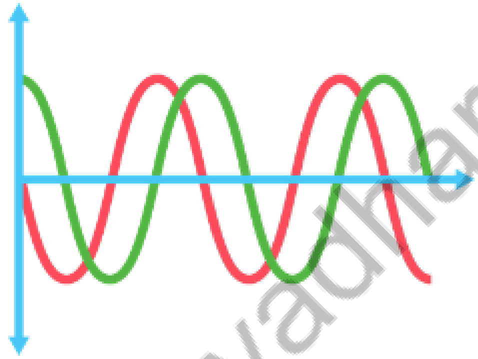
Course: Advanced Analog IC Design



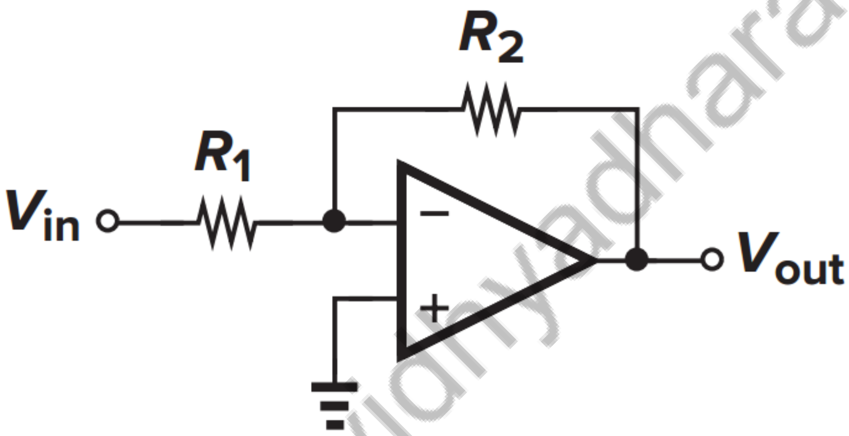
Lecture 2: Switched-Capacitor Circuits

Reference: Design of Analog CMOS Integrated Circuits by Behzad Razavi

Prof. Sanjay Vidhyadharan

website: sanjayvidhyadharan.in

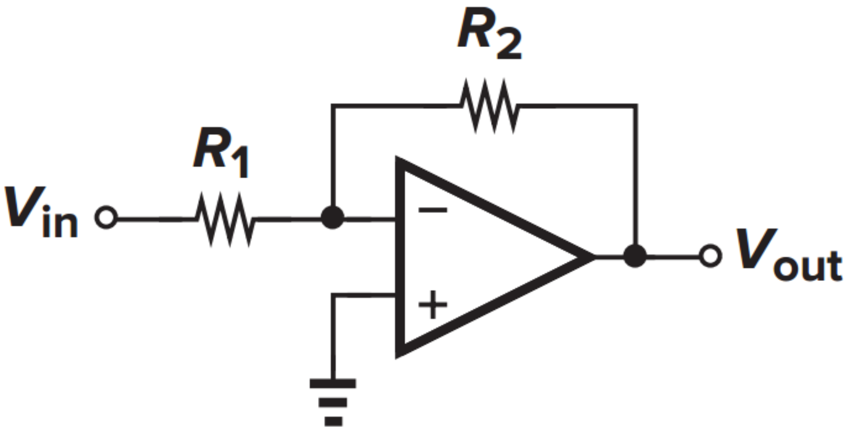
Simple Continuous Time Amplifier

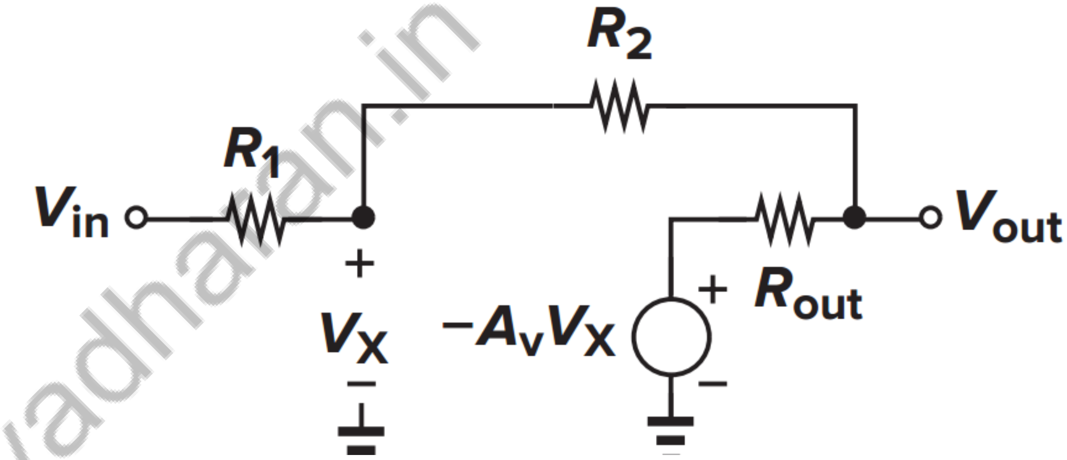


$V_{in} / R_1 = - V_{out} / R_2$

Gain= $-R_2/R_1$.

Simple Continuous Time Amplifier



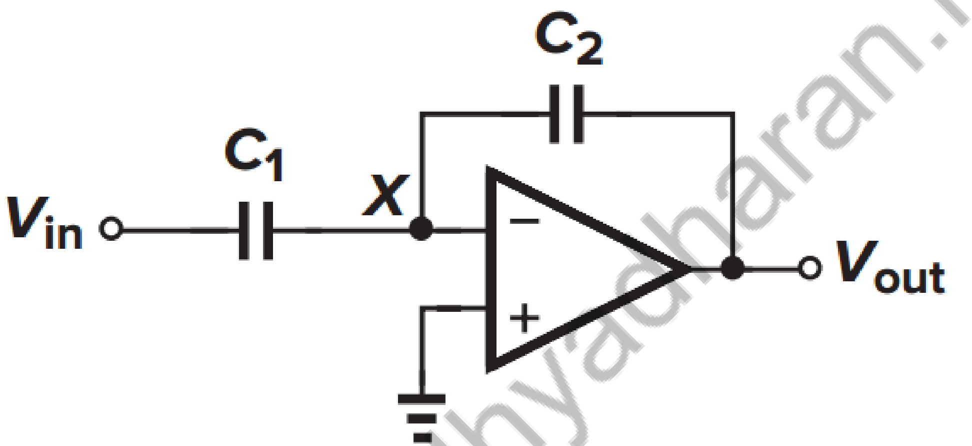


$$-A_v\left(\frac{V_{out}-V_{in}}{R_1+R_2}R_1+V_{in}\right)-R_{out}\frac{V_{out}-V_{in}}{R_1+R_2}=V_{out}$$

$$\frac{V_{out}}{V_{in}}=-\frac{R_2}{R_1}\cdot\frac{A_v-\frac{R_{out}}{R_2}}{1+\frac{R_{out}}{R_1}+A_v+\frac{R_2}{R_1}}$$

1. Closed-loop gain suffers from inaccuracies
2. Input resistance of the amplifier, approximately equal to R1, loads the preceding stage. R1 has to be low for High gain. While high R1 while introducing thermal noise .
3. $R_{out}/R_2 \ll A_v$

