Jitter Measurement in Crystal Oscillators

APPLICATION NOTE QTAN-103

Jitter Measurement in Hybrid Oscillators

Q-TECH CORPORATION

Hi-Reliability Hybrid Crystal Oscillators

Introduction To Jitter

What is Jitter?

This simple and intuitive definition is provided by the SONET specification1:

"Jitter is defined as the short-term variations of a digital signal's significant instants from their ideal positions in time."

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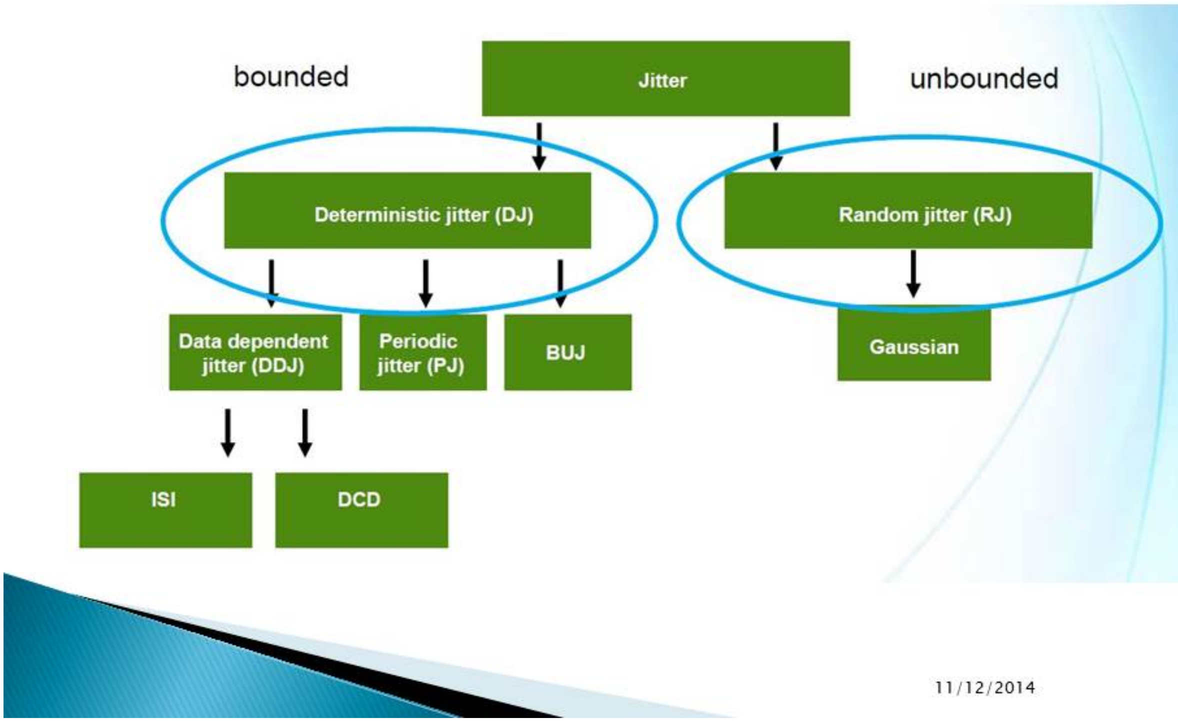
Introduction To Jitter Contd.



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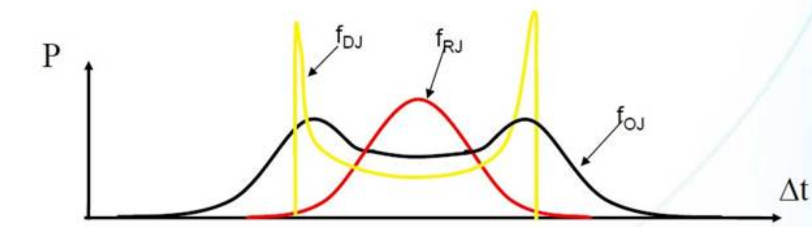
Introduction To Jitter Contd.

- The overall jitter PDF is equal to the convolution of RJ PDF with the DJ PDF, as shown in this equation:

$$f_{OJ}(\Delta t) = f_{DJ}(\Delta t) * f_{RJ}(\Delta t) = \int_{-\infty}^{\infty} f_{DJ}(u) f_{RJ}(\Delta t - u)\, du$$



Introduction To Jitter Contd.

