3

Phase Noise Measurement with Sigma-Delta TDC

Daiki Hirabayashi, Yusuke Osawa, Naohiro Harigai, Haruo Kobayashi

Osamu Kobayashi †, Kiichi Niitsu ‡, Takahiro J. Yamaguchi, Nobukazu Takai

Division of Electronics and Informatics, Gunma University, Kiryu 376-8515 Japan email: k_haruo@el.gunma-u.ac.jp

† Semiconductor Technology Academic Research Center (STARC) , Yokohama 222-0033 Japan

‡ Graduate School of Engineering, Nagoya University, Nagoya 464-8603 Japan

Introduction

Background

Conventional Phase Noise Measurement

- Spectrum analyzers are necessary
- Measurement for a long time

Very costly!!

In order to test many LSIs in parallel...

Many spectrum analyzers

Research Objective

Measure the phase noise without a spectrum analyzer

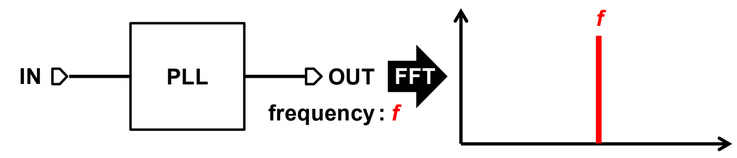
Sigma-Delta TDC

- Good linearity
- Small circuitry
- Fine time resolution
- The phase noise power spectrum can be obtained by FFT of ΣΔ TDC output

