Jitter Decomposition in Ring Oscillators

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Outline

◆ Motivation

◆ Overview

◆ Proposed Method
  ▲ Time Lag Correlation
  ▲ Verification of the Theory
  ▲ Simulation in Ring Oscillator

◆ Conclusions and Future Work
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**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

\[ TJ \ (BER) = 2 \cdot Q_{BER} \cdot |RJ| + |DJ| \]

<table>
<thead>
<tr>
<th>2 \cdot Q_{BER}</th>
<th>BER</th>
</tr>
</thead>
<tbody>
<tr>
<td>12.72</td>
<td>10^{-10}</td>
</tr>
<tr>
<td>13.41</td>
<td>10^{-11}</td>
</tr>
<tr>
<td>14.07</td>
<td>10^{-12}</td>
</tr>
<tr>
<td>14.70</td>
<td>10^{-13}</td>
</tr>
<tr>
<td>15.30</td>
<td>10^{-14}</td>
</tr>
<tr>
<td>15.80</td>
<td>10^{-15}</td>
</tr>
<tr>
<td>16.44</td>
<td>10^{-16}</td>
</tr>
<tr>
<td>16.93</td>
<td>10^{-17}</td>
</tr>
</tbody>
</table>
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

<table>
<thead>
<tr>
<th>Specification</th>
<th>Infiniband</th>
</tr>
</thead>
<tbody>
<tr>
<td>Data Rate</td>
<td>2.5 Gb/s</td>
</tr>
<tr>
<td>TX RJ</td>
<td>0.17 UI</td>
</tr>
<tr>
<td>TX TJ</td>
<td>0.35 UI</td>
</tr>
<tr>
<td>RX DJ</td>
<td>0.41 UI</td>
</tr>
<tr>
<td>RX RJ</td>
<td>---</td>
</tr>
<tr>
<td>RX SJ</td>
<td>---</td>
</tr>
<tr>
<td>RX DJ+RJ</td>
<td>---</td>
</tr>
<tr>
<td>RX TJ</td>
<td>0.70 UI</td>
</tr>
</tbody>
</table>

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

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

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

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

\[ \Delta T_0 \quad \Delta T_1 = j_1 \quad \Delta T_2 = j_1 + j_2 \]

\[ \text{Cycle-to-Cycle jitter: } j_{CC1} = j_2 - j_1 \]

\[ j_{CCi} \quad J_i \quad \Delta T_i \]

Integral

Integral
### Classification of Jitter

- **Magnitude is**
  - bounded
  - unbounded

- **Magnitude is characterized by**
  - **Peak-to-Peak** (PP) value
  - **Root Mean Square** (RMS) value

#### Total Jitter

- **Sinusoid Jitter** (SJ)
- **Deterministic Jitter** (DJ)
- **Random Jitter** (RJ)

#### RMS & PP of a Convoluted Jitter

<table>
<thead>
<tr>
<th>Sample Size (#)</th>
<th>RMS (ps)</th>
<th>PP (ps)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1000</td>
<td>5.02</td>
<td>8.21</td>
</tr>
<tr>
<td>11000</td>
<td>5.02</td>
<td>8.45</td>
</tr>
<tr>
<td>101000</td>
<td>5.03</td>
<td>8.85</td>
</tr>
</tbody>
</table>

- $5\sqrt{2}$ ps
- 0.5 ps
Conventional Histogram-based Methods

**Histogram-based methods**

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

**Flow of jitter separation**

- Captures samples
- Counts hits of the events
- Jitter separation

**Extraction of DJ in histogram-based Method**

- PP value of the DJ
- Hits (#)
- Jitter (s)

Extraction of DJ in histogram-based Method
Issues of the Histogram-based Methods

- 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

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

\[ f_m = 100\text{kHz vs. 100MHz} \]
**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?
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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, $\alpha$
- $f_m$ of SJ vs. System Central Frequency, $f_0$

- Down to 0.05 UI
- Applicable to $\alpha=1\sim20$
- Independent of the $f_m$ frequency ranges and $f_0$
Simulation in Ring Oscillators (I)

Jitter Injection

Sinusoid Noise

Thermal Noise

Ring Oscillator

Jitter (s) vs. Period Number (#)

VDD
Simulation in Ring Oscillators (II)

Separate Source Injection

Device Under Test

Sample Capture

Golden Values

Correlation Matrix

Jitter Extraction

\[
\text{VDD} \quad \text{Vctl} \quad \text{Vin} \quad \text{Vout}
\]

Diagram of ring oscillator circuit with gates and nodes labeled.
Simulation in Ring Oscillators (III)

Assumption

- Thermal noise introduces RJ
- Supply sinusoid noise causes SJ
Simulation Results

<table>
<thead>
<tr>
<th>Injected Sinusoid Noise (mV)</th>
<th>Golden Values</th>
<th>Proposed Method</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$f_m$ (MHz)</td>
<td>PP (ps)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$f_m$ (MHz)</td>
</tr>
<tr>
<td>2.5</td>
<td>100</td>
<td>21.5</td>
</tr>
<tr>
<td>1.25</td>
<td>100</td>
<td>11</td>
</tr>
<tr>
<td>2.5</td>
<td>200</td>
<td>25</td>
</tr>
<tr>
<td>1.25</td>
<td>200</td>
<td>12.5</td>
</tr>
</tbody>
</table>

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?