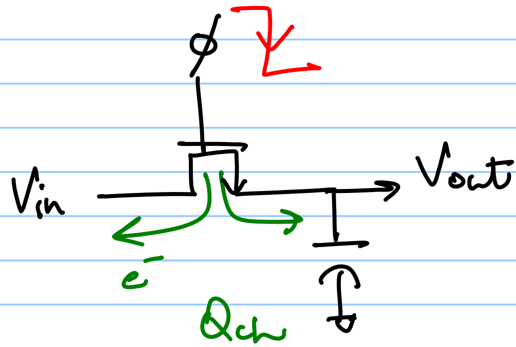
ECE 517 – Lecture 15

Note Title 3/3/2017



$V_{out} = V_{in}$ ideal

Body factor

$$\Rightarrow V_{in}\left(1 + \frac{WLC_{ox}}{C_H}\right) + \gamma \frac{WLC_{ox}}{C_H}\sqrt{2\phi_B + V_{in}} - \frac{WLC_{ox}}{C_H}\left(V_{DD} - V_{THN} + \gamma\sqrt{2\phi_B}\right)$$

- $V_{in}\left(1 + \frac{WLC_{ox}}{C_H}\right)$: gain
- $\gamma \frac{WLC_{ox}}{C_H}\sqrt{2\phi_B + V_{in}}$: distortion
- $-\frac{WLC_{ox}}{C_H}\left(V_{DD} - V_{THN} + \gamma\sqrt{2\phi_B}\right)$: offset

Charge injection errors

→ gain error ✓
offset error ✓
nonlinearity ✗

↓ figure of merit
FoM of switch

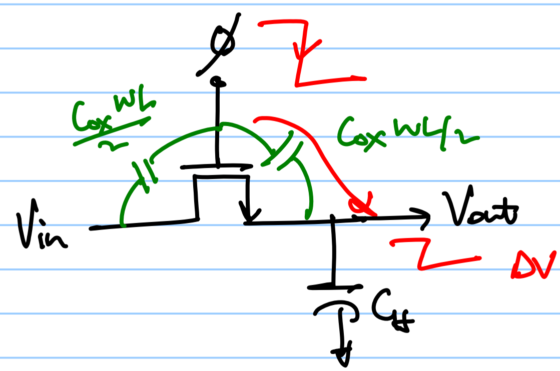
$$F \triangleq (\tau \Delta V)^{-1}$$ large value is desired

$$\tau = R_{on} C_H$$
$$= \frac{1}{\mu_n C_{ox} \frac{W}{L} (V_{DD} - V_{in} - V_{THN})} \cdot C_H$$

$$\Delta V = \frac{WLC_{ox}}{C_H} \left(V_{DD} - V_{in} - V_{THN}\right)$$

$$F = \frac{1}{\tau \Delta V} = \frac{\mu_n}{L^2}$$ ← Benefit by scaling length (L)!

② Clock feedthrough:



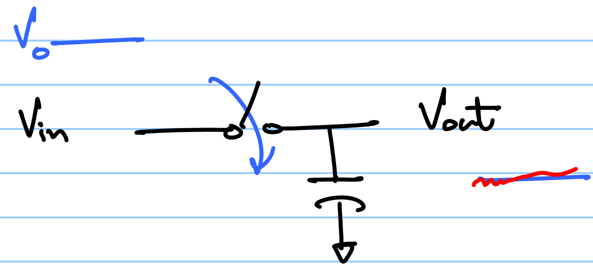
overlap capacitance

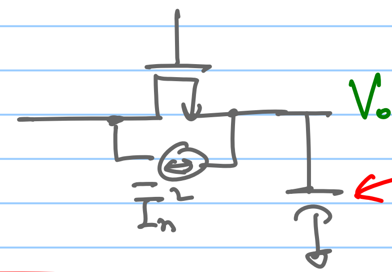
$$\Delta V = V_{CLK} \cdot \frac{W C_{ov}'}{W C_{ov}' + C_H}$$

