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
  \[ V_{\text{out}}(t) = V_0 \cos(\omega_0 t + \phi_0) \]

- Practical oscillator output
  \[ V_{\text{out}}(t) = V_0 [1 + A(t)] \cos(\omega_0 t + \phi(t)) \]
Timing Jitter

Timing Jitter is time domain representation of phase noise.

Standard deviation of the phase uncertainty, $\delta_\tau$

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

![Clock Diagram with setup and hold times](image)
Impulse Sensitivity Function

- ISF = $\Gamma(\omega_0 \tau)$
- Characterizes phase response of oscillator due to arbitrary noise source

$\Delta\phi_{\text{impulse}} = \Gamma(\omega_0 \tau) \Delta q/q_{\text{max}}, \Delta q \ll q_{\text{max}}$

- ISF is periodic with $2\pi$
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

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

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

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

\[ i(t) = I_0 \cos(\Delta \omega t) \]

Current at \( n\omega_0 + \Delta \omega \) will result in two equal sideband at \( \pm \Delta \omega \) \( S_\phi(\omega) \), \( \Delta \omega \ll \omega_0 \)

\( S_\nu(\omega) \) 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.

\[
\mathcal{L}\{\Delta \omega\} = 10 \log \left( \frac{\Gamma_{\text{rms}}^2}{q_{\text{max}}^2} \cdot \frac{\bar{i}_n^2}{\Delta f} \cdot \frac{1}{2 \cdot \Delta \omega^2} \right)
\]

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
- \( A = \frac{f_{\text{rise}}}{f_{\text{fall}}} \)

\[
\Gamma_{rms}^2 = \frac{1}{\pi} \left[ \int_0^{1/f_{\text{rise}}} x^2 \, dx + \int_0^{1/f_{\text{fall}}} x^2 \, dx \right] = \frac{1}{3\pi} \left( \frac{1}{f_{\text{rise}}} \right)^3 (1 + A^3)
\]

\[
\Gamma_{dc} = \frac{2\pi}{\eta^2 N^2} \left( \frac{1-A}{1+A} \right)
\]
Measuring ISF for $V_{DD}$ Noise

Clock Buffer Characterization

- Fix input clock transition time
- Apply impulse function noise source to $V_{DD}$
- Measure $\frac{1}{2}V_{DD}$ 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