V} / G = \pm 0.372 \text{ V}$.
The time constant is $\tau = 400 \text{k}\Omega \times 442 \text{nF} = 176.8 \text{ ms}$.

- At what times does $V_o$ reach $\pm 10 \text{ V}$?
  Transitions at $\pm \frac{0.1 + 0.372}{5 \text{ V}/100 \text{ ms}} = \pm 9.4 \text{ ms}$.
  Thus: 1) Beginning until $-9.4 \text{ ms} \implies V_o = +10 \text{ V}$.
  2) $+9.4 \text{ ms}$ 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)
  Begining until $-9.4 \text{ ms} \implies V_o = +10 \text{ V}$. Then, from $+9.4 \text{ ms}$ until $-9.4 \text{ ms}$ 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 $+9.4 \text{ ms}$ 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 $RC = 176.8 \text{ ms}$. 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.