Presentation 4

Analyzing Digital Jitter and its Components
Analyzing Digital Jitter and its Components

Agenda

- Jitter Overview – Measurement Methodologies
- Why Separate Jitter?
- Separating Jitter with the DCA-J
Jitter

- ITU-T Definition:
  A Measure of the short term time variations of the significant instances of a digital signal from their ideal positions in time.

- MJSQ Definition:
  The deviation of a signal edge time at a defined amplitude of the signal from a reference time.

Classes of Jitter Measurements

- Jitter Generation
  - How much jitter is the device under test (DUT) generating?
  - Transmitter measurement

- Jitter Transfer
  - How much of the jitter received by a DUT is passed along to the transmitted signal via the recovered clock?
  - Repeater measurement
  - Typically associated with synchronous networks

- Jitter Tolerance
  - How much jitter on the input signal can the DUT tolerate and still produce an acceptable bit error ratio (BER)
  - Receiver measurement
## Analyzing Digital Jitter and its Components

### Jitter Methodologies & Market Segment Use

<table>
<thead>
<tr>
<th>Category</th>
<th>WAN</th>
<th>SAN</th>
<th>LAN</th>
<th>Back Plane</th>
<th>PC &amp; Server</th>
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<tr>
<td>&lt;= 1 Gb/s</td>
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<td>1.5 Gb/s</td>
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<td>3 Gb/s</td>
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<td>5/6 Gb/s</td>
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<td>10 Gb/s</td>
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- **SONET/SDH**
  - Jitter Generation
  - Jitter Transfer
  - Jitter Tolerance
- **Banded**
  - Jitter Generation – requiring separation of jitter into sub-components
  - Jitter Tolerance – defined by stressed eye

### Proprietary
- Some use of Enterprise methods

### Digital Design
- Jitter Gen
- Cycle-to-Cycle
- N-Cycle

### Enterprise Methodology
- Emerging OIF standard - CEI

### Why Separate Jitter?

- Mechanism to enable fast estimates of Total Jitter (TJ) at low BER
- Tool to support budgeting of jitter in new and evolving designs
- Diagnostic tool for troubleshooting jitter

- **Total Jitter (TJ)**
  - **Deterministic Jitter (DJ)**
  - **Random Jitter (RJ)**
  - **Data Dependent Jitter (DDJ)**
  - **Inter-symbol Interference (ISI)**
  - **Duty Cycle Distortion (DCD)**
  - **Periodic Jitter (PJ)**
Enterprise jitter methodology

- Assess jitter in terms of its impact on system performance
- Bottom line is bit-error-ratio (BER)

- Which waveform is most likely to cause poor BER due to jitter?

*Let's figure out what's going on*

Assessing the impact of jitter on BER

- System BER less than 1 error per trillion bits (10^-12)
- 'Total' jitter needs to be determined to similar probabilities
- There are things the eye diagram simply cannot tell us

*Breaking apart the jitter into its various components will efficiently lead us to an accurate measurement*
Pruning the Enterprise Jitter Family Tree

Signal jitter can be composed of several types from several mechanisms.

- Total Jitter (TJ)
  - Deterministic Jitter (DJ)
  - Random Jitter (RJ)
  - Periodic Jitter (PJ)
- Data Dependent Jitter (DDJ)
- Inter-symbol Interference (ISI)
- Duty Cycle Distortion (DCD)

What Does Data Dependent Jitter Look Like?

- 270K Samples: mean 24.33867 ns, std dev 9.84/2 ps, p-p 46.1 ps
- 1.35M Samples: mean 24.33751 ns, std dev 10.3503 ps, p-p 46.3 ps
What Does Random Jitter Look Like?

- **270K Samples**
  - Mean: 24.24173 ns
  - Std dev: 7.2957 ps
  - P-p: 33.8 ps

- **1.35M Samples**
  - Mean: 24.24363 ns
  - Std dev: 7.3905 ps
  - P-p: 45.2 ps

What Does Periodic Jitter Look Like?

- **270K Samples**
  - Mean: 24.22632 ns
  - Std dev: 18.0436 ps
  - P-p: 60.8 ps

- **1.35M Samples**
  - Mean: 24.22723 ns
  - Std dev: 19.8822 ps
  - P-p: 67.8 ps
Correlated or uncorrelated to the data?