Simple continuous time amplifier with Capacitors



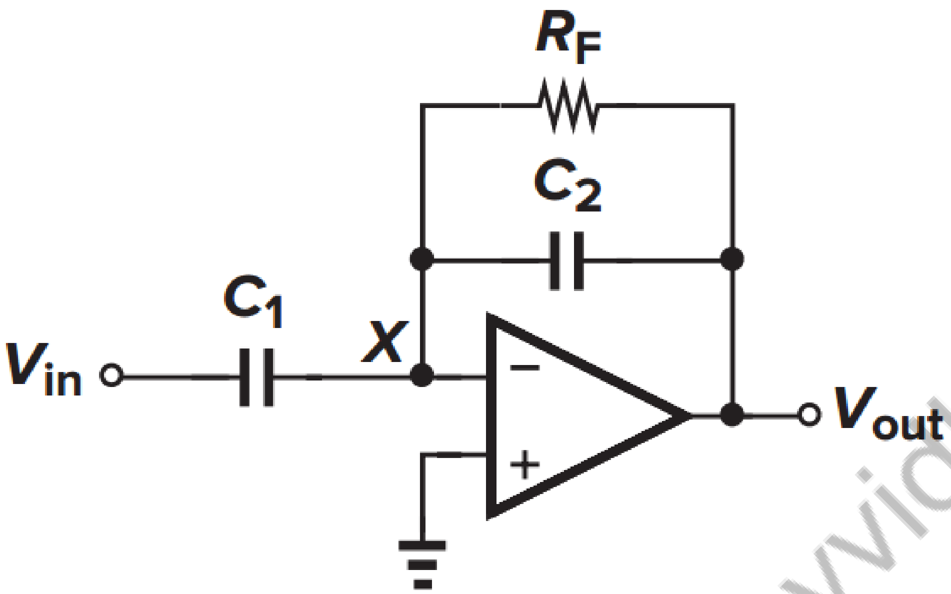
$Vin* C_1\omega = - Vout* C_2\omega$

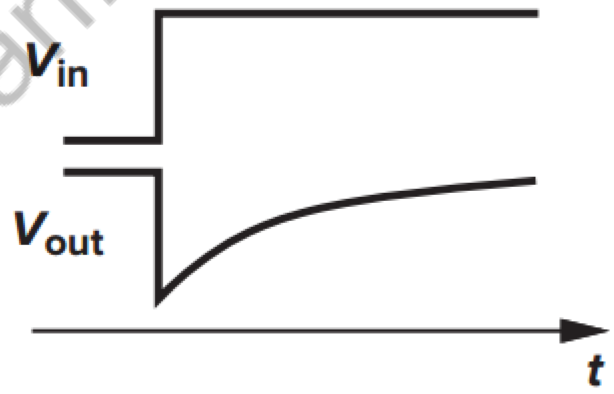
Gain= $-C_1/C_2$.

No Noise . Less Area requirement

1. No DC feedback.
2. Can get Saturated due to offset

Simple continuous time amplifier with Capacitors





Step response

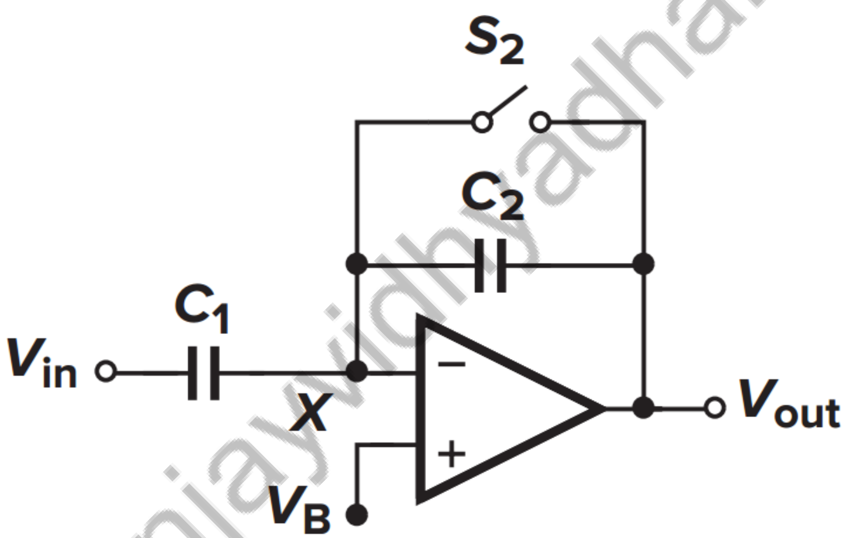
$$\frac{V_{out}}{V_{in}}(s) \approx -\frac{R_F \dfrac{1}{C_2 s}}{R_F + \dfrac{1}{C_2 s}} \div \frac{1}{C_1 s}$$

$$= -\frac{R_F C_1 s}{R_F C_2 s + 1}$$

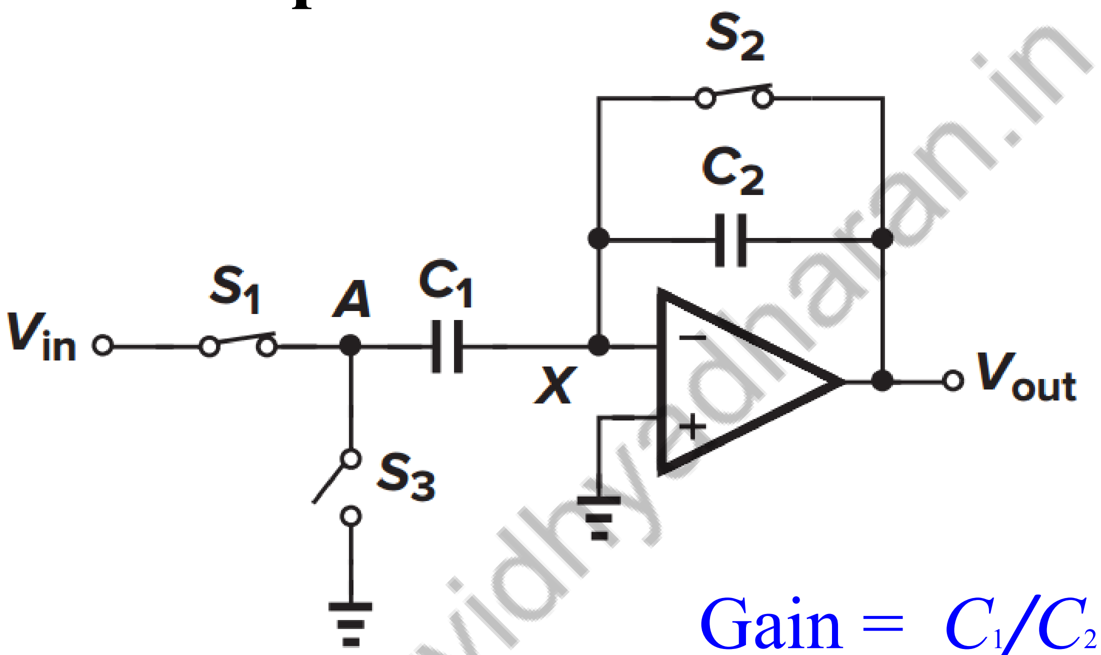
1. Only useful for High Frequencies
2. Large R_F requires more silicon area
3. Circuit may not be suited to amplify wideband

$V_{out}/V_{in} \approx -C_1/C_2$ only if $\omega \gg (R_F C_2)^{-1}$.