$W \uparrow \Rightarrow \Delta V \uparrow$

for precision $C_H \gg C_{ov}' W$

③ Thermal Noise





C_H is determined by the $\frac{KT}{C}$ noise considerations

Sampled noise on the capacitor

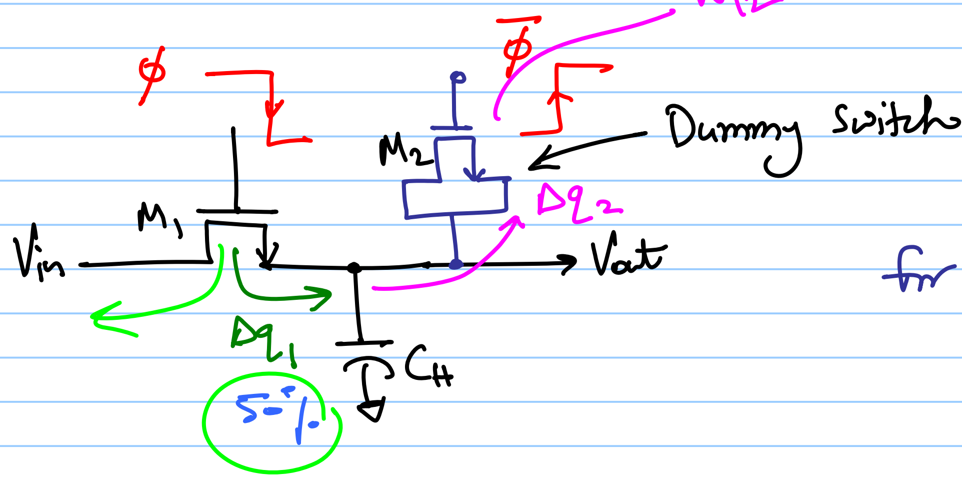
$$V_{n,rms} = \sqrt{\frac{KT}{C_H}}$$

$$SNR = 20 \log_{10}\left(\frac{V_o}{V_{n,rms}}\right)$$

$C_H \uparrow$ for higher SNR ⇒ ENOB

Charge Injection Cancellation!

(A) Dummy switch



for perfect cancellation

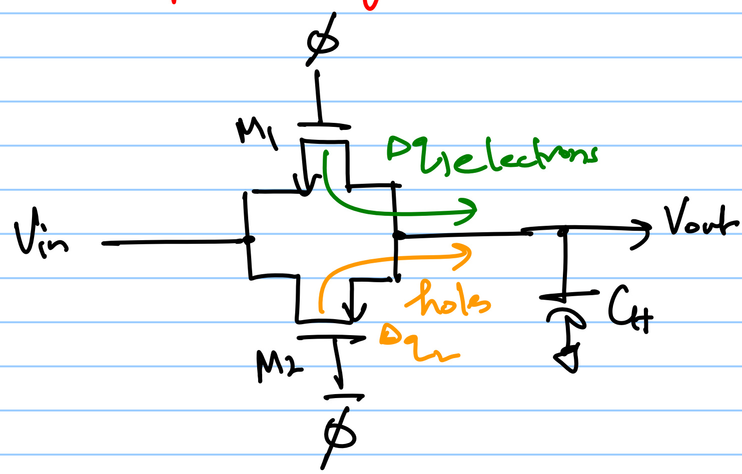
$$\Delta q_1 = \Delta q_2$$

$$\frac{W_1 L_1 C_{ox}}{2}\left(V_{CLK} - V_{in} - V_{THN_1}\right) = W_2 L_2 C_{ox}\left(V_{CLK} - V_{in} - V_{THN_2}\right)$$

for $W_2 = \frac{W_1}{2}$ & $L_2 = L_1$, this scheme may work.

* Also helps cancel clock feedthrough

(13) Complementary Switches



for perfect cancellation of $\bar{e}$ by holes

$$\Delta q_1 = \Delta q_2$$

$$\frac{W_1 L_1 C_{ox}}{2}\left(V_{CLK} - V_{in} - V_{THN}\right) = \frac{W_2 L_2 C_{ox}}{2}\left(V_{in} - |V_{THP}|\right)$$

$$\Rightarrow \quad V_{CLK} - V_{in} - V_{THN} = V_{in} - |V_{THP}|$$

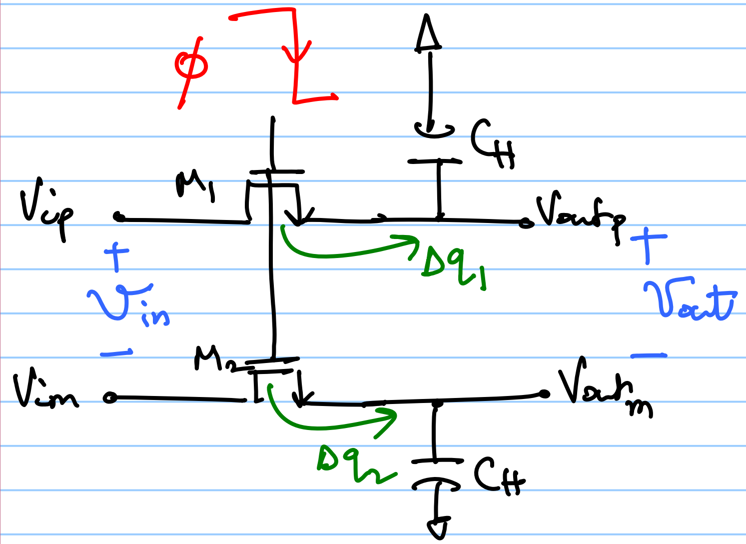
$$\Rightarrow \quad V_{in} = \frac{\left(V_{CLK} - V_{THN} + |V_{THP}|\right)}{2}$$