There are several ways in which jitter may be measured on a single waveform. These are:

- *Period jitter*
- *Cycle-cycle jitter*
- *Time interval error (TIE).*

Introduction To Jitter Contd.

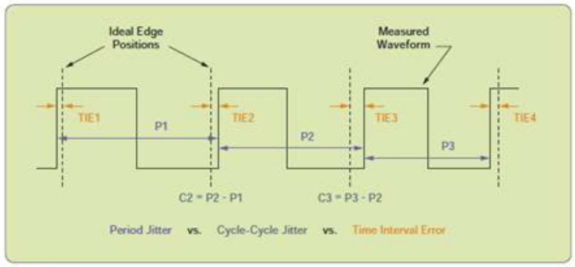


Figure 2.4a

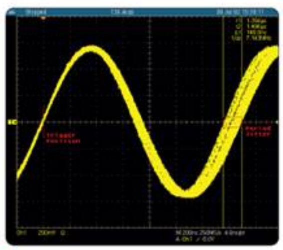


Figure 2.4b

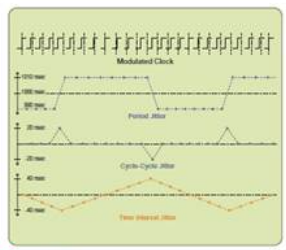


Figure 2.4c

Introduction To Jitter Contd.

Timing variations relative to the ideal transition time are called **phase jitter** (Fig. 1 top).

Signal level variations also occur in digital systems; are called **amplitude jitter** (Fig. 1 bottom).

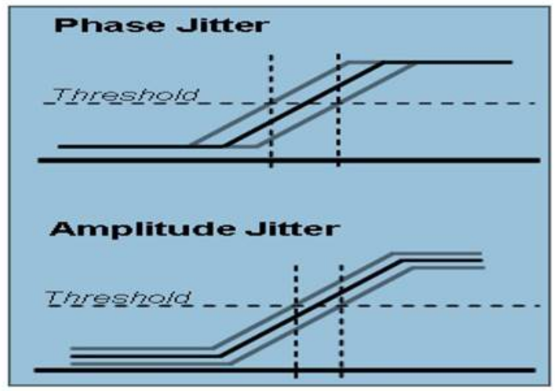


Figure 1. Phase and amplitude jitter influence digital systems and can cause bit errors.

Jitter Statistics

- **Mean Value**: The arithmetic mean, or average, value of a clock period is the nominal period. This is the reciprocal of the frequency that a frequency counter would measure.
- **Standard Deviation**: The standard deviation, represented by the Greek character sigma (σ), is the average amount by which a measurement varies from its mean value. It is particularly useful in describing Gaussian processes, for which the distribution is completely specified by the mean and standard deviation.

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Jitter Statistics Contd.

- **Maximum, Minimum and Peak-Peak Values**: The Max and Min values generally refer to values actually observed during a measurement interval, and the Peak-Peak value is simply the Max minus the Min. These measurements should be used judiciously. For a deterministic signal, these values may equal the true values even after a relatively short measurement interval. But for a random signal with a Gaussian distribution, there is theoretically no limit on the max and min values, so the observed peak-peak value will generally grow over time. For this reason, the peak-peak value should be used in conjunction with the population size and some knowledge of the type of distribution.

Jitter Statistics Contd.

- **Population**: The population is the number of individual observations included in a statistical data set. For a random process, a high population intuitively gives greater confidence that the measurement results are repeatable. If the characteristics of the distribution are known or can be estimated, it is possible to calculate the population needed to reduce the measurement uncertainty below a desired point.

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Jitter Measurement and Visualization

"To guess is cheap. To guess wrong is expensive." Chinese Proverb

- A **histogram** is a diagram that plots the measurement values in a data set against the frequency of occurrence of the Measurements. If the number of measurements in the data set is large, the histogram provides a good estimate of the probability density function (pdf) of the set. For example, if you rolled a fair die 1000 times and recorded the results, they might be as depicted in Figure 3.2a, where the HITS axis shows the number of times each value occurred. Note that a histogram provides no information about the order in which the observations occurred.