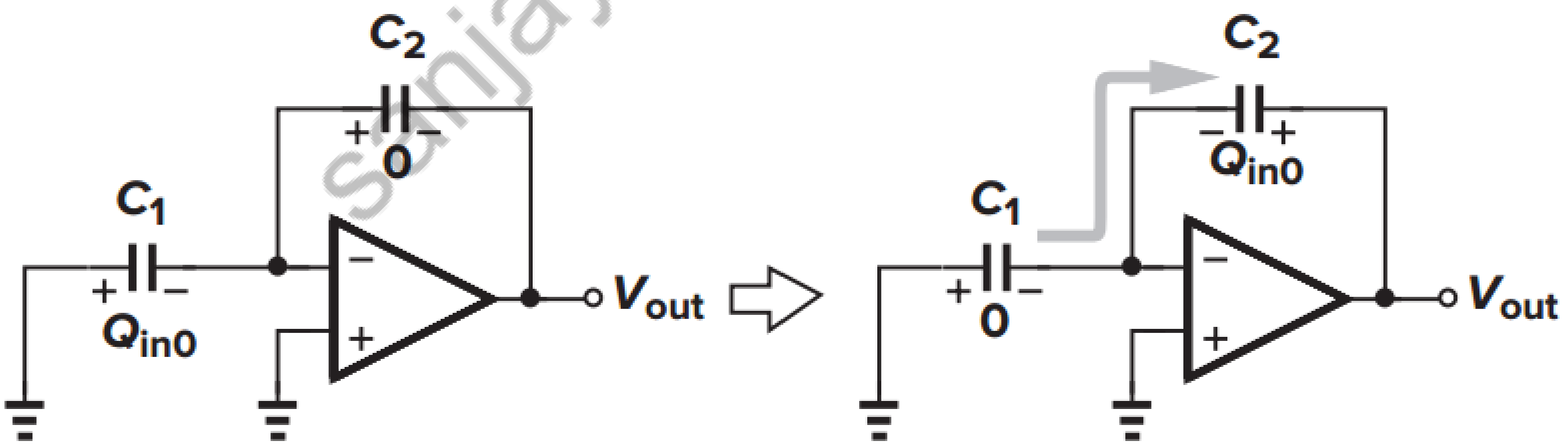
Use of feedback switch to define dc input level



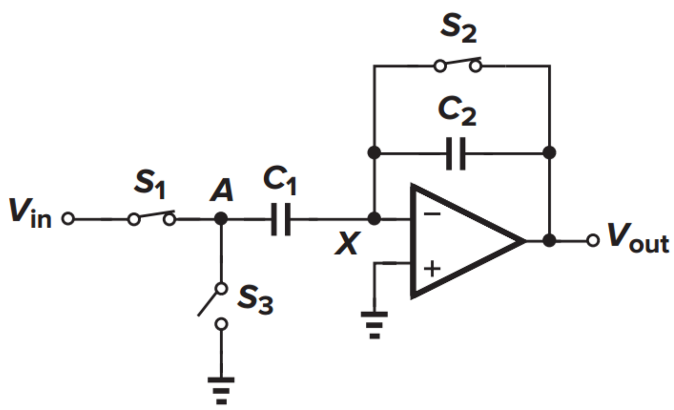
Switched-capacitor amplifier.

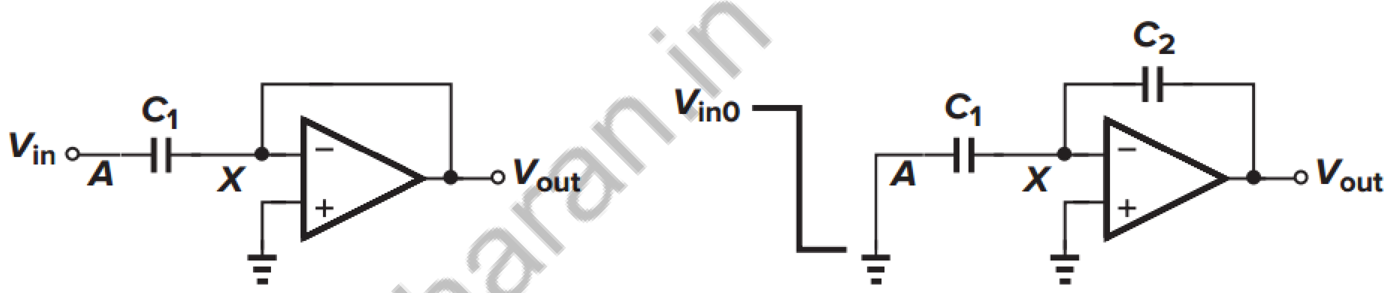


Gain = C_1/C_2.



Switched-capacitor amplifier.

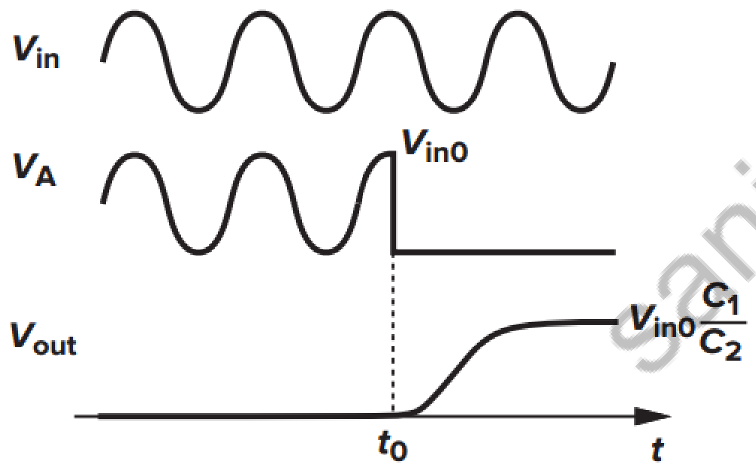




1. During sampling the input, output set to zero

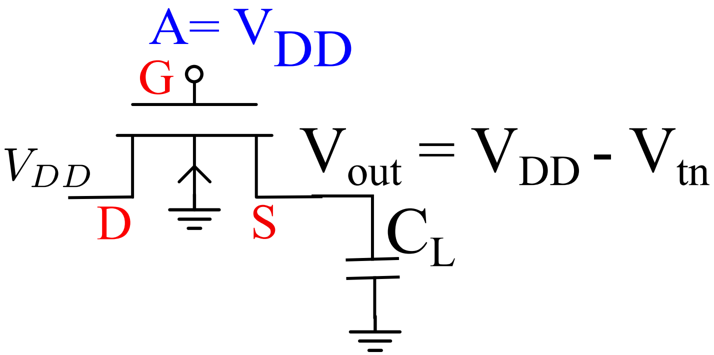
2. After sampling, for $t > t0$, the circuit ignores the input voltage amplifying the sampled voltage

