• 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 $G = 1 + \frac{563}{190} = 297.3$.
With such a large gain, it will saturate when $V_i = \pm 10 V / G = \pm 0.034 V$.

Times when $|V_i| < 0.034$, are

$T_1 = \pm \frac{0.1 - 0.034}{5 V/100 \text{ ms}} = \pm 1.320 \text{ ms}$.

$T_2 = \pm \frac{0.1 + 0.034}{5 V/100 \text{ ms}} = \pm 2.680 \text{ ms}$.

• Sketch $V_o$.

1) From start to $-2.680 \text{ ms}$, $V_o = -10 \text{ V}$
2) From $-2.680 \text{ ms}$ to $-1.320 \text{ ms}$, $V_o$ = transitions from $-10 \text{ V}$ to $+10 \text{ V}$
3) From $-1.320 \text{ ms}$ to $0 \text{ ms}$, $V_o = +10 \text{ V}$
4) From $0 \text{ ms}$ to $+1.320 \text{ ms}$, $V_o = -10 \text{ V}$
5) From $+1.320 \text{ ms}$ to $+2.680 \text{ ms}$, $V_o$ = transitions from $-10 \text{ V}$ to $+10 \text{ V}$
6) From $+2.680 \text{ ms}$ to end, $V_o = +10 \text{ V}$

• At what times does $V_o$ reach $\pm 10 \text{ V}$?

1) From start to $-2.680 \text{ ms}$, $V_o = -10 \text{ V}$
3) From $-1.320 \text{ ms}$ to $0 \text{ ms}$, $V_o = +10 \text{ V}$
4) From $0 \text{ ms}$ to $+1.320 \text{ ms}$, $V_o = -10 \text{ V}$
6) From $+2.680 \text{ ms}$ 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 V/100 ms. Op amps are ideal)

Thresholds at \( \pm \frac{1.88 \text{k}\Omega}{517+1.88 \text{k}\Omega} \times 10 \text{ V} = \pm 0.036 \text{ V} \).

Conditions:
1) If \( V_i < V_+ \implies V_o = +10 \text{ V} \) and \( V_+ = +0.036 \text{ V} \).
2) If \( V_i > V_+ \implies V_o = -10 \text{ V} \) and \( V_+ = -0.036 \text{ V} \).

• Sketch \( V_o \).
  
  1) Initially, \( V_o = +10 \text{ and } V_+ = +0.036 \text{ V} \)
  2) when \( V_i \) crosses +0.036 V, then \( V_o = -10 \text{ and } V_+ = -0.036 \text{ V} \)
  3) when \( V_i \) crosses −0.036 V, then \( V_o = +10 \text{ and } V_+ = +0.036 \text{ V} \)
  4) when \( V_i \) crosses +0.036 V, then \( V_o = -10 \text{ and } V_+ = -0.036 \text{ V} \)

• 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 ms \( \implies V_o = +10 \text{ V} \).
  2) −1.28 ms until 0 ms \( \implies V_o = -10 \text{ V} \).
  3) 0 ms until +2.72 ms \( \implies V_o = +10 \text{ V} \).
  4) +2.72 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 \( G = \frac{-524 \text{k}\Omega}{19.8 \text{k}\Omega} = -26.46 \).

With such a large gain, it will saturate when \( V_i = \pm 10 \text{ V} / G = \pm 0.378 \text{ V} \).

The time constant is \( \tau = 524 \text{k}\Omega \times 571 \text{nF} = 299.2 \text{ ms} \).

- At what times does \( V_o \) reach \( \pm 10 \text{ V} \)?

  Transitions at \( \pm \frac{0.1 + 0.378}{5 \text{ V}/100 \text{ ms}} = \pm 9.6 \text{ ms} \).

  Thus: 1) Beginning until \(-9.6 \text{ ms} \implies V_o = +10 \text{ V} \).

  2) \(+9.6 \text{ ms} \) 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 \(-9.6 \text{ ms} \implies V_o = +10 \text{ V} \). Then, from \(+9.6 \text{ ms} \) until \(-9.6 \text{ ms} \) 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 \(+9.6 \text{ ms} \) 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 \( RC = 299.2 \text{ ms} \). 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.