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Phase Noise Measurement Technique Using Delta-Sigma TDC Without Reference Clock

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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

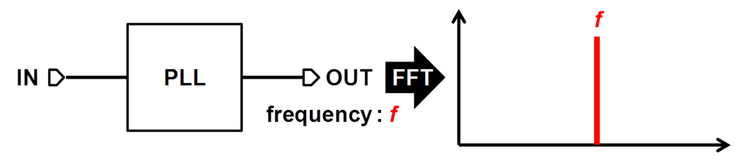
Delta-Sigma TDC (Time-to-Digital Converter)

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

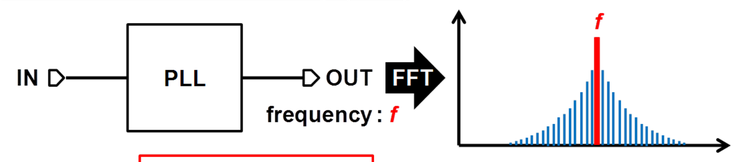
Low Cost & High Quality Test

Phase Noise

Ideal Phase-Locked Loop (PLL)



Actual Phase-Locked Loop (PLL)



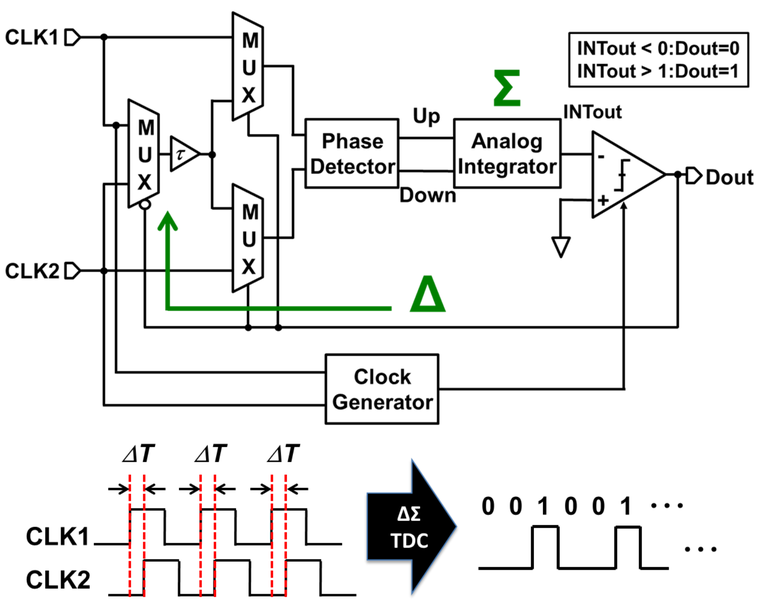
Phase Noise = Various frequencies

cause an error in the system

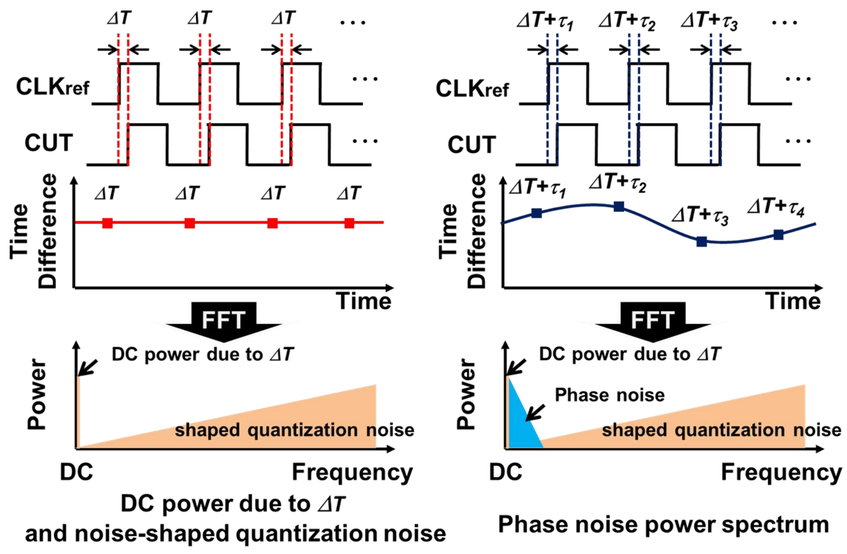
It is necessary to measure the noise amount

