Proactive Use of Finite Aperture Time in Sampling Circuit for Sensor Interface

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Research Background

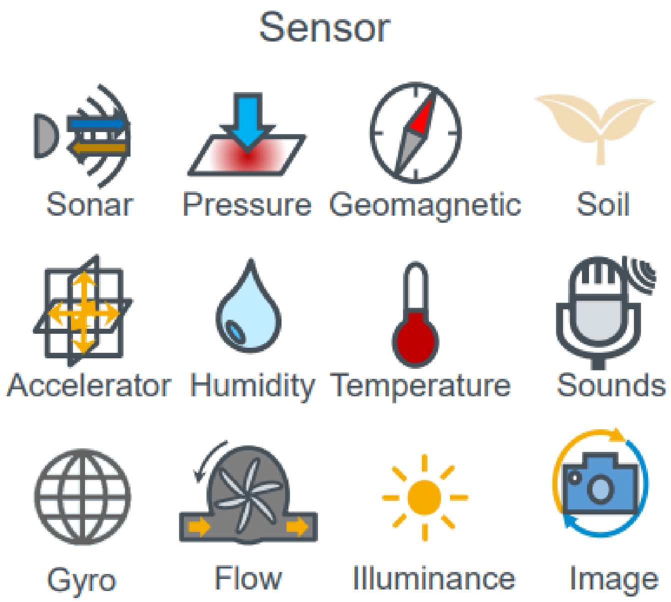
IoT systems prevail

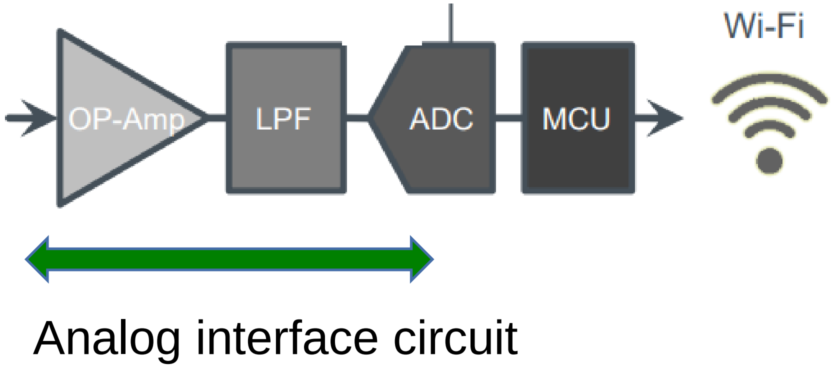
A lot of sensors

low frequency signals

Analog interface circuit

low power, miniature size



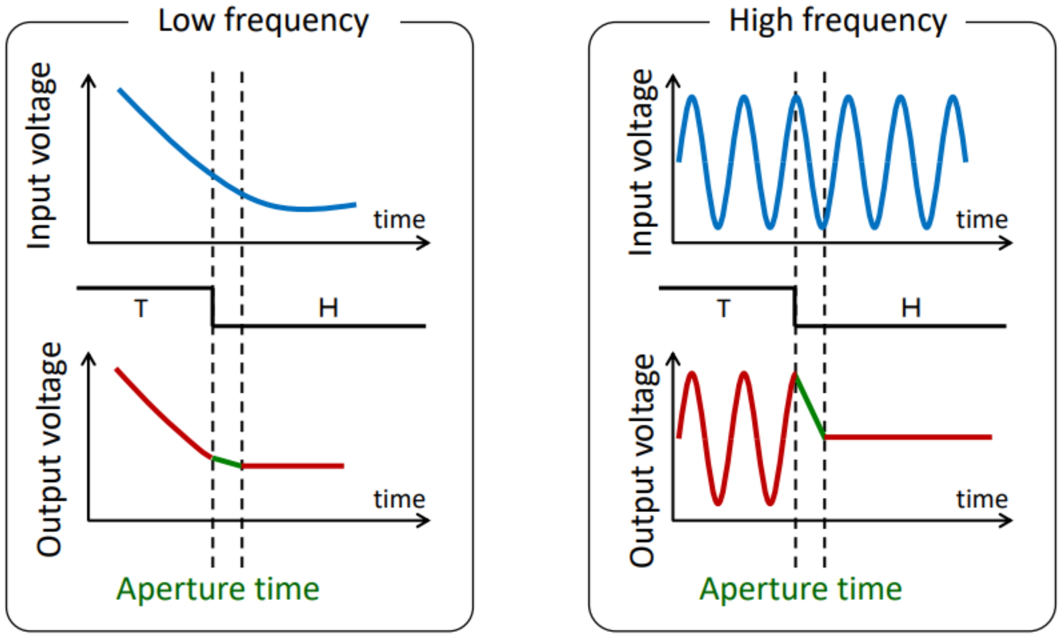


