• 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 $5 \text{ V}/100 \text{ ms}$. Op amps are ideal)

This is a non-inverting amplifier with a gain of $G = 1 + \frac{558}{177} = 316.3$. With such a large gain, it will saturate when $V_i = \pm 10 \text{ V} / G = \pm 0.032 \text{ V}$.

Times when $|V_i| < 0.032$, V, are

$T_1 = \pm \frac{0.1 - 0.032}{5 \text{ V} / 100 \text{ ms}} = \pm 1.360 \text{ ms}$.

$T_2 = \pm \frac{0.1 + 0.032}{5 \text{ V} / 100 \text{ ms}} = \pm 2.640 \text{ ms}$.

• Sketch $V_o$.
  1) From start to $-2.640 \text{ ms}$, $V_o = -10 \text{ V}$
  2) From $-2.640 \text{ ms}$ to $-1.360 \text{ ms}$, $V_o = \text{ transitions from } -10 \text{ V to } +10 \text{ V}$
  3) From $-1.360 \text{ ms}$ to $0 \text{ ms}$, $V_o = +10 \text{ V}$
  4) From $0 \text{ ms}$ to $+1.360 \text{ ms}$, $V_o = -10 \text{ V}$
  5) From $+1.360 \text{ ms}$ to $+2.640 \text{ ms}$, $V_o = \text{ transitions from } -10 \text{ V to } +10 \text{ V}$
  6) From $+2.640 \text{ ms}$ to end, $V_o = +10 \text{ V}$

• At what times does $V_o$ reach $\pm 10$ V?
  1) From start to $-2.640 \text{ ms}$, $V_o = -10 \text{ V}$
  3) From $-1.360 \text{ ms}$ to $0 \text{ ms}$, $V_o = +10 \text{ V}$
  4) From $0 \text{ ms}$ to $+1.360 \text{ ms}$, $V_o = -10 \text{ V}$
  6) From $+2.640 \text{ ms}$ 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 $\pm 10\ V$?

• 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 $\pm \frac{1.86\ k\Omega}{402+1.86\ k\Omega} \times 10\ V = \pm 0.046\ V$.

Conditions:
1) If $V_i < V_+ \implies V_o = +10\ V$ and $V_+ = +0.046\ V$.
2) If $V_i > V_+ \implies V_o = -10\ V$ and $V_+ = -0.046\ V$.

• Sketch $V_o$.
  1) Initially, $V_o = +10$ and $V_+ = +0.046\ V$
  2) when $V_i$ crosses $+0.046\ V$, then $V_o = -10$ and $V_+ = -0.046\ V$
  3) when $V_i$ crosses $-0.046\ V$, then $V_o = +10$ and $V_+ = +0.046\ V$
  4) when $V_i$ crosses $+0.046\ V$, then $V_o = -10$ and $V_+ = -0.046\ V$

• At what times does $V_o$ reach $\pm 10\ V$?
  Transitions at $\pm \frac{0.1-0.046}{5\ V/100\ ms} = \pm 1.08\ ms$.
  1) Beginning until $-1.08\ ms \implies V_o = +10\ V$.
  2) $-1.08\ ms$ until $0\ ms \implies V_o = -10\ V$.
  3) $0\ ms$ until $+2.92\ ms \implies V_o = +10\ V$.
  4) $+2.92\ ms$ until end $\implies V_o = -10\ V$.

• Does this circuit suffer from multiple transitions?
  Yes
This is a low pass filter with a gain of \( G = -\frac{443 \text{k}\Omega}{11.6 \text{k}\Omega} = -38.19 \).
With such a large gain, it will saturate when \( V_i = \pm 10 \text{ V} / G = \pm 0.262 \text{ V} \).
The time constant is \( \tau = 443 \text{k}\Omega \times 532 \text{nF} = 235.7 \text{ ms} \).

- At what times does \( V_o \) reach \( \pm 10 \text{ V} \)?
  Transitions at \( \pm \frac{0.1+0.262}{5 \text{V}/100 \text{ms}} = \pm 7.2 \text{ ms} \).
  Thus: 1) Beginning until \(-7.2 \text{ ms} \Rightarrow V_o = +10 \text{ V} \).
    2) \(+7.2 \text{ ms} \) until end \(\Rightarrow V_o = -10 \text{ V} \).

- Sketch \( V_o \) (this is difficult because of the exponential – indicate the main features of the curve)
  Beginning until \(-7.2 \text{ ms} \Rightarrow V_o = +10 \text{ V} \). Then, from \(+7.2 \text{ ms} \) until \(-7.2 \text{ ms} \) 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 \(+7.2 \text{ ms} \) until end \(\Rightarrow V_o = -10 \text{ V} \).

- 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 \( RC = 235.7 \text{ ms} \). 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.