Jitter Decomposition in Ring Oscillators

Qingqi Dou and Jacob A. Abraham

Computer Engineering Research Center

Department of Electrical and Computer Engineering

University of Texas at Austin

Outline

- Motivation
- Overview
- Proposed Method
  - Time Lag Correlation
  - Verification of the Theory
  - Simulation in Ring Oscillator
- Conclusions and Future Work

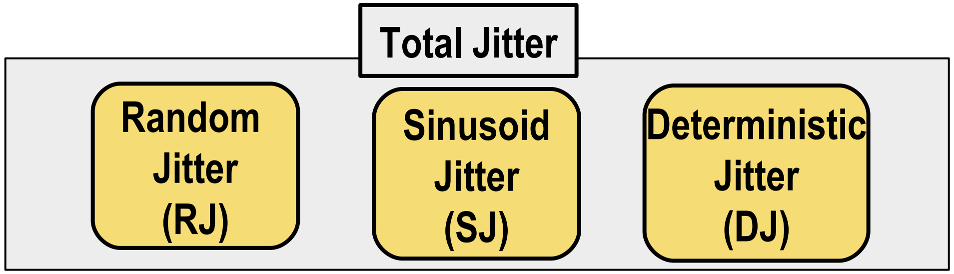
Outline

- **Motivation**
- Overview
- Proposed Method
  - Time Lag Correlation
  - Verification of the Theory
  - Simulation in Ring Oscillator
- Conclusions and Future Work

Needs for New Solutions

- **Continued demand for GHz processors and high-capacity communication systems**
  - **Low-cost high volume ICs clocked at GHz rates and beyond**
  - **Multi-Gb/s serial interfaces**
    - **PCI Express, Infiniband, Hyper Transport, Serial ATA**
- **Challenges for testing the signal integrity of the system**
  - **Direct measurement of *Bit Error Rate* (BER)**
    - **Unaffordable time**
    - **Expensive BERTester**
  - **Correlate BER with jitter**
    - **Stringent timing specifications dictated by the serial link standards**

Standards on Jitter Specifications (I)



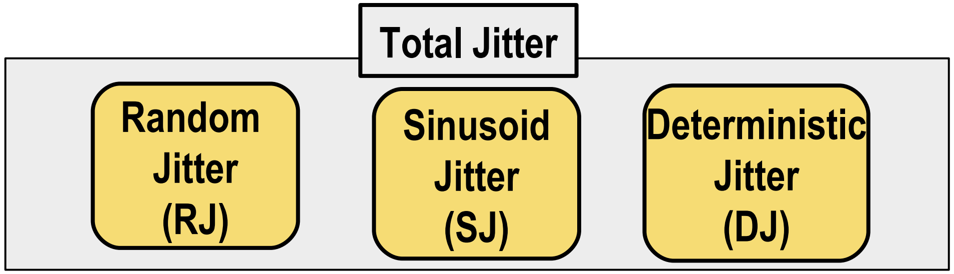
- **New definition of jitter**
  - Traditional histogram based peak-to-peak jitter is replaced by jitter separation.
- **System specifications**
  - *Total Jitter* (TJ) @ given BER

$$TJ(BER) = 2*Q_{BER} * |RJ| + |DJ|$$

Weight factor vs. BER

$2*Q_{BER}$	BER
12.72	10^{-10}
13.41	10^{-11}
14.07	10^{-12}
14.70	10^{-13}
15.30	10^{-14}
15.80	10^{-15}
16.44	10^{-16}
16.93	10^{-17}

Standards on Jitter Specifications (II)



- **New jitter tolerance test**
  - A combination of certain DJ (including some SJ) and RJ is injected into the data stream.
- **Jitter Debug**
  - Identifying dominant interferences limiting the signal integrity of system.
- **Demand for jitter decomposition**

Jitter specifications in infiniband

Specification	Infiniband
Data Rate	2.5 Gb/s
TX RJ	0.17 UI
TX TJ	0.35 UI
RX DJ	0.41 UI
RX RJ	---
RX SJ	---
RX DJ+RJ	---
RX TJ	0.70 UI

1 *Unit Interval* (UI) = 1 bit period

Motivation

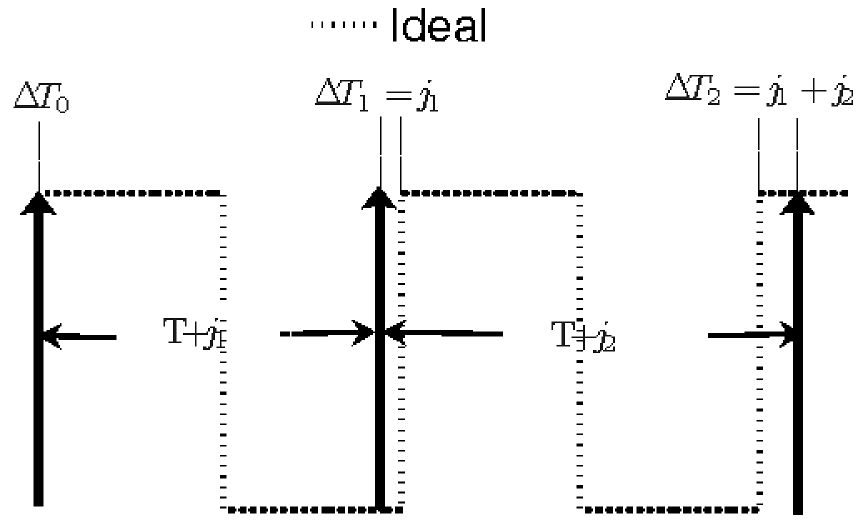
- The focus of this paper is
  - Development of an efficient approach to separate jitter