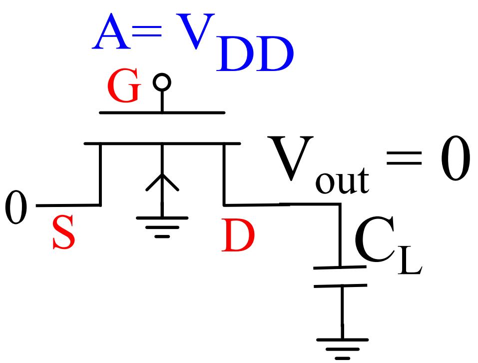
3. Note that S2 must turn on periodically to compensate for the leakage currents

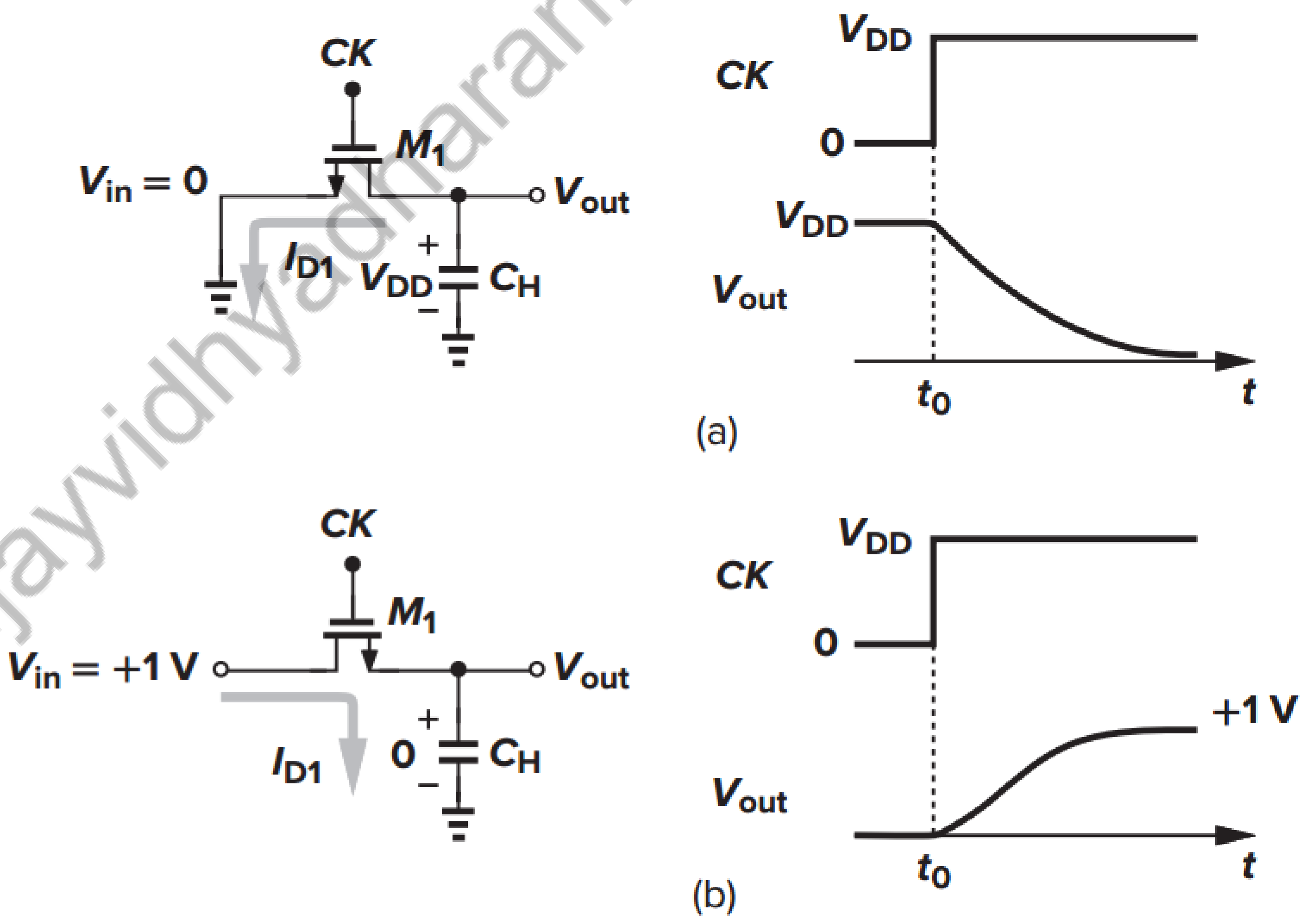


1. *Vout* settles to $Vin \cdot C_1/C_2$, the current through C_2 approaches zero. That is, the feedback capacitor does not reduce the open-loop gain of the amplifier if the output voltage is given enough time to settle. On the other hand, R_2 loads the amplifier continuously.

