Switch s has been closed until steady state is achieved. What is the value for \( V_{out} \)?

We suppose Ideal Op Amp: \( i_N = 0 \) \( i_P = 0 \)

So the current \( i_{IN} \) goes through the short:

\[ i_{IN} = V_{out} \]

On the other hand:

\[ V_{out} = A \left( V_N - V_P \right) \]

As long as \( V_{EE} < V_{out} < V_{cc} \)

another facts:

\[ V_{out} = A (0 - V_{out}) \]

\[ V_{out} = -A V_{out} \]

\[ V_{out} = 0 \]

With the switch closed: \( V_{out} = 0 \)
The switch is suddenly opened and this time there is no short.

Also recall that $V_{\text{out}} = 0$ just before switching at $t=0$ for $t \geq 0$.

Constraints imposed by the circuit:

1) $V_p = 0$

2) Use KCL at point $N$

3) $\frac{V_N - V_{IN}}{R} + i_c + i_N = 0$

4) $i_N = 0$  $V_P = 0$

5) $V_P - V_N = 0$ for $A = \infty$ when Op Amp

$V_N = 0$. Now $V_c = V_{out}$ region.

$\Rightarrow V_{\text{out}} = 3) \Rightarrow 0 - \frac{V_{IN}}{R} + C \frac{dV_c}{dt} + 0 = 0$
Now \( V_C = V_N - V_{\text{out}} \) but \( V_N = 0 \) \( \Rightarrow V_C = -V_{\text{out}} \)

\[ \therefore \quad -\frac{V_{\text{in}}}{R} + C \left( -dV_{\text{out}} \right) = 0 \]

\[ \therefore \quad \frac{dV_{\text{out}}}{dt} = -\frac{1}{RC} V_{\text{in}} \quad \text{Integrate} \]

\[ \int_{t=0}^{t} \frac{dV_{\text{out}}}{dt'} dt' = -\frac{1}{RC} \int_{t=0}^{t} V_{\text{in}}(t') dt' \]

\[ V_{\text{out}}(t) - V_{\text{out}}(t=0) = 0 \]

\[ \text{but } V_{\text{out}}(0) = 0 \]

\[ V_{\text{out}}(t) = -\frac{1}{RC} \int_{t=0}^{t} V_{\text{in}}(t') dt' \]

AS LONG AS \(-V_{\text{EE}} < V_{\text{out}} < V_C\)

So if \( V_{\text{in}} \) is monotonically increasing

at some point we reach \(-V_{\text{EE}}\) and

beyond that \( V_{\text{out}} = -V_E \)
1. **Initial Condition:** The switch is closed for a time long enough to discharge the capacitor and reset the Capacitor Voltage to 0 so that \( v_c(0)=0 \).

2. At \( t=0 \) switch is opened allowing capacitor to charge. For ideal Op Amp no current goes into Op Am and \( v_+-v_- = 0 \) assuming OpAm is not saturated.

\[
\begin{align*}
v_+ &= v_+ = 0, \quad i_c = C \frac{dv_c}{dt} \\
i_c &= i_{in}, \quad \text{and} \quad v_c = v_+ - v_- \\
\text{KCL at Node} &\quad \text{gives:} \quad \frac{v_+ - v_-}{R} + i_{in} = 0
\end{align*}
\]

Put all together \( \frac{0 - v_m}{R} + C \frac{d(0 - v_c)}{dt} = 0 \)

Thus \( \frac{dv_c}{dt} = -\frac{1}{RC} v_m \). Integrating both sides

\[
\begin{align*}
v(t) - v(0) &= -\frac{1}{RC} \int_{t=0}^{t} v_m(t') dt' \\
v(0) &= 0 \quad \text{therefore} \quad v(t) &= -\frac{1}{RC} \int_{t=0}^{t} v_m(t') dt'
\end{align*}
\]
Problem 2.34

A b is the output port.

We assume operation in linear region

\[ V_p - V_N = 0 \quad V_p = 0 \Rightarrow V_N = 0 \]

\[ L_1 \text{ through } 10k\Omega \Rightarrow V_N - V_a = 10 \times i_I \]

\[ V = 0 \Rightarrow 0 - V_a = 10i_I \quad \Rightarrow V_a = 10i_I \]

Current through R (note current direction upward so voltage drop)

from 0 to a \[ 0 - V_a = R i_a \]

\[ V_a = -R i_a \] on the other hand \[ V = -10i_I \]

\[ -10i_I = -R i_a \]

Now use KCL at node a

\[ i + i_a = 10i_I \]
\[ R_0 = \frac{V_{out}}{I_0} = \frac{V_{Test}}{0} = \infty \]
Op Amp Ideal ($R_{\text{in}} = \infty$, $R_0 = 0$), $A = \infty$

$V_\text{cc}$ and $V_\text{ee}$ are typically $5-15\, \text{V}$

$V_\text{out} = A (V_p - V_N)$

as long as

$-V_\text{ee} < V_\text{out} < V_\text{ee}$

Example 1: Voltage follower

$V_\text{out} = A (V_p - V_N)$

$V_\text{out} = A (V_p - V_\text{out})$ (shorted $V_N$ terminal to $V_0$)

but $V_p = V_\text{in}$

$V_\text{out} = A (V_\text{in} - V_\text{out})$

$V_\text{out} = A V_\text{in} - A V_\text{out}$

$(A+1) V_\text{out} = A V_\text{in}$

$V_\text{out} = \frac{A}{A+1} V_\text{in}$

for $A$ very large $\Rightarrow V_\text{out} = V_\text{in}$

$-V_\text{ee} < V_\text{in} < V_\text{cc}$

Voltage follower

This analysis is true as long as

$-V_\text{ee} < V_\text{in} < V_\text{ee}$

$V^+ > 0$, $V^- > 0$
Example 2 Non Inverting Amp.

\[ V_p \rightarrow V_o = 0 \quad \rightarrow \quad V_o \]

\[ i_o = 0 \quad \rightarrow \quad -R_2 i = V_o \]

Assume operation in linear region.

Then \[ V_o = A (V_p - V_{N}) \]

\[ V_N = R_2 i = \frac{R_2}{R_1 + R_2} V_o \]

\[ V_o = A \left( V_{in} - \frac{R_2}{R_1 + R_2} V_o \right) \]

\[ V_0 = \left( 1 + \frac{R_2}{R_1 + R_2} \right) A V_{in} \]

\[ V_o = \frac{A V_{in}}{1 + \frac{R_2}{R_1 + R_2}} \]

\[ V_o \rightarrow \frac{A V_{in}}{1 + \frac{R_2}{R_1 + R_2}} \]

\[ |V_o| > |V_{in}| \]

\[ V_o = \frac{R_2 + R_1}{R_2} V_{in} \]

\[ V_o = \frac{1}{A + \frac{R_2}{R_1 + R_2}} A V_{in} \]