Lecture 13. ISF Simulation

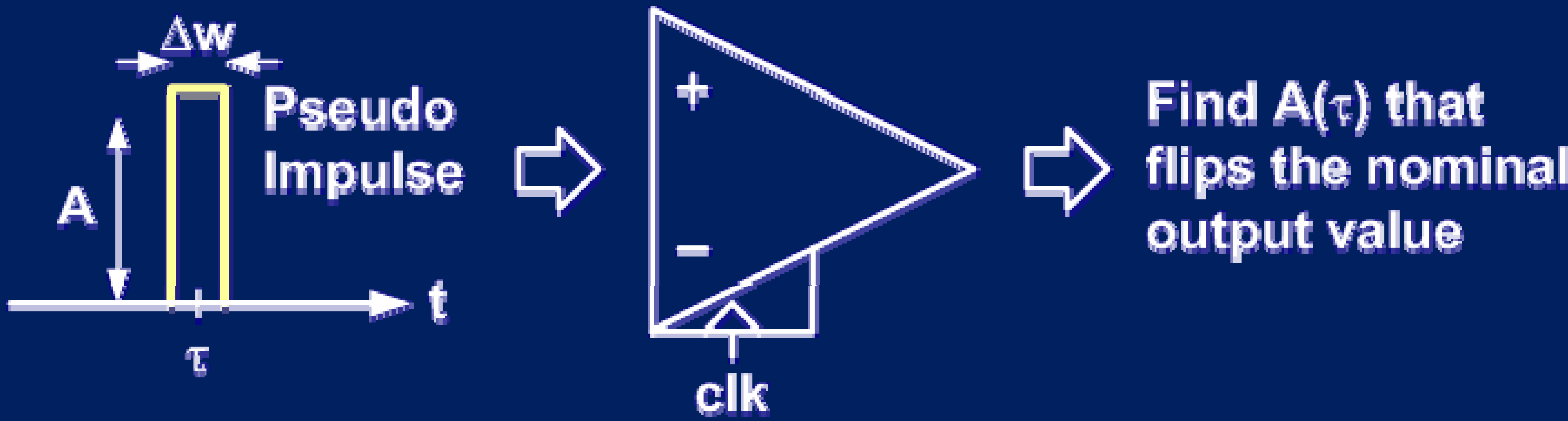
Jaeha Kim
Mixed-Signal IC and System Group (MICS)
Seoul National University
jaeha@ieee.org

ISF Simulation

- ISF represents many key characteristics of PTV circuits
  - Oscillators, samplers, comparators, …
- Previous methods measure ISF via transient simulation
  - With pseudo-impulse input stimulus
  - With step input stimulus

Previous Ways to Measure ISF (1)

