Effect of V_{DD} Noise on Phase Jitter

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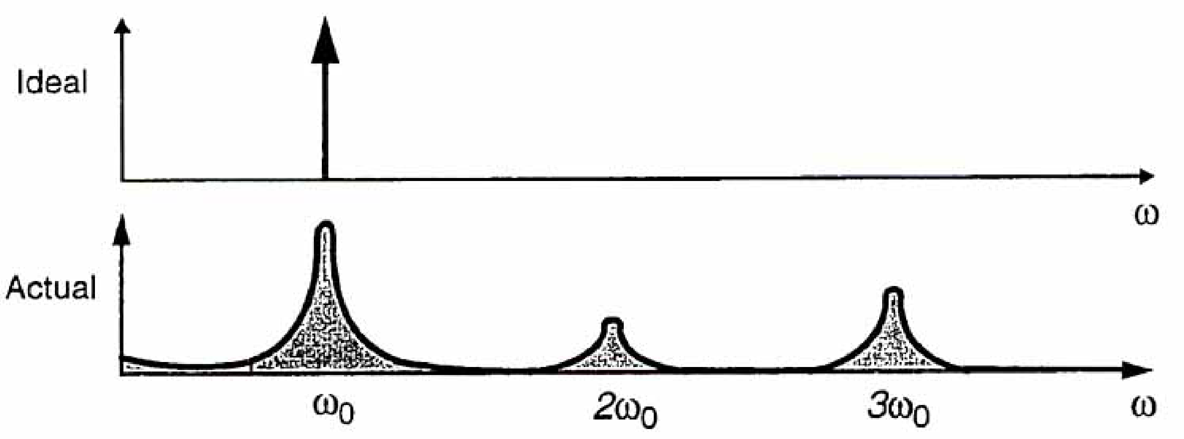
Outline

- What is phase noise and timing jitter?
- Impulse Sensitivity Function (ISF)
- Relationship of ISF and phase noise
- Minimize phase noise in circuit design
- Estimation of ISF
- Measuring ISF in circuit
- Conclusions

What is Phase Noise?

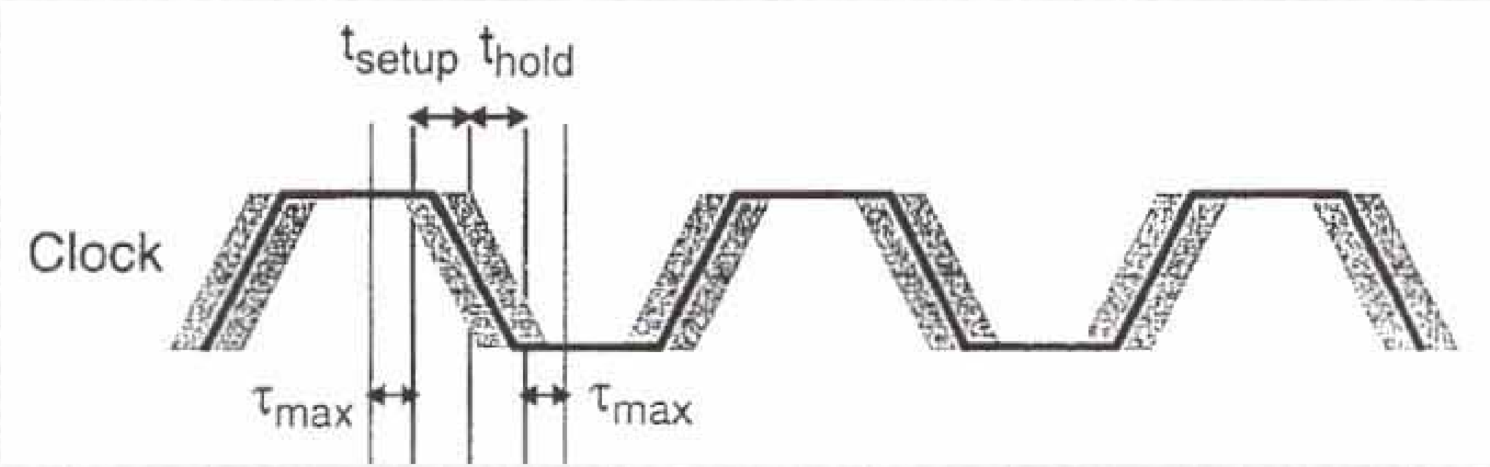
- Ideal oscillator output
  - $V_{out}(t) = V_o \cos(\omega_o t + \phi_o)$
- Practical oscillator output
  - $V_{out}(t) = V_o [1 + A(t)] \cos(\omega_o t + \phi(t))$



