P74

Phase Noise Measurement with Delta-Sigma TDC

Yusuke Osawa, Daiki Hirabayashi, 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

Kobayashi Laboratory

Introduction

Background

Conventional Phase Noise Measurement

- **Expensive** spectrum analyzer
- **Long** measurement time (~10seconds)

LSI mass production test

Significant test cost

Research Objective

Measurement the phase noise without using a spectrum analyzer

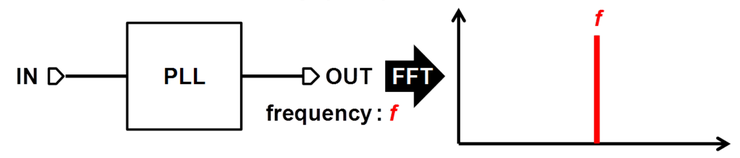
Delta-Sigma TDC (Time-to-Digital Converter)

- ✓ Good linearity
- ✓ Small circuitry
- ✓ Fine time resolution
- ✓ The phase noise frequency characteristics can be obtained by FFT

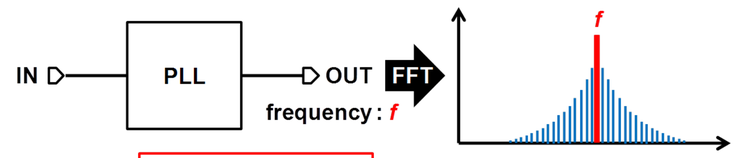
Low Cost & High Quality Test

Phase Noise

Ideal Phase-Locked Loop (PLL)



Actual Phase-Locked Loop (PLL)



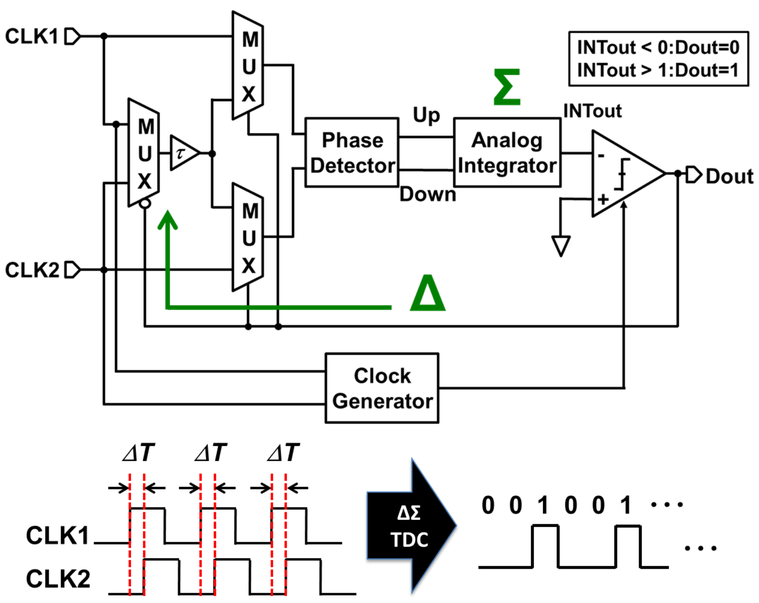
Phase Noise = Various frequencies

cause an error in the system

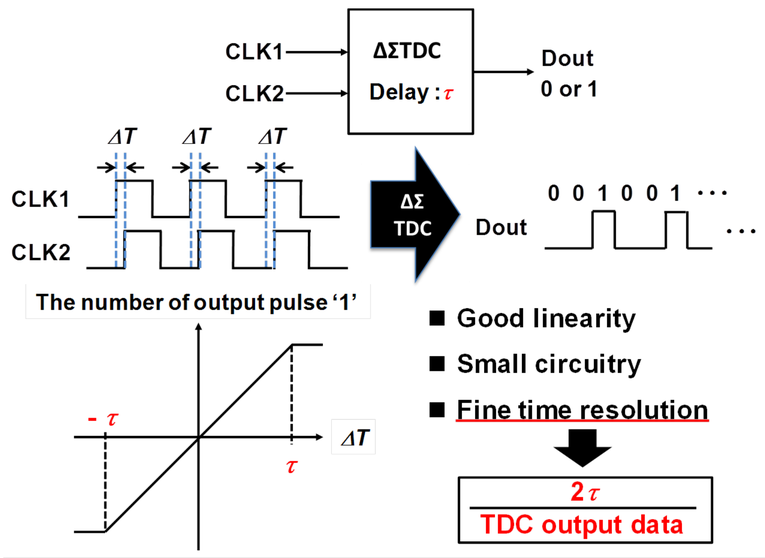
It is necessary to measure the noise amount