- **Measure response to a pseudo-impulse via transient simulation**

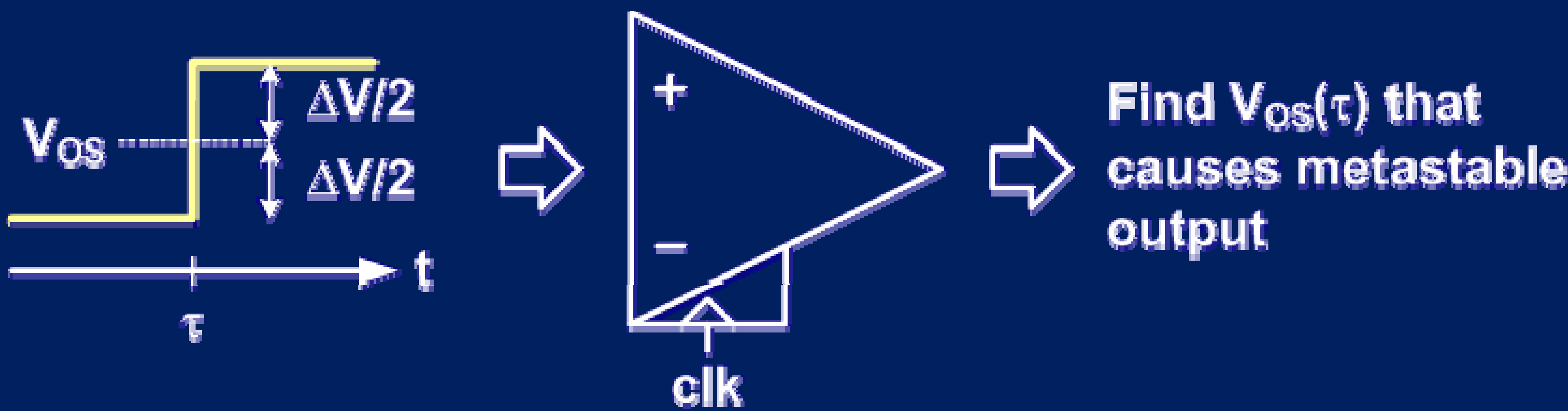


$$\Gamma(\tau) \cong \frac{\Delta w}{A(\tau)} \Big/ \sum_{n} \frac{1}{A(n\Delta w)}$$

*** T. Toifl, et al., "A 22-Gb/s PAM-4 Receiver in 90-nm CMOS SOI Technology," JSSC, Apr. 2006.**

Previous Ways to Measure ISF (2)

- Derive ISF from the step input that results in metastable state



$$\Gamma(\tau) \cong \frac{d}{d\tau}\left[\frac{V_{OS}(\tau)}{\Delta V} + \frac{1}{2}\right]$$

* M. Jeeradit, et al., "Characterizing Sampling Aperture of Clocked Comparators," VLSI Circuit Symp., June 2008.

Measure ISF via PAC analysis