Timing Jitter

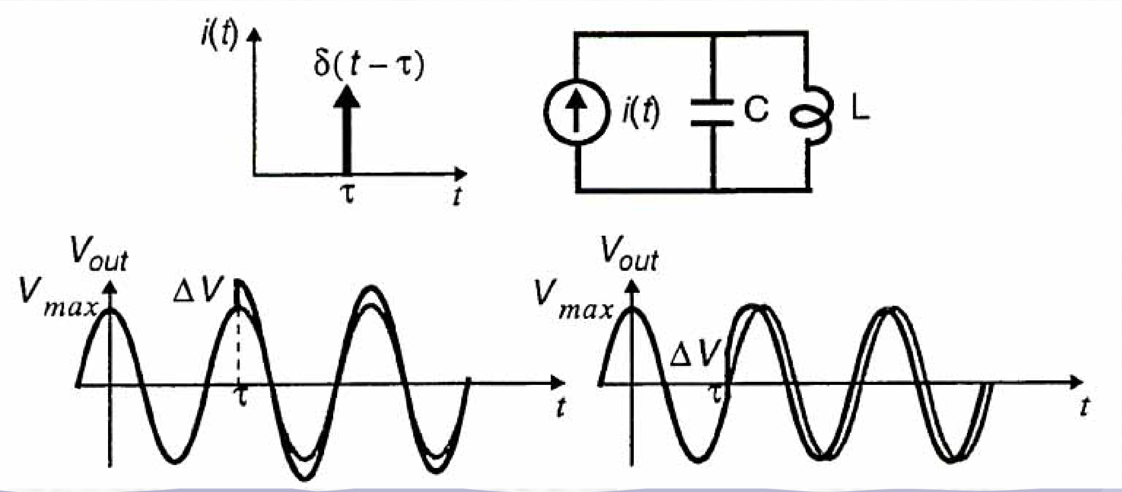
- Timing Jitter is time domain representation of phase noise
- Standard deviation of the phase uncertainty, δ_τ

$$\delta_\tau^{\ 2} = \frac{4}{\pi\omega_o}\int_0^\infty S_\phi(\omega)\sin^2\left(\frac{\omega\tau}{2}\right)d\omega$$