Use averaging to remove uncorrelated jitter

Dominant DDJ

![Graph with statistics: mean 24.3257 ns, std dev 10.3003 ps, p-p 48.3 ps, 64 avgs]

Dominant RJ

![Graph with statistics: mean 40.2024 ns, std dev 2.848 ps, p-p 12 ps, 64 avgs]

What Does it Look Like All Together?

270K Samples

![Graph with statistics: mean 40.33182 ns, std dev 21.3441 ps, p-p 99.2 ps]

1.35M Samples

![Graph with statistics: mean 40.3301 ns, std dev 20.6766 ps, p-p 92.2 ps]
Putting together the pieces

- The key to understanding the complete ‘jitter picture’ requires a systematic and efficient approach to isolating and quantifying the various components of jitter
- Just as important as pulling things apart is knowing how to put them back together for the bottom line impact on BER

Looking at Jitter Differently

<table>
<thead>
<tr>
<th>Bit Rate</th>
<th>3.125000 Gb/s</th>
<th>Pat Length</th>
<th>1023 bits</th>
<th>Div Ratio</th>
<th>1:1</th>
</tr>
</thead>
<tbody>
<tr>
<td>TJ(1E-12):</td>
<td>120.6 ps</td>
<td>DJ(δ-δ):</td>
<td>91.9 ps</td>
<td>RJ(rms):</td>
<td>2.00 ps</td>
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<tr>
<td>PJ(δ-δ):</td>
<td>58.4 ps</td>
<td>DDJ(p-p):</td>
<td>38.4 ps</td>
<td>DCD:</td>
<td>800 Ts</td>
</tr>
<tr>
<td>PJ(rms):</td>
<td>20.49 ps</td>
<td>ISI(p-p):</td>
<td>38.1 ps</td>
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</table>
Looking at Jitter Differently

Using Sampling Scope for Jitter

**Strengths**
- Wide bandwidth
- Low intrinsic jitter
- Multi-functionality
- Scalable

**Historical Weaknesses**
- Long measurement time
- Pattern trigger required for DDJ
- Errors induced by timebase delay
- Limited control of sampling interval
- No automated analysis tools
- Limited statistical sampling
A New Measurement Architecture

Eliminate Historical Weaknesses

• New Triggering Hardware
• Efficient Sampling Technique
• Automated Jitter Analysis

86100C Infiniium DCA-J

New Triggering Hardware

• Build capability into scope to derive a pattern trigger from a clock trigger
• Determine pattern length and count clock pulses

  • Generates trigger synchronous with pattern repetition – PatternLock
  • Enables precise location of samples in time
    – Focus samples anywhere in the pattern
  • Enables precise sampling interval
    – Precise periodic sampling
  • Enables optimal usage of DCA timebase
    – Minimizes error induced by timebase delay
**Efficient Sampling Technique**

- Essential to maximize utilization of samples for jitter values
- Determine the amplitude vs. time function of the edge – Edge Model
- Fix sample time at ideal edge location
- If amplitude is at threshold - implies no jitter
- Amplitude > threshold - early edge
- Amplitude < threshold - late edge
- ~100X efficiency improvement

**Edge Modeling**

- Build up samples of an edge using traditional sampling
- Curve fit to get best model of edge
- Result is mathematical transfer function of amplitude to jitter
Automated Jitter Analysis

- Use Counter hardware to focus samples on edges
- Use averaging to isolate Data-Correlated jitter
- Focus on individual edges to isolate Data-Uncorrelated jitter
- Data-Correlated jitter is Data Dependent Jitter (DDJ)
- Data-Uncorrelated Jitter is made up of Random Jitter (RJ) and uncorrelated Periodic Jitter (PJ)
Data Dependent Jitter (DDJ)

- Obtain DDJ vs. Bit record of edge positions
  - DDJ for a given edge is the difference between its average position and the ideal
  - Peak-to-peak DDJ is difference between earliest edge and latest edge

- Average out the uncorrelated jitter
  - Isolates data-correlated contributions only

- Measure mean position of every edge in pattern
  - Ideal edge position defined mean of means

- Build histograms for
  - All edges
  - Rising edges
  - Falling edges

Duty Cycle Distortion (DCD) & Inter-Symbol Interference (ISI)

