• 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 $G = 1 + \frac{338}{1.96} = 173.4$. With such a large gain, it will saturate when $V_i = \pm 10\,\text{V}/G = \pm 0.058\,\text{V}$.

Times when $|V_i| < 0.058$, are

$T_1 = \pm \frac{0.1 - 0.058}{5\,\text{V}/100\,\text{ms}} = \pm 0.840\,\text{ms}$.

$T_2 = \pm \frac{0.1 + 0.058}{5\,\text{V}/100\,\text{ms}} = \pm 3.160\,\text{ms}$.

• Sketch $V_o$.
  1) From start to $-3.160\,\text{ms}$, $V_o = -10\,\text{V}$
  2) From $-3.160\,\text{ms}$ to $-0.840\,\text{ms}$, $V_o$ = transitions from $-10\,\text{V}$ to $+10\,\text{V}$
  3) From $-0.840\,\text{ms}$ to $0\,\text{ms}$, $V_o = +10\,\text{V}$
  4) From $0\,\text{ms}$ to $+0.840\,\text{ms}$, $V_o = -10\,\text{V}$
  5) From $+0.840\,\text{ms}$ to $+3.160\,\text{ms}$, $V_o$ = transitions from $-10\,\text{V}$ to $+10\,\text{V}$
  6) From $+3.160\,\text{ms}$ to end, $V_o = +10\,\text{V}$

• At what times does $V_o$ reach $\pm 10$ V?
  1) From start to $-3.160\,\text{ms}$, $V_o = -10\,\text{V}$
  3) From $-0.840\,\text{ms}$ to $0\,\text{ms}$, $V_o = +10\,\text{V}$
  4) From $0\,\text{ms}$ to $+0.840\,\text{ms}$, $V_o = -10\,\text{V}$
  6) From $+3.160\,\text{ms}$ 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 $\pm \frac{1.13 \, k\Omega}{528+1.13 \, k\Omega} \times 10 \, V = \pm 0.021 \, V$.

Conditions:
1) If $V_i < V_+ \implies V_o = +10 \, V$ and $V_+ = +0.021 \, V$.
2) If $V_i > V_+ \implies V_o = -10 \, V$ and $V_+ = -0.021 \, V$.

• Sketch $V_o$.
  1) Initially, $V_o = +10$ and $V_+ = +0.021 \, V$
  2) when $V_i$ crosses $+0.021 \, V$, then $V_o = -10$ and $V_+ = -0.021 \, V$
  3) when $V_i$ crosses $-0.021 \, V$, then $V_o = +10$ and $V_+ = +0.021 \, V$
  4) when $V_i$ crosses $+0.021 \, V$, then $V_o = -10$ and $V_+ = -0.021 \, V$

• At what times does $V_o$ reach $\pm 10 \, V$?

  Transitions at $\pm \frac{0.1-0.021}{5 \, V/100 \, ms} = \pm 1.58 \, ms$.

  1) Beginning until $-1.58 \, ms \implies V_o = +10 \, V$.
  2) $-1.58 \, ms$ until $0 \, ms \implies V_o = -10 \, V$.
  3) $0 \, ms$ until $+2.42 \, ms \implies V_o = +10 \, V$.
  4) $+2.42 \, ms$ 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 \( G = \frac{-467 \, \text{k}\Omega}{11.2 \, \text{k}\Omega} = -41.70 \).
With such a large gain, it will saturate when \( V_i = \pm 10 \, \text{V} \), \( G = \pm 0.240 \, \text{V} \).
The time constant is \( \tau = 467 \, \text{k}\Omega \times 587 \, \text{nF} = 274.1 \, \text{ms} \).

- At what times does \( V_o \) reach \( \pm 10 \, \text{V} \)?
  Transitions at \( \pm \frac{0.1 + 0.240}{5 \, \text{V}/100 \, \text{ms}} = \pm 6.8 \, \text{ms} \).
  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)

- Does this circuit suffer from multiple transitions?

  \[ \text{No} \]

\textit{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 \( RC = 274.1 \, \text{ms} \). 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.