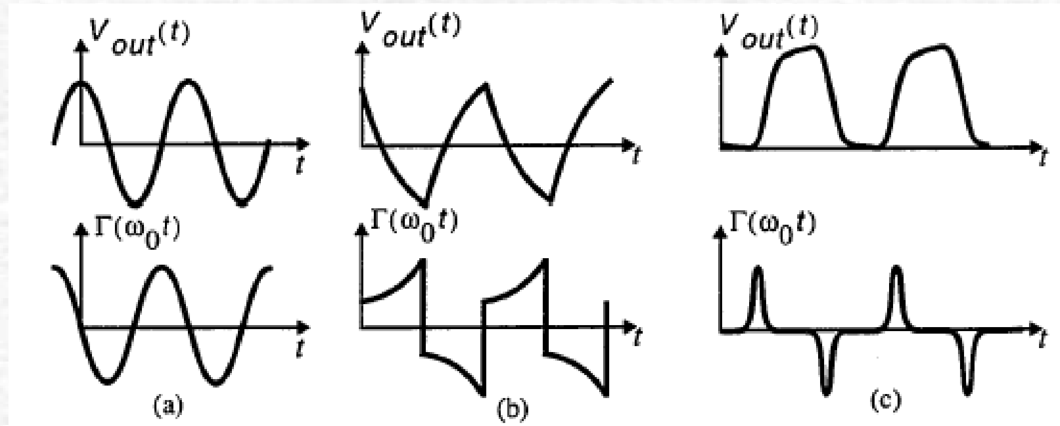
Impulse Sensitivity Function

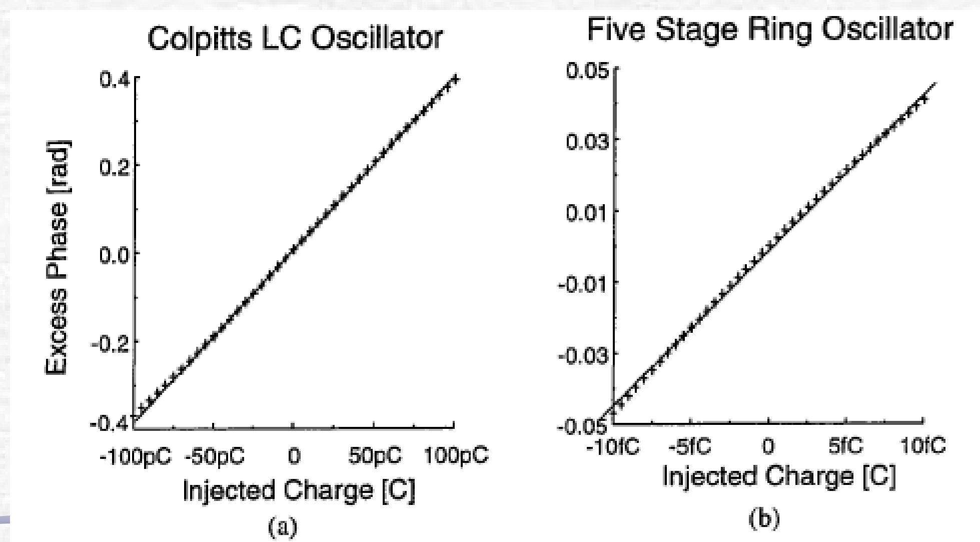
- ISF = $\Gamma(\omega_o\tau)$
- Characterizes phase response of oscillator due to arbitrary noise source
- $\Delta\phi_{impulse} = \Gamma(\omega_o\tau)\, \Delta q/q_{max}$, $\Delta q << q_{max}$
- ISF is periodic with 2π



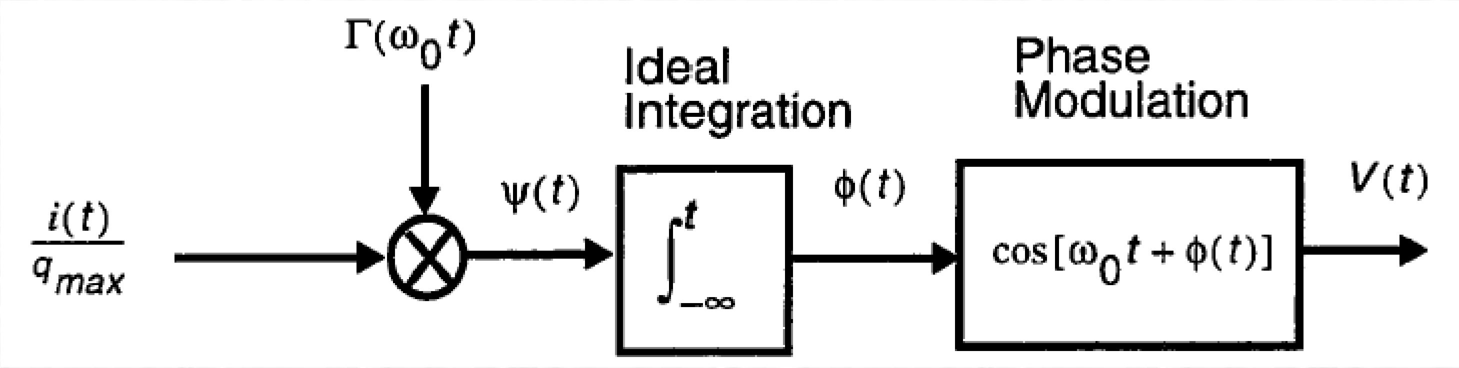
Result of ISF Simulations

- Different type of oscillations exhibit different ISF
- ISF demonstrates a LTV current to phase system





Relationship of ISF and Phase Noise



$$\phi(t) = \int_{-\infty}^{\infty} h_{\phi}(t,\tau) i(\tau) d\tau = \int_{-\infty}^{t} \frac{\Gamma(\omega_0 \tau)}{q_{max}} i(\tau) d\tau$$

$$\phi(t) = \frac{1}{q_{max}} \left[c_0 \int_{-\infty}^{t} i(\tau) d\tau + \sum_{n=1}^{\infty} c_n \int_{-\infty}^{t} i(\tau) \cos(n\omega_0 \tau) d\tau \right]$$