Outline

- Motivation
- Overview
- Proposed Method
  - Time Lag Correlation
  - Verification of the Theory
  - Simulation in Ring Oscillator
- Conclusions and Future Work

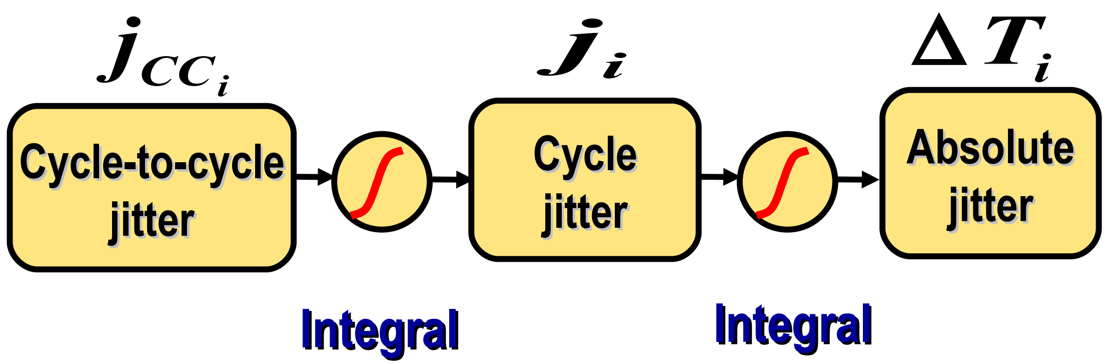
Jitter Definitions

- Jitter is defined as the **deviation** of a signal's timing event from its intended (ideal) occurrence in time



Cycle-to-Cycle jitter: $j_{CC_1} = j_2 - j_1$

- Three forms of jitter
  - Absolute jitter
  - Cycle jitter
  - Cycle-to-cycle jitter



Classification of Jitter

Total Jitter

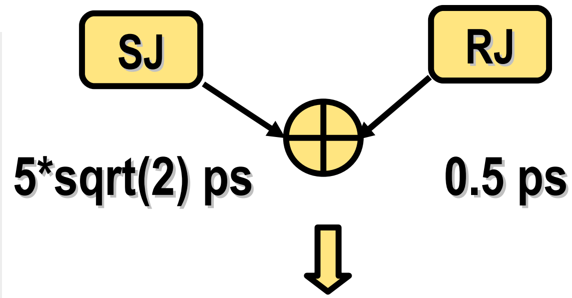
Sinusoid Jitter (SJ) | Deterministic Jitter (DJ) | Random Jitter (RJ)

- Magnitude is

  bounded | *unbounded*

- Magnitude is characterized by

  Peak-to-Peak (PP) value | *Root Mean Square* (RMS) value



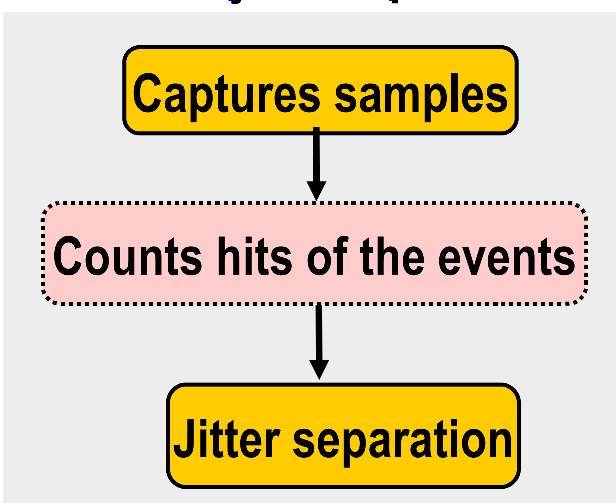
RMS & PP of a Convoluted Jitter

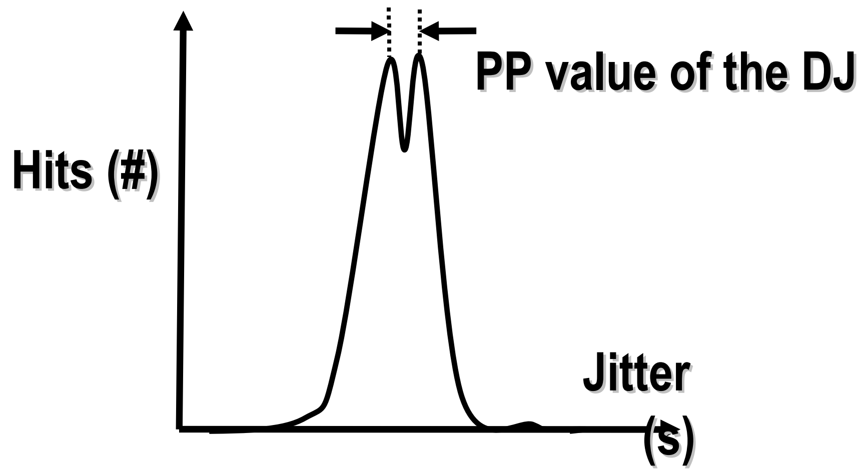
Sample Size (#)	RMS (ps)	PP (ps)
1000	5.02	8.21
11000	5.02	8.45
101000	5.03	8.85