Research Objective

Clarification of
proactive use of finite aperture time in sampling circuit

- Low-pass filter chip area reduction

- Low frequency signal quality improvement



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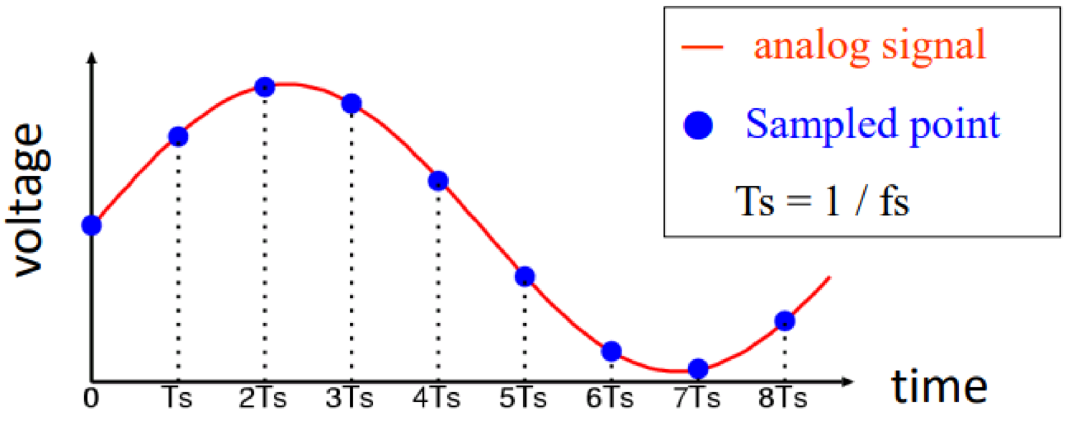
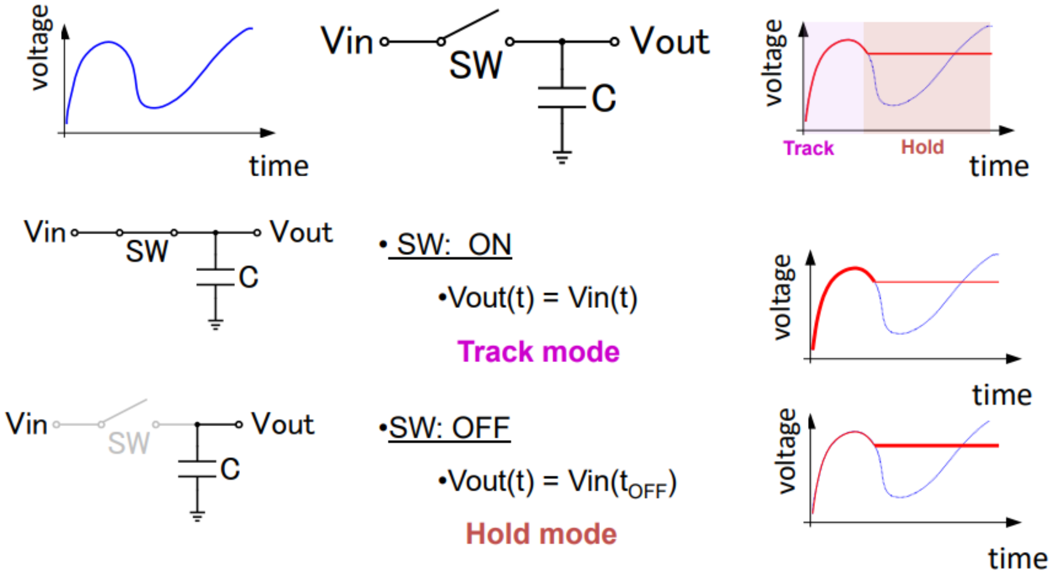
Sampling Circuit for Waveform Acquisition

