**Question:** A Student# 1713

1. Sketch $V_o$.

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

3. 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 $G = 1 + \frac{484}{156} = 311.3$. With such a large gain, it will saturate when $V_i = \pm 10 V/G = \pm 0.032$ V.

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

1. $T_1 = \pm \frac{0.1 - 0.032}{5 V/100 \text{ms}} = \pm 1.360$ ms.
2. $T_2 = \pm \frac{0.1 + 0.032}{5 V/100 \text{ms}} = \pm 2.640$ ms.

Sketch $V_o$.

1. From start to $-2.640$ ms, $V_o = -10$ V
2. From $-2.640$ ms to $-1.360$ ms, $V_o$ transitions from $-10$ V to $+10$ V
3. From $-1.360$ ms to $0$ ms, $V_o = +10$ V
4. From $0$ ms to $+1.360$ ms, $V_o = -10$ V
5. From $+1.360$ ms to $+2.640$ ms, $V_o$ transitions from $-10$ V to $+10$ V
6. From $+2.640$ ms to end, $V_o = +10$ V

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

1. From start to $-2.640$ ms, $V_o = -10$ V
2. From $-1.360$ ms to $0$ ms, $V_o = +10$ V
3. From $0$ ms to $+1.360$ ms, $V_o = -10$ V
4. From $+1.360$ ms to $+2.640$ ms, $V_o = +10$ 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 $\pm \frac{1.61 \text{k}\Omega}{393+1.61 \text{k}\Omega} \times 10 \text{ V} = \pm 0.041 \text{ V}$.

Conditions:
1) If $V_i < V_+ \implies V_o = +10 \text{ V}$ and $V_+ = +0.041 \text{ V}$.
2) If $V_i > V_+ \implies V_o = -10 \text{ V}$ and $V_+ = -0.041 \text{ V}$.

• Sketch $V_o$.
  1) Initially, $V_o = +10$ and $V_+ = +0.041$ V
  2) when $V_i$ crosses $+0.041$ V, then $V_o = -10$ and $V_+ = -0.041$ V
  3) when $V_i$ crosses $-0.041$ V, then $V_o = +10$ and $V_+ = +0.041$ V
  4) when $V_i$ crosses $+0.041$ V, then $V_o = -10$ and $V_+ = -0.041$ V

• At what times does $V_o$ reach $\pm 10$ V?
  Transitions at $\pm \frac{0.1-0.041}{5V/100\text{ms}} = \pm 1.18 \text{ ms}$.
  1) Beginning until $-1.18 \text{ ms} \implies V_o = +10 \text{ V}$.
  2) $-1.18 \text{ ms}$ until $0 \text{ ms} \implies V_o = -10 \text{ V}$.
  3) $0 \text{ ms}$ until $+2.82 \text{ ms} \implies V_o = +10 \text{ V}$.
  4) $+2.82 \text{ ms}$ until end $\implies V_o = -10 \text{ V}$.

• 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 $G = -\frac{387 \, k\Omega}{19.3 \, k\Omega} = -20.05$.
With such a large gain, it will saturate when $V_i = \pm 10$ V/$G = \pm 0.499$ V.
The time constant is $\tau = 387 \, k\Omega \times 467 \, nF = 180.7$ ms.

- At what times does $V_o$ reach $\pm 10$ V?
  Transitions at $\pm \frac{0.1 + 0.499}{5V/100\text{ms}} = \pm 12.0$ ms.
  Thus: 1) Begining until $-12.0 \text{ ms} \implies V_o = +10 \text{ V}$. 
  2) $+12.0 \text{ ms}$ 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 $-12.0 \text{ ms} \implies V_o = +10 \text{ V}$. Then, from $+12.0 \text{ ms}$ until $-12.0 \text{ ms}$ 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 $+12.0 \text{ ms}$ 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 $RC = 180.7$ 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.