Conventional Histogram-based Methods

- Histogram-based methods
  - Extracts jitter based on the *Probability Density Function* (PDF) of jitter

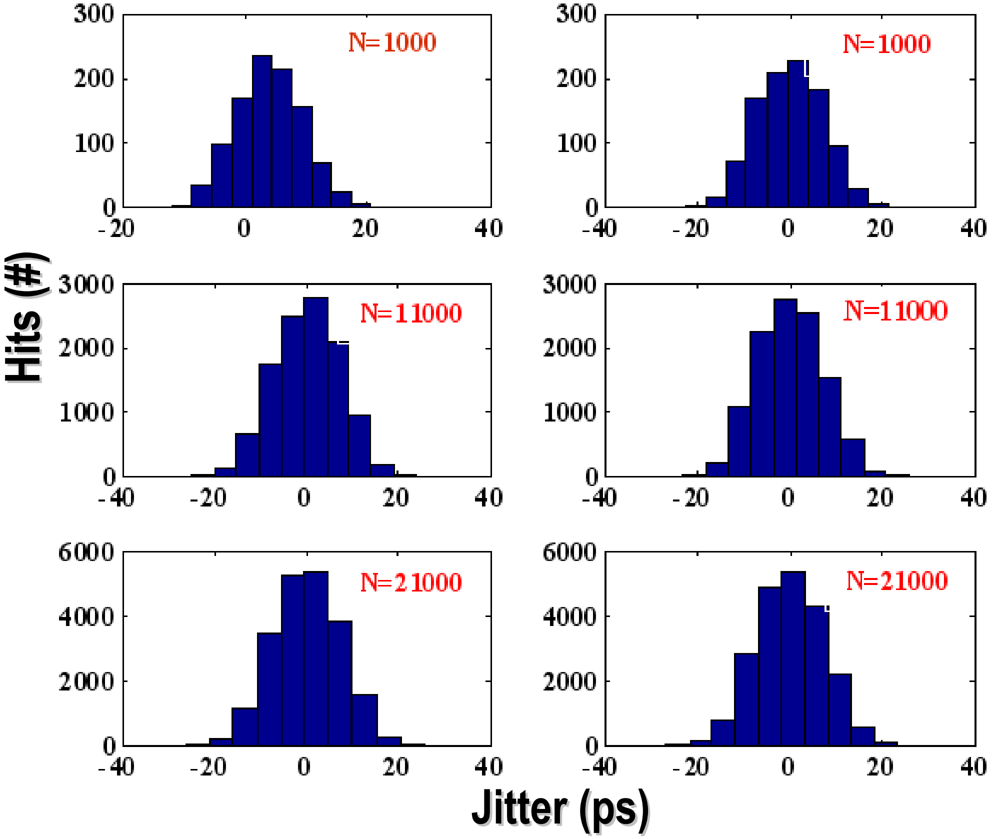
Flow of jitter separation





Extraction of DJ in histogram-based Method

Issues of the Histogram-based Methods



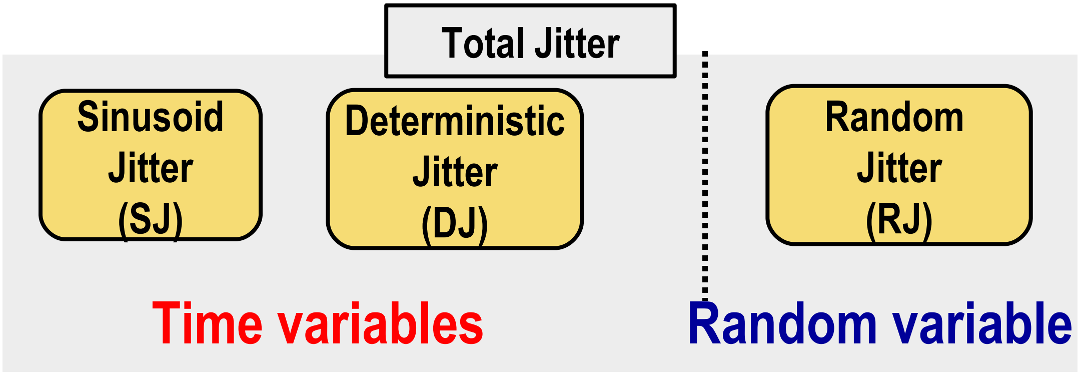
RJ: RMS value = 5 ps

SJ: PP value = 5*sqrt (2) ps

f_m =100kHz vs. 100MHz

- Loses the info how the event involve in time
  - Fails to extract the info of time variables
- Fails to separate jitter in certain cases
  - More samples do not help