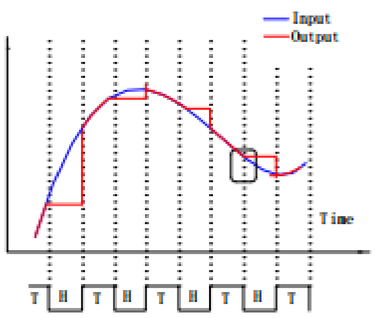
- Waveform sampling

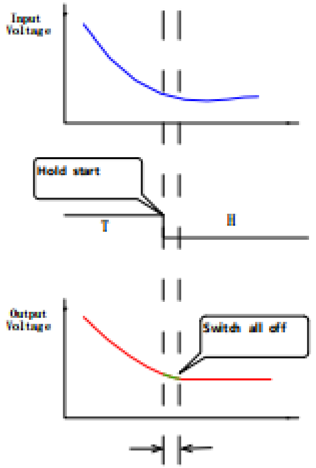


- Sampling circuit & Operation



Aperture Time in Sampling Circuit



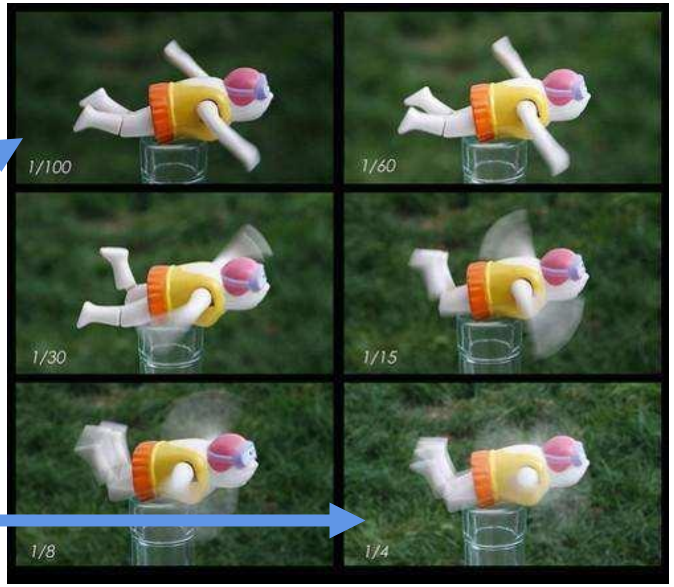


- Finite aperture time:

→ Integral time
from hold start
to switch opening end.

- Inverse of camera shutter speed
  ➡ Finite aperture time

- High speed shutter
  ➡ Clear fast moving object
- Slow speed shutter
  ➡ Clear background



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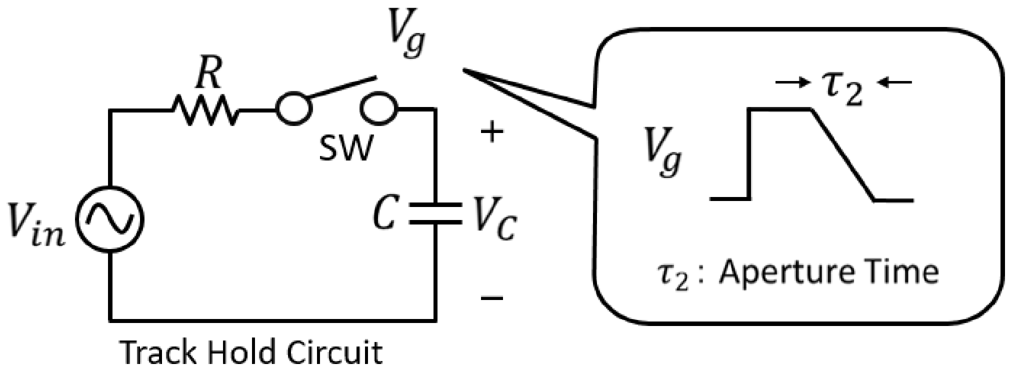
Low Pass Filtering Effect of Aperture Time



Explicit transfer function

$$\frac{V_C}{V_{in}} = \frac{sinc(\omega\tau_2)}{sinc(\omega\tau_2) + j\omega\tau_1}$$

Here τ_1= RC.

