520.492 Mixed-Signal VLSI Systems

Week 11

Analog Dynamic Techniques

References

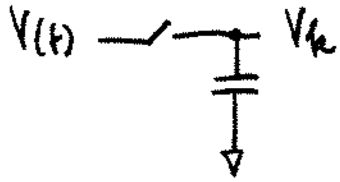
1. Franca and Tsividis: Chapter 4.
2. R. Gregorian and G.C. Temes, *Analog MOS Integrated Circuits for Signal Processing*, Wiley, 1986.

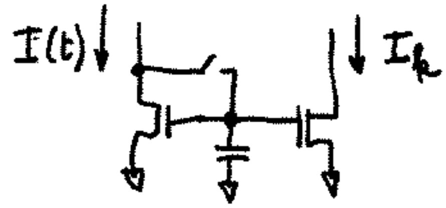
DYNAMIC ANALOG TECHNIQUES

ref: Franca and Tsividis, Chapter 4
(E.A. Vittoz)

- **Sampling**: $X(t) \rightarrow X_k = X(t_0 + k.T)$

typical:

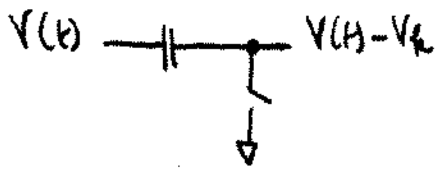


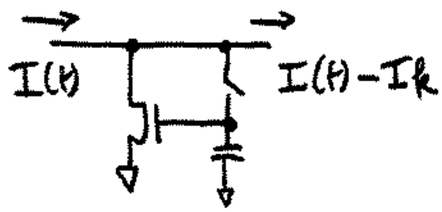


applications: short-term analog memory ("register")

- **Auto-Zeroing**: $X(t) \rightarrow X(t) - X_k$

typical:

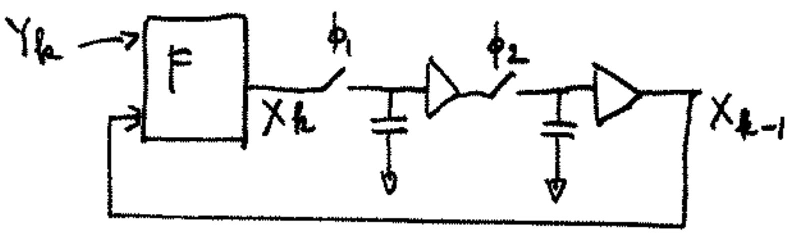


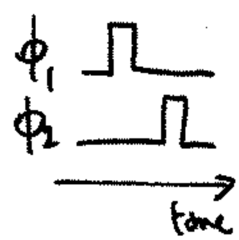


applications: cancellation of DC noise and offsets
(1/f noise; MOS mismatch; supply...)

- **Finite-State Automata**: $X_{k-1} \rightarrow X_k = F(X_{k-1}; Y_k)$

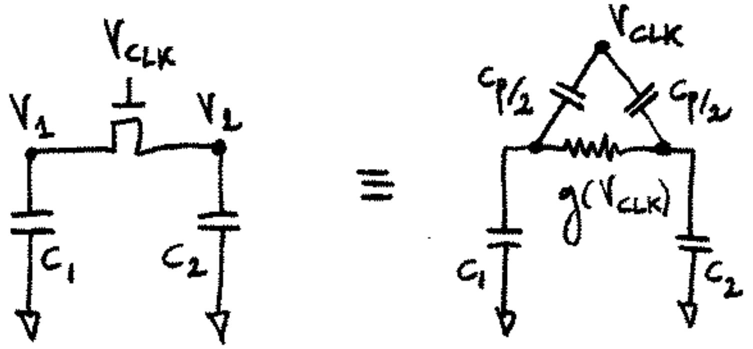
typical:

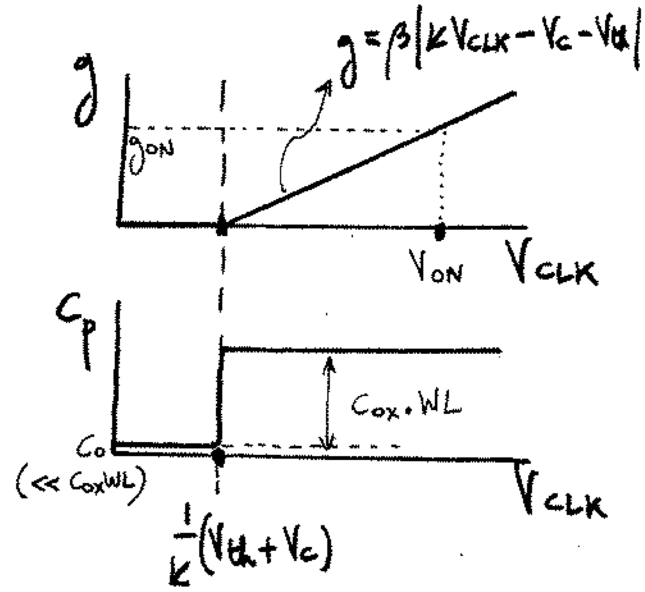




examples:
- discrete-time filters
- algorithmic D/A and A/D converters
- delta-sigma modulators
- etc...

SWITCH CHARGE INJECTION





ON

a) $V_{CLK} = V_{ON} > \frac{1}{K}(V_{th} + V_c)$ and $V_1 = V_2 \equiv V_c$

↓

b) $V_{CLK} \downarrow \Rightarrow \frac{1}{2} C_p \cdot \frac{dV_{CLK}}{dt}$ current injected in C_1 and C_2

OFF

c) $V_{CLK} = V_{off} < \frac{1}{K}(V_{th} + V_c)$

$$\Rightarrow \begin{cases} V_1 = V_c + \Delta V_1 \\ V_2 = V_c + \Delta V_2 \end{cases}$$ and $C_1 \Delta V_1 + C_2 \Delta V_2 = \Delta Q_S$

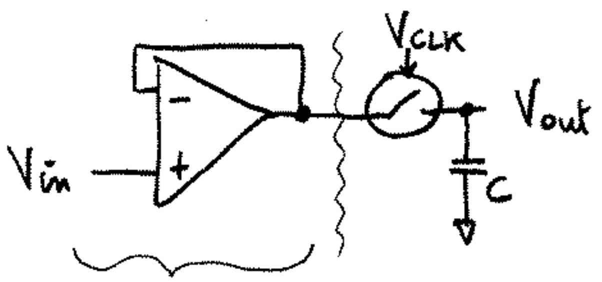
with $\Delta Q_S = -C_p \left[V_{ON} - \frac{1}{K}(V_{th} + V_c) \right]$

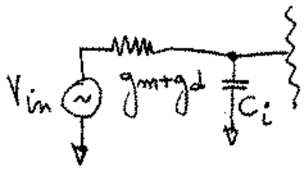
(shared among C_1 and C_2)

- $C_1 = C_2 \Rightarrow C_1 \Delta V_1 = C_2 \Delta V_2$ symmetrical charge injection

- $C_1 \neq C_2 \Rightarrow \begin{cases} C_1 \Delta V_1 \approx C_2 \Delta V_2 & \text{for } \left| \frac{d}{dt} V_{CLK} \right| > 10 \frac{g_{on}}{\min(C_1, C_2)} \\ \Delta V_1 \approx \Delta V_2 & \text{for } \left| \frac{d}{dt} V_{CLK} \right| \ll \frac{g_{on}}{\max(C_1, C_2)} \end{cases}$

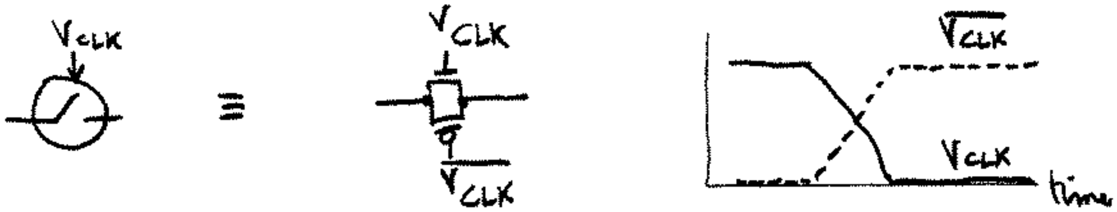
Typical situation:





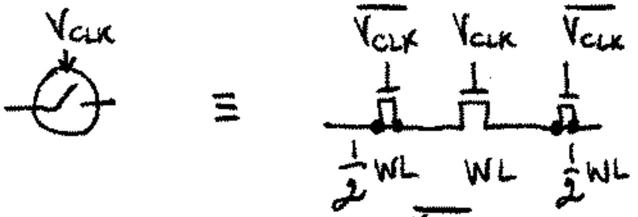
__remedy:__

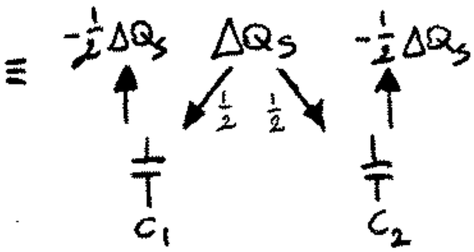
①



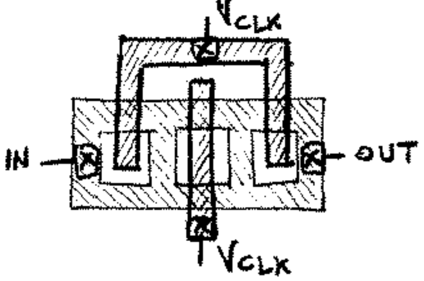
only works partially, since $\left| V_{on} - \frac{1}{k}(V_{th} + V_c) \right|$ is different for both

②





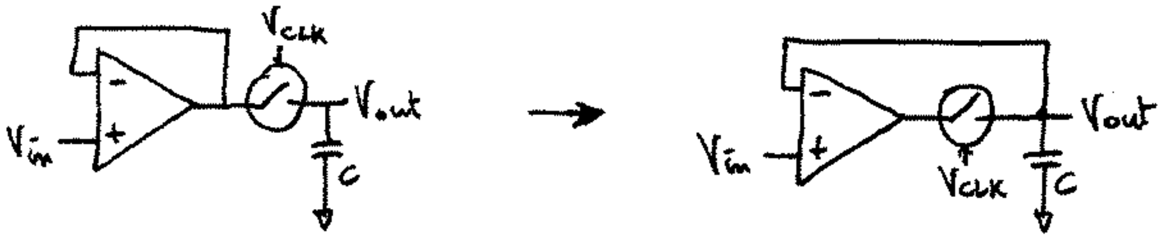
layout:



works fine as long as $\left|\frac{d}{dt} V_{CLK}\right| > 10 \cdot g_{on} / \min(C, C_i)$

③ = ① + ② works better than ②, also because g_{on} = higher

④

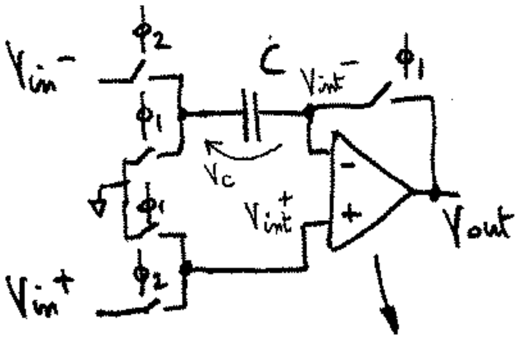


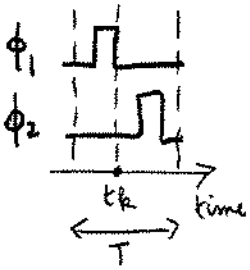
works satisfactorily only for $\left|\frac{d}{dt} V_{CLK}\right| \ll \dfrac{\min(g_{on}, g_m + g_d)}{\max(C, C_i)}$