Methods for Jitter Decomposition

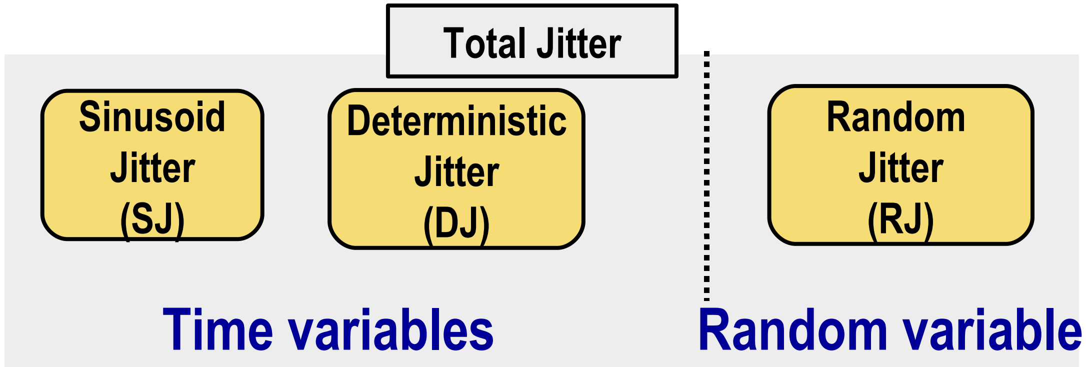


- Histogram-based Methods
  - Perfect for random variables
  - Not suitable for time variables
- Spectral Domain
  - Precise in estimating the frequency of the SJs
  - Not straightforward for dealing with jitter
- Alternative?
  - How to treat jitter as a time series?

Outline

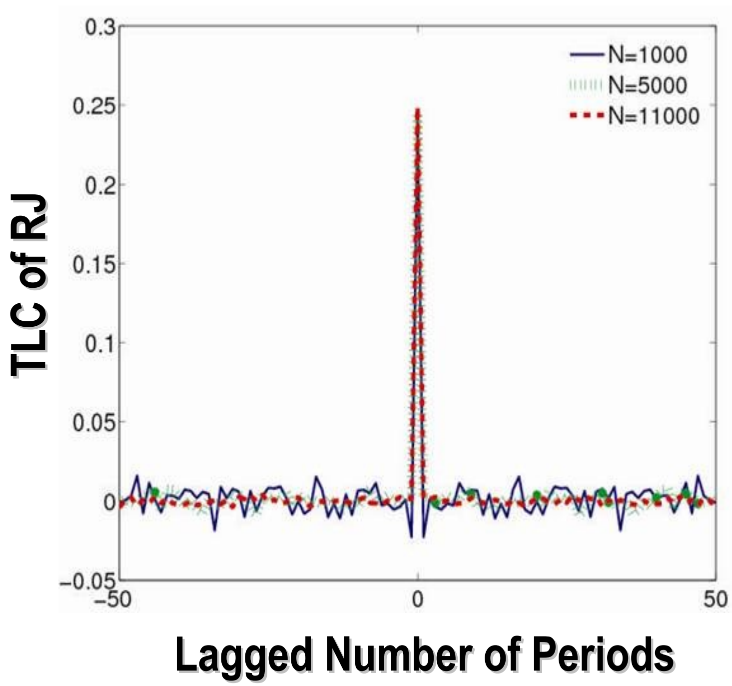
- Motivation
- Overview
- Proposed Method
  - Time Lag Correlation
  - Verification of the Theory
  - Simulation in Ring Oscillator
- Conclusions and Future Work

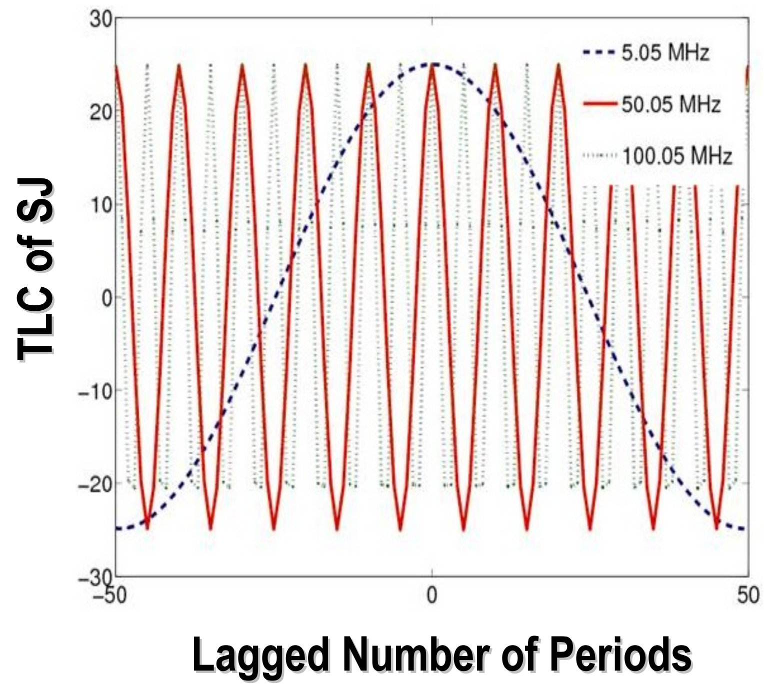
Proposed Technique for Jitter Separation (I)