Finite aperture time τ_2 ➡ Lowpass filter action

- Bad for high frequency signal sampling
- Good for low frequency signal sampling

➡ Lowpass filter simplification

Consistency with Zero Aperture Time Case

$$\frac{V_C}{V_{in}} = \frac{sinc(\omega\tau_2)}{sinc(\omega\tau_2) + j\omega\tau_1}$$

$$(\tau_1 = RC\ ,\ \tau_2 = \tau\,)$$

Transfer function in case of finite aperture time

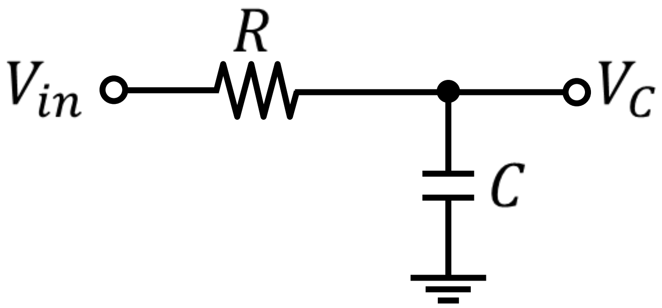
$\tau_2 \rightarrow 0$

$sinc(\omega\tau_2) \rightarrow 1$

$$\frac{V_C}{V_{in}} = \frac{1}{1 + j\omega\tau_1}$$

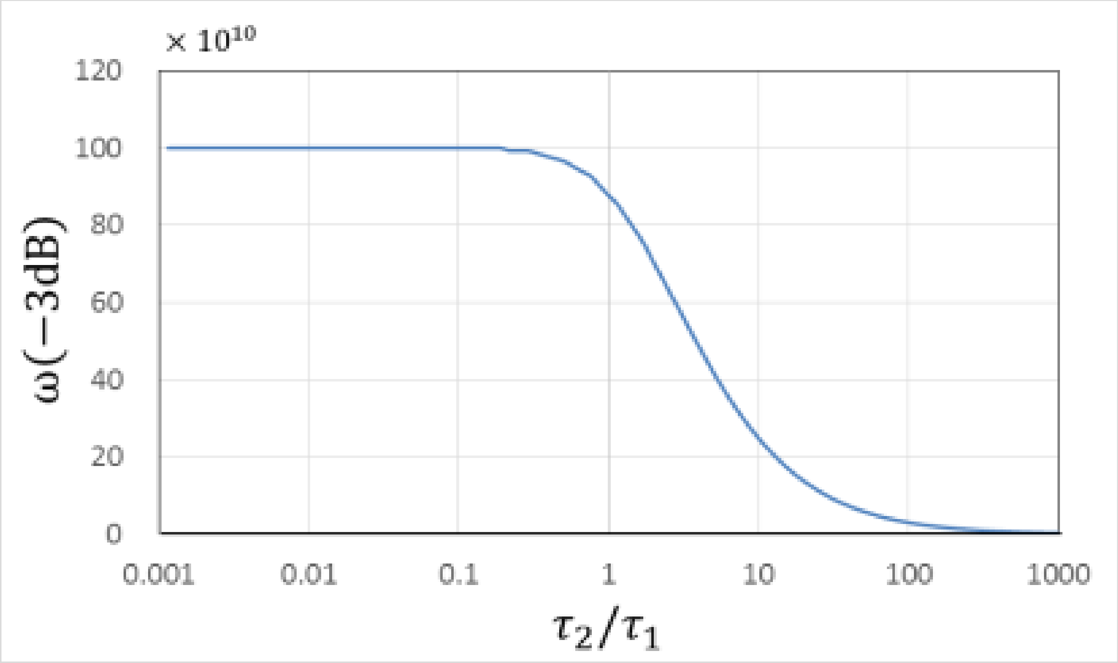
$$(\tau_1 = RC\,)$$

Transfer function in case of zero aperture time



τ_1, τ_2 Effects to Bandwidth

Numerical calculation from the derived transfer function



τ_1 (= R C) : fixed

τ_2 (aperture time) : varied

Bandwidth starts to decrease at $\tau_2 / \tau_1 = 1$

τ_1, τ_2 effects to bandwidth are comparable.

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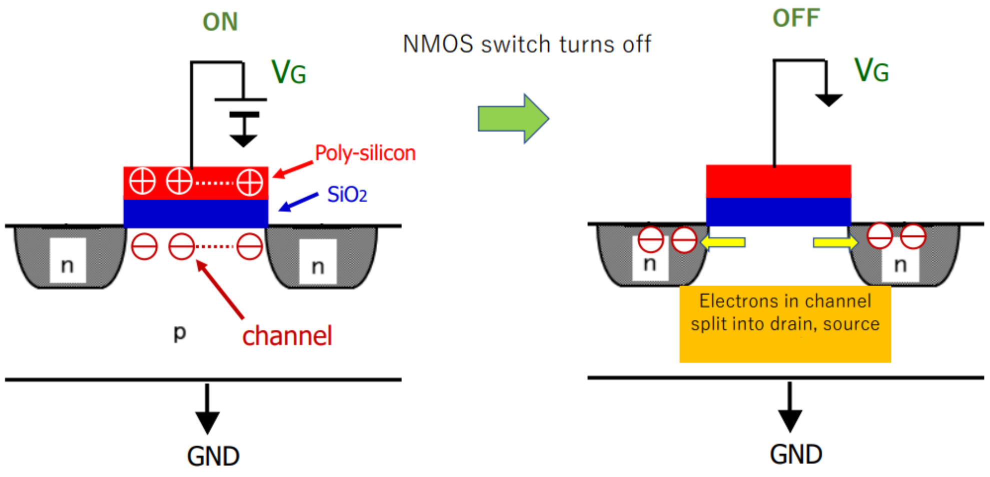
Charge Injection