Cancellation only occurs for one particular value of Vin

* Also, this circuit doesn't provide clock-feedthru cancellation

$C_{ov,PMOS} \neq C_{ov,NMOS}$

Ⓒ Differential Circuits



$$\Delta q_1 - \Delta q_2 = WLC_{ox}\left[(V_{inp} - V_{inm}) + (V_{THNp} - V_{THNm})\right]$$

$$= WLC_{ox}\left[v_{in} + \gamma\left(\sqrt{2\phi_B + V_{inp}} - \sqrt{2\phi_B + V_{inm}}\right)\right]$$

Odd function of v_{in}

* DC offset due to CI is cancelled

Non-linear term remains

$$\sqrt{2\phi_B + V_{cm} + \frac{v_{in}}{2}} - \sqrt{2\phi_B + V_{cm} - \frac{v_{in}}{2}}$$

$$= f(v_{in}) - f(-v_{in})$$: Odd function

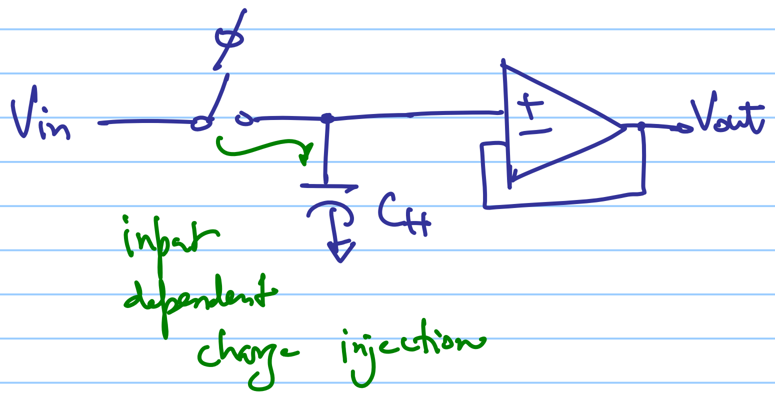
Odd function $f(v_{in}) - f(-v_{in})$

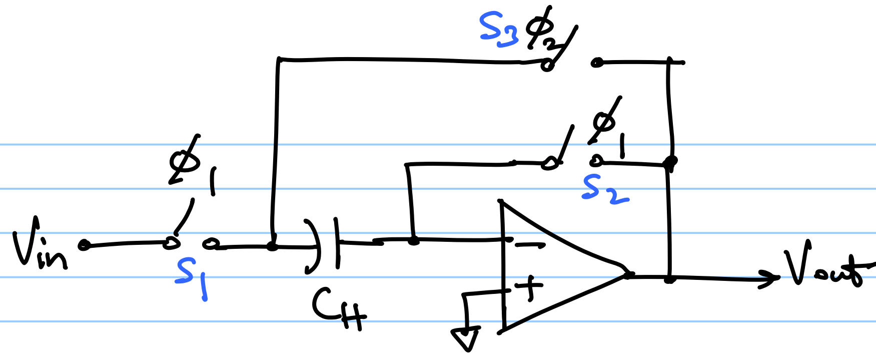
Taylor series has only odd order terms.

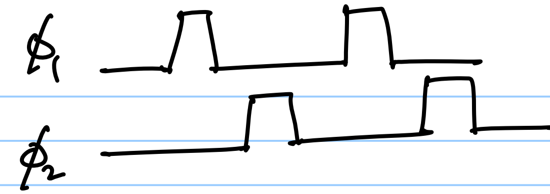
All DC and even order terms are cancelled out