- Isolate rising edge data from falling edge data
  - Difference of average locations is $J_{DCD}$
    - Maximum of the peak-to-peak values is $J_{ISI}$
  - Max (P-to-P\text{Falling}, P-to-P\text{Rising})

- DDJ$(p-p)$: 55.0 ps
- DCD: 14.6 ps
- ISI$(p-p)$: 38.2 ps
Data-Uncorrelated Jitter

Focus on only one edge at a time
• Isolates uncorrelated contributions

Counter hardware provides precise periodic sampling

Build a time sampled record
• Periodic samples of uncorrelated jitter

Build a histogram of uncorrelated jitter
• RJ, PJ Histogram

Random Jitter (RJ)

FFT time sampled record
• Aliased jitter frequency spectrum
• Shows RJ & PJ – PJ appears as spikes

Remove PJ spikes from spectrum
• Interpolate across gaps left behind
• Resultant spectrum is made up of RJ

Integrate ‘noise’ power in resultant spectrum...
• This is the random jitter (RJ)

RJ(τns): 11.59 ps
**Analyzing Digital Jitter and its Components**

### Periodic Jitter (PJ)

- **Periodic Jitter (PJ)**
  - Take RJ info from FFT and construct a Dual Dirac-delta model with appropriate slopes.
  - Match Dual Dirac-delta model to RJ, PJ histogram so that peak-peak widths match for 99.8% of volume.
  - Separation (offset) of two Gaussians corresponding to the match is the periodic jitter (PJ).

- **Histogram Data**
  - RJ(nos): 11.58 ps
  - PJ(nos): 42.0 ps
  - PJ(rms): 17.86 ps

### Deterministic Jitter (DJ) and Total Jitter (TJ)

- **Deterministic Jitter (DJ) and Total Jitter (TJ)**
  - DDJ histogram (Data-Correlated) and RJ, PJ histogram (Data-Uncorrelated) are measured directly.
  - Convolution of these histograms produces a histogram representing the PDF of all of the jitter present – Total Jitter histogram.
Deterministic Jitter (DJ) and Total Jitter (TJ)

Take RJ info from FFT and construct a Dual Dirac-delta model with appropriate slopes.

Match Dual Dirac-delta model to TJ histogram so that peak-peak widths match for 99.8% of volume.
- Same technique as used to get PJ from RJ, PJ PDF.

Separation (offset) of two Gaussians corresponding to the match is the deterministic jitter (DJ).

Extrapolate down the resultant Dual Dirac-delta model to the effective BER of interest (typically $10^{-12}$) peak-to-peak deviation is TJ.

Seeing the Complete Jitter Picture

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<td>DJ(8-6): 5.0 ps</td>
<td>RJ(rms): 11.08 ps</td>
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<td>PJ(4-3): 13.0 ps</td>
<td>DDJ(p-p): 10.9 ps</td>
<td>DCD: 700 fs</td>
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<td>PJ(rms): 5.16 ps</td>
<td>ISI(o-p): 10.6 ps</td>
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Jitter Analysis on the DCA-J

- **Low jitter timebase**
  - Lowest intrinsic RJ
    - ~800fs rms standard
    - ~200fs rms with 86107A

- **Wide bandwidth**
  - Up to 80 GHz
  - Lowest intrinsic DDJ
  - Supports wide range of bit rates

- **Scalable**
  - Supports all existing plug-ins
  - Optical & electrical jitter measurements
  - Multi-function platform

- **Jitter Mode**
  - One button simplicity

## Summary

- Need to separate jitter in today's high data rate digital designs:
  - Estimate Total Jitter (TJ) at very low BER
  - Understand the sources of jitter
  - Develop a Jitter budget

- New jitter characterization techniques provide more insight into jitter

- Resources:
  - Jitter: [www.agilent.com/find/jitter_info](http://www.agilent.com/find/jitter_info)
Glossary

- ITU-T – International Telecommunications Union
- MJSQ – Methods for Jitter and Signal Quality
- BER – Bit Error Ratio
- TIA – Time Interval Analyzer
- TJ – Total Jitter
- RJ – Random Jitter
- DJ – Deterministic Jitter
- PJ – Periodic Jitter
- DDJ – Data Dependent Jitter
- DCD – Duty Cycle Distortion
- ISI – Inter-Symbol Interference
- PDF – Probability Density Function