- TRAN-based methods are slow and prone to numerical errors
  - Δw and ΔV can't be too large or too small
- PAC-based method is more efficient
  - Measure linearized PTV response of the circuit via adjoint sensitivity analysis
  - Available from RF simulators: SpectreRF, ADS, Eldo-RF, HSPICE-RF, RF FastSPICE …
  - Gives ~5x speed-up

Linear Time-Varying System Basics*

- **Time-varying impulse response $h(t,\tau)$:**

$$y(t) = \int_{-\infty}^{t} h(t,\tau) \cdot x(\tau)\, d\tau$$

- **Time-varying transfer function $H(j\omega;t)$:**

$$Y(j\omega) = H(j\omega;t) \cdot X(j\omega)$$

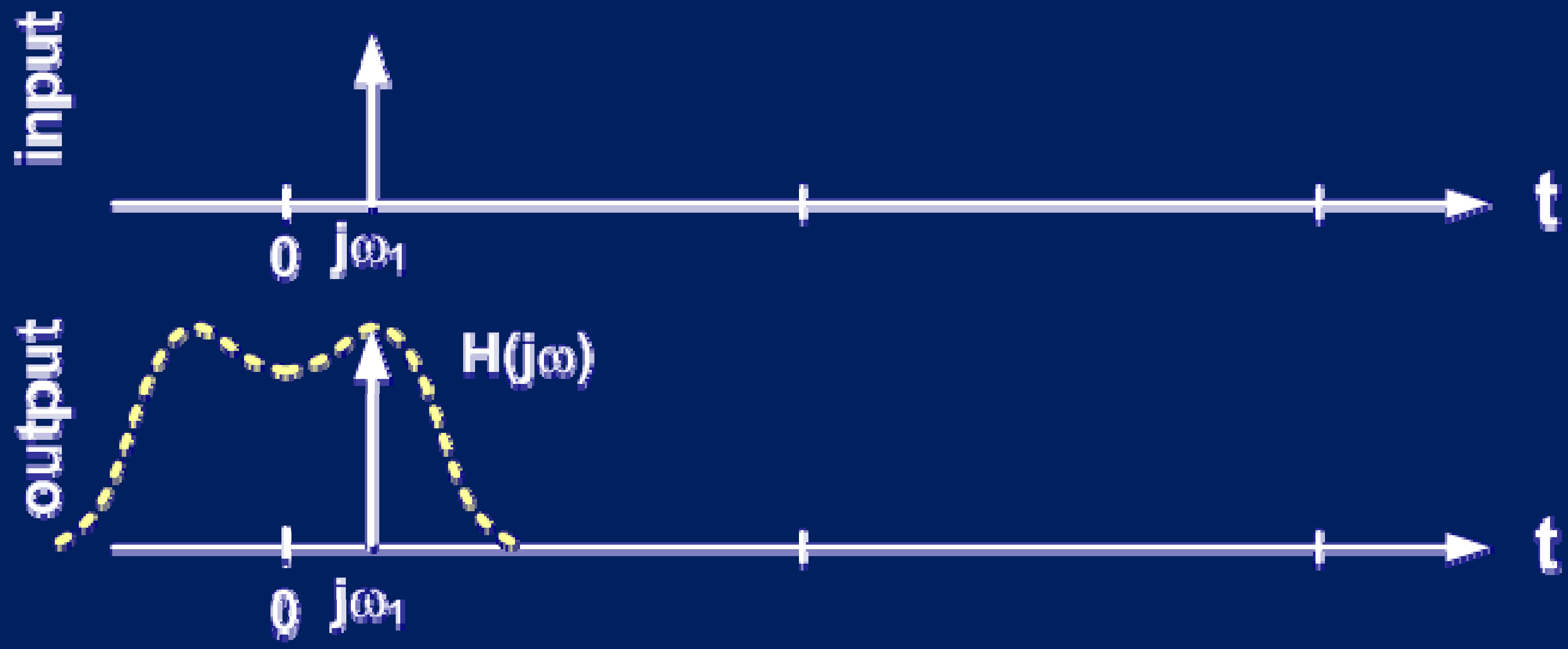
- **Relationship between $h(t,\tau)$ and $H(j\omega;t)$:**

