• 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 $G = 1 + \frac{518}{1.53} = 339.6$. With such a large gain, it will saturate when $V_i = \pm 10 V / G = \pm 0.029 V$.

Times when $|V_i| < 0.029 V$, are:

$T_1 = \pm \frac{0.1-0.029}{5V/100ms} = \pm 1.420 ms$.
$T_2 = \pm \frac{0.1+0.029}{5V/100ms} = \pm 2.580 ms$.

• Sketch $V_o$.

1) From start to $-2.580 ms$, $V_o = -10 V$
2) From $-2.580 ms$ to $-1.420 ms$, $V_o = \text{transitions from } -10 V \text{ to } +10 V$
3) From $-1.420 ms$ to $0 ms$, $V_o = +10 V$
4) From $0 ms$ to $+1.420 ms$, $V_o = -10 V$
5) From $+1.420 ms$ to $+2.580 ms$, $V_o = \text{transitions from } -10 V \text{ to } +10 V$
6) From $+2.580 ms$ to end, $V_o = +10 V$

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

1) From start to $-2.580 ms$, $V_o = -10 V$
3) From $-1.420 ms$ to $0 ms$, $V_o = +10 V$
4) From $0 ms$ to $+1.420 ms$, $V_o = -10 V$
6) From $+2.580 ms$ 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 $5 \text{ V/100 ms}$. Op amps are ideal)

Thresholds at $\pm \frac{1.73 \text{k}\Omega}{579+1.73 \text{k}\Omega} \times 10 \text{ V} = \pm 0.030 \text{ V}$.

Conditions:
1) If $V_i < V_+$ $\Rightarrow$ $V_o = +10 \text{ V}$ and $V_+ = +0.030 \text{ V}$.
2) If $V_i > V_+$ $\Rightarrow$ $V_o = -10 \text{ V}$ and $V_+ = -0.030 \text{ V}$.

• Sketch $V_o$.
  1) Initially, $V_o = +10$ and $V_+ = +0.030 \text{ V}$
  2) when $V_i$ crosses $+0.030 \text{ V}$, then $V_o = -10$ and $V_+ = -0.030 \text{ V}$
  3) when $V_i$ crosses $-0.030 \text{ V}$, then $V_o = +10$ and $V_+ = +0.030 \text{ V}$
  4) when $V_i$ crosses $+0.030 \text{ V}$, then $V_o = -10$ and $V_+ = -0.030 \text{ V}$

• At what times does $V_o$ reach $\pm 10 \text{ V}$?
  Transitions at $\pm \frac{0.1-0.030}{5 \text{ V/100 ms}} = \pm 1.40 \text{ ms}$.
  1) Beginning until $-1.40 \text{ ms} \Rightarrow V_o = +10 \text{ V}$.
  2) $-1.40 \text{ ms}$ until $0 \text{ ms} \Rightarrow V_o = -10 \text{ V}$.
  3) $0 \text{ ms}$ until $+2.60 \text{ ms} \Rightarrow V_o = +10 \text{ V}$.
  4) $+2.60 \text{ ms}$ until end $\Rightarrow V_o = -10 \text{ V}$.

• Does this circuit suffer from multiple transitions?
  Yes
This is a low pass filter with a gain of \( G = -\frac{462 \, \text{k}\Omega}{10.3 \, \text{k}\Omega} = -44.85 \).

With such a large gain, it will saturate when \( V_i = \pm 10 \, \text{V} / G = \pm 0.223 \, \text{V} \).

The time constant is \( \tau = 462 \, \text{k}\Omega \times 459 \, \text{nF} = 212.1 \, \text{ms} \).

- At what times does \( V_o \) reach \( \pm 10 \, \text{V} \)?
  
  Transitions at \( \pm \frac{0.1 + 0.223}{5 \, \text{V}/100 \, \text{ms}} = \pm 6.5 \, \text{ms} \).
  
  Thus: 1) Beginning until \(-6.5 \, \text{ms} \implies V_o = +10 \, \text{V}\).
  
  2) +6.5 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 \(-6.5 \, \text{ms} \implies V_o = +10 \, \text{V}\). Then, from +6.5 ms until \(-6.5 \, \text{ms}\) 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 +6.5 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 \( RC = 212.1 \, \text{ms} \). 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.