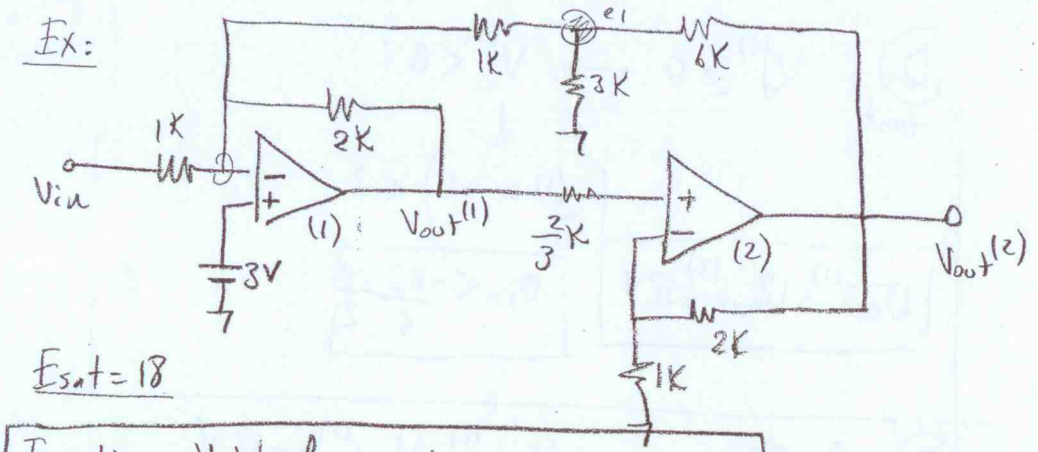
Op-Amp Example:

Ex:



$E_{sat} = 18$

Equations Valid for all op-amp regions:

$$\frac{V_-^{(1)} - V_{in}}{1} + \frac{V_-^{(1)} - V_{out}^{(1)}}{2} + \frac{V_-^{(1)} - e_1}{1} = 0 \rightarrow 5V_-^{(1)} = 2V_{in} + v_{out}^{(1)} + 2e_1 \quad (1)$$

$$\frac{e_1 - V_-^{(1)}}{1} + \frac{e_1}{3} + \frac{e_1 - V_{out}^{(2)}}{6} = 0 \rightarrow 9e_1 = 6V_-^{(1)} + V_{out}^{(2)} \quad (2)$$

Replace e_1 in (1):

$$\underbrace{\left(5 - \frac{4}{3}\right)}_{11/3} V_-^{(1)} = 2V_{in} + v_{out}^{(1)} + \frac{2}{9} v_{out}^{(2)} \quad (I)$$

$$V_+^{(2)} = V_{out}^{(1)} \quad (II)$$

$$V_-^{(2)} = \frac{V_{out}^{(2)}}{3} \quad (III)$$

(A) Op-Amp

(1)	(2)
linear	linear

$$\begin{cases} V_-^{(1)} = V_+^{(1)} = 3V \\ V_-^{(2)} = V_+^{(2)} \Rightarrow \dfrac{V_{out}^{(2)}}{3} = V_{out}^{(1)} \end{cases}$$

→ Insert in (I):

$$11 = 2V_{in} + V_{out}^{(1)} + \frac{2}{9}\underbrace{V_{out}^{(2)}}_{3V_{out}^{(1)}}$$

$$\boxed{V_{out}^{(1)} = \frac{3}{5}(11 - 2V_{in})}$$

$$\boxed{V_{out}^{(2)} = \frac{9}{5}(11 - 2V_{in})}$$

$|V_{out}^{(1)}| < 18 \rightarrow |2V_{in} - 11| < 30 \rightarrow -\frac{19}{2} < V_{in} < \frac{41}{2}$

$|V_{out}^{(2)}| < 18 \rightarrow |2V_{in} - 11| < 10 \rightarrow \frac{1}{2} < V_{in} < \frac{21}{2}$

$|V_{out}^{(1)}| < 18$ and $|V_{out}^{(2)}| < 18 \rightarrow \boxed{\frac{1}{2} < V_{in} < \frac{21}{2}}$

(B)

Op-Amp (1)	Op-Amp (2)
linear	+Sat

$V_-^{(1)} = V_+^{(1)} = 3V$; $V_{out}^{(2)} = 18\,V$

$V_{out}^{(1)} > \frac{V_{out}^{(2)}}{3} = 6$

From (I): $11 = 2V_{in} + v_{out}^{(1)} + 4$

$$\boxed{v_{out}^{(1)} = 7 - 2V_{in}}$$

$|v_{out}^{(1)}| < 18 \rightarrow -\frac{11}{2} < V_{in} < \frac{25}{2}$

$v_d^{(2)} > 0 \rightarrow v_{out}^{(1)} > 6 \rightarrow V_{in} < 1/2$

$$\boxed{-\frac{11}{2} < V_{in} < 1/2}$$

(C)

OP (I)	AMP (II)
linear	-Sat

$V_-^{(1)} = V_+^{(1)} = 3V$; $\boxed{V_{out}^{(2)} = -18\ V}$

$V_{out}^{(1)} < \frac{V_{out}^{(2)}}{3} = -6$

From (I): $11 = 2V_{in} + V_{out}^{(1)} - 4$

$\boxed{V_{out}^{(1)} = 15 - 2V_{in}}$

$|V_{out}^{(1)}| < 18 \longrightarrow \frac{-3}{2} < V_{in} < \frac{33}{2}$

$V_d^{(2)} < 0 \longrightarrow V_{out}^{(1)} < -6 \longrightarrow V_{in} > \frac{21}{2}$

Both satisfied when $\boxed{\frac{21}{2} < V_{in} < \frac{33}{2}}$

(D)

Op-Amp	
+Sat	?
+Sat	+Sat

$V_{out}^{(1)} = 18V$

$V_-^{(2)} = \frac{V_{out}^{(2)}}{3}$ has the maximum value of 6V

$V_d^{(2)} = 18 - V_-^{(2)} > 6 \longrightarrow V_d^{(2)} > 0$

(Op-Amp always in +sat)

$V_{out}^{(1)} = V_{out}^{(2)} = 18V$

From (I): $\frac{11}{3} V_-^{(1)} = 2V_{in} + 18 + 4 \longrightarrow V_-^{(1)} = \frac{6V_{in} + 6}{11}$

(D) cont

$V_d^{(1)} > 0 \longrightarrow V_-^{(1)} < 3V$

$\left(\frac{6}{11}V_{in} + 6\right) < 3$

$\boxed{V_{out}^{(1)} = V_{out}^{(2)} = 18V}$

$V_{in} < \frac{-33}{6} = \frac{-11}{2}$

(E)

Op-Amp (1)	(2)
-sat →	-sat

$V_{out}^{(1)} = V_{out}^{(2)} = -18V$

$V_-^{(1)} > 3V$

$V_-^{(1)} = \frac{6}{11} V_{in} - 6$

$V_-^{(1)} > 3 \longrightarrow \frac{6}{11} V_{in} - 6 > 3$

$\boxed{V_{out}^{(1)} = V_{out}^{(2)} = -18\ V}$

$\boxed{V_{in} > \frac{33}{2}}$