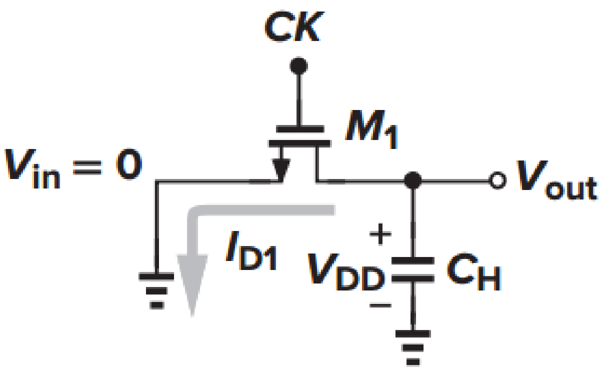
MOSFETS as Switches

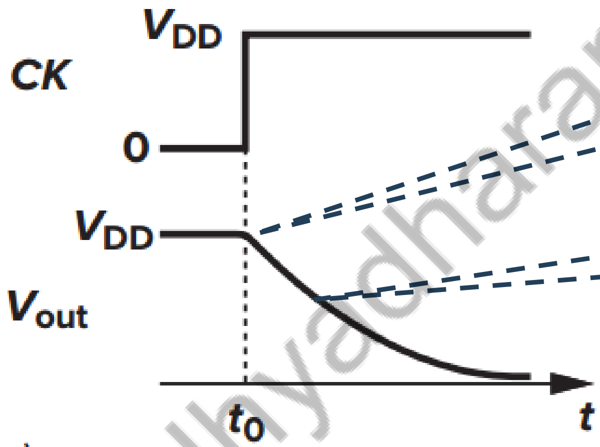






MOSFETS as Switches

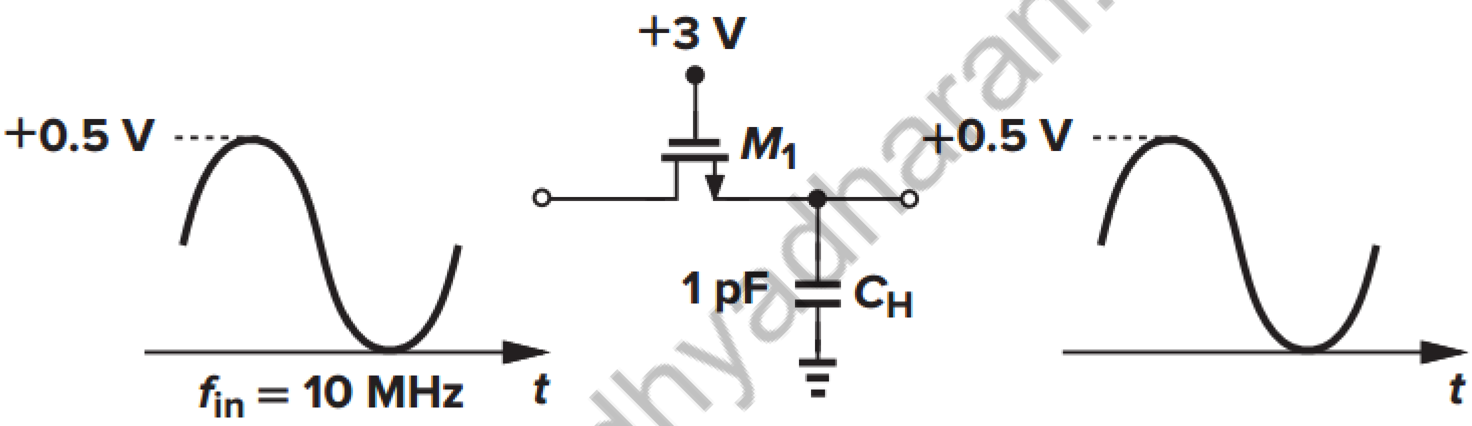




$$I_D = \frac{\mu_{nC_{ox}} W (V_{DD} - V_T)^2}{2L}$$

$V_{out} = V_{DD} - V_{tn}$
Triode

MOSFETS as Switches

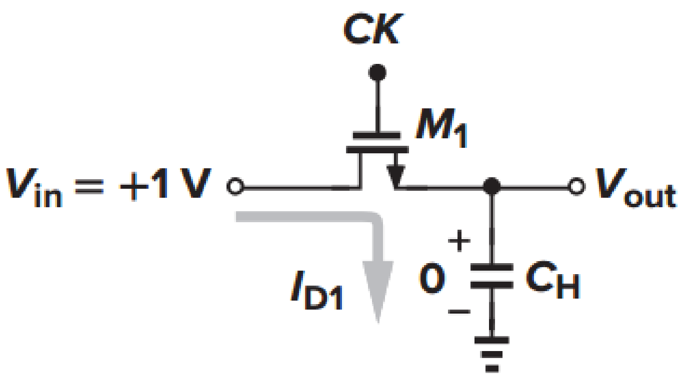


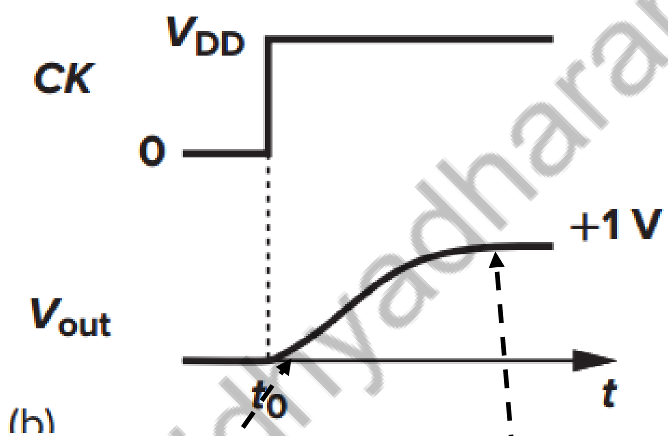
$$I_D = \frac{\mu_n C_{ox} W (V_{GS} - V_T) V_{DS}}{L}$$

Assuming that $V_{out} \approx V_{in}$,

$$R_{on1} = \frac{1}{\mu_n C_{ox} \frac{W}{L}(V_{DD} - V_{in} - V_{TH})}$$

MOSFETS as Switches





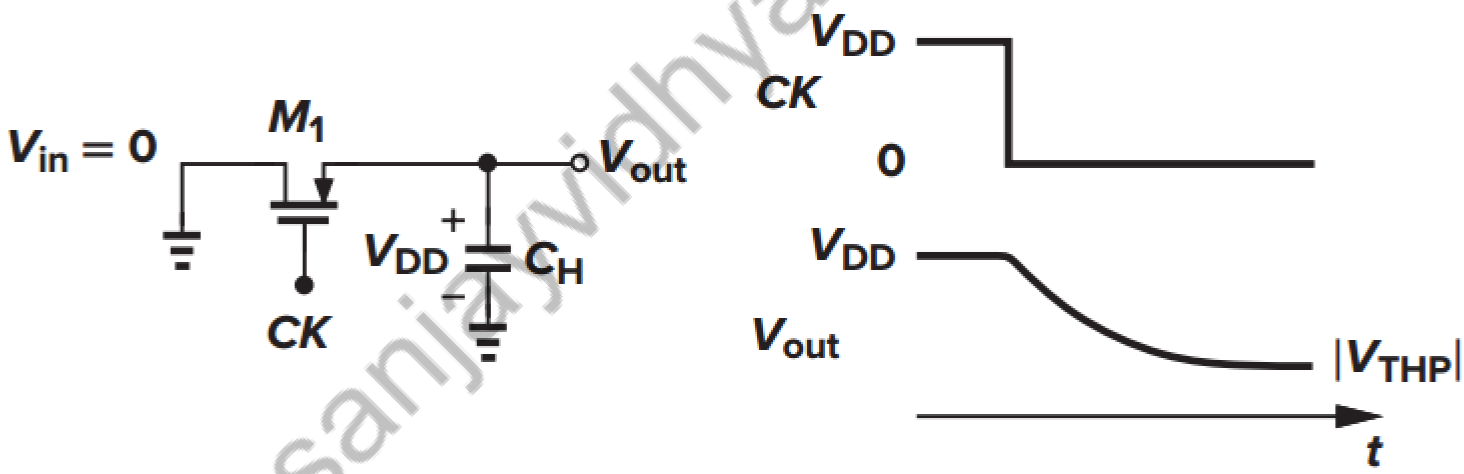
$$I_D = \frac{\mu_n C_{ox} W (V_{GS} - V_T) V_{DS}}{L}$$

$$R_{on} = \frac{1}{\mu_n C_{ox} \frac{W}{L} (V_{DD} - V_{TH})}$$

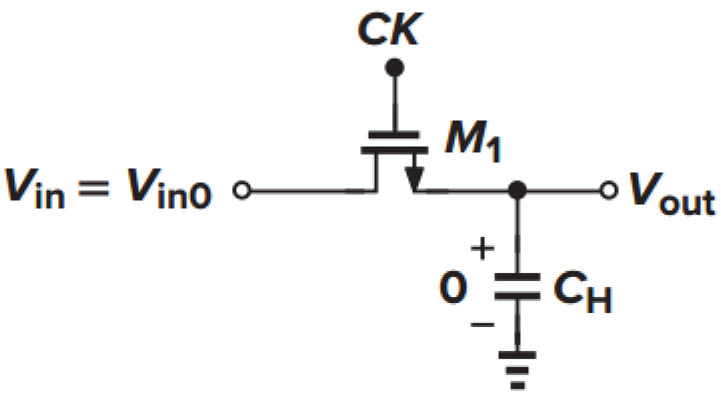
$$I_D = \frac{\mu_n C_{ox} W (V_{GS} - V_T) V_{DS}}{L}$$