$$H(j\omega;t) = \int_{-\infty}^{\infty} h(t,\tau) \cdot \exp(-j\omega(t-\tau))\, d\tau$$

*** L. Zadeh, "Frequency Analysis of Variable Networks," Proc. I.R.E. Mar. 1950.**

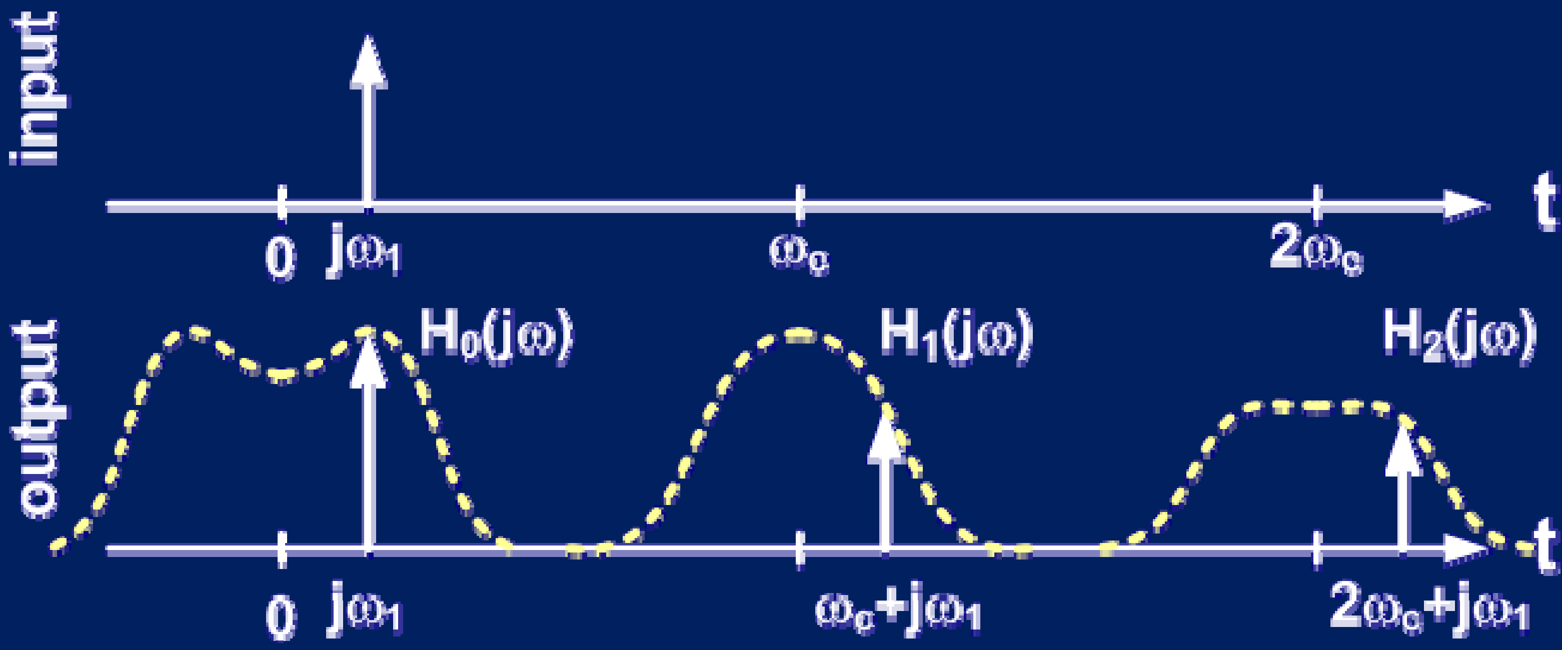
Simulating H(jω;t) via PAC Analysis

- **AC analysis reports H(jω); LTI system**



Simulating H(jω;t) via PAC Analysis

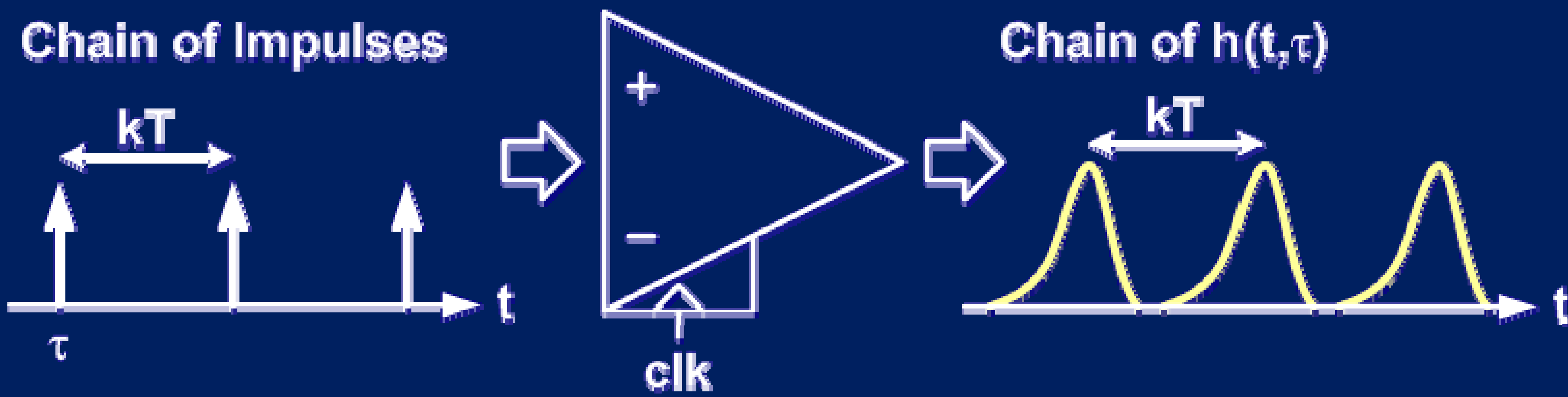
- PAC analysis reports a set of $H_m(j\omega)$



$$H(j\omega;t) = \sum_{m=-\infty}^{\infty} H_m(j\omega) \cdot \exp(jm\omega_c t)$$

Reconstructing h(t,τ) from H(jω;t)