- ***Time Lag Correlation*** **(TLC)**
  - $C_j(m) = \lim_{N \to \infty} \frac{1}{N} \sum_{n=1}^{N} (j_{n+m} * j_n)$
  - **Random variable has zero TLC except its self-correlation.**
  - **Each component of jitter evolves differently with time.**

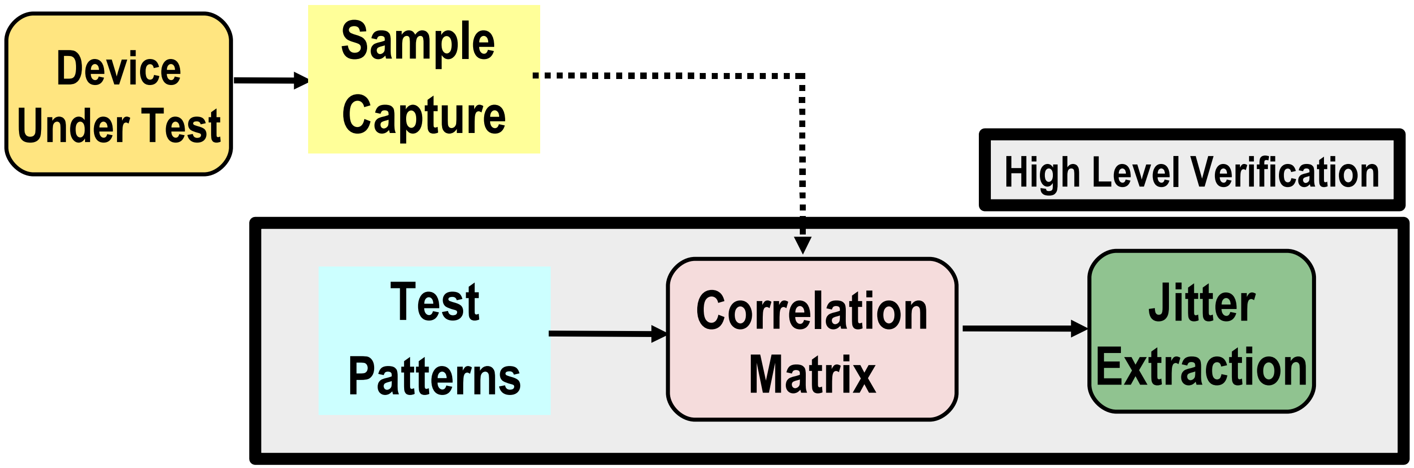
Proposed Technique for Jitter Separation (II)





- Features of TLC
  - Converges fast with sample size
  - Mainly depends on the parameters of the variables