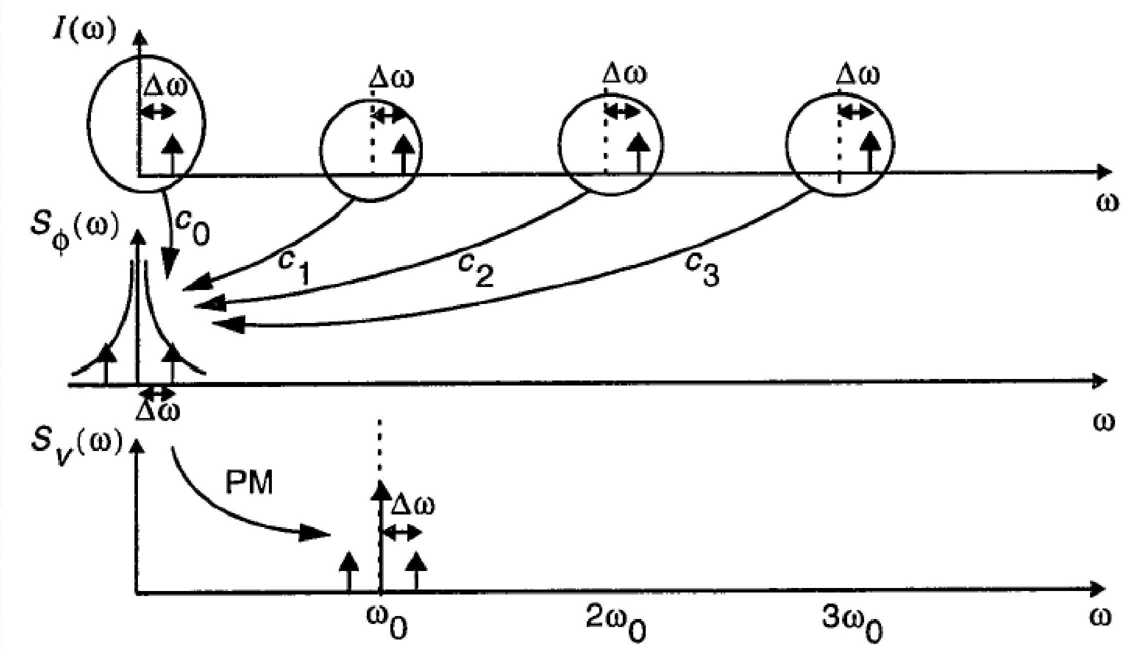
- Two step process to get phase noise
  - Linear Current to Phase conversion (ISF)
  - Nonlinear Phase to Voltage conversion

Sinusoidal Noise Source

$$i(t) = I_0 \cos(\Delta\omega t)$$

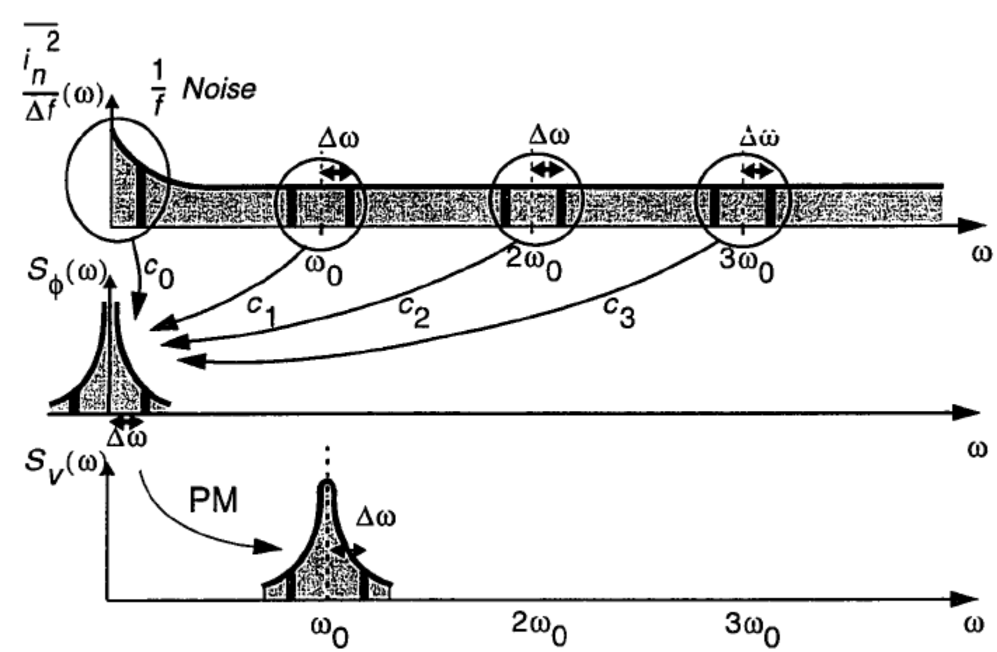
$$\phi(t) \approx \frac{I_0 c_0}{q_{max}} \int_{-\infty}^{t} \cos(\Delta\omega\tau)\,d\tau = \frac{I_0 c_0 \sin(\Delta\omega t)}{q_{max}\Delta\omega}$$

