• 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 $G = 1 + \frac{546}{1.95} = 281.0$. With such a large gain, it will saturate when $V_i = \pm 10 V / G = \pm 0.036 V$.

Times when $|V_i| < 0.036$, V, are

$T_1 = \pm \frac{0.1-0.036}{5/100 \text{ms}} = \pm 1.280 \text{ms}.$

$T_2 = \pm \frac{0.1+0.036}{5/100 \text{ms}} = \pm 2.720 \text{ms}.$

• Sketch $V_o$.
  1) From start to $-2.720 \text{ms}$, $V_o = -10 \text{ V}$
  2) From $-2.720 \text{ms}$ to $-1.280 \text{ms}$, $V_o$ = transitions from $-10 \text{ V}$ to $+10 \text{ V}$
  3) From $-1.280 \text{ms}$ to $0 \text{ ms}$, $V_o = +10 \text{ V}$
  4) From $0 \text{ ms}$ to $+1.280 \text{ms}$, $V_o = -10 \text{ V}$
  5) From $+1.280 \text{ms}$ to $+2.720 \text{ms}$, $V_o$ = transitions from $-10 \text{ V}$ to $+10 \text{ V}$
  6) From $+2.720 \text{ms}$ to end, $V_o = +10 \text{ V}$

• At what times does $V_o$ reach $\pm 10 \text{ V}$?
  1) From start to $-2.720 \text{ms}$, $V_o = -10 \text{ V}$
  3) From $-1.280 \text{ms}$ to $0 \text{ ms}$, $V_o = +10 \text{ V}$
  4) From $0 \text{ ms}$ to $+1.280 \text{ms}$, $V_o = -10 \text{ V}$
  6) From $+2.720 \text{ms}$ 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 $\pm \frac{1.82\ k\Omega}{516 + 1.82\ k\Omega} \times 10\ V = \pm 0.035\ V$.

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

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

- At what times does $V_o$ reach $\pm 10\ V$?
  Transitions at $\pm \frac{0.1 - 0.035}{5\ V/100\ ms} = \pm 1.30\ ms$.
  1) Beginning until $-1.30\ ms \implies V_o = +10\ V$.
  2) $-1.30\ ms$ until $0\ ms \implies V_o = -10\ V$.
  3) $0\ ms$ until $+2.70\ ms \implies V_o = +10\ V$.
  4) $+2.70\ ms$ 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 $G = \frac{-333 \text{k}\Omega}{14.3 \text{k}\Omega} = -23.29$.

With such a large gain, it will saturate when $V_i = \pm 10$ V / $G = \pm 0.429$ V.

The time constant is $\tau = 333 \text{k}\Omega \times 584 \text{nF} = 194.5$ ms.

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

  Transitions at $\pm \frac{0.1+0.429}{5 \text{V}/100 \text{ms}} = \pm 10.6$ ms.

  Thus: 1) Beginning until $-10.6$ ms $\implies V_o = +10$ V.

  2) $+10.6$ ms until end $\implies V_o = -10$ V.

• Sketch $V_o$ (this is difficult because of the exponential – indicate the main features of the curve)

  Beginning until $-10.6$ ms $\implies V_o = +10$ V. Then, from $+10.6$ ms until $-10.6$ ms the will go from $+10$ to $-10$ 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 $+10.6$ ms until end $\implies V_o = -10$ 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 $RC = 194.5$ 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.