Verification of the Theory

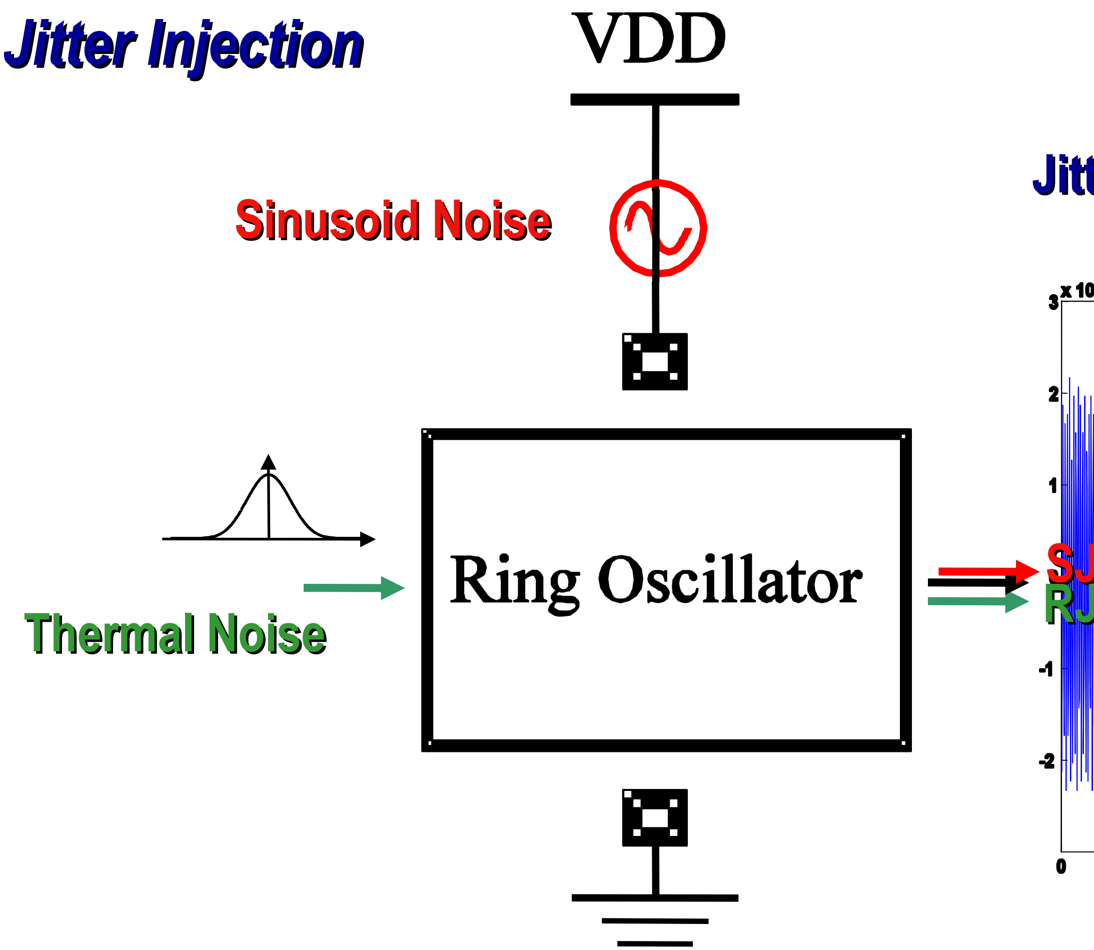


- Ratio of the TJ to UI
- Ratio of the RMS value of RJ to the PP value of SJ, α
- f_m of SJ vs. System Central Frequency, f_0

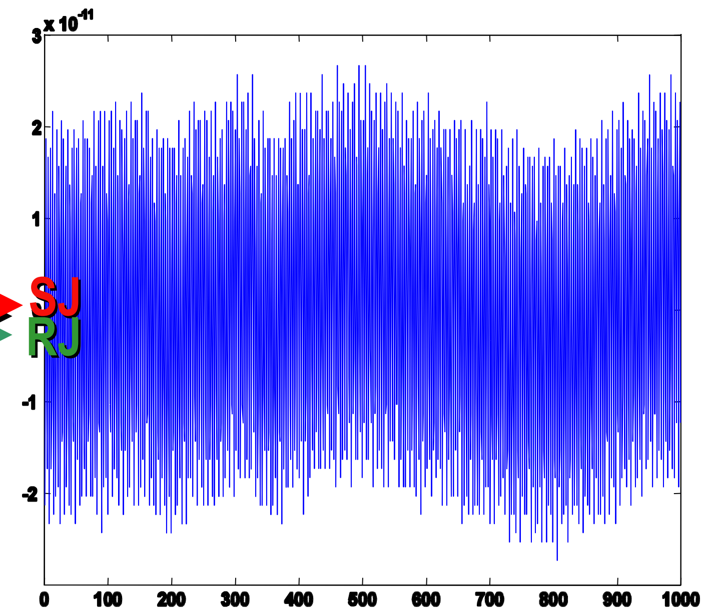
- Down to 0.05 UI
- Applicable to α=1~20
- Independent of the f_m frequency ranges and f_0

Simulation in Ring Oscillators (I)

