Power Integrity and its Impact on Clock Jitter

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Agenda

- Introduction: power rail noise and conversion to jitter
- Sampling theory and its application to jitter measurement
- Jitter measurement using an oscilloscope (TIE and period)
- Analyzing jitter in the frequency domain
- Correlating power rail ripple voltage with timing jitter
- Measurement example
Power Integrity and Clock Jitter
Power Integrity is a Leading Cause of System Jitter

Power supply noise causes clock/data jitter.

\[
\frac{1 \text{ mV RMS noise}}{1 \frac{V}{ns} \text{ slew rate}} = 1 \text{ ps RMS jitter}
\]
Power Integrity Measurements

Additional Challenge

Clock/Data

Power Rail

Power rails can carry other coupled sources
Spectrum Analysis of Ripple Voltage
Power Rail Measurement Challenges
Lower rail voltages and smaller tolerances

Examples

<table>
<thead>
<tr>
<th>Rail Value</th>
<th>Tolerance</th>
<th>Need to measure</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.3 V</td>
<td>2%</td>
<td>66 mV&lt;sub&gt;pp&lt;/sub&gt;</td>
</tr>
<tr>
<td>1.8 V</td>
<td>3%</td>
<td>30 mV&lt;sub&gt;pp&lt;/sub&gt;</td>
</tr>
<tr>
<td>1.2 V</td>
<td>2.5%</td>
<td>30 mV&lt;sub&gt;pp&lt;/sub&gt;</td>
</tr>
<tr>
<td>1 V</td>
<td>3%</td>
<td>30 mV&lt;sub&gt;pp&lt;/sub&gt;</td>
</tr>
</tbody>
</table>
Power Integrity Measurements: Primary Challenge

Challenge: Measure small ac signal on top of large dc signal

Issues to overcome:
1. Measurement system noise
2. Large DC Offset
3. Maintain high BW
Power Rail Probes…specialty tool

Circular saw
Great for a bunch of stuff.
Can’t cut door jambs.

Jamb saw.
Does one task really well.
Not useful for anything else.
Measurement Accuracy: Noise Due to Probe Attenuation Ratio

10:1 (10 mV/div)

10:1 attenuation

\[ V_{pp} = 45.2 \text{ mV} \]

34\% overstated

1:1 (10 mV/div)

1:1 attenuation

\[ V_{pp} = 33.8 \text{ mV} \]
Challenges with Insufficient Scope Offset
AC coupling mode and blocking caps eliminate ability to see DC changes

DC Drift

DC blocks
Eliminate low freq visibility

With power rail probe
see low freq DC changes
Measurement Accuracy: High BW Needed for High Frequency Transients

Both 1:1 Probes

Probe BW = 38 MHz
Vpp = 32mV
16% Under reported

500 MHz BWL filter on each

1:1 ZP1X passive 38 MHz BW

Probe BW = 2 GHz
Vpp = 42mV

1:1 ZPR20 active 2 GHz BW
Captures high-frequency transients
Measurement techniques for jitter in the time domain (oscilloscope)

Sampling of a signal

- The A/D Converter of the oscilloscope samples the continuous signal at specific points in time and delivers digital values.
- Sampling of clock signals at zero-crossing (no phase at high or low).
- ADC sample rate: \( f_{ADC} = 1/T_1 \)
- The result is a waveform record that contains waveform samples.
- The waveform samples were displayed at the screen and build up the waveform.
- Sample rate: \( \frac{\text{number of waveform samples}}{\text{time in s}} \)
- Nyquist theorem:

\[
f_{sa} \geq 2f_{max}
\]
Measurement techniques for jitter in the time domain (oscilloscope)

Sampling of a signal

- Integrated low-pass filter (bandwidth < \(0.5f_{sa}\)) in the analog front end → Nyquist theorem is conformed
- Sampling of a signal
  - Original spectrum:
  
  ![Original Spectrum](image)