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Jitter Histogram

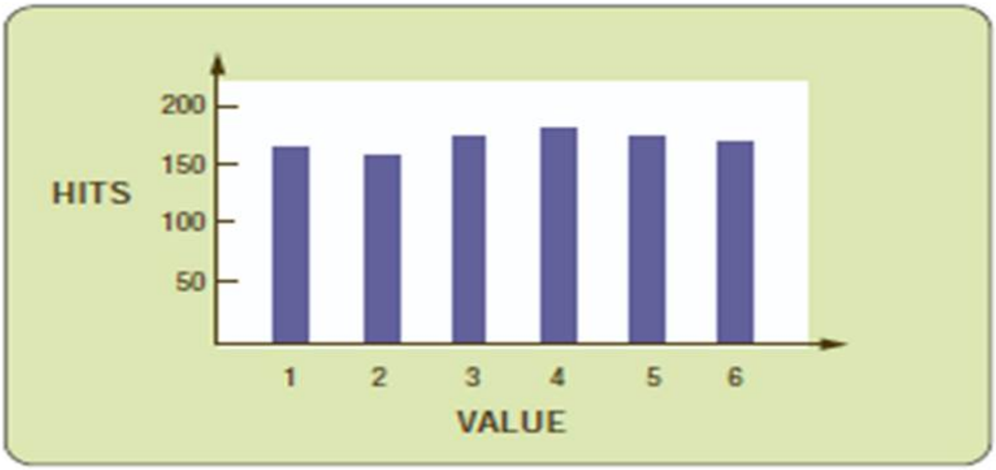

Figure 3.2a

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Jitter Separation

"All models are wrong; some models are useful"
W. Edwards Deming

Jitter separation, or jitter decomposition, is an analysis technique that uses a parameterized model to describe and predict system behavior.

To understand how real systems behave, it is often useful to use a mathematical model of the system. The behavior of such a model can be tuned by adjusting the parameters of its individual components. If the parameters of the model are chosen based on observations of the real system, then the model can be used to predict the behavior of the system in other situations.

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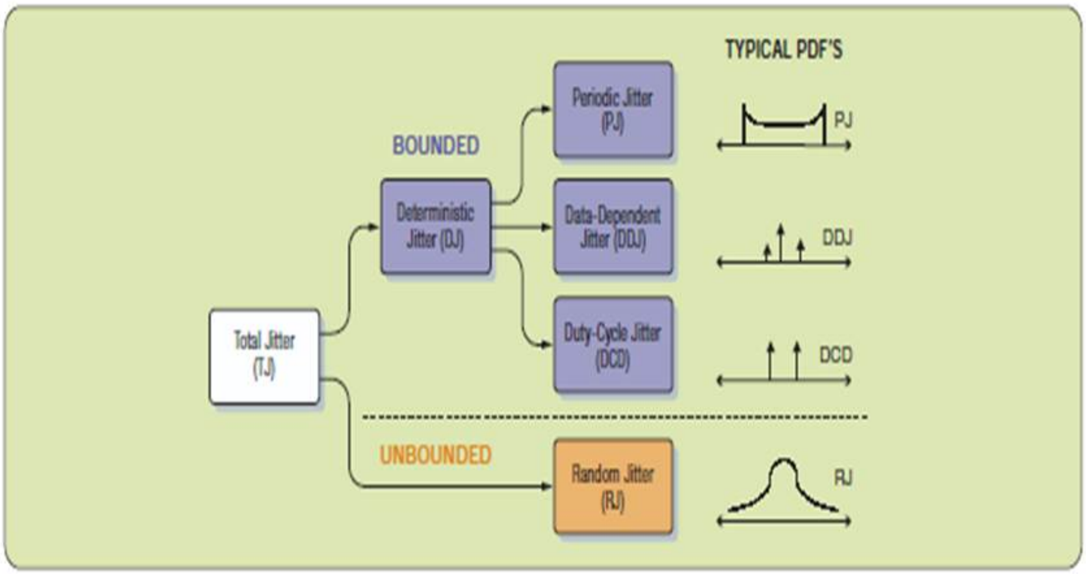
The Jitter Model