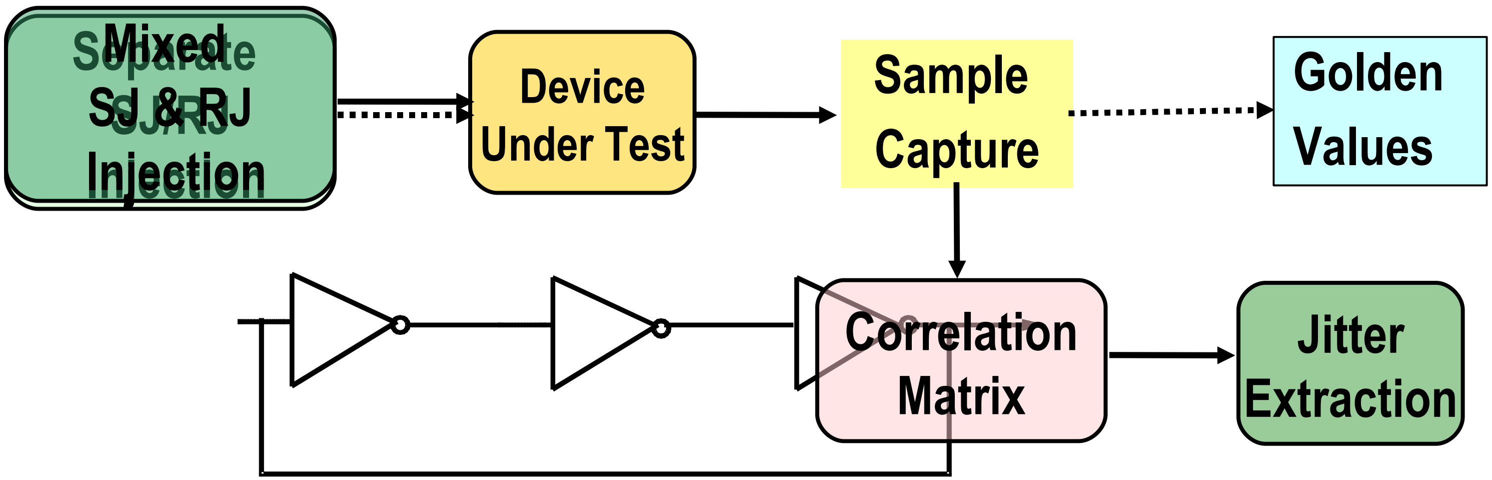
Jitter Injection

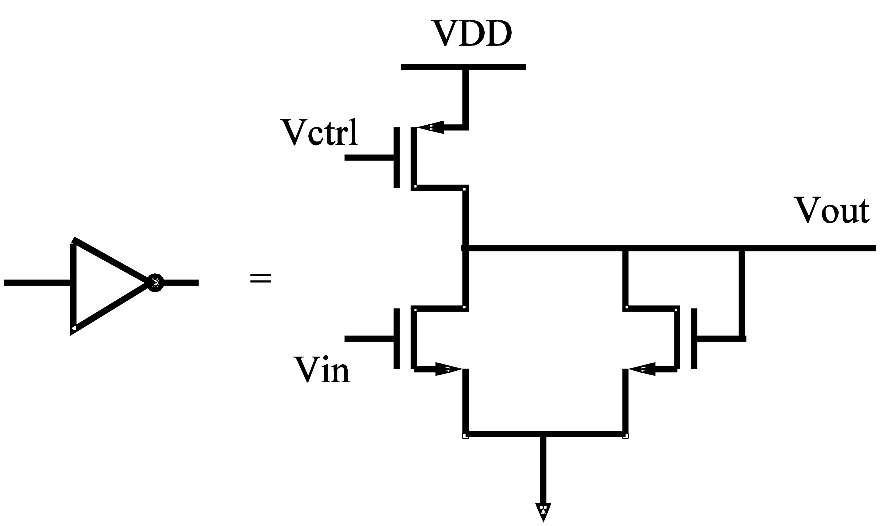


Jitter (s) vs. Period Number (#)

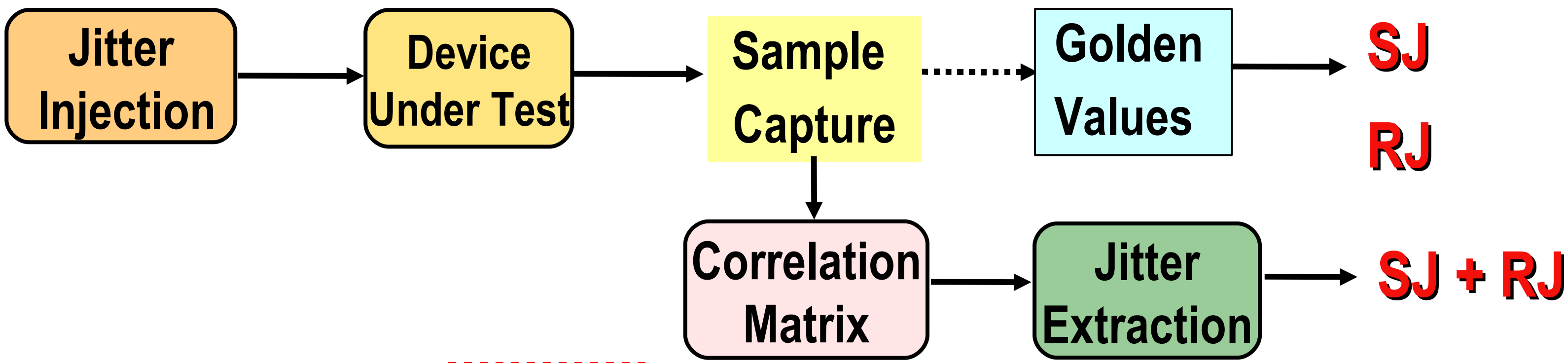


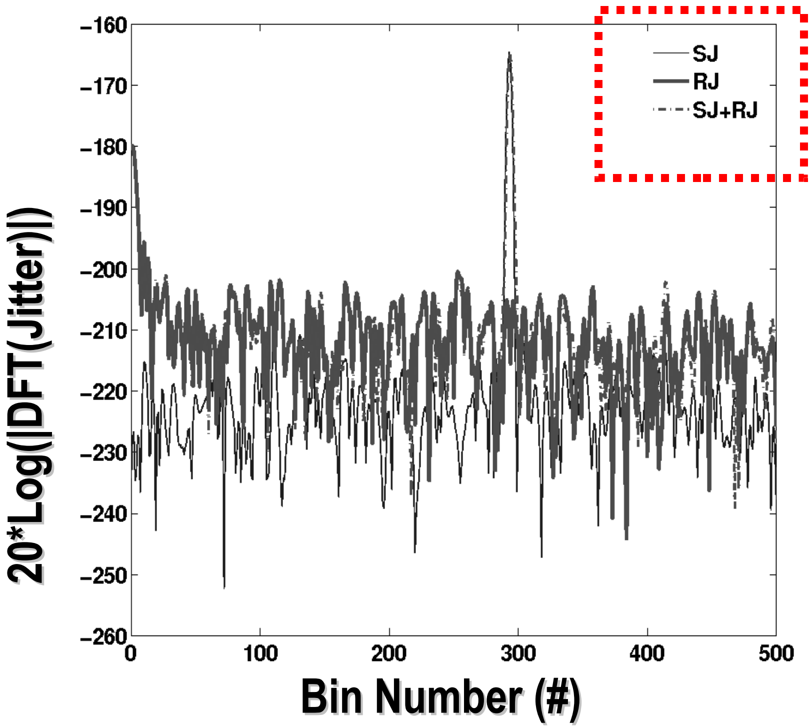
Simulation in Ring Oscillators (II)





