Using High Speed Scope for Digital Jitter Measurements

October 22nd, 2003

presented by:

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Why Jitter?

- Digital Data Transport = high speed serial
- Timing Margins are Thin
- Functional --> Parametric
- Ensure Bit Error Ratio
- Need Actionable Insight
Agenda

• Quick Review of Jitter
• Creating a Jitter Transmitter
• What’s driving Jitter specs?
• New RJ/DJ measurement tools
• Measurement examples
• Summary/Q&A
Jitter

- A Measure of the time variation of the significant instances of a digital signal from their ideal positions in time.
A Jitter Taxonomy

Total Jitter (TJ)

- Deterministic (DJ)
  - Uncorrelated
  - Periodic (PJ)
  - Duty Cycle Distortion (DCD)
- Random (RJ=σ)
  - Data Dependent (DDJ)
    - Intersymbol Interference (ISI)

Mechanisms: phase modulation of clock, Amplitude Noise, Transmission filtering, Asymmetric Drive, etc
Jitter and BER

<table>
<thead>
<tr>
<th>BER</th>
<th>Pk Dev/σ</th>
</tr>
</thead>
<tbody>
<tr>
<td>1x10^-8</td>
<td>5.73</td>
</tr>
<tr>
<td>1x10^-10</td>
<td>6.47</td>
</tr>
<tr>
<td>1x10^-12</td>
<td>7.13</td>
</tr>
<tr>
<td>1x10^-14</td>
<td>7.74</td>
</tr>
</tbody>
</table>

\[ TJ_{est} = 14\sigma \]

With DJ:
\[ TJ_{est} = DJ + 14\sigma \]

Overlap indicates BER

\[ \sigma_L \]
\[ \sigma_R \]

\[ \mu \]

Sampling Point

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Jitter in a System: a Model

Frequency & Clocking

Transmitter

Medium

PLL

Data

Threshold

LPF

RJ PJ

DCD

ISI

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A Jitter Source

RF Amps

Agilent 33250A

SS

PLL

Agilent 81134A

Data

Threshold and DC Bias

LPF

Semi-Rigid Coax or Transmission Line Filter

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Key Question

• How do you know what you have??

- **Answer #1**: Use Agilent Timing Interval and Jitter Analysis Software

- **Answer #2**: Use fundamental Measurements and own statistical analysis
What is the Accuracy of RJ and DJ in any given state?
- What is the Intrinsic or Residual Jitter?
- How much contribution to RJ do you get from DJ sources?
- How much DJ do you get from RJ source?
- What is the interaction of the DJ sources?
Calibration Process

1. Quantify Jitter Transmitter Residuals
   a. RJ
   b. DJ

2. Evaluate RJ only source
   a. Multiple values of RJ
   b. Evaluate Histogram Shape
      1. Evaluate sigma ($\sigma$)
      2. Evaluate Undesired DJ

3. Evaluate Deterministic each Jitter Source
   a. Multiple values of DJ
   b. Consider Potential for interaction with other sources
   c. Evaluate Histogram Shape
      1. Change in Baseline sigma
      2. DJ Evaluation
Process Example: all jitter sources

• Baseline
  - $\sigma = 2.7$ ps
  - $DJ = 4.8$ ps
Process Example

- **RJ Source**
  - Must choose source carefully

<table>
<thead>
<tr>
<th>Voltage (in standard deviations)</th>
<th>Probability</th>
</tr>
</thead>
<tbody>
<tr>
<td>-6</td>
<td>1x10^-6</td>
</tr>
<tr>
<td>-5</td>
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<tr>
<td>-4</td>
<td>1x10^-4</td>
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<td>5</td>
<td>1x10^-7</td>
</tr>
<tr>
<td>6</td>
<td>1x10^-8</td>
</tr>
</tbody>
</table>

Low Level: \( \sigma = 4.1 \text{ ps} \)
DJ = 4.8 ps

High Level: \( \sigma = 10.6 \text{ ps} \)
DJ = 4.8 ps
Process Example

- Periodic Source
  - Low Level
    - $\sigma = 2.7$ ps
    - DJ = 17.5 ps
  - High Level
    - $\sigma = 2.7$ ps
    - DJ = 63.5 ps
Process Example

- All combined
  - $PJ = 63.5$
  - $DDJ = 28.2$
  - $DCD = 35.1$
  - $\sigma = 10.6$ ps
  - $DJ = 154$ ps

- Total Jitter:
  - $TJ_{BERT} = 253$ ps
  - $TJ_{EST} = 302$ ps!
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Real-Time Oscilloscope Measurements

• MJSQ\textsuperscript{1} standards recommendations on jitter measurement test equipment

• Real-time oscilloscope vs. BERT
  – Capture of V vs. t data
  – Capture of threshold time-tags only
  – Statistical differences in wall-clock time
  – Jitter debug with additional views