↳ fully differential circuit eliminates all even-order non-linearity

Sample and Hold (Buffer) Circuits

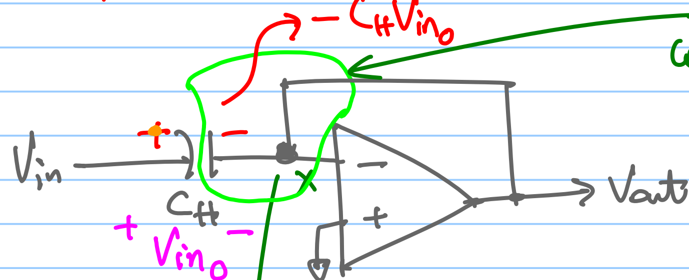




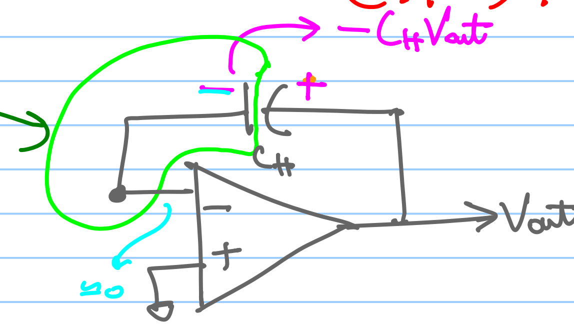


Sampling Mode $(\phi_1=1, \phi_2=0)$

Hold Mode $(\phi_1=0, \phi_2=1)$



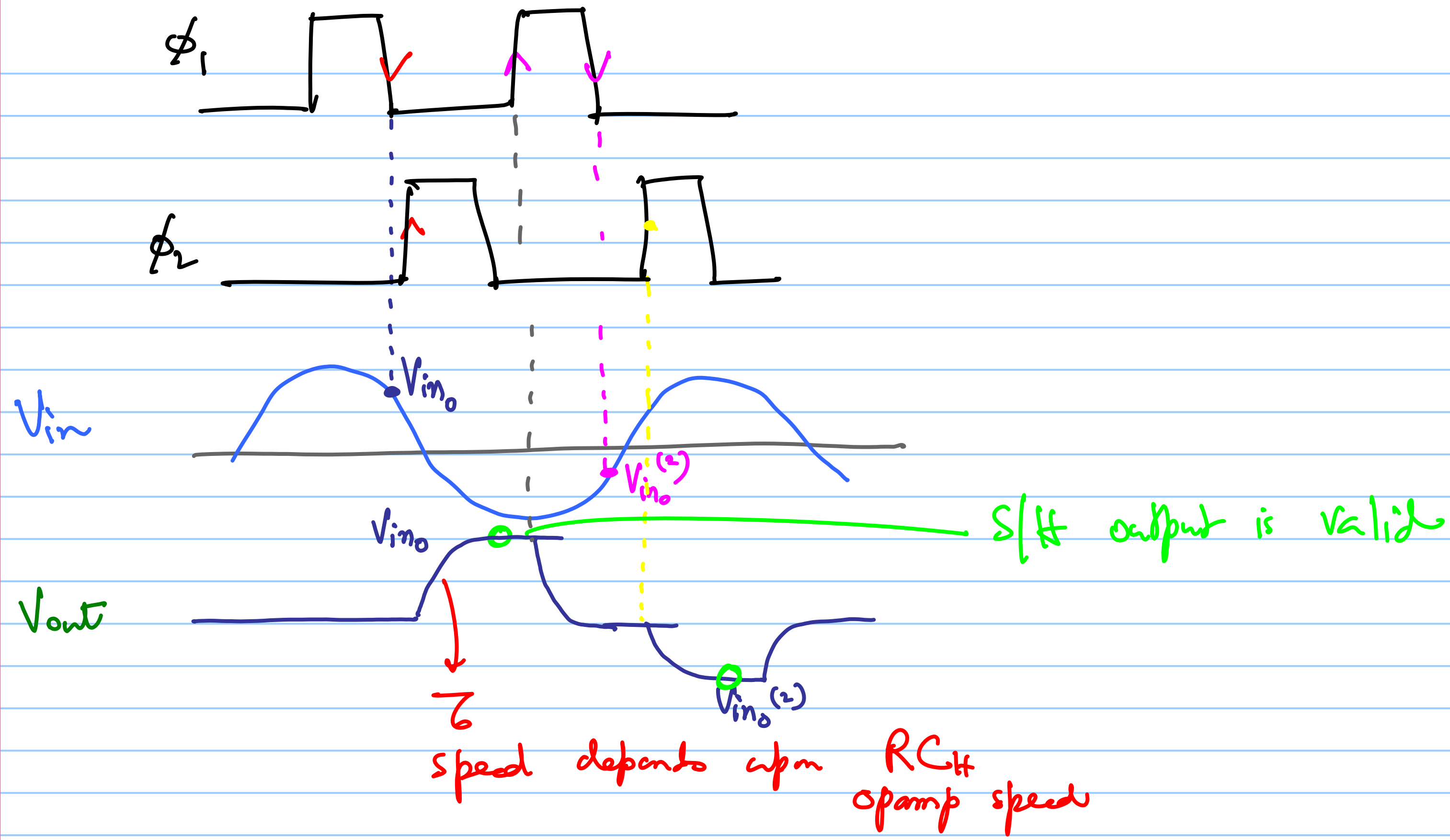
charge is conserved on this surface



$V_x = V_{out} \simeq 0$

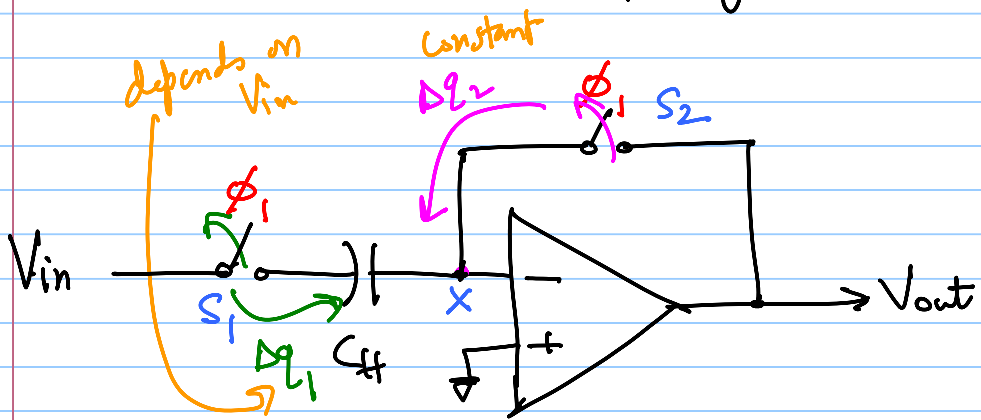
$-C_H V_{in_0} = -C_H V_{out}$

$V_{out} = V_{in_0}$



ϕ_1
ϕ_2
V_{in}
V_{in_0}
$V_{in_0}^{(2)}$
V_{out}
V_{in_0}
S/H output is valid
$V_{in_0}^{(2)}$
τ
speed depends upon RC_H
opamp speed

