• 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 $G = 1 + \frac{456}{141} = 324.4$. With such a large gain, it will saturate when $V_i = \pm 10 \text{ V} / G = \pm 0.031 \text{ V}$.

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

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

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

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

• At what times does $V_o$ reach $\pm 10 \text{ V}$?
  1) From start to $-2.620 \text{ ms}$, $V_o = -10 \text{ V}$
  3) From $-1.380 \text{ ms}$ to $0 \text{ ms}$, $V_o = +10 \text{ V}$
  4) From $0 \text{ ms}$ to $+1.380 \text{ ms}$, $V_o = -10 \text{ V}$
  6) From $+2.620 \text{ ms}$ 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 $\pm \frac{1.52 \text{k} \Omega}{430 + 1.52 \text{k} \Omega} \times 10 \text{V} = \pm 0.035 \text{V}$. 

Conditions:
1) If $V_i < V_+ \implies V_o = +10 \text{V}$ and $V_+ = +0.035 \text{V}$.
2) If $V_i > V_+ \implies V_o = -10 \text{V}$ and $V_+ = -0.035 \text{V}$.

- Sketch $V_o$.
  1) Initially, $V_o = +10$ and $V_+ = +0.035 \text{V}$
  2) when $V_i$ crosses $+0.035 \text{V}$, then $V_o = -10$ and $V_+ = -0.035 \text{V}$
  3) when $V_i$ crosses $-0.035 \text{V}$, then $V_o = +10$ and $V_+ = +0.035 \text{V}$
  4) when $V_i$ crosses $+0.035 \text{V}$, then $V_o = -10$ and $V_+ = -0.035 \text{V}$

- At what times does $V_o$ reach $\pm 10 \text{V}$?
  Transitions at $\pm \frac{0.1 - 0.035}{5 \text{V}/100 \text{ms}} = \pm 1.30 \text{ms}$.
  1) Beginning until $-1.30 \text{ms} \implies V_o = +10 \text{V}$.
  2) $-1.30 \text{ms}$ until $0 \text{ms} \implies V_o = -10 \text{V}$.
  3) $0 \text{ms}$ until $+2.70 \text{ms} \implies V_o = +10 \text{V}$.
  4) $+2.70 \text{ms}$ 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 \( G = -\frac{475 \text{k}\Omega}{16.3 \text{k}\Omega} = -29.14 \). With such a large gain, it will saturate when \( V_i = \pm 10 \text{V} / G = \pm 0.343 \text{V} \).

The time constant is \( \tau = 475 \text{k}\Omega \times 423 \text{nF} = 200.9 \text{ms} \).

- At what times does \( V_o \) reach \( \pm 10 \text{V} \)?
  
  Transitions at \( \pm \frac{0.1+0.343}{5 \text{V}/100 \text{ms}} = \pm 8.9 \text{ms} \).
  
  Thus: 1) Beginning until \(-8.9 \text{ms} \implies V_o = +10 \text{V}\).
  
  2) \(+8.9 \text{ms} \) 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)

- 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 \( RC = 200.9 \text{ms} \). 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.