• 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 $G = 1 + \frac{506}{1.90} = 267.3$.

With such a large gain, it will saturate when $V_i = \pm 10 V / G = \pm 0.037 V$.

Times when $|V_i| < 0.037$, V, are

$T_1 = \pm \frac{0.1 - 0.037}{5 V/100 \text{ms}} = \pm 1.260 \text{ ms}$.

$T_2 = \pm \frac{0.1 + 0.037}{5 V/100 \text{ms}} = \pm 2.740 \text{ ms}$.

• Sketch $V_o$.

  1) From start to $-2.740 \text{ ms}$, $V_o = -10 V$
  2) From $-2.740 \text{ ms}$ to $-1.260 \text{ ms}$, $V_o$ = transitions from $-10 V$ to $+10 V$
  3) From $-1.260 \text{ ms}$ to $0 \text{ ms}$, $V_o = +10 V$
  4) From $0 \text{ ms}$ to $+1.260 \text{ ms}$, $V_o = -10 V$
  5) From $+1.260 \text{ ms}$ to $+2.740 \text{ ms}$, $V_o$ = transitions from $-10 V$ to $+10 V$
  6) From $+2.740 \text{ ms}$ to end, $V_o = +10 V$

• At what times does $V_o$ reach ±10 V?

  1) From start to $-2.740 \text{ ms}$, $V_o = -10 V$
  3) From $-1.260 \text{ ms}$ to $0 \text{ ms}$, $V_o = +10 V$
  4) From $0 \text{ ms}$ to $+1.260 \text{ ms}$, $V_o = -10 V$
  6) From $+2.740 \text{ ms}$ 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 $\pm \frac{1.69\, \text{k}\Omega}{371 + 1.69\, \text{k}\Omega} \times 10\, V = \pm 0.045\, V$.  

Conditions:  
1) If $V_i < V_+ \implies V_o = +10\, V$ and $V_+ = +0.045\, V$.  
2) If $V_i > V_+ \implies V_o = -10\, V$ and $V_+ = -0.045\, V$.  

• Sketch $V_o$.  
  1) Initially, $V_o = +10$ and $V_+ = +0.045\, V$  
  2) when $V_i$ crosses $+0.045\, V$, then $V_o = -10$ and $V_+ = -0.045\, V$  
  3) when $V_i$ crosses $-0.045\, V$, then $V_o = +10$ and $V_+ = +0.045\, V$  
  4) when $V_i$ crosses $+0.045\, V$, then $V_o = -10$ and $V_+ = -0.045\, V$  

• At what times does $V_o$ reach $\pm 10\, V$?  
  Transitions at $\pm \frac{0.1 - 0.045}{5\, V/100\, ms} = \pm 1.10\, ms$.  
  1) Beginning until $-1.10\, ms \implies V_o = +10\, V$.  
  2) $-1.10\, ms$ until $0\, ms \implies V_o = -10\, V$.  
  3) $0\, ms$ until $+2.90\, ms \implies V_o = +10\, V$.  
  4) $+2.90\, ms$ until end $\implies V_o = -10\, V$.  

• Does this circuit suffer from multiple transitions?  
  Yes
This is a low pass filter with a gain of $G = \frac{-410 \text{k}\Omega}{15.7 \text{k}\Omega} = -26.11$.
With such a large gain, it will saturate when $V_i = \pm 10 \text{ V} / G = \pm 0.383 \text{ V}$.
The time constant is $\tau = 410 \text{k}\Omega \times 571 \text{nF} = 234.1 \text{ ms}$.

- At what times does $V_o$ reach $\pm 10 \text{ V}$?
  Transitions at $\pm 0.1 + 0.383 \frac{5 \text{ V}}{100 \text{ ms}} = \pm 9.7 \text{ ms}$.
  Thus: 1) Beginning until $-9.7 \text{ ms} \Rightarrow V_o = +10 \text{ V}$.
  2) $+9.7 \text{ ms}$ until end $\Rightarrow V_o = -10 \text{ V}$.

- Sketch $V_o$ (this is difficult because of the exponential – indicate the main features of the curve)
  Begining until $-9.7 \text{ ms} \Rightarrow V_o = +10 \text{ V}$. Then, from $+9.7 \text{ ms}$ until $-9.7 \text{ ms}$ 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 $+9.7 \text{ ms}$ until end $\Rightarrow V_o = -10 \text{ V}$.

- 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 $RC = 234.1 \text{ ms}$. 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.