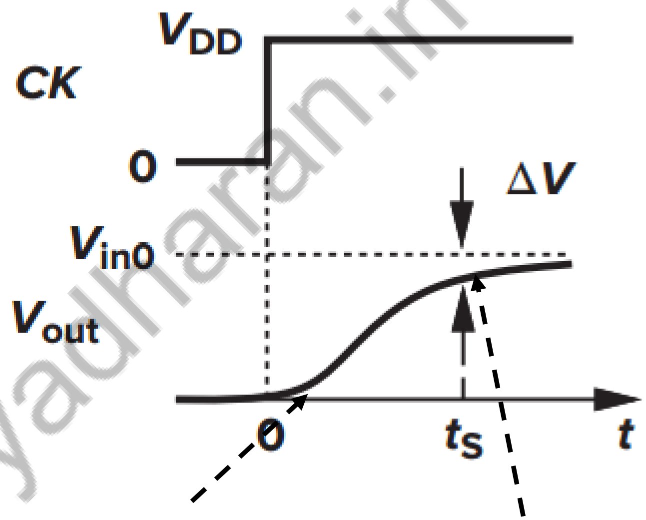
MOSFETS as Switches

Sampling circuit using PMOS switch



Speed Considerations





Sampling speed is given by two factors:
ON resistance of the switch
Value of the sampling capacitor

$$R_{on} = \frac{1}{\mu_n C_{ox} \frac{W}{L}(V_{DD} - V_{TH})}$$

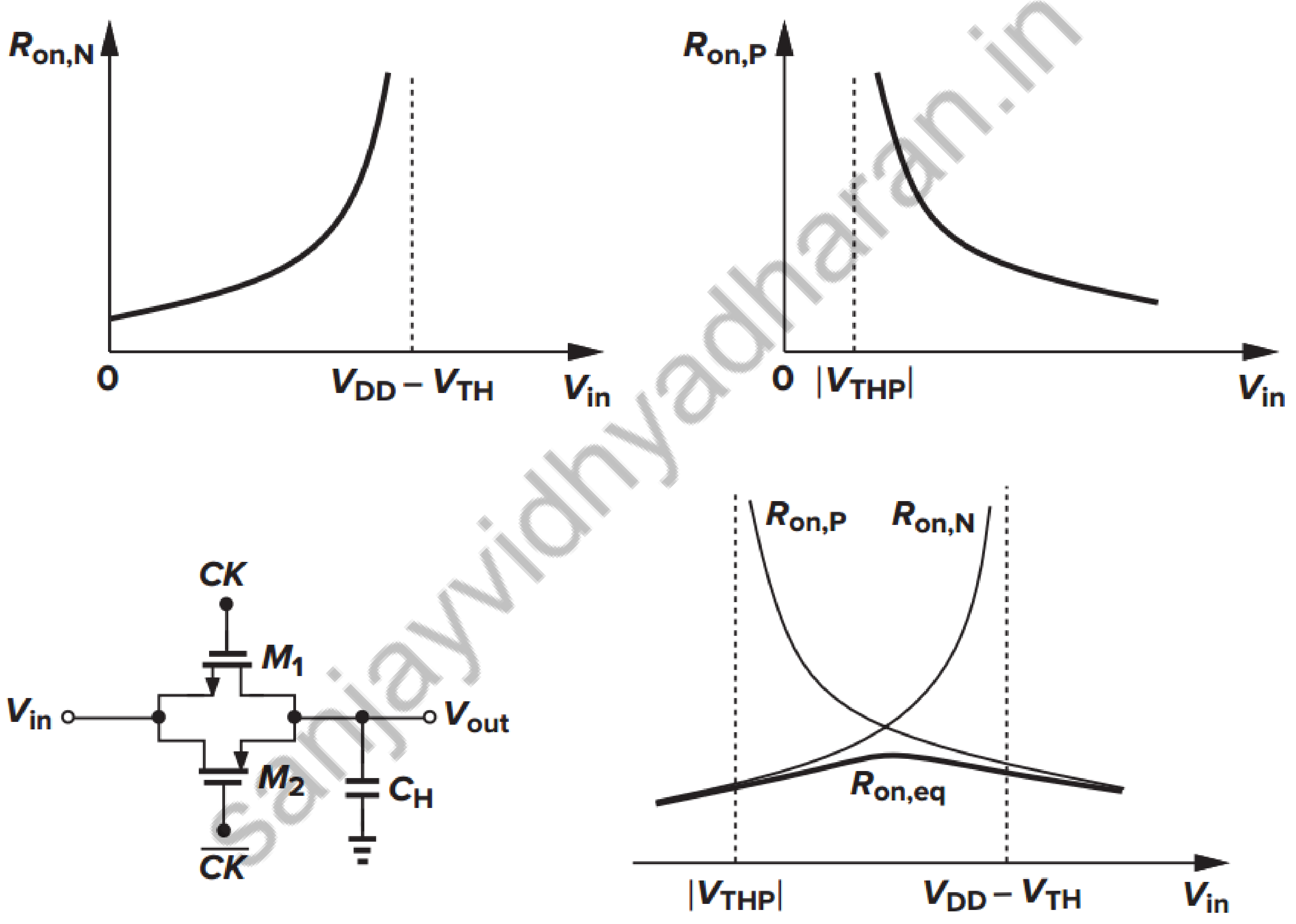
$$R_{on1} = \frac{1}{\mu_n C_{ox} \frac{W}{L}(V_{DD} - V_{in} - V_{TH})}$$

Ron also depends on the input level For example, if we restrict the variation of Ron to a range of 4 to 1, then the maximum input level is given by

$$\frac{1}{\mu_n C_{ox} \frac{W}{L}(V_{DD} - V_{in,max} - V_{TH})} = \frac{4}{\mu_n C_{ox} \frac{W}{L}(V_{DD} - V_{TH})}$$

This value falls around $V_{DD}/2$, translating to severe swing limitations.
Device threshold voltage directly limits the voltage swings.