Simulation & Measurement Technique & Phase Noise

Block Diagram of Delta-Sigma TDC



Principle of Delta-Sigma TDC

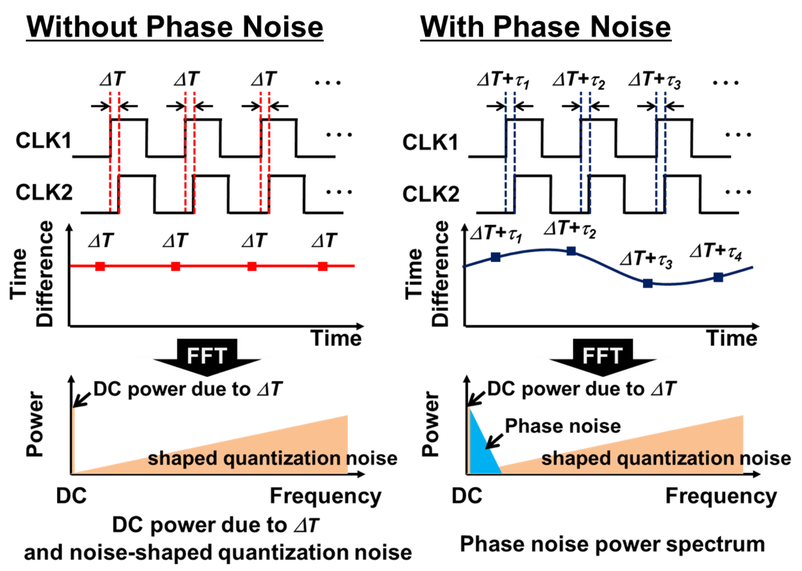


- Good linearity
- Small circuitry
- Fine time resolution

2τ / TDC output data

The longer measurement time, the finer the time resolution.

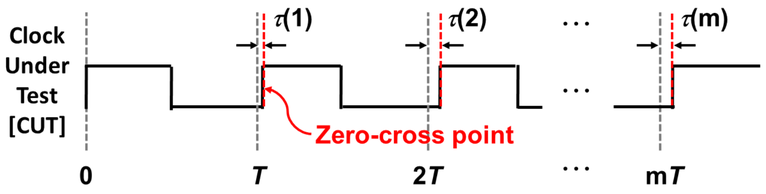
Principle of Phase Noise Measurement



DC power due to ΔT and noise-shaped quantization noise

Phase noise power spectrum

Analytical Discussion



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

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

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

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

$$\therefore \phi(mT) = -2\pi f_{in}\tau(m)$$: Phase Noise (time domain)

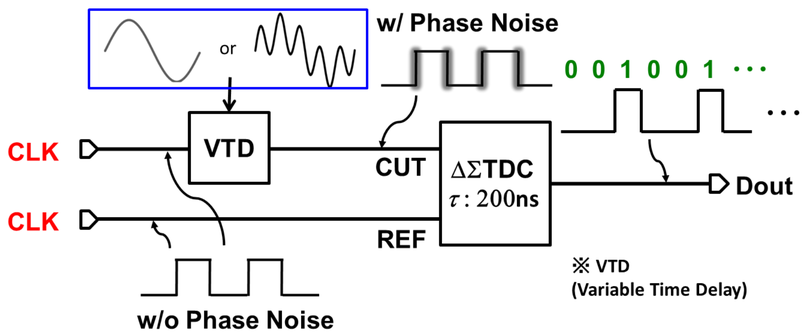
$\tau(m)$: the zero-crossing variation function and sinusoidal input ω_1

$$\tau(m) = T \cdot \alpha_1 \cdot \sin(\omega_1 mT)$$

$$\phi(mT) = -2\pi\alpha_1 \cdot \sin(\omega_1 mT)$$

$$\therefore \Phi(\omega_1) = \frac{1}{2}(2\pi\alpha_1)^2$$: Phase Noise (frequency domain)