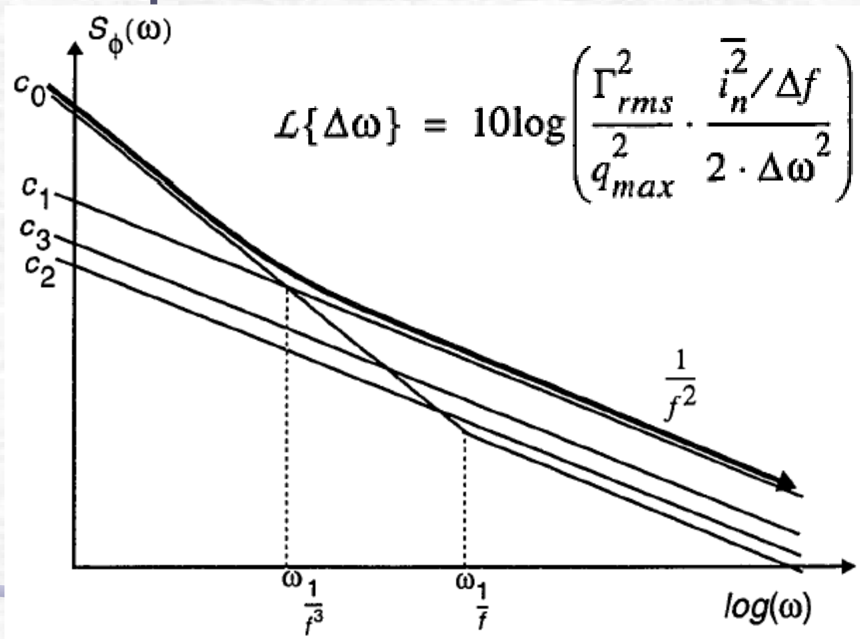
- Current at $n\omega_o + \Delta\omega$ will result in two equal sideband at $\pm\Delta\omega$ $S_\phi(\omega)$, $\Delta\omega << \omega_o$
- $S_v(\omega)$ is nonlinear transfer function with $\phi(t)$ as the input



General Noise Source

- Device's flicker noise is scaled by c_0 and become $1/f^3$ region in the phase noise spectrum