Simulation in Ring Oscillators (III)





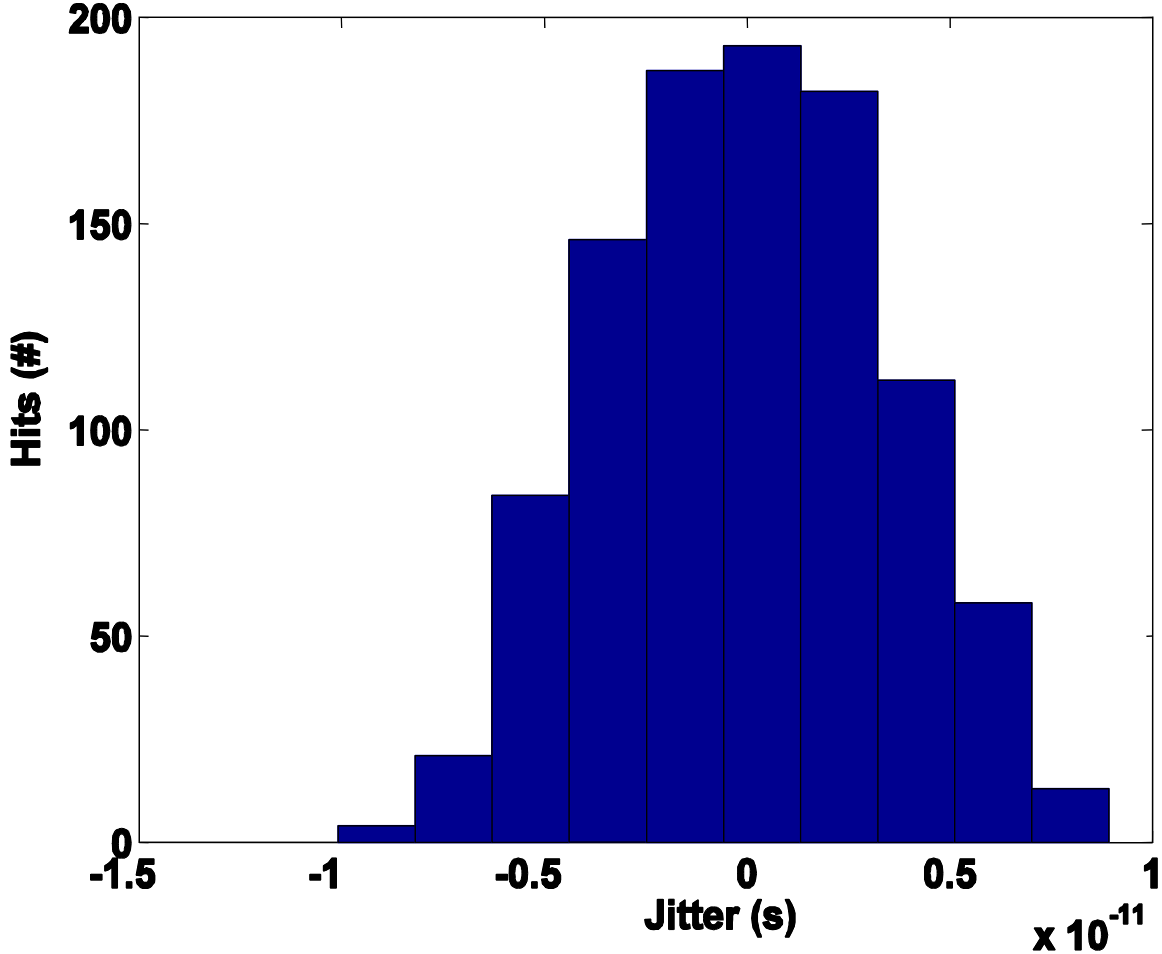
- Assumption
  - Thermal noise introduces RJ
  - Supply sinusoid noise causes SJ

Simulation Results

Injected Sinusoid Noise (mV)	Golden Values			Proposed Method		
	f_m (MHz)	PP (ps)	RMS (ps)	f_m (MHz)	PP (ps)	RMS (ps)
2.5	100	21.5	2.5	99.4	21.2	3.5
1.25	100	11	2.5	97.2	10.1	3.4
2.5	200	25	2.5	164.8	24.7	3.5
1.25	200	12.5	2.5	161.8	11.9	3.4

Sample size = 1000

Histogram-based Method



Conclusions and Future Work

- An efficient technique for jitter decomposition is presented.
  - Able to extract the parameters of time variables
  - Able to separate jitter when histogram-based method fails
- Application of this technique to estimate the BER will be investigated.

Thanks

Any Questions?