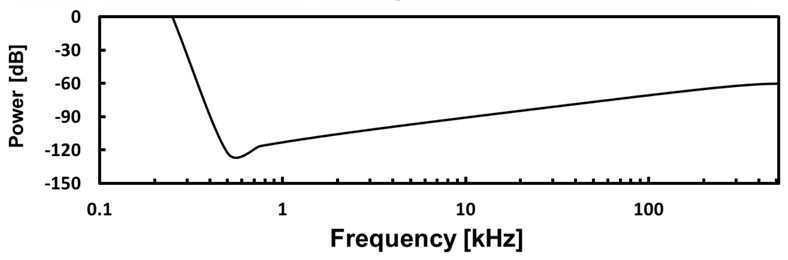
MATLAB Simulation



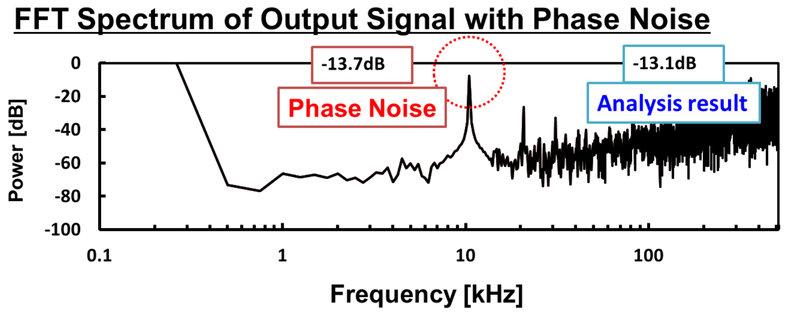
Simulation Conditions			
Case	Ⅰ	Ⅱ	Ⅲ
Delay of ΣΔ TDC (τ)	200ns	200ns	200ns
Input frequency	1MHz	1MHz	1MHz
Phase variation of CUT	10kHz	50kHz	10kHz & 50kHz
The number of ΣΔ TDC (τ) data	4096	4096	4096

Simulation Result (Ⅰ)

FFT Spectrum of Output Signal without Phase Noise

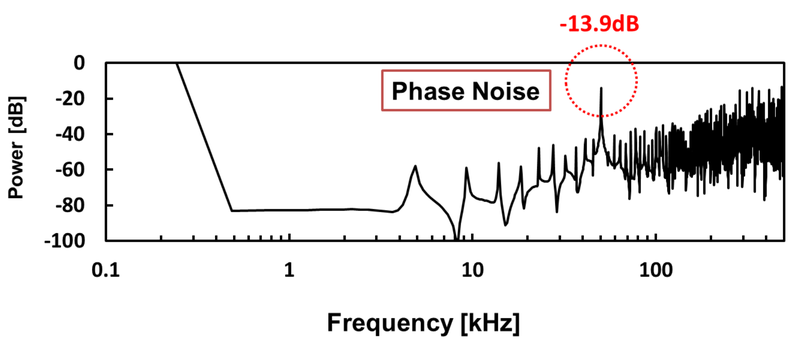


FFT Spectrum of Output Signal with Phase Noise



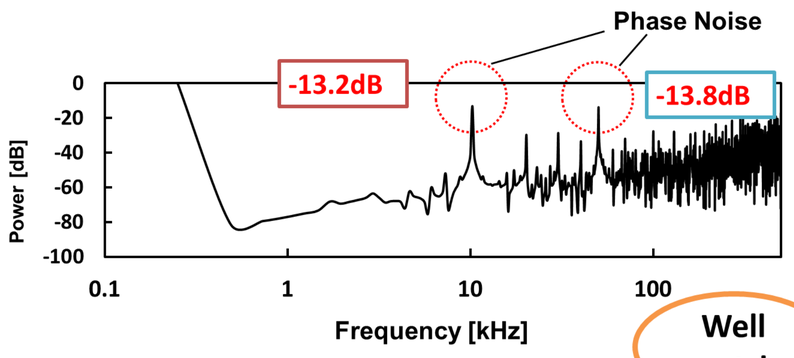
Simulation Result (Ⅱ)

FFT Spectrum with Phase Noise at 50kHz



Simulation Result (Ⅲ)

FFT Spectrum with Phase Noise at 10kHz and 50kHz



Well match

Single sinusoidal phase noise result

Ⅰ . 10kHz	Ⅱ . 50kHz
-13.7dB	-13.9dB

Linear superposition

Conclusion

- We have proposed a phase noise measurement technique for a clock using a delta-sigma TDC.
- We have verified effectiveness of the proposed method by MATLAB simulations.
- A multi-bit delta-sigma TDC with linearization techniques can further reduce the measurement time.
- Low cost and high quality phase noise test can be realized.