NMOS switch on-state: Channel charge in NMOS

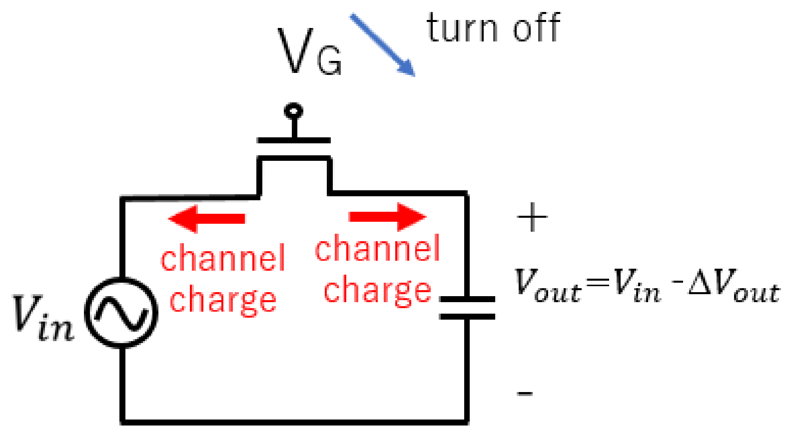
NMOS turns off ➡ Channel charge is dispelled into source and drain

➡ Charge injection

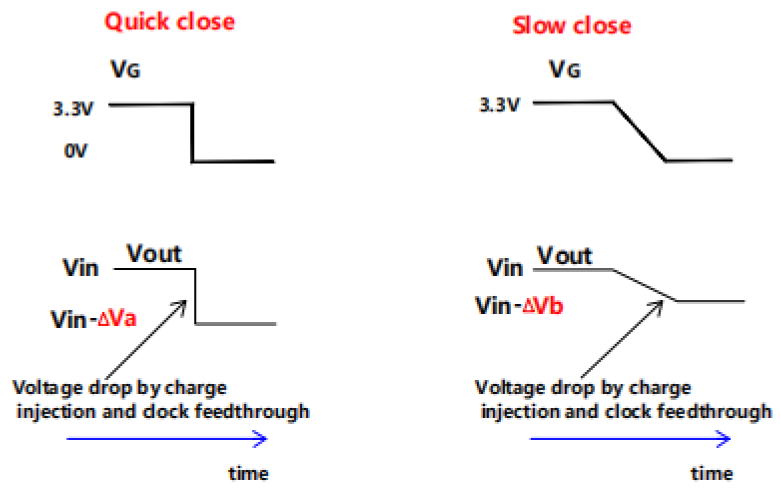
Charge Injection and Pedestal Error

- Charge injection

➡ Pedestal error ΔV_{out}



- Pedestal error caused by
  - Charge injection
  - Clock feedthrough



- Long aperture time

➡ Pedestal error reduction

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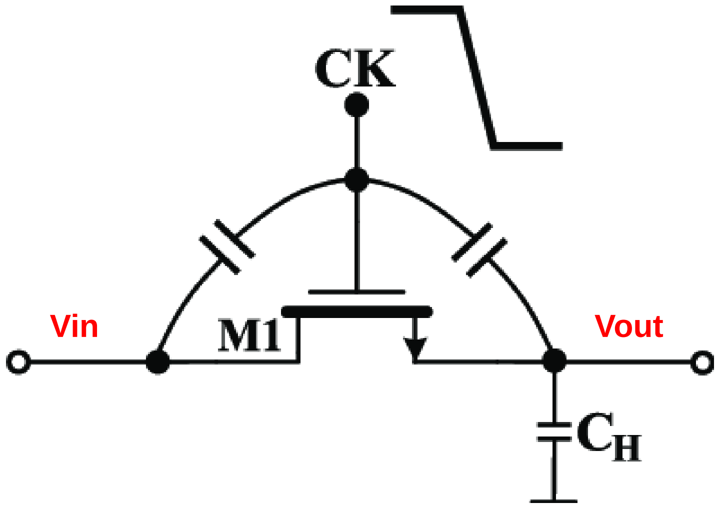
Clock Feedthrough in Sampling Circuit



