• 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 $G = 1 + \frac{572}{1.19} = 481.7$.
With such a large gain, it will saturate when $V_i = \pm 10 \text{V}/G = \pm 0.021 \text{V}$.

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

\[ T_1 = \pm \frac{0.1-0.021}{5 \text{V/100 ms}} = \pm 1.580 \text{ms}. \]
\[ T_2 = \pm \frac{0.1+0.021}{5 \text{V/100 ms}} = \pm 2.420 \text{ms}. \]

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

• At what times does $V_o$ reach $\pm 10$ V?
  1) From start to $-2.420 \text{ms}$, $V_o = -10 \text{V}$
  3) From $-1.580 \text{ms}$ to $0 \text{ms}$, $V_o = +10 \text{V}$
  4) From $0 \text{ms}$ to $+1.580 \text{ms}$, $V_o = -10 \text{V}$
  6) From $+2.420 \text{ms}$ to end, $V_o = +10 \text{V}$

• 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 $\pm \frac{1.91\,\text{k}\Omega}{328+1.91\,\text{k}\Omega} \times 10\,\text{V} = \pm 0.058\,\text{V}$.

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 $\pm 10\,\text{V}$?
  Transitions at $\pm \frac{0.1-0.058}{5\,\text{V}/100\,\text{ms}} = \pm 0.84\,\text{ms}$.
  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
This is a low pass filter with a gain of \[ G = -\frac{565 \text{k}\Omega}{18.5 \text{k}\Omega} = -30.54. \]
With such a large gain, it will saturate when \( V_i = \pm 10 \text{ V} / G = \pm 0.327 \text{ V} \).
The time constant is \( \tau = 565 \text{k}\Omega \times 357 \text{nF} = 201.7 \text{ ms} \).

- At what times does \( V_o \) reach \( \pm 10 \text{ V} \)?
  
  Transitions at \( \pm \frac{0.1 + 0.327}{5 \text{ V} / 100 \text{ ms}} = \pm 8.5 \text{ ms} \).
  
  Thus: 1) Begining until \(-8.5 \text{ ms} \implies V_o = +10 \text{ V} \).
  
  2) \(+8.5 \text{ ms} \) 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)

  Begining until \(-8.5 \text{ ms} \implies V_o = +10 \text{ V} \). Then, from \(+8.5 \text{ ms} \) until \(-8.5 \text{ ms} \) the will go from \(+10 \text{ V} \) 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 \(+8.5 \text{ ms} \) 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 \( RC = 201.7 \text{ ms} \). 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.