Phase Noise Measurement Technique & Simulation

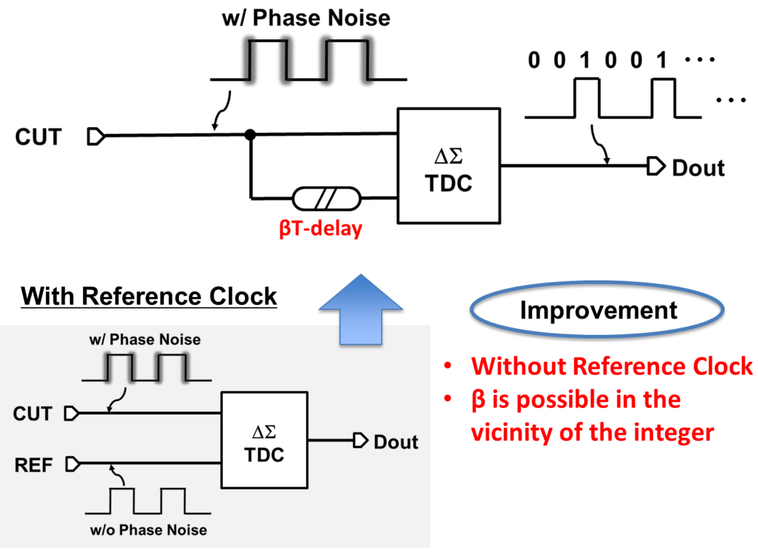
Block Diagram of Delta-Sigma TDC



Principle of Phase Noise Measurement With Reference Clock

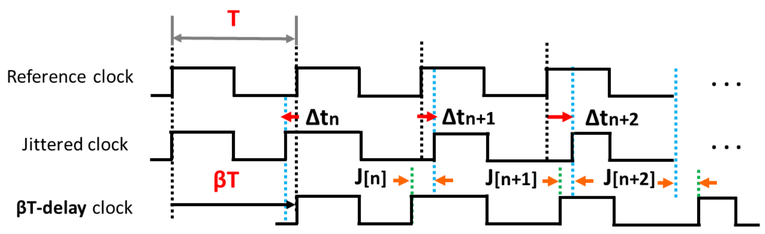


Phase Noise Measurement Technique Without Reference Clock



Measurement Technique & Simulation

Analytical Discussion



$$J(n) = \Delta t(n+1) - \Delta t(n)$$
$$= \tau(m+1) - \tau(m) + (\beta - 1)T$$
$$= T \cdot \alpha_1[sin(\omega_1(m+1)T) - sin(\omega_1 \cdot mT)] + (\beta - 1)T$$
$$= 2T \cdot \alpha_1 \, sin(\omega_1 T/2) \, cos(\omega_1(m + 1/2)T) + (\beta - 1)T$$

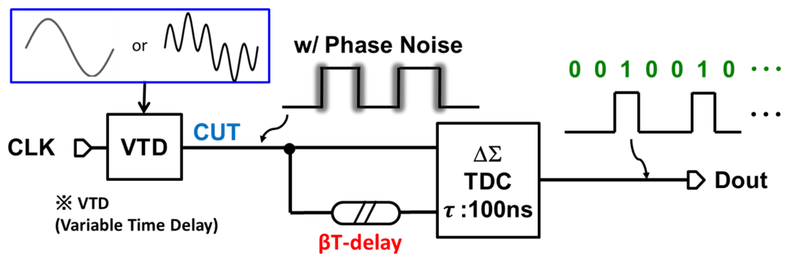
Phase Noise (time domain)

$$\therefore \phi'(mT) = 2T \cdot \alpha_1 \, sin(\omega_1 T/2) \, cos(\omega_1(m + 1/2)T)$$

Phase Noise (frequency domain)

$$\therefore \Phi'(\omega_1) = \frac{1}{2}(2\pi\alpha_1)^2 \, [2 \sin 2(\omega_1 T/2)]^2$$
$$\cong \frac{1}{2}(2\pi\alpha_1)^2 {\omega_1}^2 T^2 \qquad (\because \omega_1 T/2 \ll 1)$$