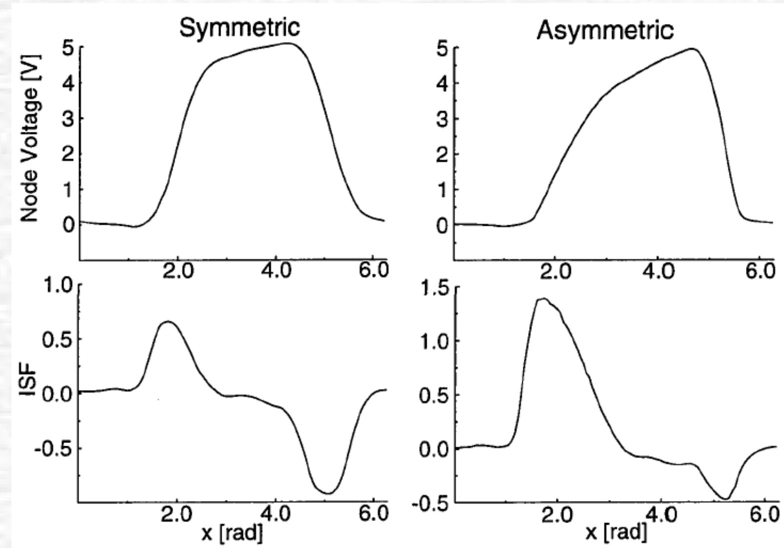


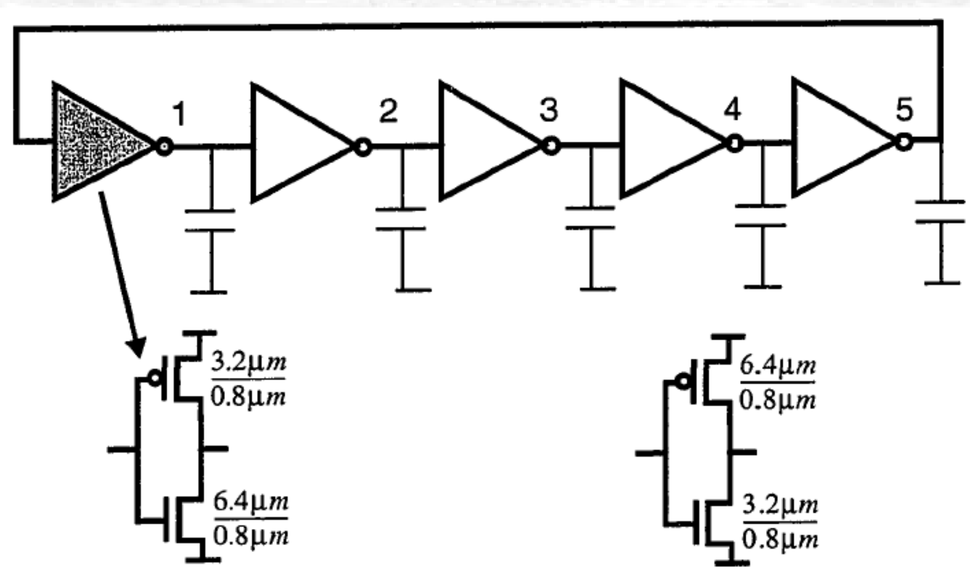
$$\mathcal{L}\{\Delta\omega\} = 10\log\left(\frac{\Gamma_{rms}^2}{q_{max}^2}\cdot\frac{\overline{i_n^2}/\Delta f}{2\cdot\Delta\omega^2}\right)$$

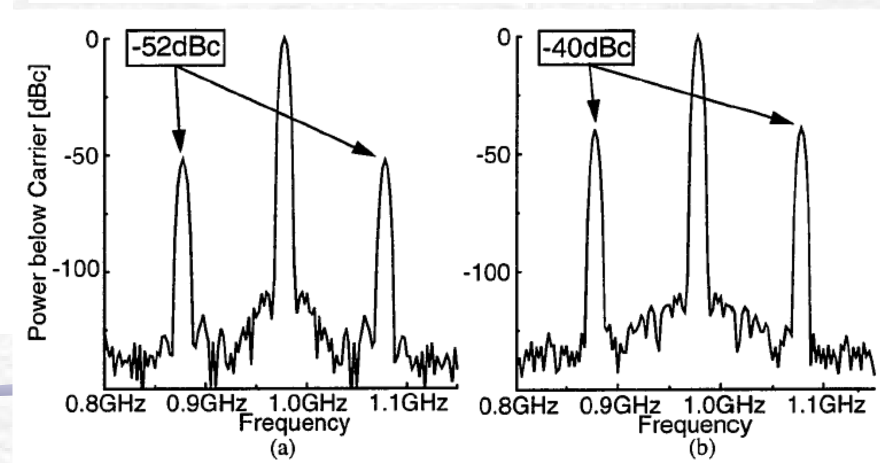
- Important to minimize the DC component of the ISF to lower $1/f^3$ corner
- Lower RMS value of ISF to lower phase noise