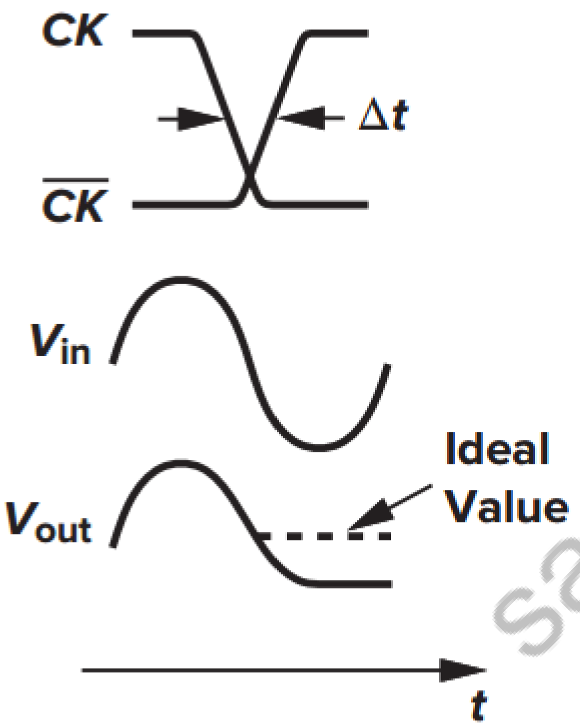
Speed Considerations

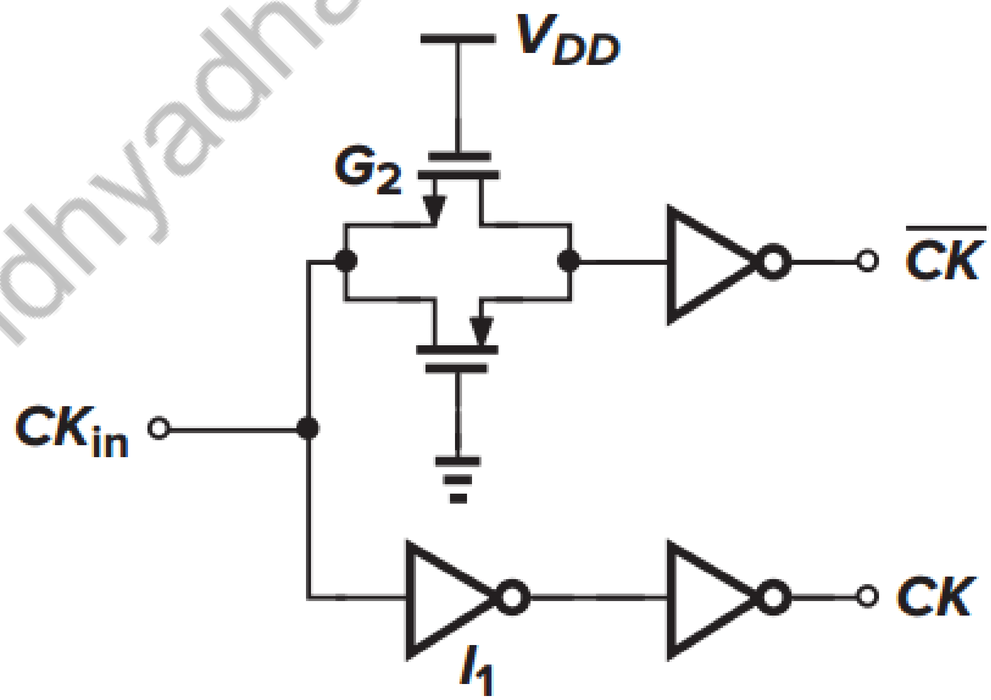


if $\mu_n C_{ox}(W/L)_N = \mu_p C_{ox}(W/L)_P$, then $R_{on,eq}$ is independent of the input level.

Precision Considerations

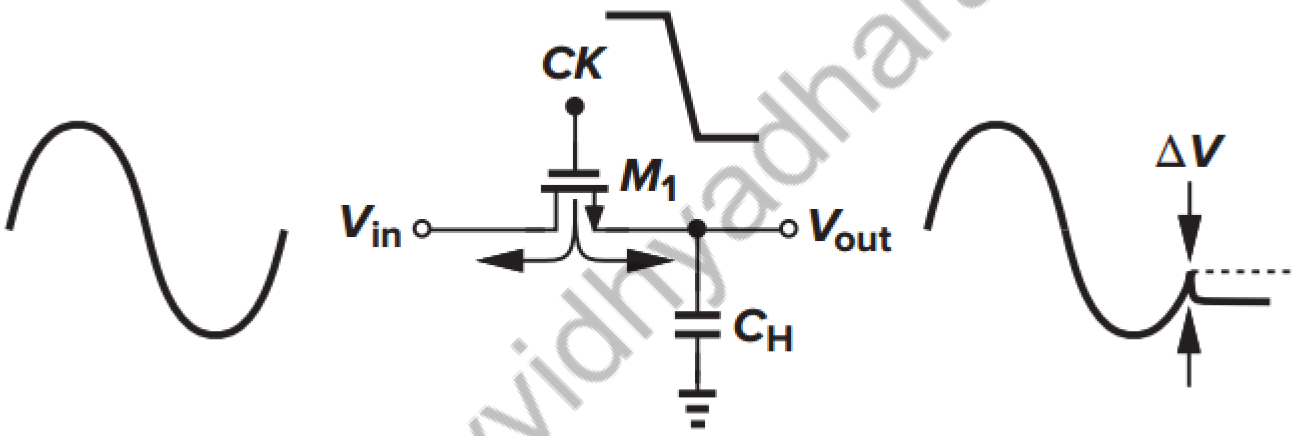
Distortion generated if complementary switches do not turn off simultaneously.