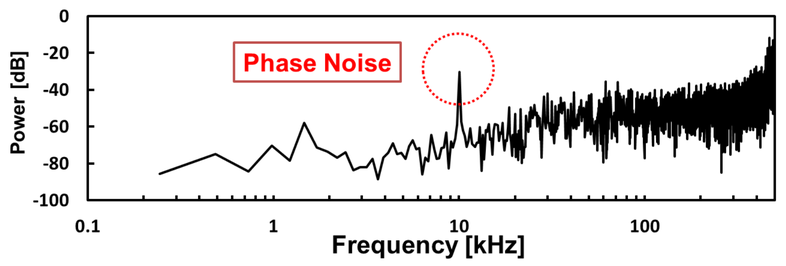
MATLAB Simulation



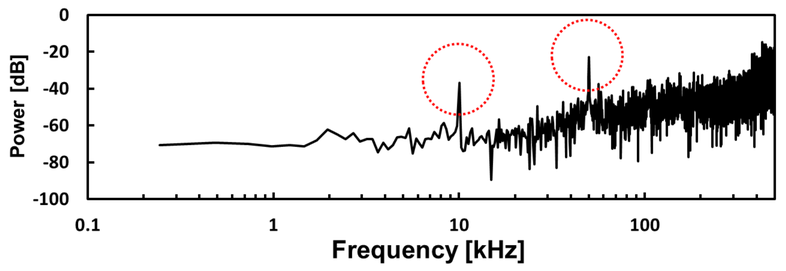
Simulation Conditions				
Case	Ⅰ	Ⅱ	Ⅲ	Ⅳ
Delay of ΔΣ TDC (τ)	200ns	200ns	200ns	200n
Input frequency	1MHz	1MHz	1MHz	1MHz
The number of ΔΣ TDC data	4096	4096	4096	4096
Phase variation of CUT	10kHz	50kHz	10kHz & 50kHz	10kHz
βT-delay	1T	1T	1T	0.95T or 1.05T

Simulation Results (Ⅰ & Ⅱ)

FFT Spectrum with Phase Noise at 10kHz



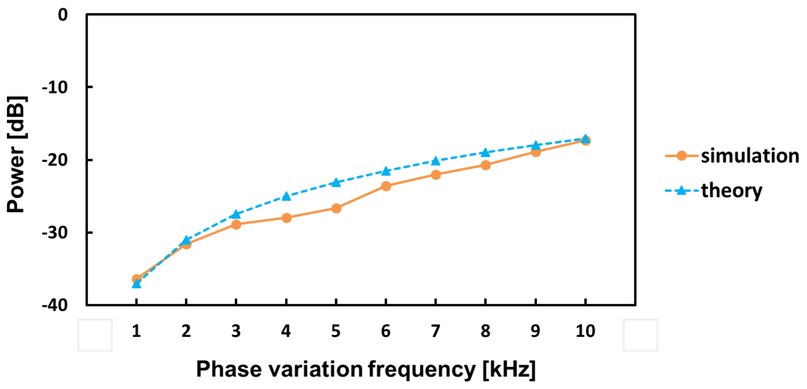
FFT Spectrum with Phase Noise at 10kHz & 50kHz



Phase Noise

Simulation Result (Ⅲ)

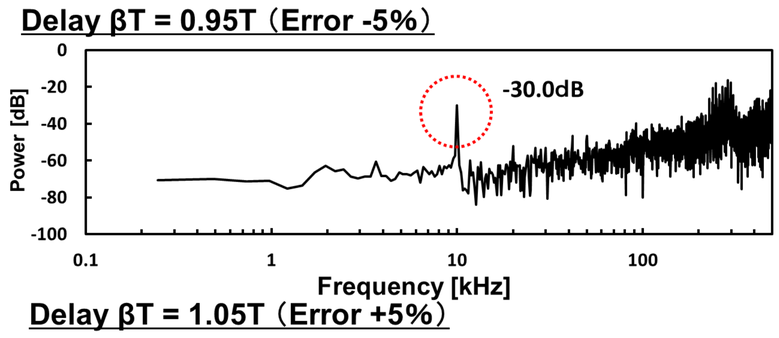
Comparison of Simulation Results and Theory



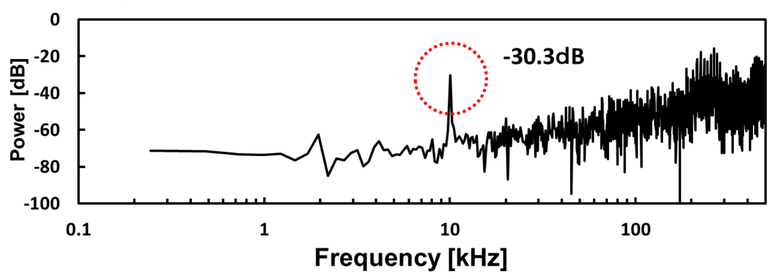
Theoretical expression : $\Phi'(\omega_1) = \frac{1}{2}(2\pi\alpha_1)^2 {\omega_1}^2 T^2$ $(\alpha_1 = 0.1)$

Simulation Result (Ⅳ)

Delay βT = 0.95T（Error -5%）



Delay βT = 1.05T（Error +5%）



Conclusion

■ **Proposal of phase noise measurement techniques using ΔΣTDC without reference clock**

- Low cost testing without spectrum analyzer
- On-chip high precision phase noise measurement
- Fine time resolution measurement with ΔΣTDC
- Power spectrum obtained by FFT of TDC digital output

■ **Their MATLAB simulation verification**

- Superposition of several sinusoidal phase variation components
- Comparison with theoretical analysis and simulation results
- Measurement method with several delay β values