- **Finite-point inverse Fourier transform**



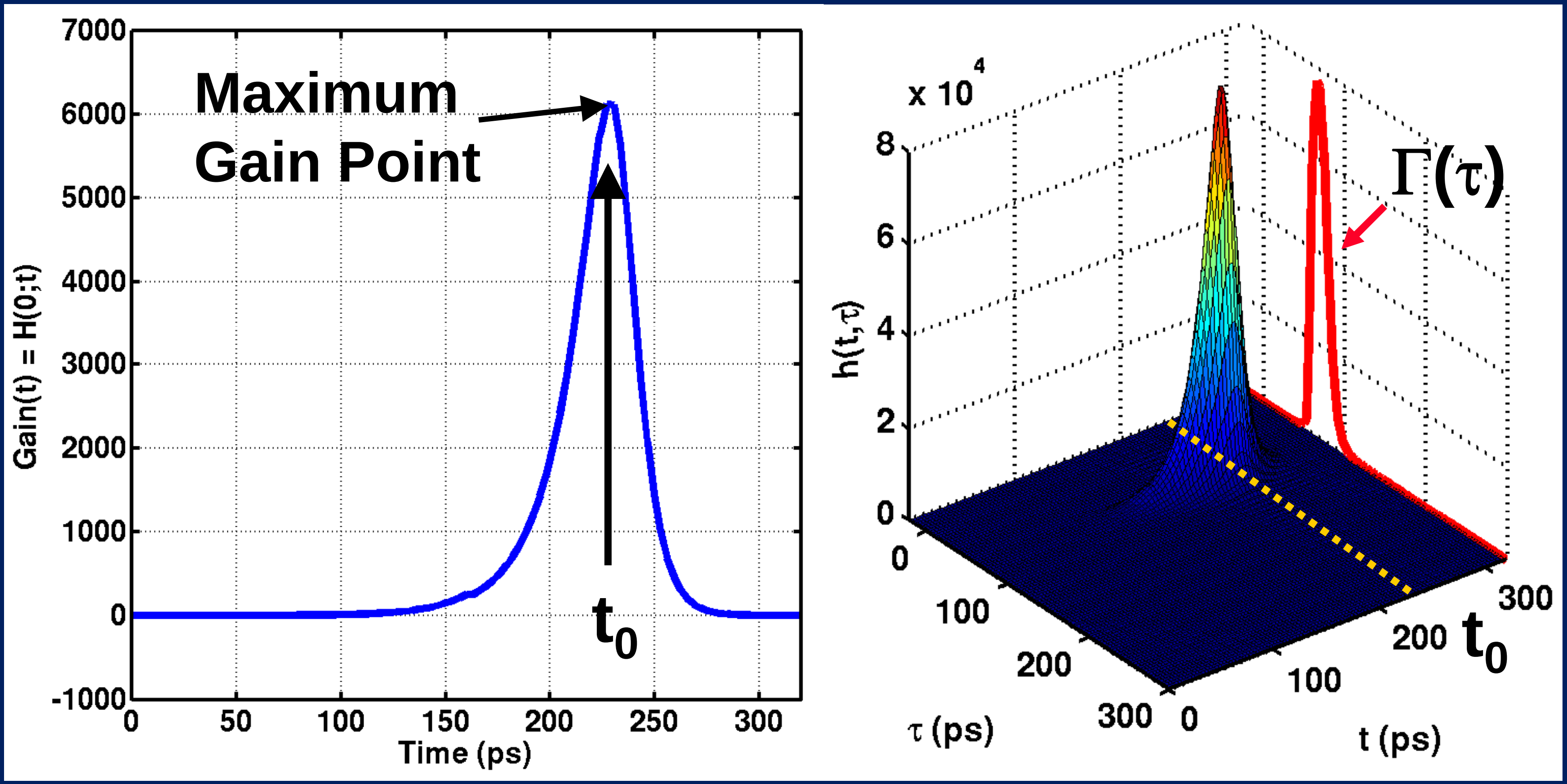
$$x(t) = \sum_{n} \delta(t - \tau - nkT)$$