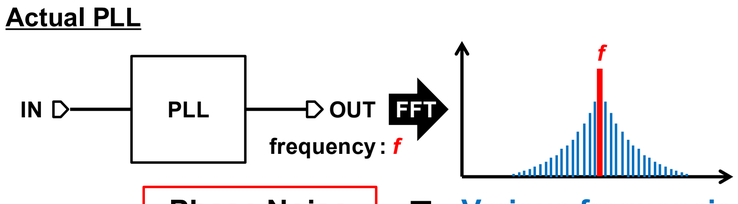
Low Cost & High Quality Test

Phase Noise

Ideal PLL



Actual PLL



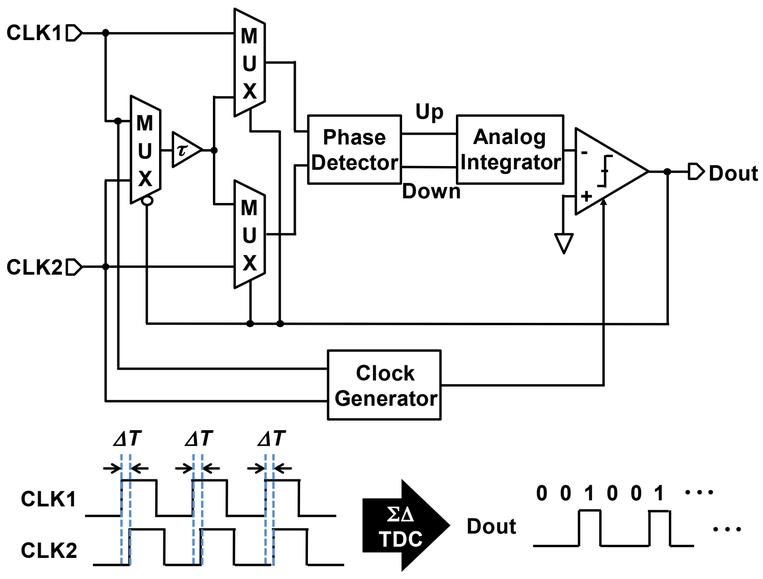
Phase Noise = **Various frequencies**

cause errors in communication systems

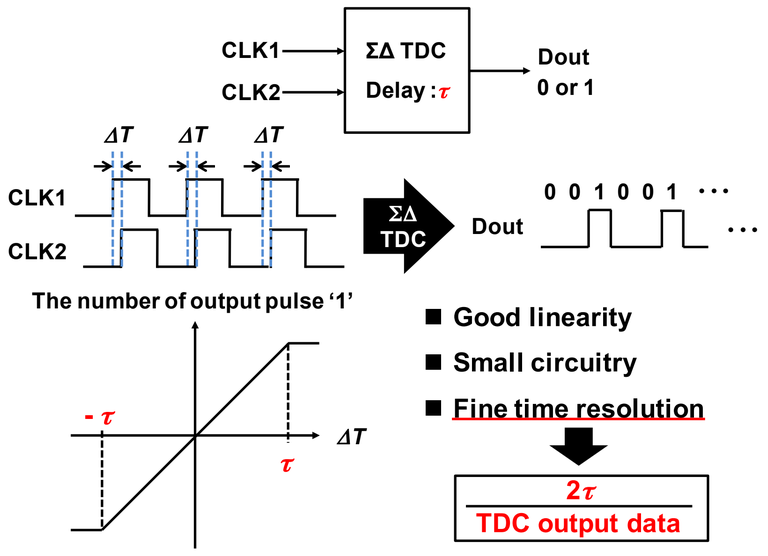
Its measurement & testing is necessary

Measurement Technique & Simulation

Block Diagram of Sigma-Delta TDC



Operation of Sigma-Delta TDC

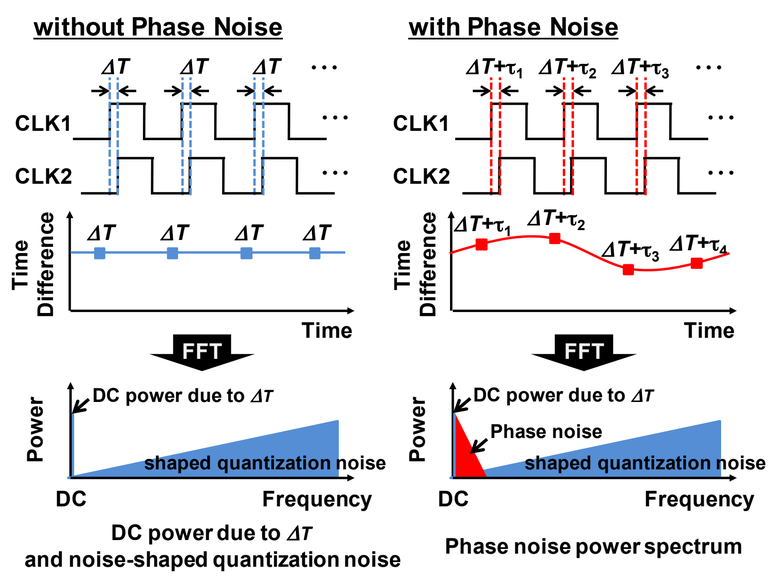


- Good linearity
- Small circuitry
- Fine time resolution

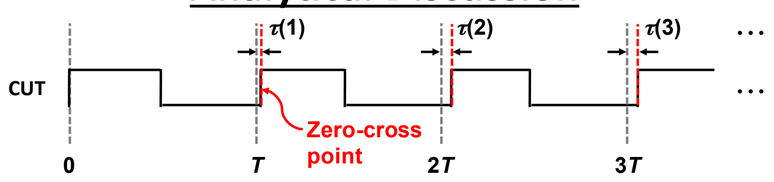
$\frac{2\tau}{\text{TDC output data}}$

The longer measurement time, the finer the time resolution.

Principle of Phase Noise Measurement



Analytical Discussion



CUT (CLK1) with phase noise $\phi(t)$

$$CUT \approx sin\left(2\pi f_{in} t + \phi(t)\right)$$

The m-th zero-crossing rising edge timing
(Phase from the reference CLK2 without phase noise)

$$2\pi f_{in}\left(mT + \tau(m)\right) + \phi(mT) = 2\pi m$$

$$\therefore \phi(mT) = -2\pi f_{in}\tau(m)$$

τ(m) : the zero-crossing variation function and sinusoidal input ωj

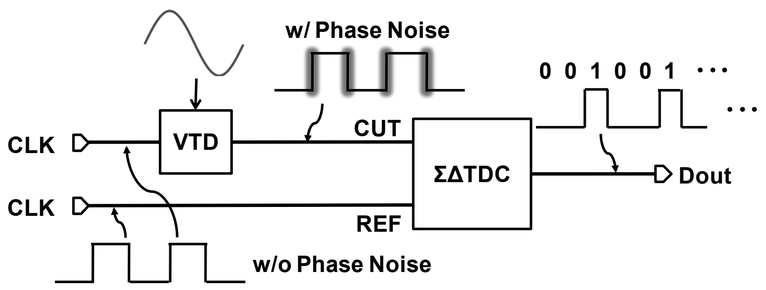
$$\tau(m) = T \cdot \alpha_j \cdot sin\left(\omega_j \cdot mT\right)$$

