• 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)

This is a non-inverting amplifier with a gain of $G = 1 + \frac{483}{174} = 278.6$.
With such a large gain, it will saturate when $V_i = \pm 10 V/G = \pm 0.036 V$.

Times when $|V_i| < 0.036$, V, are

$T_1 = \pm \frac{0.1-0.036}{5 V/100 ms} = \pm 1.280 ms$.
$T_2 = \pm \frac{0.1+0.036}{5 V/100 ms} = \pm 2.720 ms$.

• Sketch $V_o$.
  1) From start to $-2.720$ ms, $V_o = -10$ V
  2) From $-2.720$ ms to $-1.280$ ms, $V_o = \text{transitions from } -10 \text{ V to } +10 \text{ V}$
  3) From $-1.280$ ms to 0 ms, $V_o = +10$ V
  4) From 0 ms to $+1.280$ ms, $V_o = -10$ V
  5) From $+1.280$ ms to $+2.720$ ms, $V_o = \text{transitions from } -10 \text{ V to } +10 \text{ V}$
  6) From $+2.720$ ms to end, $V_o = +10$ V

• At what times does $V_o$ reach ±10 V?
  1) From start to $-2.720$ ms, $V_o = -10$ V
  3) From $-1.280$ ms to 0 ms, $V_o = +10$ V
  4) From 0 ms to $+1.280$ ms, $V_o = -10$ V
  6) From $+2.720$ 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 $\pm \frac{1.61 \text{k}\Omega}{588 + 1.61 \text{k}\Omega} \times 10$ V = $\pm 0.027$ V.

Conditions:
1) If $V_i < V_+$ $\implies$ $V_o = +10$ V and $V_+ = +0.027$ V.
2) If $V_i > V_+$ $\implies$ $V_o = -10$ V and $V_+ = -0.027$ V.

• Sketch $V_o$.
  1) Initially, $V_o = +10$ and $V_+ = +0.027$ V
  2) when $V_i$ crosses $+0.027$ V, then $V_o = -10$ and $V_+ = -0.027$ V
  3) when $V_i$ crosses $-0.027$ V, then $V_o = +10$ and $V_+ = +0.027$ V
  4) when $V_i$ crosses $+0.027$ V, then $V_o = -10$ and $V_+ = -0.027$ V

• At what times does $V_o$ reach $\pm 10$ V?
  Transitions at $\pm \frac{0.1 - 0.027}{5 \text{V}/100 \text{ms}} = \pm 1.46$ ms.
  1) Beginning until $-1.46$ ms $\implies$ $V_o = +10$ V.
  2) $-1.46$ ms until 0 ms $\implies$ $V_o = -10$ V.
  3) 0 ms until $+2.54$ ms $\implies$ $V_o = +10$ V.
  4) $+2.54$ ms until end $\implies$ $V_o = -10$ V.

• Does this circuit suffer from multiple transitions?
  [Yes]
• Sketch $V_o$ (this is difficult because of the exponential – indicate the main features of the curve)

• 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)

This is a low pass filter with a gain of $G = \frac{-355 \text{k}\Omega}{11.1 \text{k}\Omega} = -31.98$.
With such a large gain, it will saturate when $V_i = \pm 10 \text{ V} / G = \pm 0.313 \text{ V}$.
The time constant is $\tau = 355 \text{k}\Omega \times 521 \text{nF} = 185.0 \text{ ms}$.

• At what times does $V_o$ reach ±10 V?
  Transitions at $\pm 0.1 + 0.313 \frac{5 \text{ V}}{100 \text{ ms}} = \pm 8.3 \text{ ms}$.
  Thus: 1) Beginning until $-8.3 \text{ ms} \implies V_o = +10 \text{ V}$.
  2) +8.3 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)
  Beginning until $-8.3 \text{ ms} \implies V_o = +10 \text{ V}$. Then, from +8.3 ms until $-8.3 \text{ ms}$ the will go from +10 to $-10 \text{ V}$, following the flipped 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 +8.3 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 $RC = 185.0 \text{ ms}$. 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.