$$y(t) = \sum_{n} h(t, \tau + nkT)$$

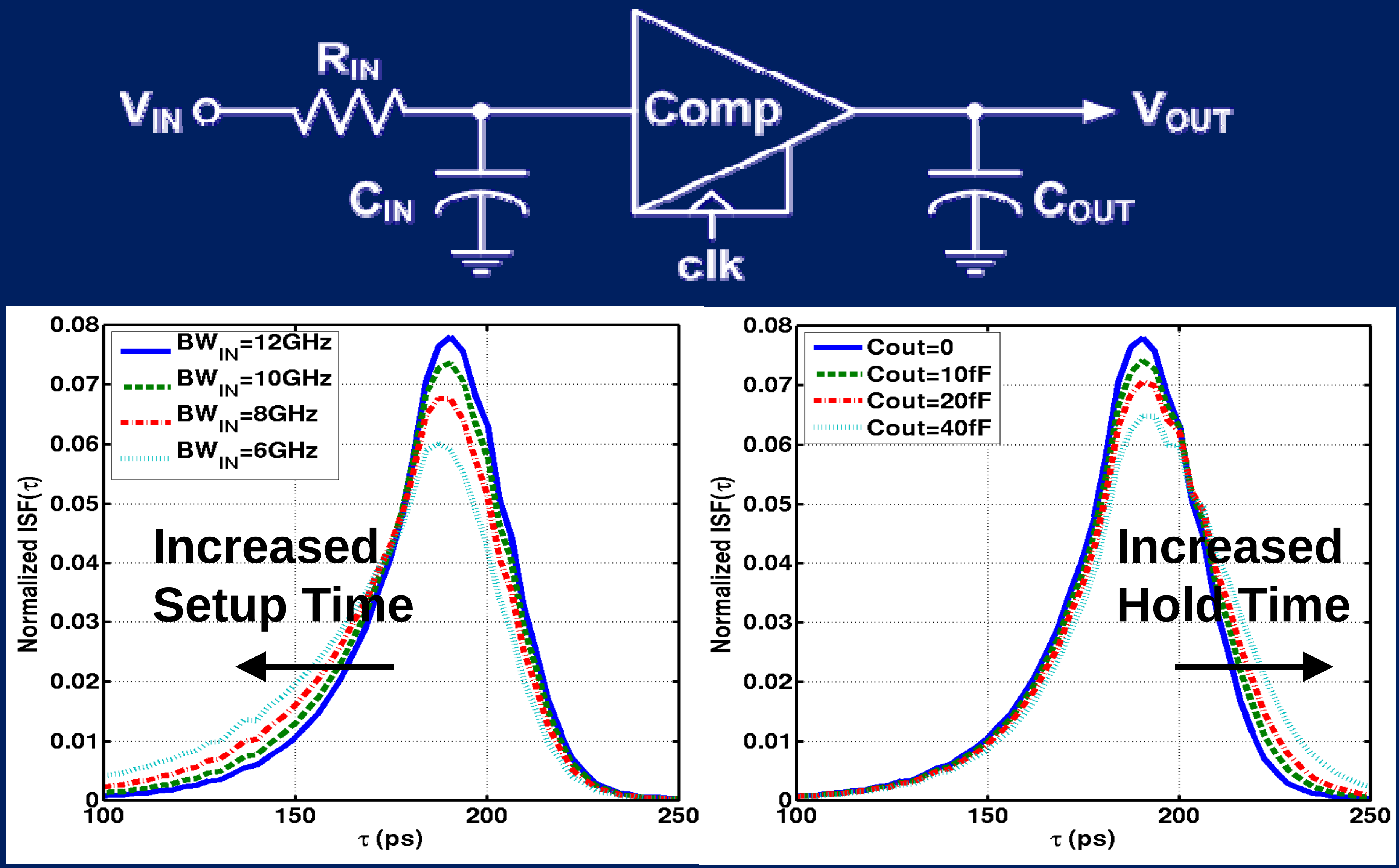
$$h(t,\tau) \cong \frac{1}{kT} \sum_{n=-\infty}^{\infty} H(jn\omega_c / k; t) \cdot \exp(jn\omega_c (t - \tau)/k)$$