Minimizing Low Frequency Noise Contribution

- DC value of the ISF relates to the symmetry of the waveform

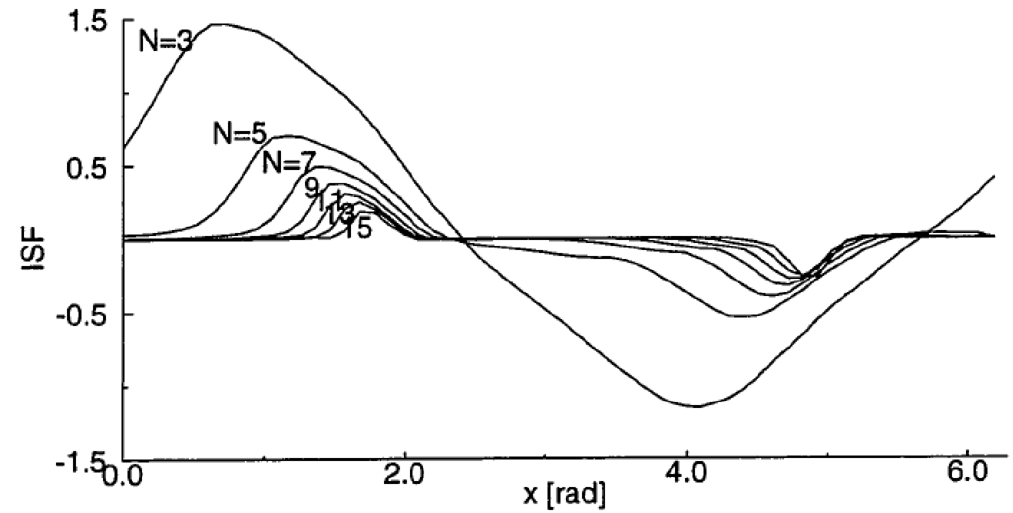


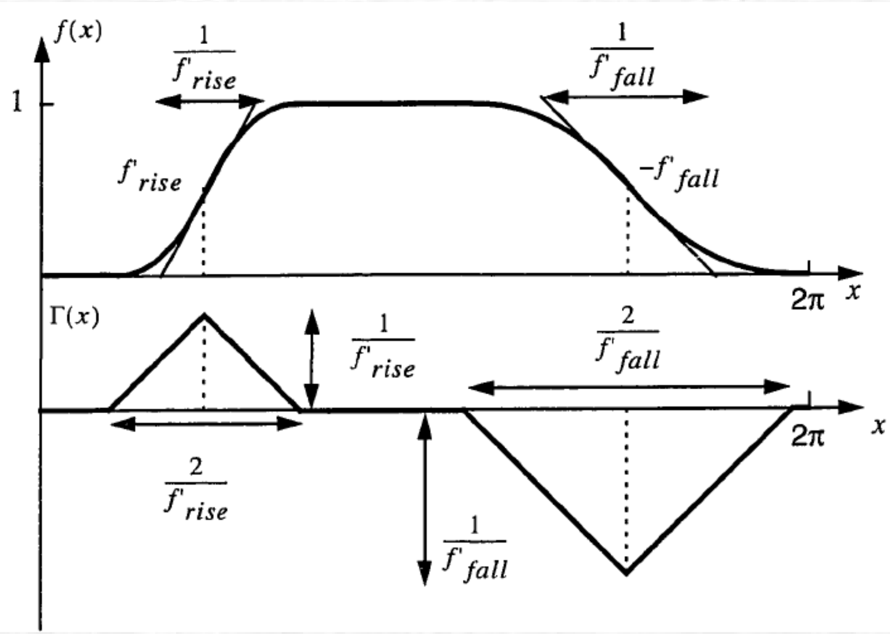




Estimation of ISF

- Estimate using triangular function
- Peak and width of ISF inversely related to slope of transition
- $A = f_{rise}/f_{fall}$





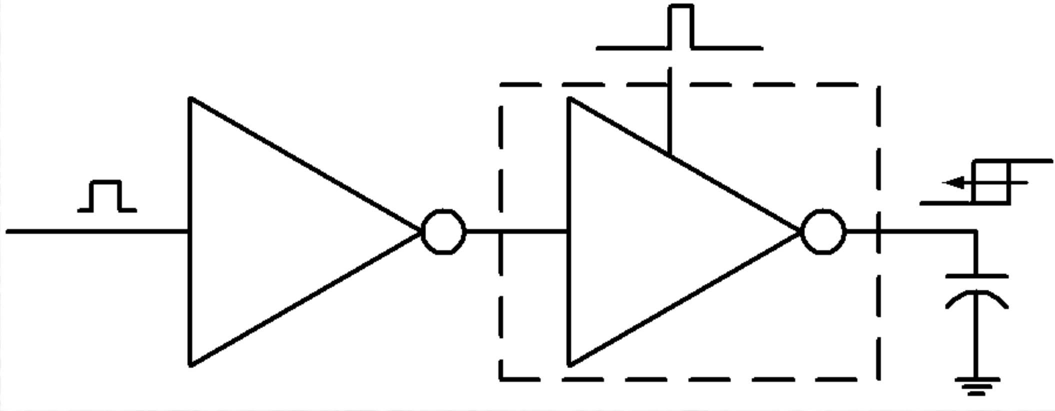
$$\Gamma_{rms}^2 = \frac{1}{\pi}\left[\int_0^{1/f'_{rise}} x^2 dx + \int_0^{1/f'_{fall}} x^2 dx\right] = \frac{1}{3\pi}\left(\frac{1}{f'_{rise}}\right)^3 (1 + A^3)$$

$$\Gamma_{dc} = \frac{2\pi}{\eta^2} \frac{1}{N^2}\left(\frac{1 - A}{1 + A}\right)$$