Real-Time Oscilloscope Measurements

- Bottom-line is accurate estimate of TJ at specified BER level
- Acquiring enough data to measure a $10^{-12}$ BER would take a lot of time
- What if we could estimate RJ/DJ accurately to predict TJ?
- Extracting RJ and DJ
  - Curve fit of histogram
  - Spectrum analysis
Real-Time Oscilloscope Example

2.5Gbps PRBS Pattern 128-bits \( (2^5-1) \)
- Capture 1Mpts of data at 20GSa/s
- \( 50\mu s/400ps = 125,000 \) UI~1000 patterns
- Calculate confidence level:
  - For no errors, acquire \( 3.84/\text{BER} \) UI for 95%
  - Example: 125,000 UI per acquisition
    - \( 3.84^{12} / 125,000 = 30,072,000 \) acquisitions
    - This would take over 3 days!
M1 Time Interval and Jitter Analysis

- Patent license agreement with Agilent Technologies
- Offered as Agilent Time Interval and Jitter Analysis Software
- Leveraging 20+ years of ASA’s clock, timing and data jitter measurement expertise
M1 Time Interval and Jitter Analysis

- Comprehensive suite of RJ/DJ extraction methods in compliance with MJSQ recommendations
- Additional analysis tools for decomposing jitter signature during functional debug and system characterization
Rj/Dj Methods

• Pattern-Marker based
  – one method

• Best Fit/Equivalent Jitter based
  – two methods based on Edge Jitter/TIE
  – two methods based on Pulsewidth Jitter
  – five methods based on TIA-Style sampling

• Duty-Cycle Distortion
  – Calculated independently of RJ/DJ
All Non-Pattern Methods

Combination of BERT-scan and Curve Fit

- Individual event data is combined to form a Bathtub Curve
- The tails are fitted to extract RJ/DJ values
- The RJ/DJ values are used to extrapolate down to lower BERs

![Bathtub Curve / BER Estimation](image)

Actual Data

Extrapolated Data

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SATA 1.5Gbps Example

- Eye-diagram view allows alignment of entire data acquisition vs. recovered clock
- Mask testing for measuring data-valid window
SATA 1.5Gbps Example

- Bathtub curve shows extrapolated data for estimating TJ and eye opening at lower BERs
- Accumulate mode allows longer time captures to identify random occurrences and converge toward more accurate TJ estimates
SATA 1.5Gbps Example

Application Specific Measurement Window

- Provides critical measurements vs. the specified values
- Accumulate mode and stop on failure allow test to run hands-free
- DJ appears to contribute as much toward TJ as RJ
  - DJ = 0.073 UI pk
  - TJ = 0.155 UI pk

![Application Specific Measurement Window](image-url)
Sometimes the measurement trend can identify RJ vs. PJ, but not in this case.

A histogram will better identify the distribution of measured pulsewidth values.
SATA 1.5Gbps Example

- Identify a major source of DJ as a side-tail to the RJ distribution
SATA 1.5Gbps Example

- Identify periodic and data dependent jitter frequencies
- Troubleshooting tool for eliminating accidental crosstalk jitter or identifying ISI
Clock PLL Example

- 456 MHz distributed clock signal
- Includes a PLL with divide-by-4 feedback loop between VCO and phase detector
- Only 32ps of p-p jitter
Clock PLL Example

- This isn’t the kind of distribution we want for our perfect clock!
Clock PLL Example

- Isolated energy peak at 114 MHz suggests sub-harmonic coupling
Clock PLL Example

- Revisit our measurement trend
- Zoom in to find that 114 MHz crystal output is finding its way into the VCO output
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Summary

• Increasing signal bandwidths are creating jitter sources (ISI, dispersion, etc.)
  – Need a jitter transmitter for simulation and calibration of test equipment
  – Need RJ/DJ separation to speed analysis time and compliance testing

• Analysis tools provide much greater insight as to root cause, beyond RJ/DJ

• Resources:
  – Jitter  www.agilent.com/find/jitter_info
  – Oscilloscopes www.agilent.com/find/infiniimax
Agilent 54850 Infiniium Performance Series

• 4 channels
• Up to 32 MB deep memory
• Up to 20 GSa/s sample rate/channel
• Infiniium award-winning usability
• Timing Interval & Jitter Analysis Software

www.agilent.com/find/infiniimax

<table>
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<tr>
<th>Model</th>
<th>BW</th>
<th>Channels</th>
<th>Sample Rate Per Channel</th>
<th>Standard Mem/Ch</th>
<th>Optional Mem/Ch</th>
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<td>2.5GHz</td>
<td>4</td>
<td>20GSa/s</td>
<td>256K</td>
<td>1M/32M</td>
</tr>
<tr>
<td>54854A</td>
<td>4 GHz</td>
<td>4</td>
<td>20 GSa/s</td>
<td>256K</td>
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