- 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 $G = 1 + \frac{532}{10} = 484.6$. With such a large gain, it will saturate when $V_i = \pm 10 V/G = \pm 0.021 V$.

Times when $|V_i| < 0.021, V_i$ are

$T_1 = \pm \frac{0.1 - 0.021}{5 V/100 ms} = \pm 1.580 ms$.

$T_2 = \pm \frac{0.1 + 0.021}{5 V/100 ms} = \pm 2.420 ms$.

- Sketch $V_o$.
  1) From start to $-2.420$ ms, $V_o = -10$ V
  2) From $-2.420$ ms to $-1.580$ ms, $V_o$ = transitions from $-10$ V to $+10$ V
  3) From $-1.580$ ms to $0$ ms, $V_o = +10$ V
  4) From $0$ ms to $+1.580$ ms, $V_o = -10$ V
  5) From $+1.580$ ms to $+2.420$ ms, $V_o$ = transitions from $-10$ V to $+10$ V
  6) From $+2.420$ ms to end, $V_o = +10$ V

- At what times does $V_o$ reach $\pm 10$ V?
  1) From start to $-2.420$ ms, $V_o = -10$ V
  3) From $-1.580$ ms to $0$ ms, $V_o = +10$ V
  4) From $0$ ms to $+1.580$ ms, $V_o = -10$ V
  6) From $+2.420$ 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 $\pm \frac{1.77 \, \text{k}\Omega}{306 + 1.77 \, \text{k}\Omega} \times 10 \, \text{V} = \pm 0.058 \, \text{V}$.

Conditions:
1) If $V_i < V_+ \implies V_o = +10 \, \text{V}$ and $V_+ = +0.058 \, \text{V}$.
2) If $V_i > V_+ \implies V_o = -10 \, \text{V}$ and $V_+ = -0.058 \, \text{V}$.

• Sketch $V_o$.
  1) Initially, $V_o = +10$ and $V_+ = +0.058 \, \text{V}$
  2) when $V_i$ crosses $+0.058 \, \text{V}$, then $V_o = -10$ and $V_+ = -0.058 \, \text{V}$
  3) when $V_i$ crosses $-0.058 \, \text{V}$, then $V_o = +10$ and $V_+ = +0.058 \, \text{V}$
  4) when $V_i$ crosses $+0.058 \, \text{V}$, then $V_o = -10$ and $V_+ = -0.058 \, \text{V}$

• At what times does $V_o$ reach $\pm 10$ V?
  Transitions at $\pm \frac{0.1\, \text{V}}{5 \, \text{V}/100 \, \text{ms}} = \pm 0.84 \, \text{ms}$.
  1) Beginning until $-0.84 \, \text{ms} \implies V_o = +10 \, \text{V}$.
  2) $-0.84 \, \text{ms}$ until $0 \, \text{ms} \implies V_o = -10 \, \text{V}$.
  3) $0 \, \text{ms}$ until $+3.16 \, \text{ms} \implies V_o = +10 \, \text{V}$.
  4) $+3.16 \, \text{ms}$ until end $\implies V_o = -10 \, \text{V}$.

• 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 $G = -\frac{549 \text{k}\Omega}{19.0 \text{k}\Omega} = -28.89$.
With such a large gain, it will saturate when $V_i = ±10 \text{ V} / G = ±0.346 \text{ V}$.
The time constant is $\tau = 549 \text{k}\Omega \times 329 \text{nF} = 180.6 \text{ ms}$.

• At what times does $V_o$ reach ±10 V?
  Transitions at $±\frac{0.1+0.346}{5 \text{ V}/100 \text{ms}} = ±8.9 \text{ ms}$.
  Thus: 1) Beginning until $-8.9 \text{ ms} \implies V_o = +10 \text{ V}$.  
    2) $+8.9 \text{ ms}$ 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)
  Beginning until $-8.9 \text{ ms} \implies V_o = +10 \text{ V}$. Then, from $+8.9 \text{ ms}$ until $-8.9 \text{ ms}$ 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 $+8.9 \text{ ms}$ 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 $RC = 180.6 \text{ ms}$. 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.