Extracting ISF from $h(t,\tau)$

- ISF: $\Gamma(\tau) = h(t_0,\tau)$

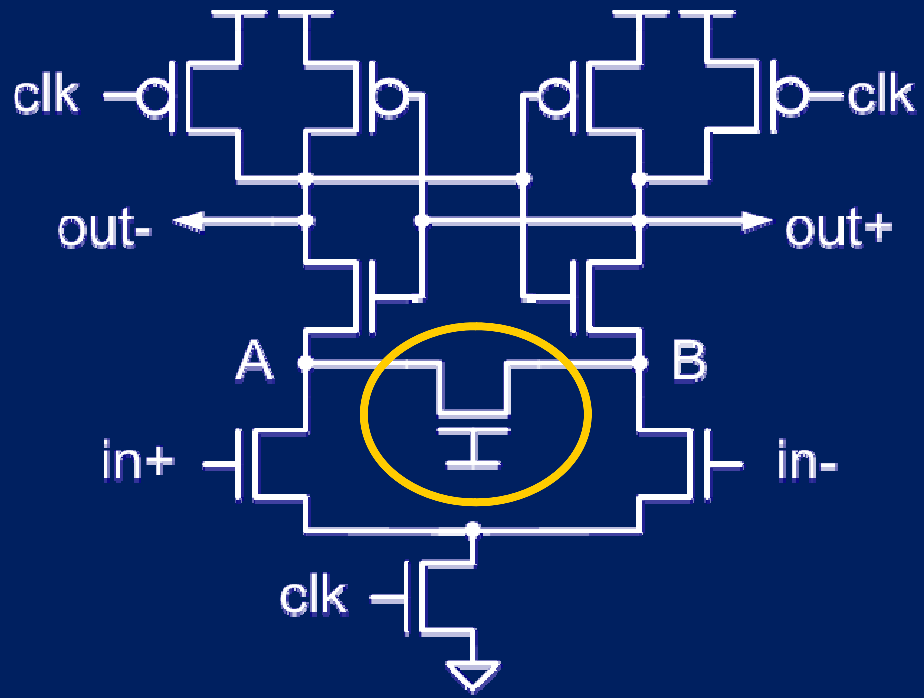


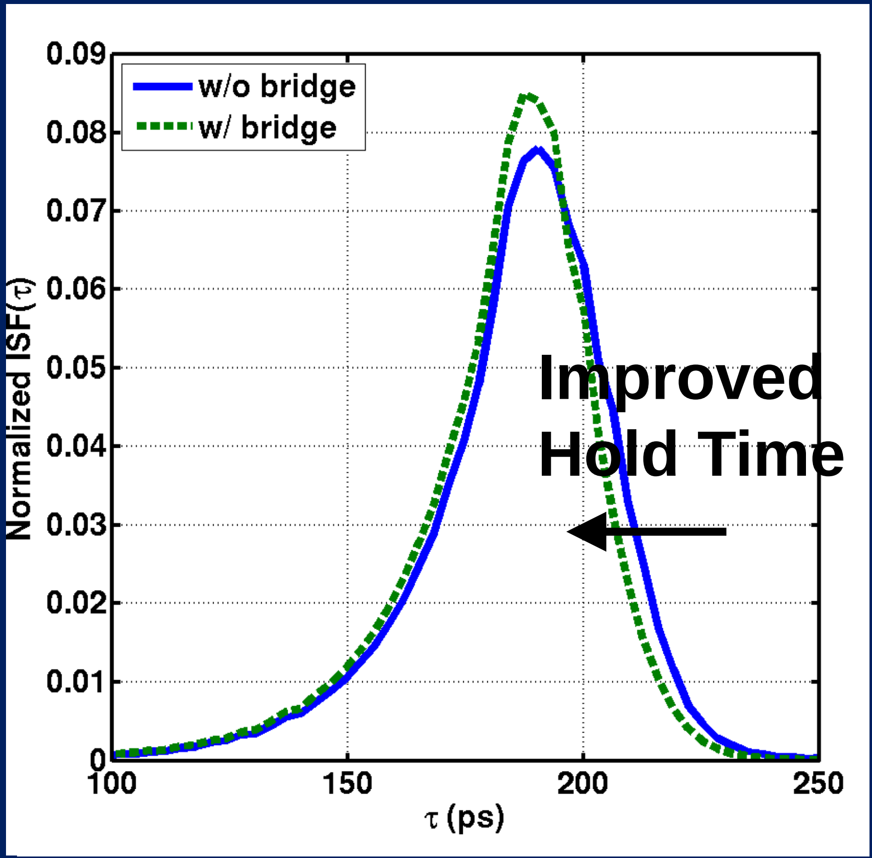
Effects of Input and Output Loading



Effects of the Bridging Device

- Improves hold time and metastability





Simulated ISF of a Ring Oscillator

- **48 sec. vs 225 sec.**