  - Spectrum after sampling:
  
  ![Spectrum after Sampling](image)

→ Frequency spectrum is copied at multiplies of the sample rate
Measurement techniques for jitter in the time domain (oscilloscope)

**Interpolation**

- E.g.: 4:1 Interpolation $\rightarrow f_{sa}' = 4f_{sa}$
- Rectangular low-pass filter $\triangleq \text{Sin}(x)/x$ interpolation
  - Attenuates the undesired spectral images

### Diagram

- Resulting spectrum:

![Diagram showing frequency spectrum and interpolation process](image-url)
Measurement techniques for jitter in the time domain (oscilloscope)

TIE measurement

- TIE works for data and clock signals
- CDR/PLL is typically required to generate the $t_{REF,n}$ values
  - CDR (clock data recovery) or PLL
  - Recovery of TX clock
  - TX clock may be modulated (PCIe SSC)
- By recovering the TX clock, the TIE analyzes the impact of transmission
Measurement techniques for jitter in the time domain (oscilloscope)

Software Clock Data Recovery (CDR)

- CDR generates a reference clock from a high-speed serial data stream
- The generated clock signal matches the frequency and is aligned to the phase of the data stream
Measurement techniques for jitter in the time domain (oscilloscope)

Statistics

- Standard deviation, Mean value, Max, Min, Peak-peak...
- Population:
  - Number of individual observations included in the statistical data set (= event count)
  - Important to „judge“ random processes

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<table>
<thead>
<tr>
<th>Meas Results</th>
<th>Current</th>
<th>+Peak</th>
<th>-Peak</th>
<th>mu (Avg)</th>
<th>RMS</th>
<th>StdDev</th>
<th>Event count</th>
<th>Wave count</th>
</tr>
</thead>
<tbody>
<tr>
<td>Meas 1</td>
<td>30.7 ns</td>
<td>31.031 ns</td>
<td>29.044 ns</td>
<td>30.001 ns</td>
<td>30.008 ns</td>
<td>637.43 ps</td>
<td>4541</td>
<td>4541</td>
</tr>
<tr>
<td>Period</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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Statistics: Reset
Measurement techniques for jitter in the time domain (oscilloscope)

Combined measurement

- 3 ways of viewing jitter results: track; histogram; spectrum
Jitter Time Trend (track)

Clock period vs. time

Aligned with clock period

Sampling rate = clock rate
Measurement techniques for jitter in the time domain (oscilloscope)

Sampling of jitter

- Original spectrum
- Jitter spectrum
Measurement frequency response (JTF)

TIE measurement with 1 MHz PLL
Jitter and Power Measurement with an Oscilloscope

Measure jitter (TIE, period, C-C) → track → FFT

Measure Vcc ripple → FFT
Spectrum Analysis of Jitter and Power Rail

Jitter track

Power Rail Spectrum

Jitter spectrum
Spectrum Analysis of Jitter and Power Rail

Jitter track

Power Rail Spectrum

Jitter spectrum

1 ps additional jitter
Comparison of power rail ripple and jitter

Jitter spectrum

Noise spectrum
Effect of power rail noise on Jitter

- Jitter spectrum
- Noise spectrum
- Injected noise
- Additional jitter ~ 1 ps
Summary

- Voltage ripple on power rails is converted to jitter via the slew rate of clock and data signals
  - Even small ripple voltage can result in significant jitter
  - PSRR will reduce this effect in clock circuits but high frequencies are often passed through
- Specialized power rail probes are ideal for accurate noise measurement
  - Large offset range with 1:1 attenuation
  - Wide bandwidth
  - Low loading
- Spectrum analysis is a powerful tool for analyzing sources of noise and jitter
  - FFT of the Jitter time trend (track) shows frequency content of jitter
  - FFT of voltage ripple displays corresponding spectrum for the power rail
  - Increased voltage noise leads to increased jitter