• Sketch $V_o$.

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

• Does this circuit suffer from multiple transitions?

(Note: 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 $G = 1 + \frac{414}{1.19} = 348.9$. With such a large gain, it will saturate when $V_i = \pm 10 V / G = \pm 0.029 V$.

Times when $|V_i| < 0.029$, are

$T_1 = \pm \frac{0.1 - 0.029}{5 \, \text{V/100 ms}} = \pm 1.420 \, \text{ms}$.

$T_2 = \pm \frac{0.1 + 0.029}{5 \, \text{V/100 ms}} = \pm 2.580 \, \text{ms}$.

• Sketch $V_o$.

1) From start to $-2.580 \, \text{ms}$, $V_o = -10 \, \text{V}$
2) From $-2.580 \, \text{ms}$ to $-1.420 \, \text{ms}$, $V_o$ = transitions from $-10 \, \text{V}$ to $+10 \, \text{V}$
3) From $-1.420 \, \text{ms}$ to $0 \, \text{ms}$, $V_o = +10 \, \text{V}$
4) From $0 \, \text{ms}$ to $+1.420 \, \text{ms}$, $V_o = -10 \, \text{V}$
5) From $+1.420 \, \text{ms}$ to $+2.580 \, \text{ms}$, $V_o$ = transitions from $-10 \, \text{V}$ to $+10 \, \text{V}$
6) From $+2.580 \, \text{ms}$ to end, $V_o = +10 \, \text{V}$

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

1) From start to $-2.580 \, \text{ms}$, $V_o = -10 \, \text{V}$
3) From $-1.420 \, \text{ms}$ to $0 \, \text{ms}$, $V_o = +10 \, \text{V}$
4) From $0 \, \text{ms}$ to $+1.420 \, \text{ms}$, $V_o = -10 \, \text{V}$
6) From $+2.580 \, \text{ms}$ 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 $\pm \frac{1.38\, k\Omega}{558 + 1.38\, k\Omega} \times 10\, V = \pm 0.025\, V$.

Conditions:
1) If $V_i < V_+$ $\implies$ $V_o = +10\, V$ and $V_+ = +0.025\, V$.
2) If $V_i > V_+$ $\implies$ $V_o = -10\, V$ and $V_+ = -0.025\, V$.

• Sketch $V_o$.
  1) Initially, $V_o = +10$ and $V_+ = +0.025\, V$
  2) when $V_i$ crosses $+0.025\, V$, then $V_o = -10$ and $V_+ = -0.025\, V$
  3) when $V_i$ crosses $-0.025\, V$, then $V_o = +10$ and $V_+ = +0.025\, V$
  4) when $V_i$ crosses $+0.025\, V$, then $V_o = -10$ and $V_+ = -0.025\, V$

• At what times does $V_o$ reach $\pm 10\, V$?
  Transitions at $\pm \frac{0.1 - 0.025}{5\, V/100\, ms} = \pm 1.50\, ms$.
  1) Beginning until $-1.50\, ms$ $\implies$ $V_o = +10\, V$.
  2) $-1.50\, ms$ until $0\, ms$ $\implies$ $V_o = -10\, V$.
  3) $0\, ms$ until $+2.50\, ms$ $\implies$ $V_o = +10\, V$.
  4) $+2.50\, ms$ until end $\implies$ $V_o = -10\, V$.

• Does this circuit suffer from multiple transitions?
  Yes
Sketch $V_o$ (this is difficult because of the exponential – indicate the main features of the curve)

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 low pass filter with a gain of $G = -\frac{322 \text{k}\Omega}{12.3 \text{k}\Omega} = -26.18$.
With such a large gain, it will saturate when $V_i = \pm 10$ V/ $G = \pm 0.382$ V.
The time constant is $\tau = 322 \text{k}\Omega \times 358 \text{nF} = 115.3$ ms.

At what times does $V_o$ reach $\pm 10$ V?
Transitions at $\pm \frac{0.1 + 0.382}{5 \text{V}/100 \text{ms}} = \pm 9.6$ ms.
Thus: 1) Beginning until $-9.6$ ms $\Rightarrow V_o = +10$ V.
2) $+9.6$ ms until end $\Rightarrow V_o = -10$ V.

Sketch $V_o$ (this is difficult because of the exponential – indicate the main features of the curve)
Beginning until $-9.6$ ms $\Rightarrow V_o = +10$ V. Then, from $+9.6$ ms until $-9.6$ ms the will go from $+10$ to $-10$ V, following the flipped 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 $+9.6$ ms until end $\Rightarrow V_o = -10$ 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 $RC = 115.3$ 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.