• 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 $G = 1 + \frac{582}{181} = 322.5$. With such a large gain, it will saturate when $V_i = \pm 10 V/G = \pm 0.031 V$.

Times when $|V_i| < 0.031$, V, are

$T_1 = \pm \frac{0.1-0.031}{5V/100\text{ms}} = \pm 1.380 \text{ ms}$.
$T_2 = \pm \frac{0.1+0.031}{5V/100\text{ms}} = \pm 2.620 \text{ ms}$.

• Sketch $V_o$.
  1) From start to −2.620 ms, $V_o = −10 V$
  2) From −2.620 ms to −1.380 ms, $V_o = \text{transitions from } −10 \text{ V to } +10 \text{ V}$
  3) From −1.380 ms to 0 ms, $V_o = +10 V$
  4) From 0 ms to +1.380 ms, $V_o = −10 V$
  5) From +1.380 ms to +2.620 ms, $V_o = \text{transitions from } −10 \text{ V to } +10 \text{ V}$
  6) From +2.620 ms to end, $V_o = +10 V$

• At what times does $V_o$ reach ±10 V?
  1) From start to −2.620 ms, $V_o = −10 V$
  3) From −1.380 ms to 0 ms, $V_o = +10 V$
  4) From 0 ms to +1.380 ms, $V_o = −10 V$
  6) From +2.620 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 $\pm 10\,\text{V}$?

• Does this circuit suffer from multiple transitions?

(Notes: voltage axis not to scale. The slope of the voltage may be approximated as $5\,\text{V}/100\,\text{ms}$. Op amps are ideal)

Thresholds at \( \pm \frac{1.94\,\text{k}\Omega}{544+1.94\,\text{k}\Omega} \times 10\,\text{V} = \pm 0.036\,\text{V} \).

Conditions:
1) If $V_i < V_+$ \( \Rightarrow \) $V_o = +10\,\text{V}$ and $V_+ = +0.036\,\text{V}$.
2) If $V_i > V_+$ \( \Rightarrow \) $V_o = -10\,\text{V}$ 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 $+0.036\,\text{V}$, then $V_o = -10$ and $V_+ = -0.036\,\text{V}$
  3) when $V_i$ crosses $-0.036\,\text{V}$, then $V_o = +10$ and $V_+ = +0.036\,\text{V}$
  4) when $V_i$ crosses $+0.036\,\text{V}$, then $V_o = -10$ and $V_+ = -0.036\,\text{V}$

• At what times does $V_o$ reach $\pm 10\,\text{V}$?
  Transitions at \( \pm \frac{0.1-0.036}{5\,\text{V}/100\,\text{ms}} = \pm 1.28\,\text{ms} \).
  1) Beginning until $-1.28\,\text{ms} \Rightarrow V_o = +10\,\text{V}$.
  2) $-1.28\,\text{ms}$ until $0\,\text{ms} \Rightarrow V_o = -10\,\text{V}$.
  3) $0\,\text{ms}$ until $+2.72\,\text{ms} \Rightarrow V_o = +10\,\text{V}$.
  4) $+2.72\,\text{ms}$ until end \( \Rightarrow \) $V_o = -10\,\text{V}$.

• Does this circuit suffer from multiple transitions?
  \[\text{Yes}\]
This is a low pass filter with a gain of $G = -\frac{450 \text{k} \Omega}{13.5 \text{k} \Omega} = -33.33$.
With such a large gain, it will saturate when $V_i = \pm 10 \text{ V} / G = \pm 0.300 \text{ V}$.
The time constant is $\tau = 450 \text{k} \Omega \times 544 \text{nF} = 244.8 \text{ ms}$.

- At what times does $V_o$ reach $\pm 10 \text{ V}$?
  Transitions at $\pm \frac{0.1+0.300}{5 \text{ V} / 100 \text{ ms}} = \pm 8.0 \text{ ms}$.
  Thus: 1) Beginning until $-8.0 \text{ ms} \implies V_o = +10 \text{ V}$.
  2) $+8.0 \text{ ms} \text{ until end} \implies V_o = -10 \text{ V}$.

- Sketch $V_o$ (this is difficult because of the exponential – indicate the main features of the curve)
  Beginning until $-8.0 \text{ ms} \implies V_o = +10 \text{ V}$. Then, from $+8.0 \text{ ms}$ until $-8.0 \text{ ms}$ it 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 $+8.0 \text{ ms}$ 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 $RC = 244.8 \text{ ms}$. 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.