Measuring ISF for V_{DD} Noise

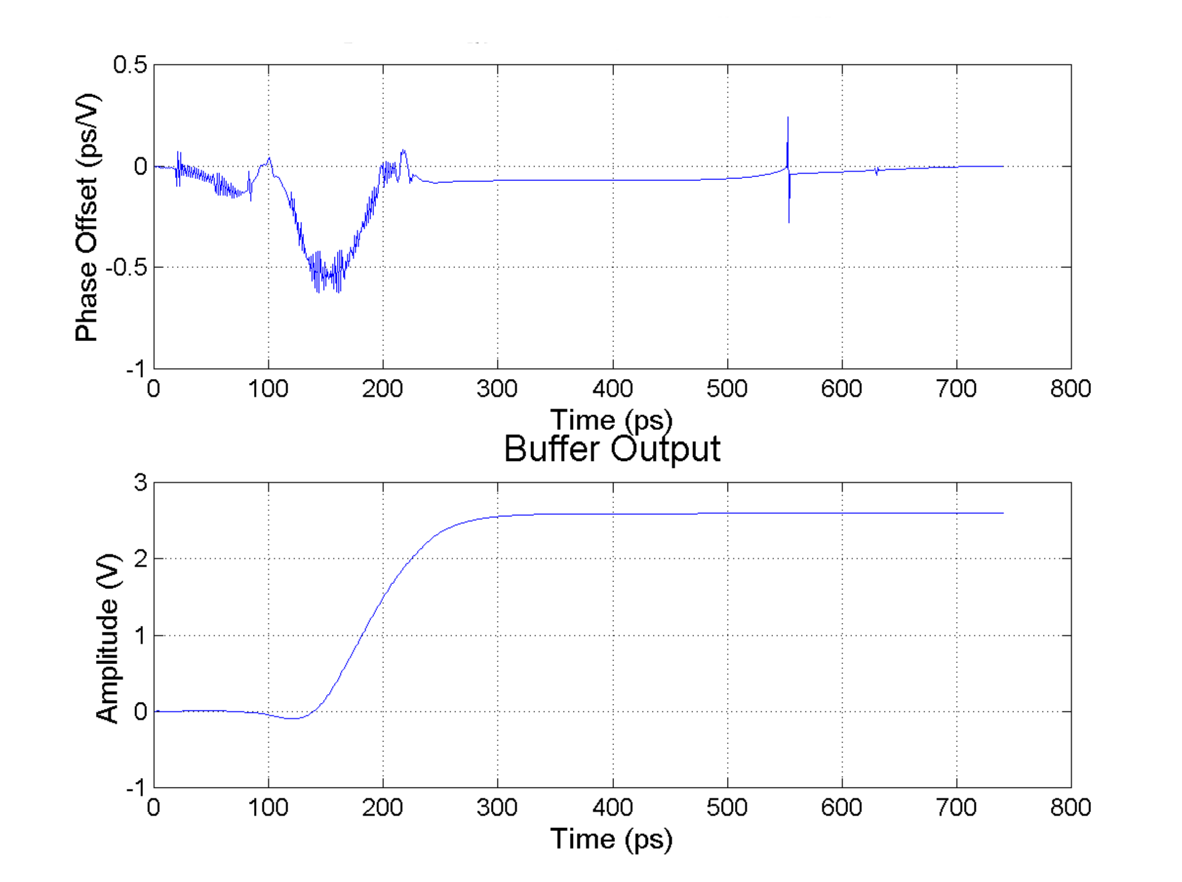
Clock Buffer Characterization

- Fix input clock transition time
- Apply impulse function noise source to V_{DD}
- Measure ½V_{DD} crossing of output
- Sweep transition time of V_{DD} noise
- Compare results with noiseless case to get phase change



Measuring ISF for V_{DD} Noise

- V_{DD} noise simulation
- Agrees with earlier analysis on shape of ISF
- Maximum occurs at the transition



Conclusions

- Phase noise and timing jitter are related
- RMS and DC value of ISF directly relates to the shape of the phase noise spectrum
- Design goal: symmetry is important for minimizing phase noise
- The ISF can be used to calculate the phase jitter due to supply noise