Slow motion recap of this S/H circuit



* When S_1 turns off: Δq_1 is injected into C_H

$$\Delta q_1 = WLC_{ox}(V_{CLK} - V_{in} - V_{THN_1})$$

↳ $f(\sqrt{V_{in}})$

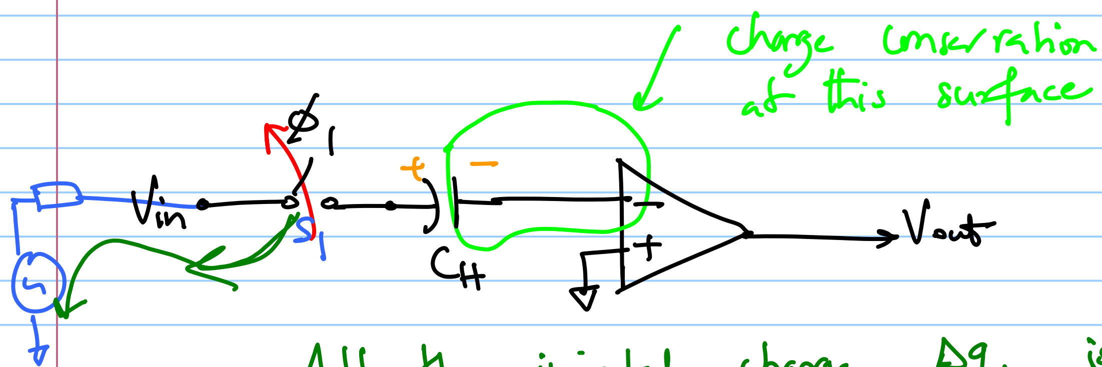
* When S_2 turns off: Δq_2 is injected into C_H

$$\Delta q_2 = WLC_{ox}(V_{CLK} - V_{THN_2})$$

↳ constant charge independent of V_{in}

↳ offset not distortion

Can be cancelled by fully differential operation



All the injected charge Δq_1 is absorbed into source V_{in}

↳ none of Δq_1 is stored on C_H

Bottom plate Sampling

$\phi_{1a} \Rightarrow \phi_1$ falling edge is advanced!