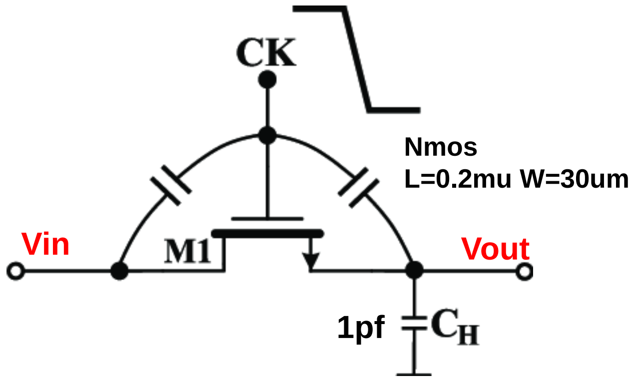
$$\Delta V = V_{CK}\frac{WC_{ov}}{WC_{ov}+C_H}$$

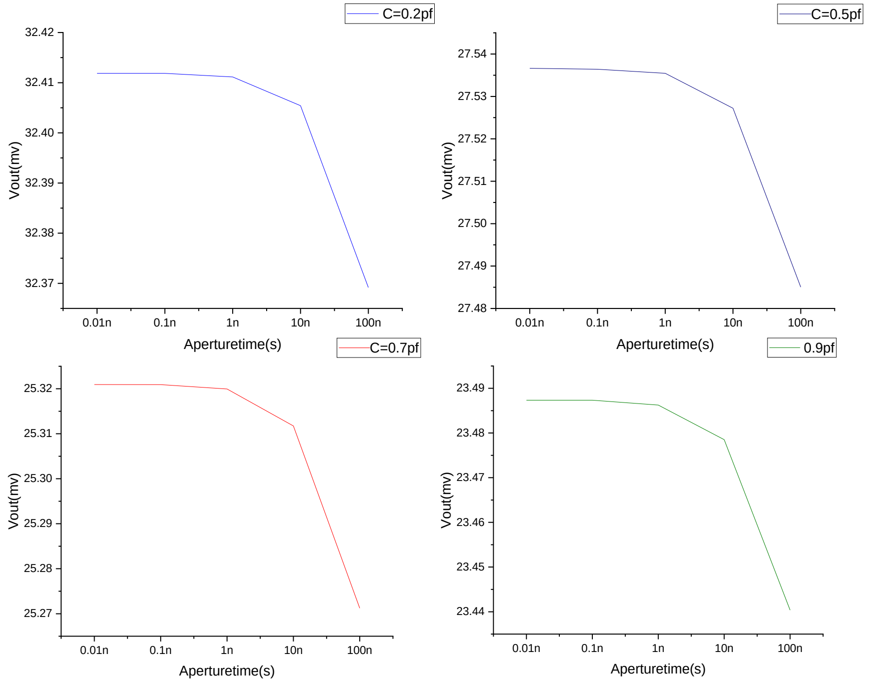
Clock feed-through:
Cgs and Cgd signals is coupled to the source and drain to affect the signal.

ideal state： no parasitic capacitance ➡ Vin=Vout

actual situation ： parasitic capacitance ➡ Vout=Vin- ΔV_{out}

Simulation Result:Clock Feedthrough in Sampling Circuit





- Aperture time increases ➡ Pedestal error ΔVout decreases.
- For long aperture time, C increases ➡ Pedestal error ΔVout decreases.

A slower gate input voltage signal provides a longer time for the MOSFET currents to compensate the coupling voltage.