$$\phi(mT) = -2\pi\alpha_j \cdot sin\left(\omega_j \cdot mT\right)$$

$$\therefore \Phi(\omega_j) = \frac{1}{2}\left(2\pi\alpha_j\right)^2$$

Phase noise power spectrum

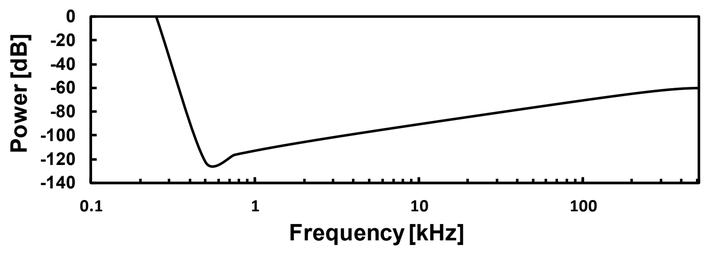
MATLAB Simulation



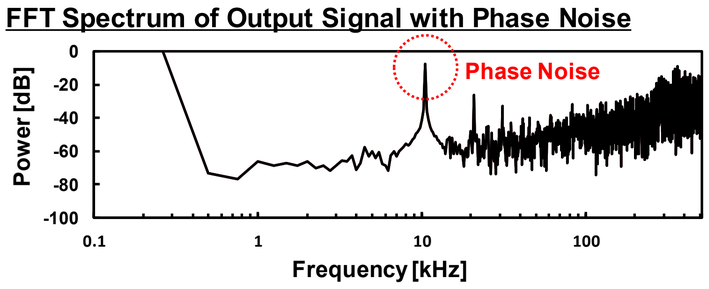
Simulation Conditions	
Delay of ΣΔ TDC (τ)	200ns
Input frequency	1MHz
Phase variation of CUT	10kHz
The number of ΣΔ TDC data	4096

Simulation Result

FFT Spectrum of Output Signal without Phase Noise

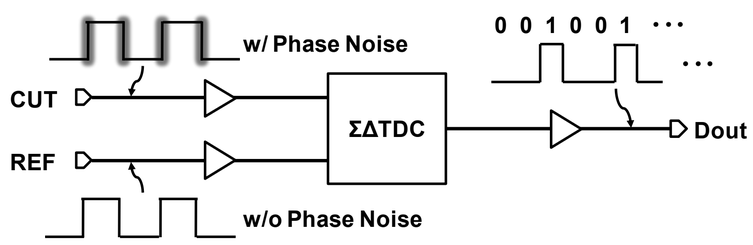


FFT Spectrum of Output Signal with Phase Noise



Phase Noise

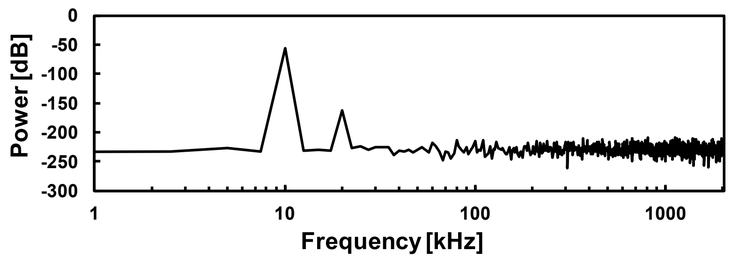
SPECTRE Simulation



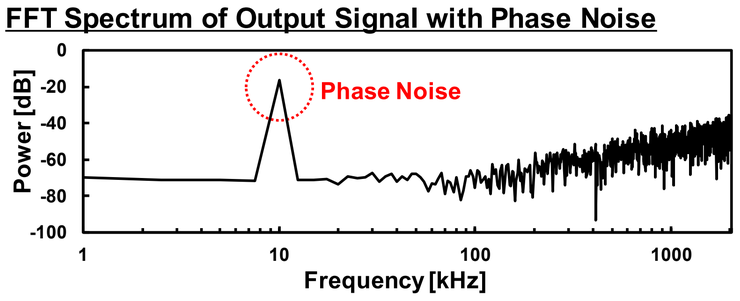
Simulation Conditions	
Process	180nm CMOS
Delay of ΣΔ TDC (τ)	500ps
Input frequency	10.24MHz
Phase variation of CUT	10kHz
The number of ΣΔ TDC data	4096

Simulation Result

Spectrum of Input Signal with Phase Noise



FFT Spectrum of Output Signal with Phase Noise



Conclusion

- Proposal of phase noise measurement using sigma-delta TDC.
- Verification by MATLAB and SPECTRE simulations.
- A multi-bit sigma-delta TDC with linearization techniques can further reduce the measurement time.
- Low cost and high quality phase noise test can be realized.