and without ② or ③

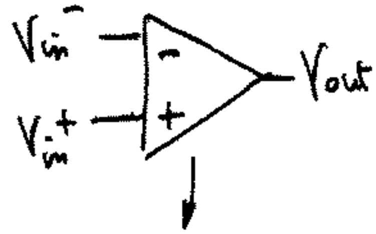
DYNAMIC AUTO-ZEROING TECHNIQUES

→ offset and drift cancellation





≡



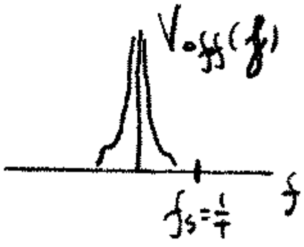
$$V_{out} = A\left(V_{int}^+ - V_{int}^- - V_{off}(t)\right) \rightarrow V_{out} = A\left(V_{in}^+ - V_{in}^- - \underline{\underline{V_{off}^{eff}}}(t)\right)$$

- ϕ_1 : auto-zero: $V_{int}^- \equiv V_{out}$, $V_{int}^+ \equiv 0$ $\Rightarrow$ $V_{out_k} = V_{C_k} = -\frac{A}{A+1} V_{off_k}$

  (sampled @ $t_k = t_0 + kT$)

- ϕ_2 : amplify: $V_{out} = A\left(V_{in}^+ - \left(V_{in}^- - \frac{A}{A+1} V_{off_k}\right) + V_{off}(t)\right)$

$$A \rightarrow \infty \Rightarrow V_{out} \approx A\left(V_{in}^+ - V_{in}^- - \underbrace{\left(V_{off}(t) - V_{off_k}\right)}_{V_{off}^{eff}(t)}\right)$$



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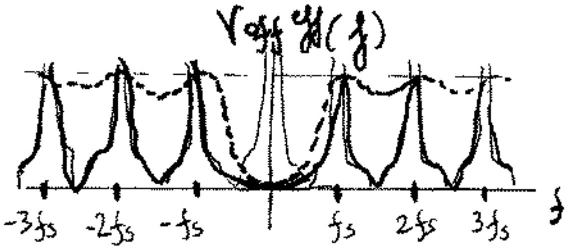


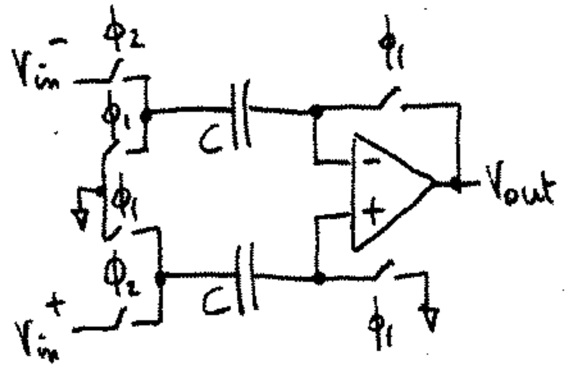
⇒ Low-frequency components of $V_{off}(f)$ are virtually eliminated:

- offsets
- 1/f noise
- power supply variations
- etc...

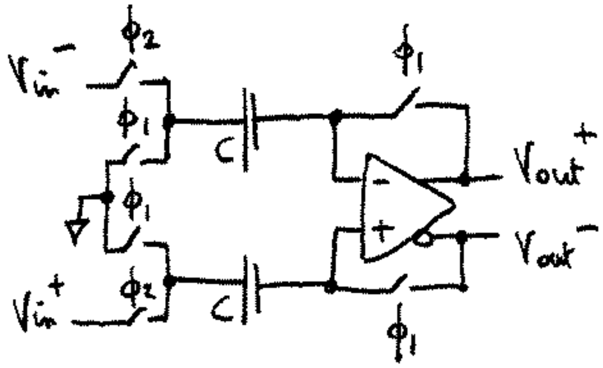
except: switch charge injection

Improvements: Reduce switch charge injection

① Balanced input:

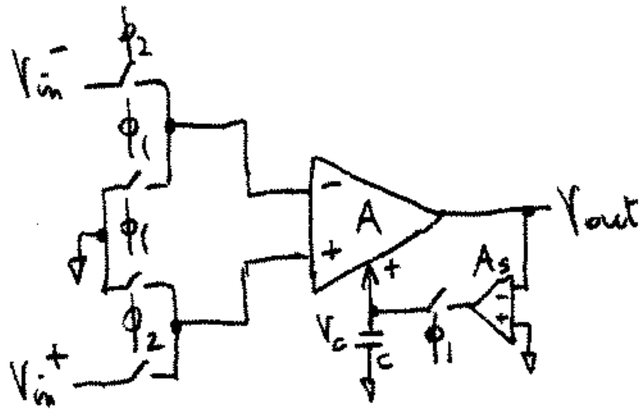


OR:



also reduces effect of parasitic C at the amplifier input node

② Weak secondary input:



$$V_{out} = A\left(V_{in}^+ - V_{in}^- - V_{off}\right) + A_S V_c$$

- ϕ_1 : $V_{in}^+ - V_{in}^- \equiv 0$; $V_{out} = 0$

  $$\Rightarrow V_{c_k} = -\frac{A}{A_S} V_{off_k} + \underbrace{C \Delta Q_s}_{\text{CHARGE INJECTION}}$$

- ϕ_2 : $V_{out} = A\left(V_{in}^+ - V_{in}^- - V_{off}^{eff}(t)\right)$

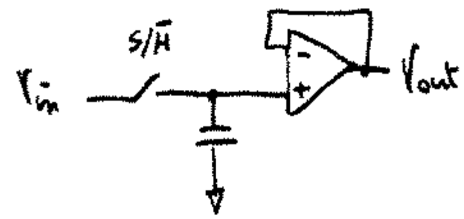
$$\Rightarrow \quad V_{off}^{eff}(t) = \underbrace{\left(V_{off}(t) - V_{off_k}\right)}_{V_{off}^{eff}(t) \text{ w/o switch injection}} - \underbrace{\frac{A_S}{A} C \Delta Q_s}_{\text{CHARGE INJECTION SCALED BY } A_S/A}$$