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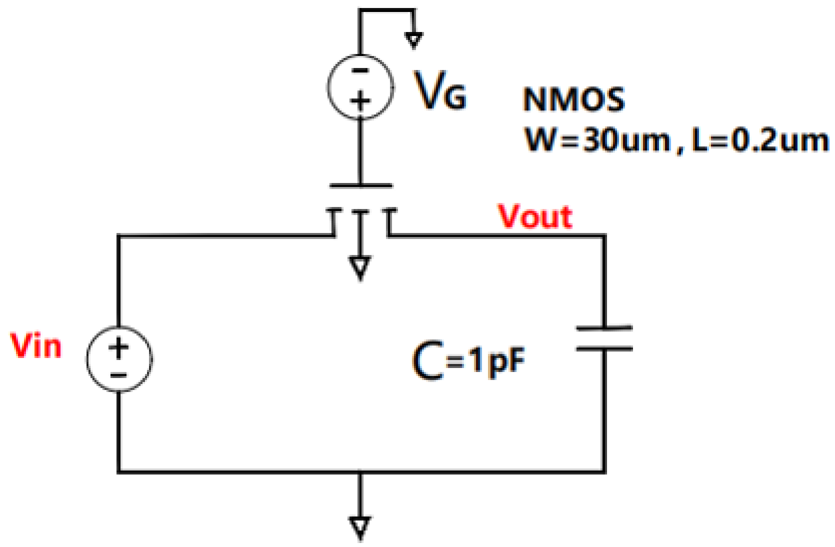
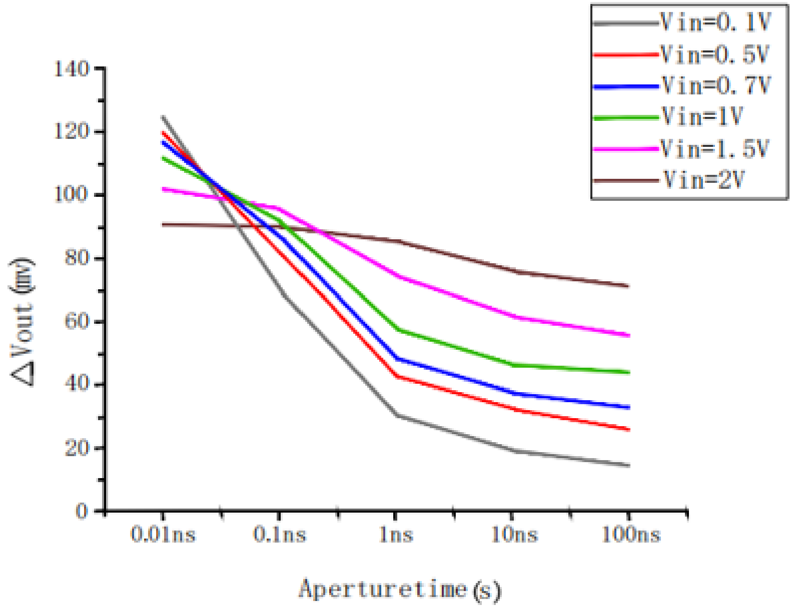
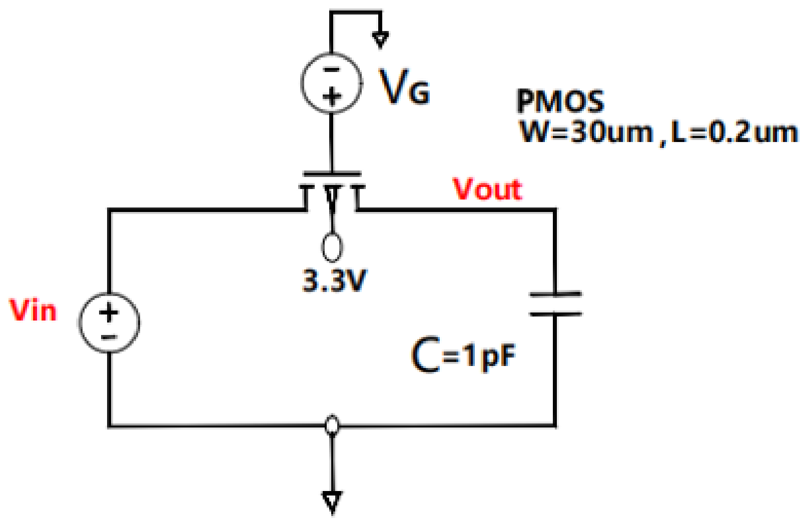
Simulation Result: Pedestal Error in N-ch Sampling Circuit