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Types of Jitter

Jitter Term	Description
TJ Total Jitter	The summation (or convolution) of deterministic and random jitter. Total jitter is the peak to peak value obtained. TJ = DJ + n × RJ where n = number of standard deviations corresponding to the required BER.
RJ Random Jitter	The principal source is Gaussian (white) noise within system components. It interacts with the slew rate of signals and produces timing errors at the switching points.
DJ Deterministic Jitter	Jitter with non-Gaussian probability density function. It is always bounded in amplitude and with specific causes. Sources are imperfections of devices, crosstalk, EMI, grounding problems.
PJ Periodic Jitter	Also called Sinusoidal Jitter due to its sinusoidal form. The source is usually interference form signals related to the data pattern, ground bounce or power supply variations.
DDJ Data dependent Jitter	Consists of Inter Symbol interference (ISI), Duty Cycle distortion (DCD), and Echo Jitter (ECJ). Timing errors vary with data pattern. Primary source are component and system bandwidth limitations. Higher frequency signals have less time to settle than lower frequency ones. This leads to changes in the start conditions for transitions at different frequencies and produces timing errors dependent on the data pattern being applied.
ISI Inter Symbol Interference	Inter symbol interference is the most common form of DDJ. It is usually caused by bandwidth limitations of transmission lines. It affects single bits surrounded by the bit of the opposite state.
DCD Duty Cycle Distortion	Duty Cycle Distortion Jitter is caused when certain bit states have different durations. "1" is always longer than "0" or vice versa. Caused by bias setting, and insufficient VCC supply of a component.
ECJ Echo Jitter	Echo Jitter is caused by component/line mismatch, it depends on the data pattern. Line length influence the magnitude of ECJ as well.

Random Jitter

- **Random jitter** is timing noise that cannot be predicted, because it has no discernable pattern. A classic example of random noise is the sound that is heard when a radio receiver is tuned to an inactive carrier frequency.
- While a random process can, in theory, have any probability distribution, random jitter is assumed to have a Gaussian distribution for the purpose of the jitter model.

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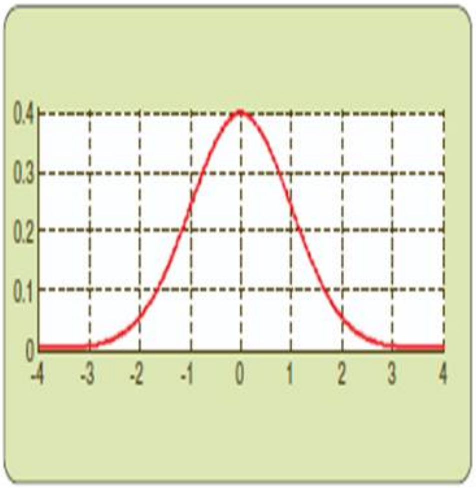
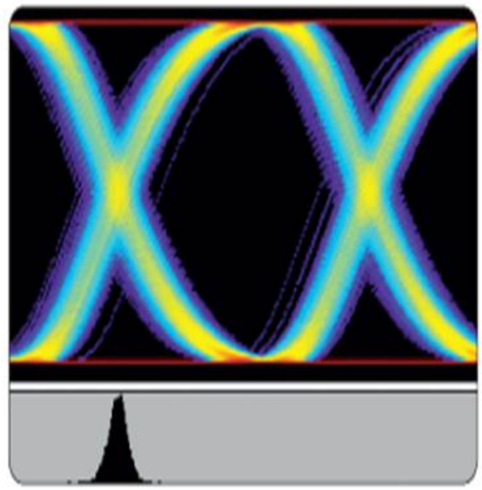
Random Jitter





Random Jitter

- System components or external influences can cause Unbounded Jitter. Most prominent is Random Jitter (RJ), which is caused by white noise prevalent in all active and passive components. Amplifiers and line drivers multiply the energy of noise. By its nature, energy distribution of white noise is Gaussian so RJ can be described by the probability density function:

$$\mathbf{PDF}_{\,\mathbf{RJ}}\,(\mathbf{x}) = \frac{1}{\sigma\sqrt{2\pi}}\exp\left(-\frac{(x-\mu)^2}{2\sigma^2}\right)$$

Equation 1

where x is the independent value and σ (sigma) the RMS value and μ (mu) the mean of the distribution. Jitter is defined as deviation from the ideal state, which means it has positive and negative variations relative to the ideal state. For this reason μ in jitter analysis is always 0 and can be omitted. Equation 1 indicates that independently of how large x may become, the probability of certain jitter causing events may become very small, but it will never reach the x-axis. Due to its wide frequency spectrum white noise is very difficult to suppress or attenuate without impacting the actual signal.