Precision Considerations

Charge injection

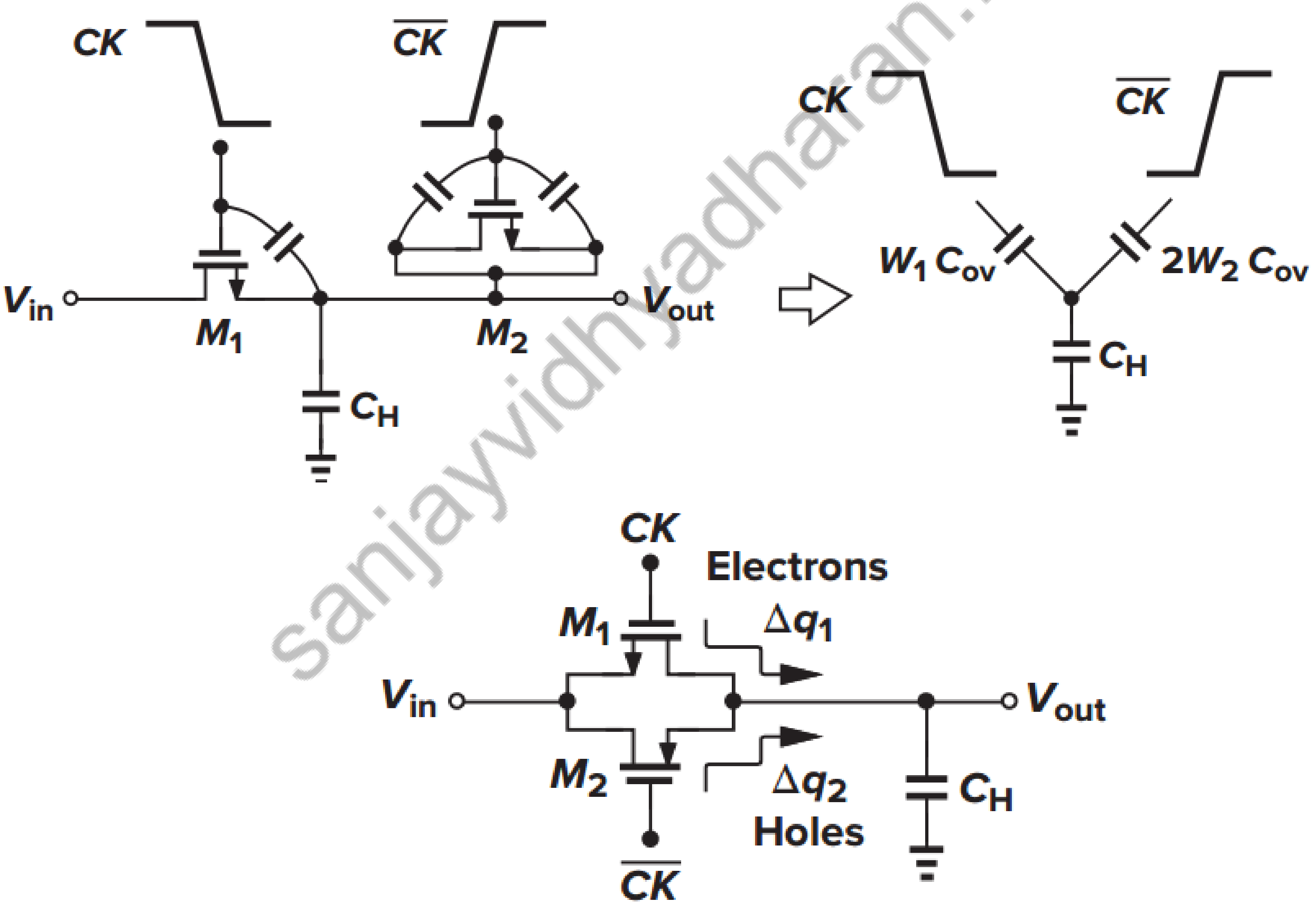


$$Q_{ch} = WLC_{ox}(V_{DD} - V_{in} - V_{TH})$$

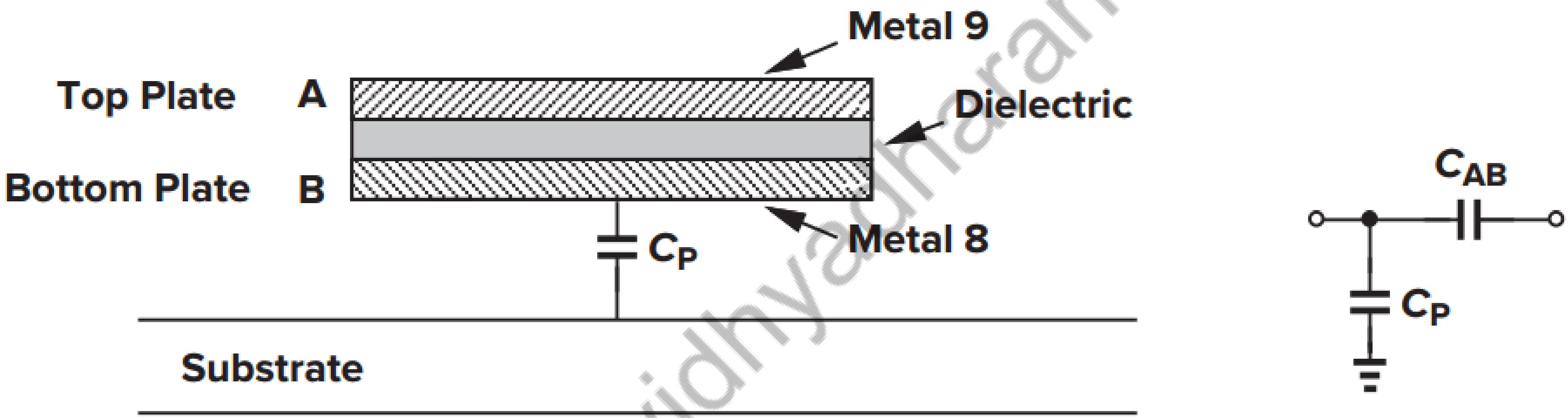
$$\Delta V = \frac{WLC_{ox}(V_{DD} - V_{in} - V_{TH})}{2C_H}$$

Precision Considerations

Clock feedthrough

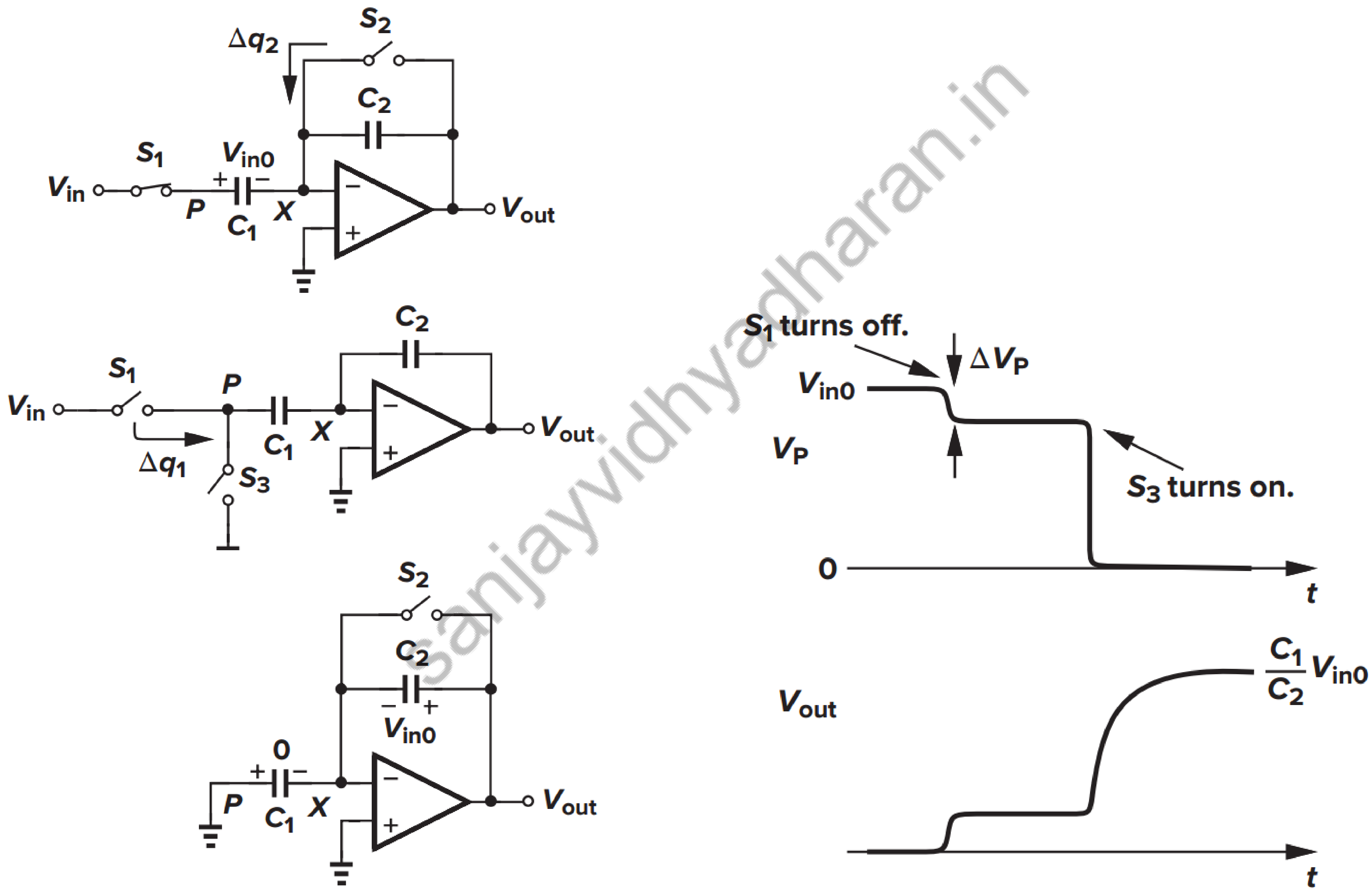


4. Implementing Capacitors



C_P, to the underlying substrate—a value typically 5 to 10% of the main capacitance

5. Switched Capacitance Amp



6. Switched Capacitance Voltage Doubler

Precision Multiply-by-Two Circuit

Switched Capacitance Amp suffers from speed and precision degradation due to the low feedback factor