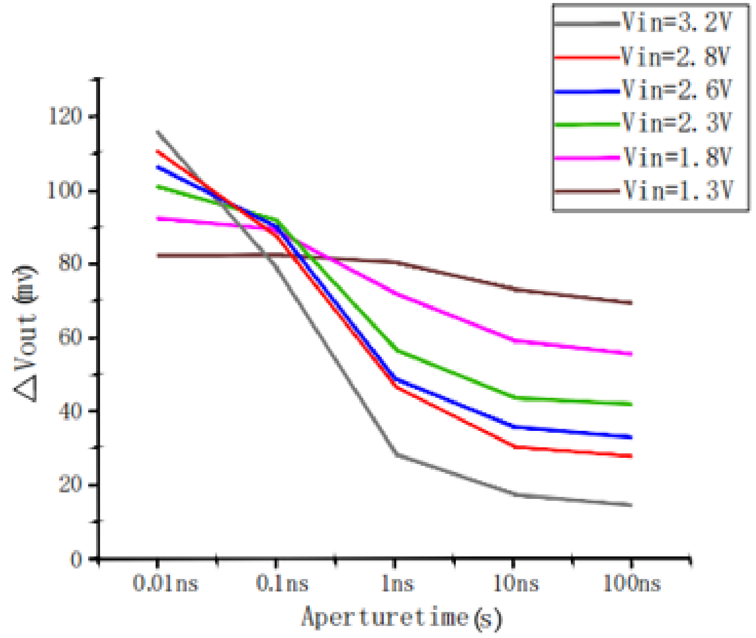




- Both charge injection, clock feedthrough are included in simulation
- Aperture time increases → Pedestal error ΔVout decreases.
- For long aperture time, Vin decreases → Pedestal error ΔVout decreases.

Simulation Result: Pedestal Error in P-ch Sampling Circuit

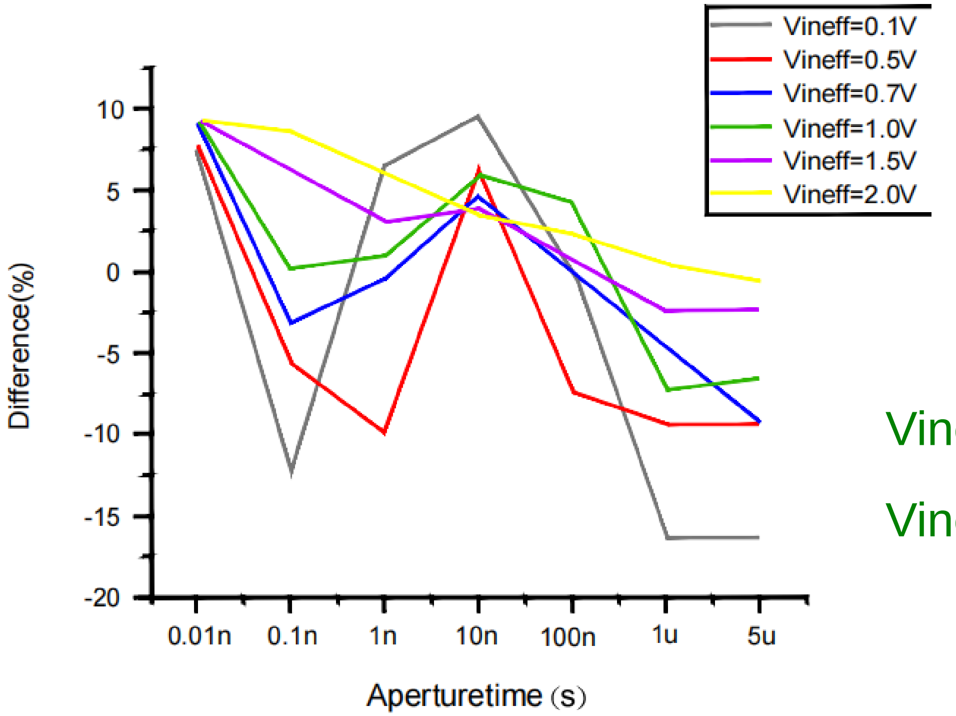




- Both charge injection, clock feedthrough are included in simulation
- Aperture time increases → Pedestal error ΔVout decreases.
- For long aperture time, Vdd - Vin decreases

→ Pedestal error ΔVout decreases.

Pedestal Error Difference in N-ch, P-ch Sampling Circuits



Vineff = Vin for N-ch sampling circuit

Vineff = Vdd-Vin for P-ch

Pedestal error difference between N-ch, P-ch sampling circuits.

⬇

Within ± 10% for the same Vineff

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Summary

- Finite aperture time in sampling circuit:

  Integral time from hold start to switch opening end.

- High frequency signal acquisition:

  ➡ Performance deterioration

- Low frequency signal acquisition:

  ➡ Proactive use for lowpass filtering

  Explicit transfer function

- Pedestal error:

  ➡ Caused by charge injection and clock feedthrough.

- Pedestal error reduction for long aperture time.

Thank you for your listening