- 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 $G = 1 + \frac{519}{1.95} = 267.2$. With such a large gain, it will saturate when $V_i = \pm 10\,V/G = \pm 0.037\,V$.

Times when $|V_i| < 0.037\,V$, are

$T_1 = \pm \frac{0.1-0.037}{5\,V/100\,ms} = \pm 1.260\,ms.$

$T_2 = \pm \frac{0.1+0.037}{5\,V/100\,ms} = \pm 2.740\,ms.$

- Sketch $V_o$.
  1) From start to $-2.740\,ms$, $V_o = -10\,V$
  2) From $-2.740\,ms$ to $-1.260\,ms$, $V_o = \text{transitions from } -10\,V \text{ to } +10\,V$
  3) From $-1.260\,ms$ to $0\,ms$, $V_o = +10\,V$
  4) From $0\,ms$ to $+1.260\,ms$, $V_o = -10\,V$
  5) From $+1.260\,ms$ to $+2.740\,ms$, $V_o = \text{transitions from } -10\,V \text{ to } +10\,V$
  6) From $+2.740\,ms$ to end, $V_o = +10\,V$

- At what times does $V_o$ reach $\pm 10\,V$?
  1) From start to $-2.740\,ms$, $V_o = -10\,V$
  3) From $-1.260\,ms$ to $0\,ms$, $V_o = +10\,V$
  4) From $0\,ms$ to $+1.260\,ms$, $V_o = -10\,V$
  6) From $+2.740\,ms$ to end, $V_o = +10\,V$

- Does this circuit suffer from multiple transitions?
  Yes
• Sketch $V_o$.

• At what times does $V_o$ reach $\pm 10$ 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 $\pm \frac{1.73 \text{k} \Omega}{410 + 1.73 \text{k} \Omega} \times 10 \text{ V} = \pm 0.042 \text{ V}$.

Conditions:
1) If $V_i < V_+ \implies V_o = +10 \text{ V}$ and $V_+ = +0.042 \text{ V}$.
2) If $V_i > V_+ \implies V_o = -10 \text{ V}$ and $V_+ = -0.042 \text{ V}$.

• Sketch $V_o$.
  1) Initially, $V_o = +10$ and $V_+ = +0.042 \text{ V}$
  2) when $V_i$ crosses $+0.042 \text{ V}$, then $V_o = -10$ and $V_+ = -0.042 \text{ V}$
  3) when $V_i$ crosses $-0.042 \text{ V}$, then $V_o = +10$ and $V_+ = +0.042 \text{ V}$
  4) when $V_i$ crosses $+0.042 \text{ V}$, then $V_o = -10$ and $V_+ = -0.042 \text{ V}$

• At what times does $V_o$ reach $\pm 10$ V?
  Transitions at $\pm \frac{0.1 - 0.042}{5 \text{ V}/100 \text{ ms}} = \pm 1.16 \text{ ms}$.
  1) Beginning until $\pm 1.16 \text{ ms} \implies V_o = +10 \text{ V}$.
  2) $-1.16 \text{ ms}$ until $0 \text{ ms} \implies V_o = -10 \text{ V}$.
  3) $0 \text{ ms}$ until $+2.84 \text{ ms} \implies V_o = +10 \text{ V}$.
  4) $+2.84 \text{ ms}$ 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 \( G = \frac{-529 \text{k}\Omega}{12.8 \text{k}\Omega} = -41.33 \).

With such a large gain, it will saturate when \( V_i = \pm 10 \text{ V} / G = \pm 0.242 \text{ V} \).

The time constant is \( \tau = 529 \text{k}\Omega \times 585 \text{nF} = 309.5 \text{ ms} \).

- **At what times does \( V_o \) reach \( \pm 10 \text{ V} \)?**
  - Transitions at \( \pm \frac{0.242}{5 \text{ V} / 100 \text{ ms}} = \pm 6.8 \text{ ms} \).
  - Thus: 1) Beginning until \(-6.8 \text{ ms} \implies V_o = +10 \text{ V} \).
    - 2) +6.8 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 \(-6.8 \text{ ms} \implies V_o = +10 \text{ V} \). Then, from +6.8 ms until \(-6.8 \text{ ms} \) 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 +6.8 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 \( RC = 309.5 \text{ ms} \). 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.