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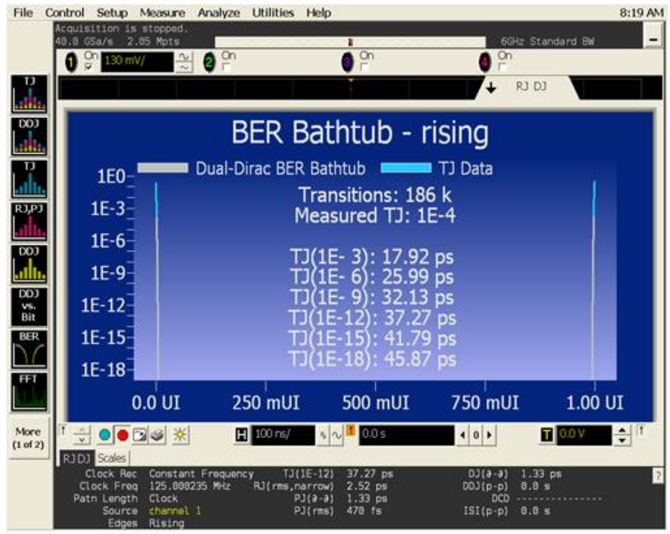
BIT ERROR RATE (BER)

BER is the measured bit error rate, NErr the number of error bits and Nbits the entire number of compared bits.
BER = NErr / NBits



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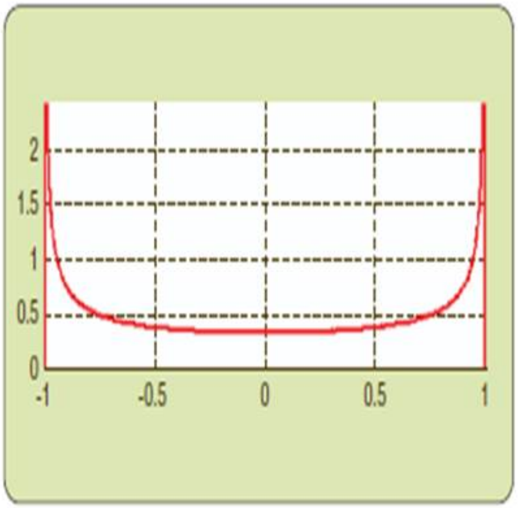
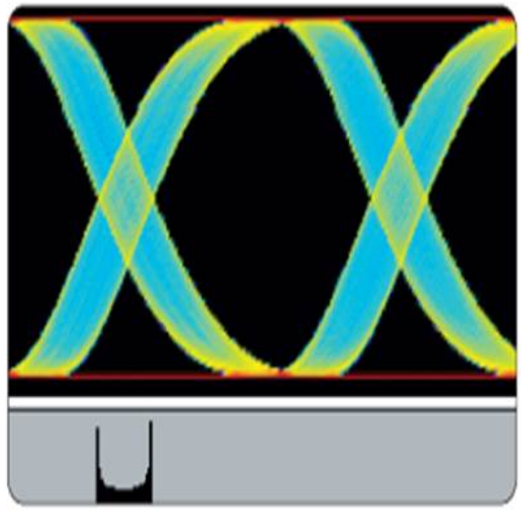
Deterministic Jitter

- **Deterministic jitter** is timing jitter that is repeatable and predictable. Because of this, the peak-to-peak value of this jitter is bounded, and the bounds can usually be observed or predicted with high confidence based on a reasonably low number of observations.

Deterministic Jitter





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Periodic Jitter

- Jitter that repeats in a cyclic fashion is called periodic jitter. An example was shown in Figure 2.4c, where the TIE time trend shows a repeating triangle wave. Since any periodic waveform can be decomposed into a Fourier series of harmonically related sinusoids, this kind of jitter is sometimes called sinusoidal jitter.

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Duty-Cycle Dependent Jitter

Jitter that may be predicted based on whether the associated edge is rising or falling is called Duty-Cycle Jitter (DCD). There are two common causes of DCD:

- 1. The slew rate for the rising edges differs from that of the falling edges.
- 2. The decision threshold for a waveform is higher or lower than it should be

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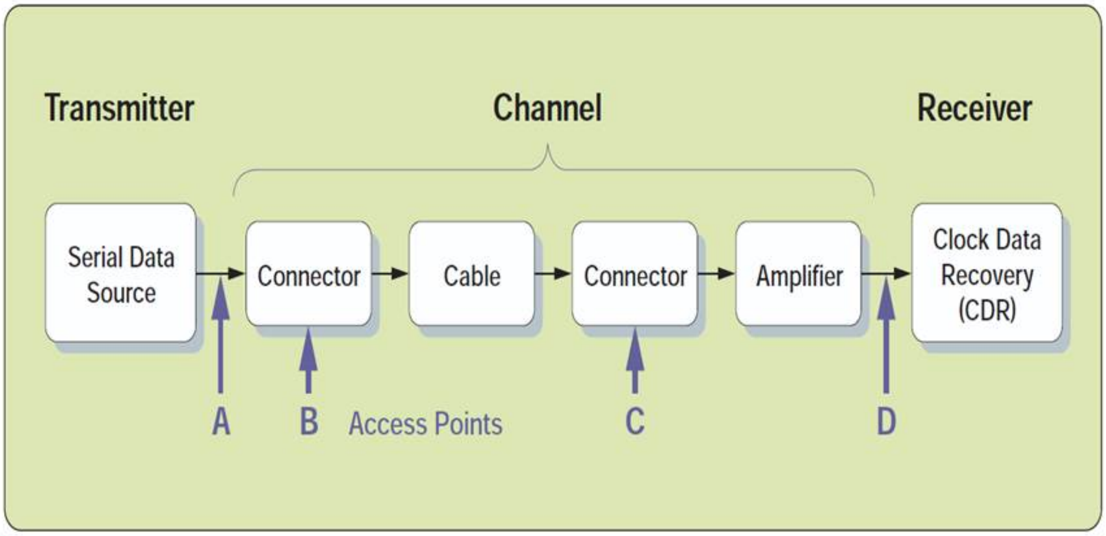
The Jitter Budget



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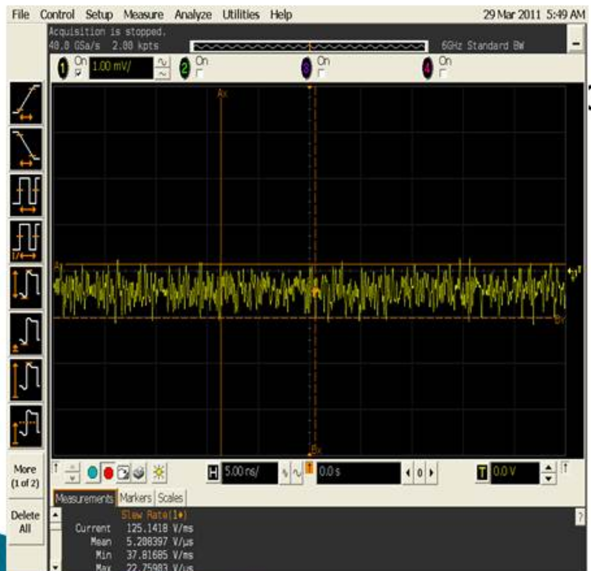
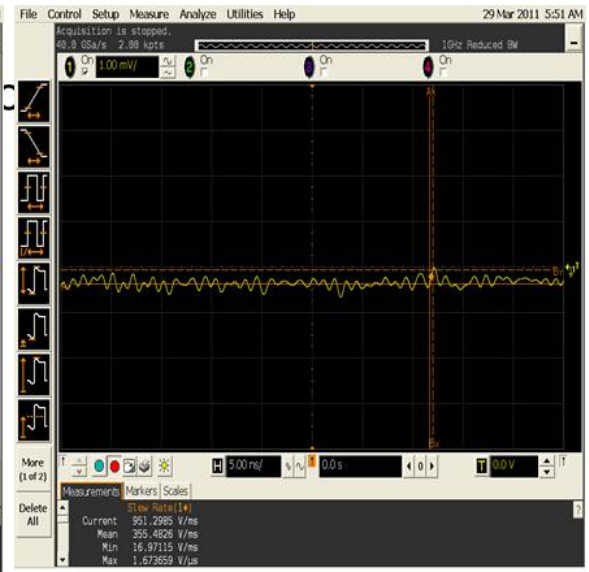
Noise Reduction Software





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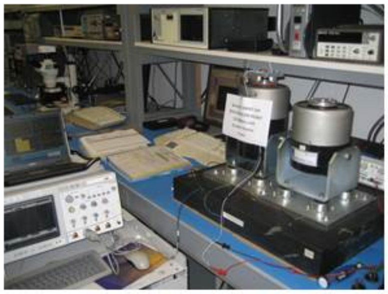
Jitter measurements under vibration



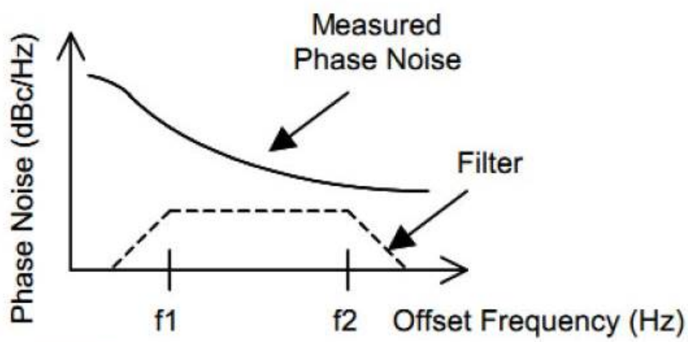
Random Vibration
Operating LVDS 3.3Vdc
120.000MHz
50Hz – 2000Hz
All axes, 37.8g RMS

RMS Period Jitter				
Serial No.	**Baseline**	**X-Axis**	**Y-Axis**	**Z-Axis**
8607	3.31E-12	3.12E-12	3.42E-12	3.40E-12
6934	3.24E-12	3.13E-12	3.45E-12	3.60E-12
P-P Period Jitter				
Serial No.	**Baseline**	**X-Axis**	**Y-Axis**	**Z-Axis**
8607	22.1E-12	20.0E-12	22.9E-12	22.7E-12
6934	21.1E-12	19.9E-12	20.0E-12	24.9E-12
Calculated Period Jitter				
Serial No.	**Baseline**	**X-Axis**	**Y-Axis**	**Z-Axis**
8607	48.4E-12	45.6E-12	50.0E-12	49.7E-12
6934	47.4E-12	47.4E-12	50.5E-12	52.6E-12

Frequency (PPM)				
Serial No.	**Baseline**	**X-Axis**	**Y-Axis**	**Z-Axis**
8607	2.94	3.72	4.01	3.93
6934	8.16	7.60	6.25	7.53

Phase Jitter

Phase Jitter is calculated by filtering the measured phase noise data with an industry standard defined filter, and integrating the result across offset frequency to derive an RMS phase jitter value. The data sheet reports phase jitter in units of time (UI) at a specific carrier frequency. The value of f1 and f2 (and roll-off characteristics, if appropriate) as dictated in data sheet or by application requirements. It is not possible to directly measure peak values from a phase noise graph.



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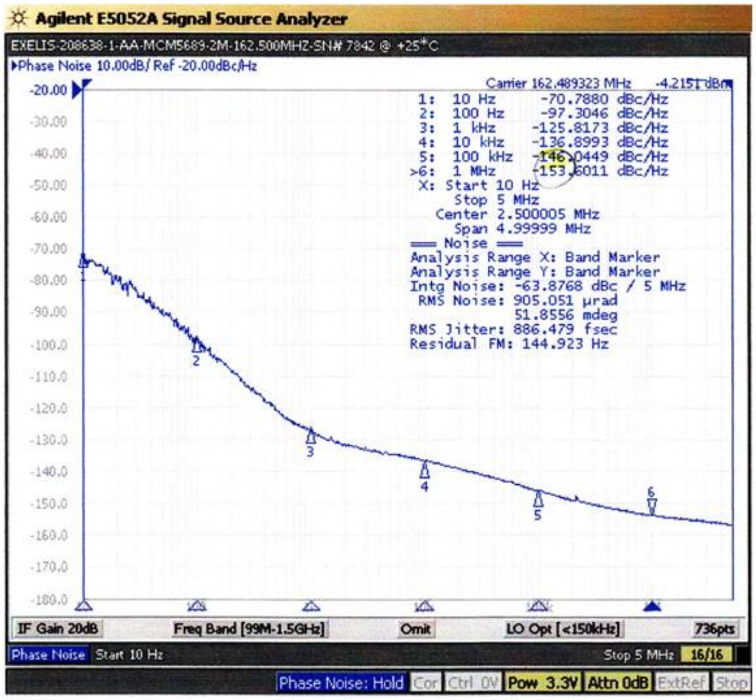
Phase Noise and Phase Jitter

Phase noise, static,
LVDS 3.3Vdc
156.25MHz
10Hz - 1MHz

Phase Jitter, integrated
from 10Hz to 20MHz



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Jitter of a QT93LW-80MHz