charge injection is optimally reduced for $A_S \ll A$

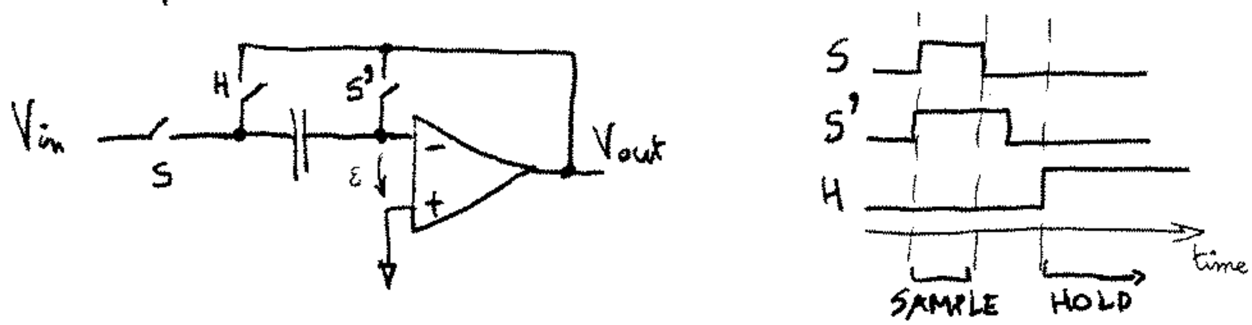
DYNAMIC SAMPLING TECHNIQUES

a) Voltage-mode S/H

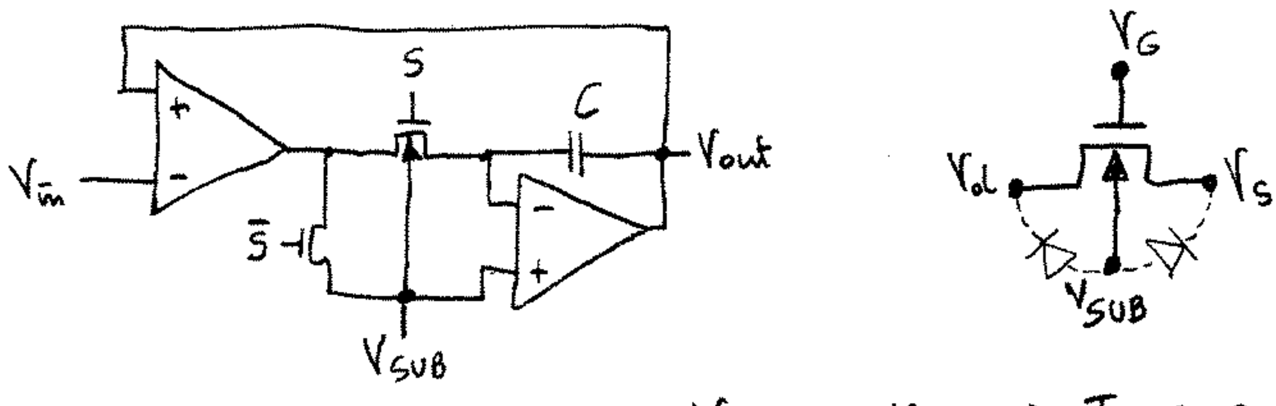
- Basic structure:



- Offset-compensated S/H:



- Leakage-reduced S/H:

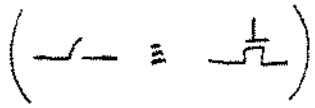


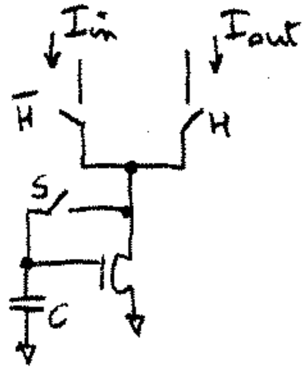
$V_d, V_s \equiv V_{SUB} \Rightarrow I_S \approx 0$

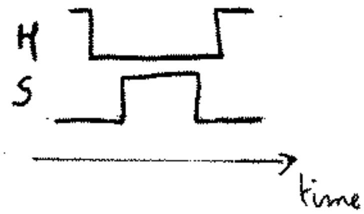
(diode leakage)

b) Current-mode S/H

- Basic structure:

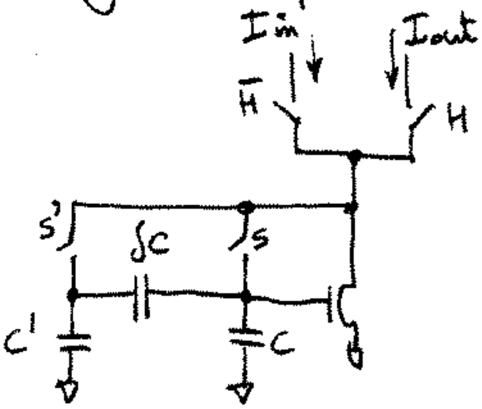




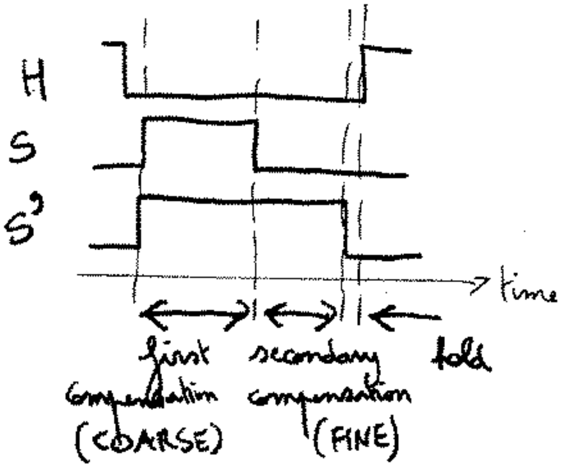


problems:
- charge injection is amplified by g_m
- output is not available in sample mode

- Switch injection compensation by low-sensitivity auxiliary input:



$\delta C \ll C, C'$ ⇒ more effective



- Uninterrupted output: