JITTER FUNDAMENTALS

THE REFERENCE STANDARD FOR SIGNAL INTEGRITY ANALYSIS

WAVECREST
A TECHNOLOGIES COMPANY

Wavecrest SIA-3000

THE REFERENCE STANDARD FOR SIGNAL INTEGRITY ANALYSIS

File input/output function buttons load and store measurement data, tool configurations and data patterns.

Horizontal and vertical controls adjust scale and position viewing characteristics.

Large, high-resolution color display makes it easy to see multiple analysis tools.

Tool/field selection and input buttons.

Tool function buttons display tool selections, start/stop measurements, continuous run or clear current display measurements.

120 MB Superdisk drive provides PC compatibility, data loading and archiving.

Measurement channels configurable with up to 10 channel cards.

USB connectors for auxiliary devices, such as keyboard and pointing devices.

Macro buttons simplify frequent keystroke sequences with one-button acquisition.

Keypad for active field data entry. Dial varies values or scrolls through choices.

Calibration source.

Menu selection activates pull-down menus, allows navigation of choices and online help. Display controls scroll through open/close tools, add views and maximize window.

Contents

Enhance speed, throughput and accuracy with one powerful instrument

Every day, clock speeds get faster and data rates increase. This relentless acceleration makes signal integrity and flawless operation increasingly difficult to achieve — in the lab and on the production floor. In fact, test engineers and production managers can no longer rely solely on conventional test equipment and expect fast, accurate, repeatable results.

That's why we developed the ***WAVECREST*** SIA-3000™, the reference standard for signal integrity analysis. This powerful test and measurement solution — together with a suite of advanced, application-specific software and accessories — enables design and test engineers to fully characterize devices faster and easier than ever before. When you put the ***WAVECREST*** SIA-3000 to work, you will see three immediate benefits:

Versatility

The SIA-3000 provides the functionality of an oscilloscope, BER tester, time interval analyzer and spectrum analyzer — plus advanced jitter separation capabilities these instruments can't offer. Its scalable platform features up to 10 single-ended or differential, fully parallel channels. And it can analyze electrical or optical components, in the lab or in production.

Speed

The SIA-3000 uses patented algorithms to measure jitter significantly faster than conventional equipment, so you can increase throughput, reduce cost of test and improve time to market. It also enables comprehensive testing at production-level speeds, so you can integrate it in production to lower development costs and provide correlation to lab tests.

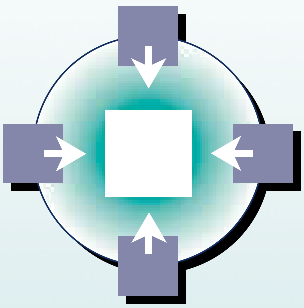
Accuracy

The SIA-3000 can measure data rates up to 4.5 Gb/s with 200 femtosecond resolution. Its triggerless architecture eliminates errors common to trigger-based instruments. And it delivers the precise, quantifiable — and repeatable — results you need to ensure interoperability.

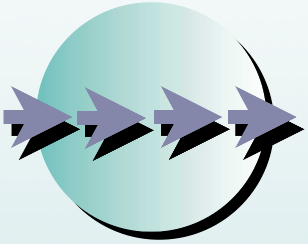
Since 1987, ***WAVECREST*** has developed and patented innovative test and measurement instruments for datacom, telecom, microprocessors and other high-tech industries. Around the world, market leaders trust our equipment to ensure device reliability and quality in the lab and on the production test floor.

In the following pages, we explain how the SIA-3000 builds on this heritage of success. We provide a detailed examination of the causes and effects of jitter. We look at its components and how to quantify them — a task the SIA-3000 is designed to handle. We also review typical applications such as PLL/clock, datacom and databus.

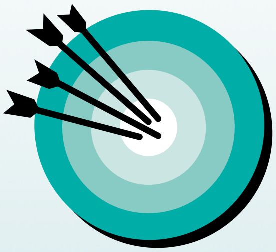
Along the way, in the lower margins, you will find a long list of proof points. When you read them, you will understand why the SIA-3000 is the most powerful signal integrity analysis instrument available today.



Versatility



Speed



Accuracy

Understanding Jitter

Traditionally, measuring jitter has been critical to determining the performance of high-speed digital communications systems. Recently, as internal and external data rates of computers and networks have increased to unprecedented levels, reducing jitter has become an even higher priority for ensuring high reliability in high-speed databuses and integrated circuits.

Defining jitter

Jitter is the deviation of a timing event of a signal from its ideal position. Jitter affects a system as a whole, and can be introduced by every circuit element used to generate, convey and receive signals. As a result, understanding the amount of jitter introduced by each element of a system is imperative for predicting overall system performance.

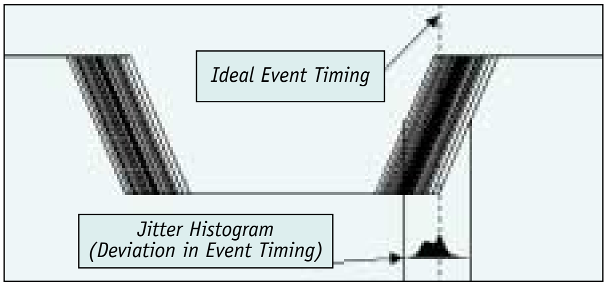


***Figure 1**. Timing jitter is the deviation from the ideal timing of an event. Jitter is composed of both deterministic and Gaussian (random) content. TJ is the convolution of all independent jitter component PDFs.*

Effects of jitter

As microprocessor and communication chip clock rates rise, jitter increasingly impedes system performance. For example, a nanosecond of jitter in a 100baseT (100 Mb/s) device represents a 10% data uncertainty problem (see Fig. 2a). If you double the speed of the device, however, the same error becomes a 20% uncertainty problem (assuming the jitter remains unchanged). If your system only allows 15% uncertainty for operation, the existing jitter would cause system failure (see Fig. 2b). This same nanosecond of jitter in a Gigabit Ethernet device could represent a data uncertainty problem greater than 100%. For these reasons, it has become increasingly important to characterize, model, simulate and quantify all jitter components. Knowing the frequency and amplitude of these components helps identify the root cause and establish whether or not the jitter poses a problem.

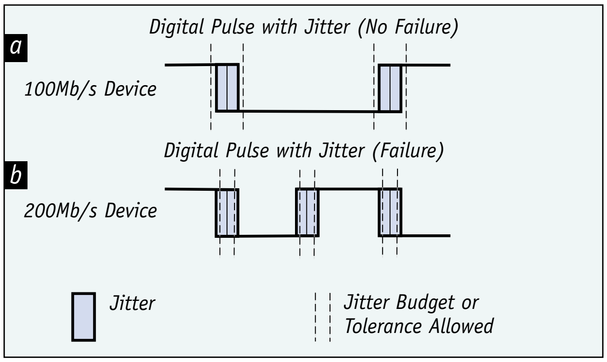
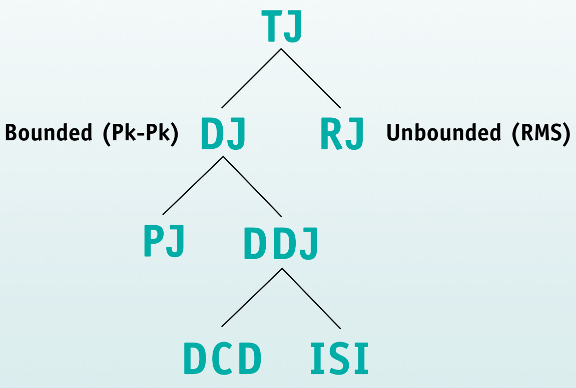


***Figure 2a.** A 100 Mb/s digital device with jitter less than the budget. **Figure 2b.** A 200 Mb/s device with the same amount of jitter as in 2a, where jitter exceeds the allowable amount.*

Identifying jitter components

Total jitter (TJ) includes deterministic jitter (DJ) and random jitter (RJ). DJ can be further separated into periodic jitter (PJ), data dependent jitter (DDJ), duty cycle distortion (DCD) and intersymbol interference (ISI). The SIA-3000 is the only instrument available today that can measure all these components individually.



Jitter Categories

Total jitter (TJ) is the convolution of all independent jitter component Probability Density Functions (PDF). A PDF describes the likelihood of a given measurement relative to all other possible measurements, and is typically represented by a normalized histogram. TJ includes contributions from all deterministic and random components, and is a pk-pk value specified for a given sample size or Bit Error Rate (BER).

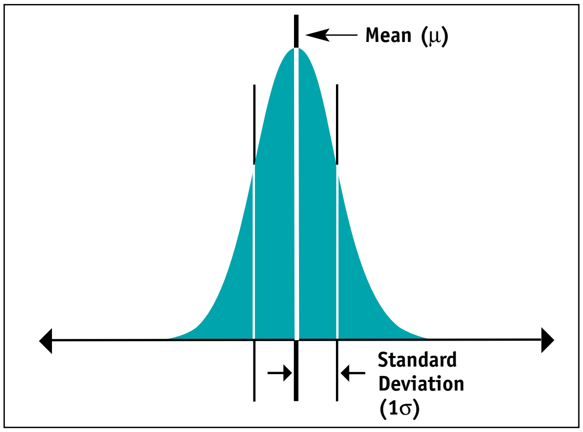


***Figure 3**. A Gaussian distribution with a mean (μ) and a standard deviation (σ). This figure represents a PDF for a Gaussian distribution.*

Random jitter

Random jitter (RJ) is characterized by a Gaussian distribution and assumed to be unbounded. As a result, it generally affects long-term device stability. Because RJ is Gaussian in nature, the distribution is quantified by the standard deviation or 1σ and mean (μ) as shown in Fig. 3. Because RJ can be modeled as a Gaussian distribution, it can be used to predict pk-pk jitter as a function of BER. This means that for a BER 1.3×10^{-3}, 6σ would provide a pk-pk range that includes all of the samples except an amount represented by mulitplying the total number of samples by 0.0013. For serial communication standards, such as Fibre Channel and Gigabit Ethernet, TJ is typically described at a BER of 10^{-12}, which is 14.069 times the 1σ value.

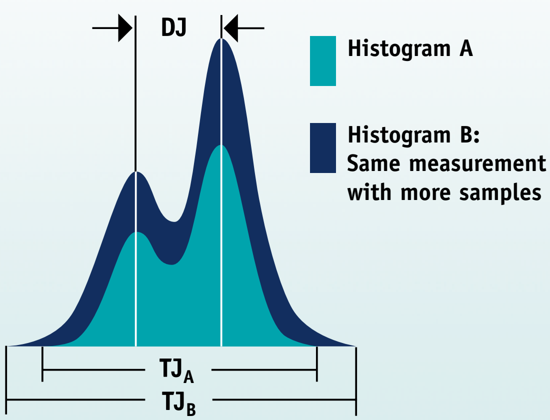
BER	TJ value
1.3×10^{-3}	$6 \times \sigma$
3.17×10^{-5}	$8 \times \sigma$
2.87×10^{-7}	$10 \times \sigma$
9.87×10^{-9}	$12 \times \sigma$
1.28×10^{-12}	$14 \times \sigma$
1×10^{-12}	$14.069 \times \sigma$

***Table 1**. TJ values at various BER for a single Gaussian distribution.*

Table 1 shows TJ values at various BER. It is important to note that it is incorrect to use a 1σ value from an arbitrary histogram to estimate BER. For example, the 1σ value of a histogram with more than one peak does not correctly quantify the jitter histogram, because the histogram

Random and deterministic jitter separation

DJ is characterized by a bounded pk-pk value that does not increase with more samples. RJ is unbounded and its pk-pk value increases, resulting in larger TJ values with more samples. Proprietary algorithms enable the SIA-3000 to separate TJ into its RJ and DJ components for analysis.



may contain both RJ and DJ components. For this type of histogram, the correct way to determine RJ involves separating the RJ portion with the TailFit algorithm (see p. 6).

Deterministic jitter

Deterministic jitter (DJ) has a non-Gaussian PDF and is characterized by its bounded pk-pk amplitude. There are several types of DJ, including periodic jitter (PJ), duty cycle distortion (DCD) and intersymbol interference (ISI). DCD and ISI are types of data dependent jitter (DDJ). (Other types of DDJ are still being investigated.) PJ, also referred to as sinusoidal jitter, has a signature that repeats at a fixed frequency. For example, PJ could be the result of unwanted modulation, such as electromagnetic interference (EMI). PJ is quantified as a pk-pk number, specified with a frequency and magnitude. DCD is the result of any difference in the mean time allocated for the logic states in an alternating bit sequence (e.g., 0, 1, 0, 1). Different rise and fall times and threshold variations of a device could cause DCD.

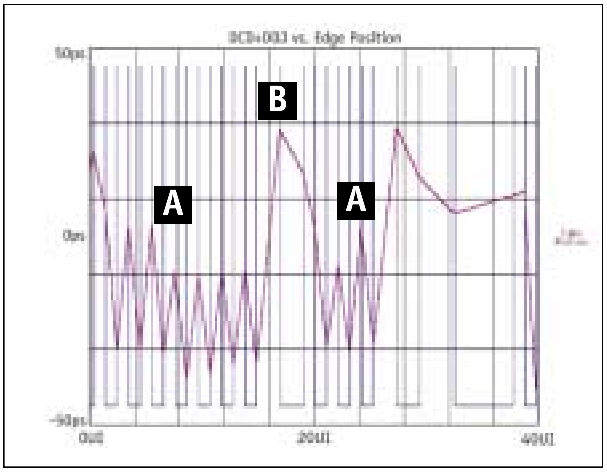
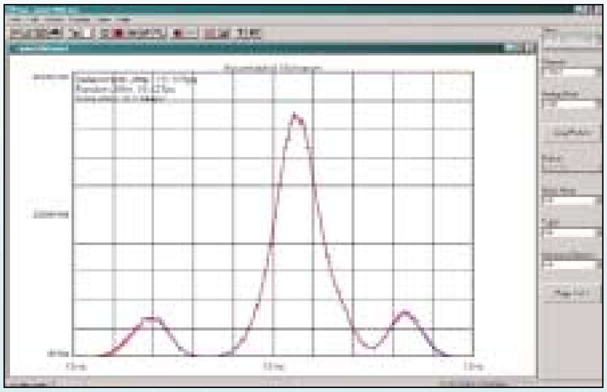


Figure 4. *Here we see the amount of DDJ (y axis) as a function of the bit position. Region A is a high-transition density 1010 pattern and the jitter is typically in the 0 to -40 ps range, while the low-density region B is in the 6 to 30 ps range. The differences in the mean offsets between regions A and B indicate potential bandwidth problems.*

DCD and ISI are functions of the data history that occur when the transition density changes. For example, Fibre Channel systems and devices are commonly tested with a Compliant Jitter Tolerance Pattern (CJTPAT) that stresses DCD and ISI by alternating long strings of zeros or ones with short strings of zeros or ones within the pattern. DCD occurs when long strings of ones or zeros cause the voltage level to drift and consequently delay the edge transition. ISI occurs when the transmission medium propagates the frequency components of data (symbols) at different rates. One example of DCD and ISI is when jitter changes as a function of edge density (see Fig. 4).

Integrated VISI software

The SIA-3000 integrates Virtual Instruments™ Signal Integrity (VISI) software, which analyzes signal integrity with patented algorithms available exclusively from ***WAVECREST.*** *These algorithms enable VISI software to separate jitter into DJ and RJ, and measure TJ.*



Quantifying Jitter Components

Quantifying jitter components from measured data is the foundation of true signal integrity analysis. It involves statistics, DSP, algorithms and basic assumptions about the data histograms.

Understanding histograms

In the time domain, jitter data are typically collected from one particular edge to another edge. For example, a period measurement is taken between a rising edge and the next rising edge. The histogram of period measurements contains a mixture of DJ and RJ processes. Traditionally, the TJ histograms included DJ and RJ components, and were quantified by a pk-pk value and a 1σ. However, given the Gaussian nature of the random component, it is incorrect to quantify a jitter histogram with a pk-pk number without specifying the number of samples. Therefore, for a given jitter histogram containing RJ, the pk-pk value will increase with more samples. Furthermore, in the presence of DJ, the 1σ of the total distribution does not depict the Gaussian component RJ.

The TJ histogram represents the TJ PDF. However, if the DJ and RJ processes are independent, then the total PDF is the convolution of the RJ PDF and DJ PDF. If DJ was absent from the jitter histogram, then the distribution would be Gaussian. Adding DJ to the histogram effectively broadens the distribution while maintaining Gaussian tails, and the RJ value will be the average of the right and left tail (later, we discuss how RJ is obtained from the histograms). Adding DJ to the distribution effectively separates the mean of the right and left Gaussian distribution. The difference between the two means, μ_L and μ_R, is the DJ (see Fig. 5). The tail portions of the histogram represent the RJ component of the TJ histogram.

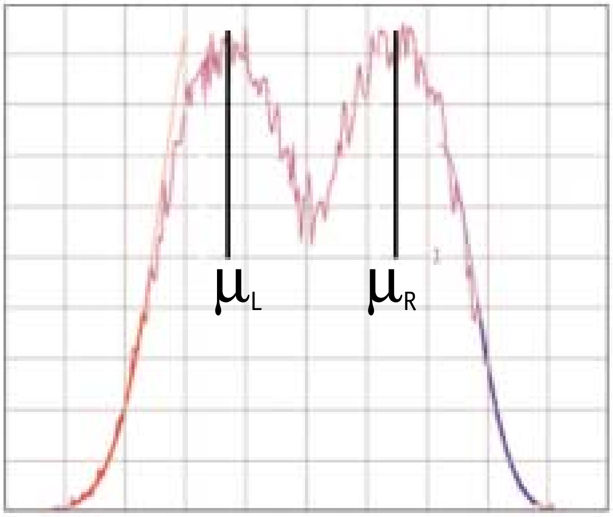


***Figure 5**. A bimodal distribution that contains both RJ and DJ components, achieved by adding a single DJ component to an otherwise Gaussian distribution.*

Multi-function measurement

Because the SIA-3000 completes the signal integrity measurements normally conducted on four separate instruments, it allows you to conserve capital and change instrument set-ups without changing connections to the device.

TailFit™ Algorithm

The TailFit algorithm — a patented ***WAVECREST*** innovation — is capable of separating RJ from actual measurement distributions by using the Gaussian nature of the tail regions of non-Gaussian histograms. The algorithm first identifies a tail region of the histogram, then fits the data with a Gaussian histogram that best coincides with the tail region. The process repeats for each side of the histogram. The RJ values for the tails are averaged to represent the RJ for the distribution when calculating TJ. Figure 5 shows a Gaussian tail fit to the left (red) and right (blue) of the distribution. Chi-squared is used as a gauge to determine the quality of fit. It is an iterative process, and ends when the results converge. To limit the iterative process, an estimate of the initial fitting parameters is made by the algorithm using the tail portions of the distribution. Most important, you can determine the DJ and RJ components, regardless of the shape of the data histogram.

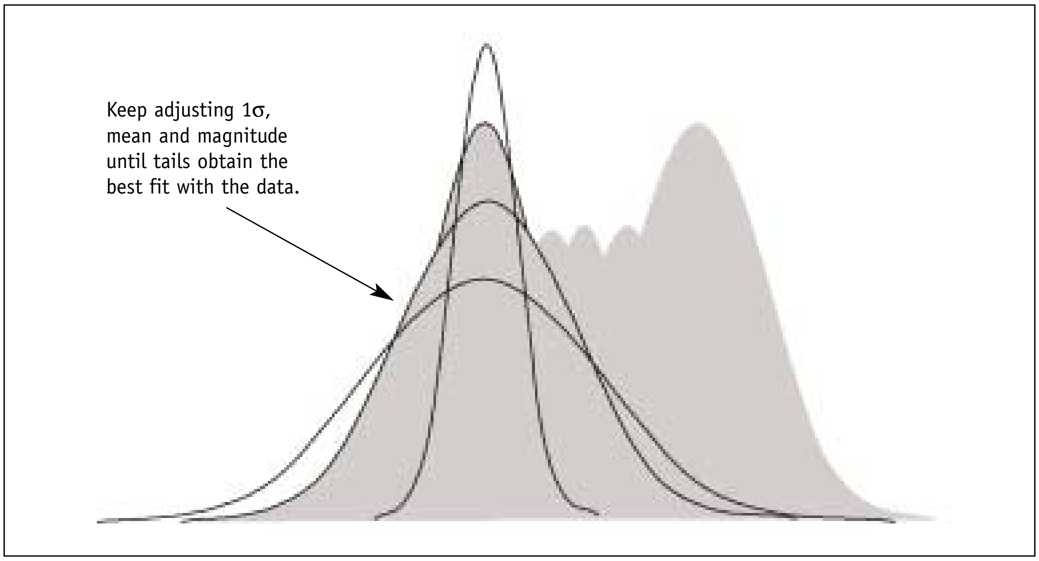
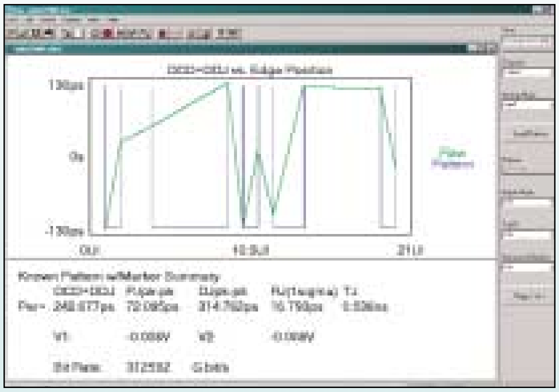


Figure 6. *The TailFit algorithm enables the user to identify a Gaussian curve with a coincident tail region in order to quantify the random or Gaussian component of the distribution. Various curves are fitted against the distribution until an optimal match is found. Then, the 1σ of the matched curve is used as the RJ value for that particular tail. This is repeated for both sides of the distribution, and the two RJ values are averaged to get the overall RJ value.*

Fast data rates

The SIA-3000 can measure data rates up to 4.5 Gb/s with 200 femtosecond resolution, so you can test faster devices and measure jitter more accurately.



Sources of Jitter

Understanding the underlying cause of jitter is crucial to signal integrity analysis. Determining the source of jitter allows you to characterize and eliminate the potential problem. Here, we examine the most frequent causes of DJ and RJ. Some common sources of DJ include EMI, crosstalk and reflections.

Electromagnetic interference

EMI is the result of unwanted radiated or conducted emissions from a local device or system. Switching-type power supplies are common sources of EMI. These devices can radiate strong, high-frequency electric and magnetic fields, and they can conduct a large amount of electrical noise into a system if they lack adequate shielding and output filtering. EMI can couple or induce noise currents in a signal conductor and corrupt the signal by altering its bias. Because the interfering signal is deterministic, the resulting jitter is also deterministic. EMI may also corrupt a ground reference plane or a supply voltage plane by introducing transient noise currents. Noise currents can sporadically alter the effective input thresholds of signal receivers. Given that logic signals require a finite time to change states, a sporadic change in receiver threshold results in signal jitter.

Crosstalk

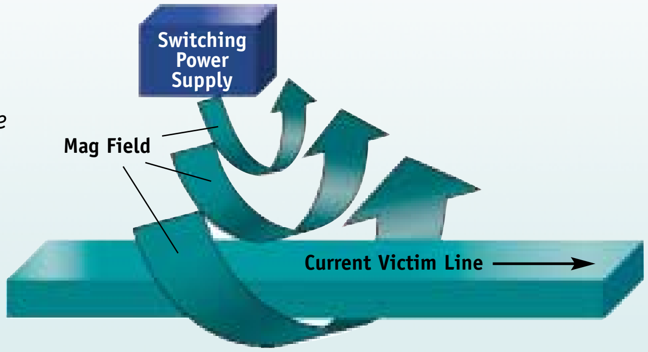
Crosstalk occurs when the magnetic or electric fields of a signal on a conductor are inadvertently coupled to an adjacent signal-carrying conductor. The coupled signal components algebraically add to the desired signal, and can slightly alter its bias depending on the amount of coupling and the frequency content of the interfering signal. The altered bias translates into jitter as the signal transitions the receiver's threshold.

Reflections

Reflections in a data signal channel create DJ due to the signal interfering with itself. Signal reflections occur when impedance mismatches are present in the channel. With copper technology, optimum signal power transfer occurs when the transmitter and receiver have the same characteristic impedance as the medium. If an impedance mismatch is present at the receiver, a portion of the energy is reflected back through the medium to the transmitter. Reflections typically come from uncontrolled stubbing and incorrect terminations. Reflected energy, or energy not available to the receiver, reduces the signal-to-noise ratio at the receiver and increases jitter. If the transmitter is also mismatched, the transmitter absorbs a portion of the reflected signal energy while the remainder is reflected toward the receiver (again). Eventually, the delayed signal energy arrives at the receiver, out of phase with the original signal. The portion that is absorbed is algebraically summed with first-time arriving signal energy, resulting in DJ (specifically, ISI) from the receiver's perspective.

Identify EMI and other jitter sources

EMI is a common source of jitter. It is the result of unwanted radiated or conducted emissions from a power supply or similar source. With the SIA-3000, you can pinpoint jitter from EMI as well as Gaussian noise, crosstalk, reflections and other sources.



Common sources of RJ include shot noise, flicker noise and thermal noise.

Shot noise

Shot noise is broadband “white” noise generated when electrons and holes move in a semiconductor. Shot noise amplitude is a function of average current flow. The current fluctuations about the average value give rise to noise. This will depend on the process. For example, in a semiconductor it is the randomness of the density of electrons and holes. In a signal channel, shot noise contributes to RJ.

Flicker noise

Flicker noise has a spectral distribution that is proportional to $1/f^{\alpha}$ where α is generally close to unity. Because flicker noise is proportional to $1/f$, its contribution is most dominant at lower frequencies. The origin of flicker noise is a surface effect due to fluctuations in the carrier density as electrons are randomly captured and emitted from oxide interface traps.

Thermal noise

Thermal noise can be represented by broadband “white” noise, and has flat spectral density. It is generated by the transfer of energy between “free” electrons and ions in a conductor. The amount of energy transfer and, therefore, the amount of noise, are related to temperature. Thermal noise is unrelated to signal current flow, but it is a contributor to RJ in systems with low signal-to-noise ratios. Electron scattering due to a nonperfect lattice structure causes RJ. The deviations of the lattice structure are due to crystal vibrations or phonons. Ions do not remain at their ideal crystal location because of thermal energy. The deviation of the lattice structure from its ideal position can induce electron scattering. The amplitude of the ionic perturbation decreases with temperature and at sufficiently low temperatures impurity and defect scattering dominates. However, reducing the temperature will not completely eliminate RJ because of intrinsic defects, such as impurities, missing atoms, or discontinuities in the lattice structure caused by an interface. In these cases, the defect or impurity causes a localized scattering center, giving rise to RJ.

Multiple configurable channels

The SIA-3000 offers direct inputs for multi-lane, single-ended or differential I/O, which increases throughput and eliminates bandwidth limitations associated with probes and baluns. No factory configurations are necessary.

PLL/Clock Distribution Applications

Clocking is a primary concern in the design and manufacture of high-speed digital systems. Typically, clock signals are the highest-frequency signals in modern computer systems, and they are the signals that circuitry loads down the most. These factors contribute to clock timing uncertainties. Plus, clock-dependent circuits such as phase locked loops (PLLs) are significantly affected by clock signal instability. As a result, system clock signals and clock-dependent circuits must be thoroughly characterized to ensure system reliability.

Timing margins

The significance of timing uncertainties is inversely proportional to cycle time. A common design practice allows 10% of the clock period for timing uncertainties. This period is called a timing margin. Timing margins protect against signal degradation from jitter, crosstalk, EMI and other causes. As a system's clock frequency is increased, timing uncertainties become a more significant portion of the timing margin. For example, a one-nanosecond timing margin in a 100 MHz system represents a nominal 10% timing uncertainty. But a one-nanosecond timing margin in a 500 MHz system represents a 50% timing uncertainty.

A PLL generates a clock signal in phase with an input signal. Variations in frequency of the input signal may or may not be exhibited on the output clock, depending on the loop response of the PLL. The corner frequency of a PLL defines the highest modulation frequency that can pass from the input signal to the output clock.

PLL output jitter

Characterizing the frequency of the modulation can help identify the root cause of jitter. Potential sources include:

- Power supply noise
- Internal switching noise
- Noise on the PLL's reference frequency signal
- Crosstalk and other EMI sources
- Under-damped PLL feedback loop
- PLL feedback loop oscillations

Signal integrity

*The **WAVECREST** SIA-3000, with VISI software, can characterize the following:*

- *TJ, DJ and RJ quantities for repeating patterns and clock-data*
- *DJ breakdown into DCD and ISI, as well as PJ*
- *Spectral view of RJ and PJ*
- *System reliability to 10^{-16} BER*
- *Reference clock jitter*
- *Rise and fall times*
- *Voltage levels*

Jitter analysis in a circuit

There are several metrics used to define PLL performance. Metrics are selected depending on the target application of the PLL.

In the following example, the SIA-3000 and VISI software analyze jitter sources in a circuit with a PLL. The analysis starts with a histogram of period measurements to identify the magnitude of the jitter problem. Fig. 7 is an example of a non-Gaussian histogram, indicating that DJ is present. The figure shows a Gaussian tail in red fit to the left of the distribution, and a Gaussian tail in blue fit to the right of the distribution. The average of the right and left standard deviation provides the RJ value, while the difference between the mean of the two Gaussian distributions provides the DJ value.

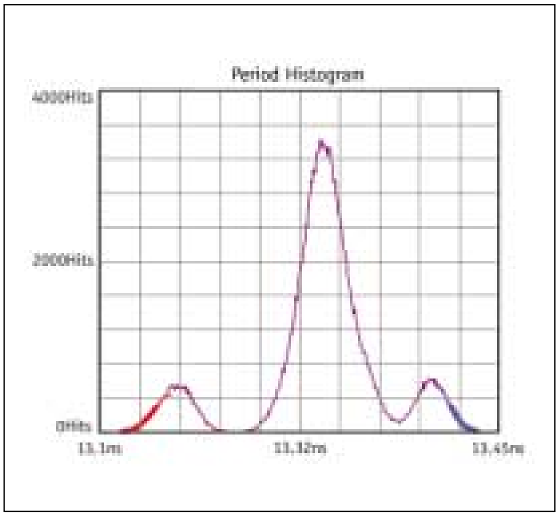


Figure 7. *This histogram of period measurements includes RJ and DJ. Note that the tails have been matched to a Gaussian distribution.*

Accumulated Time Analysis

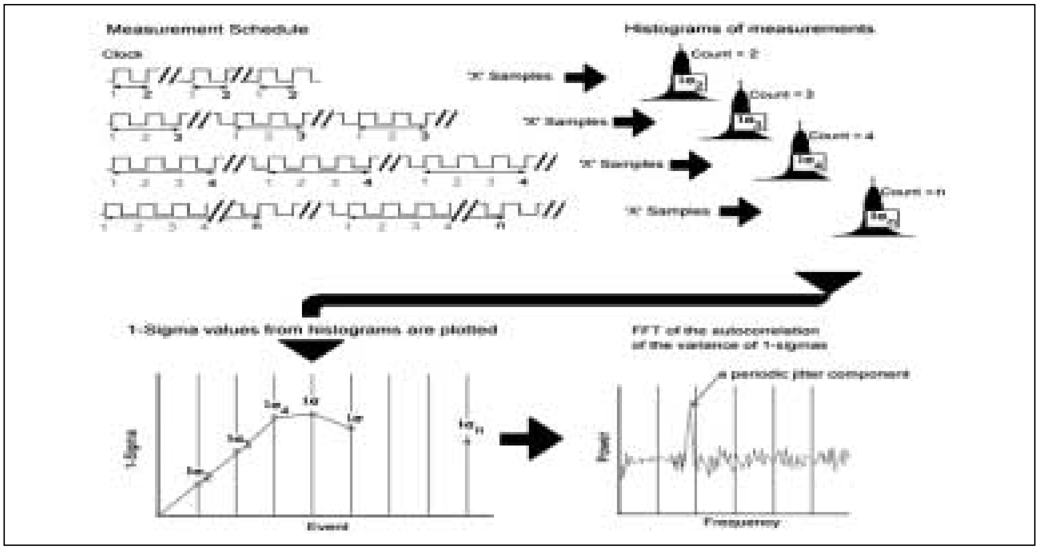
To identify the root cause of the DJ, it is necessary to identify the frequency and amplitude of the jitter components. To do this, we use Accumulated Time Analysis, a patented ***WAVECREST*** algorithm that creates a frequency vs. jitter diagram.

Accumulated Time Analysis automatically acquires period histograms over an increasing range of periods. The span of periods is determined by the –3dB low-frequency cutoff. In the time domain, a plot of the 1σ vs. span can be viewed. The plot allows us to see how jitter accumulates with time. The time domain data can be converted to the frequency domain by performing an FFT of the variance of the 1σ values (see Fig. 8).

Assessing PLL metrics

*The **WAVECREST** SIA-3000 with VISI software can perform many PLL metrics, including:*

- *PLL lock time*
- *Period jitter*
- *Adjacent cycle jitter*
- *Short- and long-cycle probabilities*
- *PLL loop response*
- *Slew rate*
- *Rambus® DRCG compliance*
- *Frequency modulation*
- *Allan variance*
- *Phase noise*
- *Wander*
- *RJ, DJ and TJ*
- *Overshoot*



Different views of the FFT plot enable us to view cumulative amplitude of the interfering signal or its cycle-to-cycle impact. Cumulative amplitude diagrams are used to show the differences between the edges of the actual clock vs. the clock edges of an ideal, jitter-free clock. Alternatively, the data can be displayed with each spectral component normalized to its impact on a single period. Figure 9 is an example of a normalized jitter diagram.

Figure 8. *How the Accumulated Time Analysis algorithm creates a frequency vs. jitter diagram.*

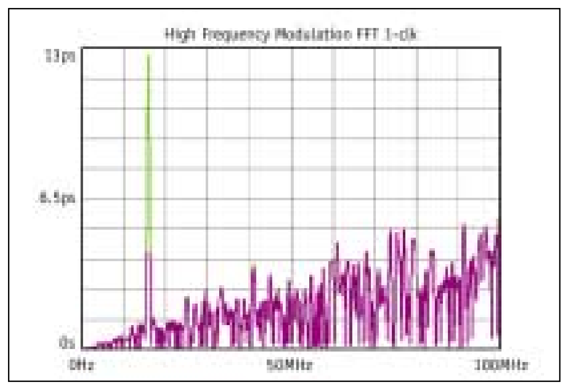
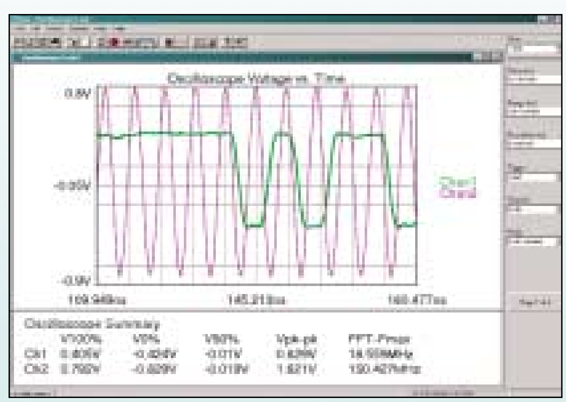


Figure 9. *Shows the impact of each spectral component on a single period. Note the roll-off effect as it goes lower in frequency. Lower-frequency components of jitter have a lower impact on a single period.*

Waveform viewer

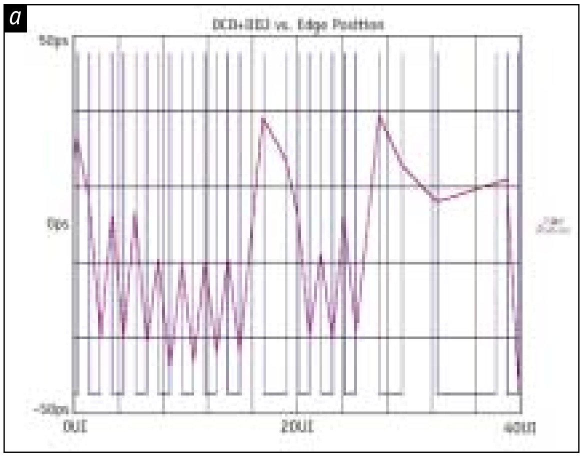
With the SIA-3000, you can view waveforms from all channels simultaneously on a single screen. This makes it easy to obtain information such as voltage levels and rise times.



Datacom Applications

Driven by the exponential growth of data communication, rates have increased tremendously over the past five years. Serial data streams in Storage Area Network (SAN) environments regularly exceed 2 Gb/s, and multi-lane 10 Gb/s Ethernet systems are expected soon. As a result, it has become increasingly difficult for designers and engineers to ensure signal integrity and measure devices for compliance — all of which makes jitter analysis tools more critical than ever. Common applications of jitter measurement include Fibre Channel (FC), Gigabit Ethernet (GBE), XAUI, InfiniBand, SONET, Serial ATA, 3GIO and Firewire components and systems. In high-speed serial communication signals, jitter is caused by many factors, including:

- Bandwidth effects on ISI
- Optical and electrical connectors and cables
- Noise on the PLL's reference frequency signal
- Power supply noise
- Internal switching noise
- Crosstalk
- Signal reflections
- Optical laser source



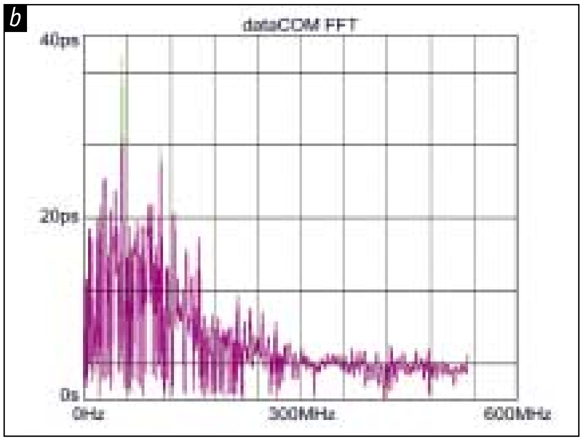


Figure 10a *shows DDJ as a function of the bit position.* ***Figure 10b*** *shows an FFT with a periodic spike at 52 MHz that contributes 38 ps of jitter. Together, these figures illustrate the DJ components of TJ.*

Analyzing jitter on high-speed devices

Measuring jitter on a high-speed serial device can be done with the SIA-3000 and DataCOM software. Data signals can be analyzed with a repeating pattern or data with a bitclock. We can determine the DCD and ISI components that can provide information about bandwidth limitations, as well as any PJ component that could be caused by crosstalk or EMI, and RJ (which affects long-term system reliability).

Comprehensive data signal analysis

The SIA-3000, with datacom-specific software, provides comprehensive data signal analysis that enables designers and engineers to characterize and analyze high-speed serial systems or devices quickly. It allows users to perform the analysis on a repeating data stream, on a data pattern with a bit clock, and on random data. These same lab tests can also be performed in a production environment.

Analysis of a typical high-speed serial device starts with examining the DCD and ISI contribution to TJ. DCD and ISI are measured from the difference between the ideal expected edge location and the mean of the actual edge location for each edge in the pattern. The DCD and ISI measurement is calculated based on the pk-pk spread of this plot. For example, Fig. 10a shows a portion of the pattern and the DCD and ISI contribution. In an ideal system, the DCD and ISI contribution would be zero, and the purple line would be horizontal at zero. The figure shows that the edges range from +30 ps to –40 ps, so the edges were late by 30 ps or early by 40 ps, depending on the location in the pattern. The large difference in the mean offsets indicates possible bandwidth problems.

Another component of DJ is PJ. PJ components are determined by taking the variance of timing measurements from the histogram at each edge. An FFT of the autocorrelation function is used to determine the periodic components. The Fourier transform of the autocorrelation function is commonly referred to as the power spectral density, or power spectrum (see Fig. 10b). The ability to determine the magnitude and frequency of the PJ component(s) enables designers and engineers to diagnose and debug any potential EMI or crosstalk problems quickly and efficiently, without the need for additional test equipment. In addition, the bandwidth used to determine the PJ components ranges from the Nyquist to a user-defined corner frequency in order to meet serial communication compliance standards, eliminating the need for a Golden PLL.

Determining RJ

It is important to quantify RJ correctly, because RJ typically determines long-term system reliability.

A view that shows the effects of DJ and RJ in terms of eye closure is shown in Figure 11. This view plots TJ in UI versus BER. The figure shows a bathtub curve that quantifies jitter at various BER levels down to 10^{-16}. Lower BER values produce larger TJ values because the RJ contribution increases with time. It is common for many datacom protocols such as FC, InfiniBand and XAUI to specify TJ at a specific BER such as 10^{-12}. The bathtub curve helps determine TJ values as a function of BER without extra measurements or additional test time.

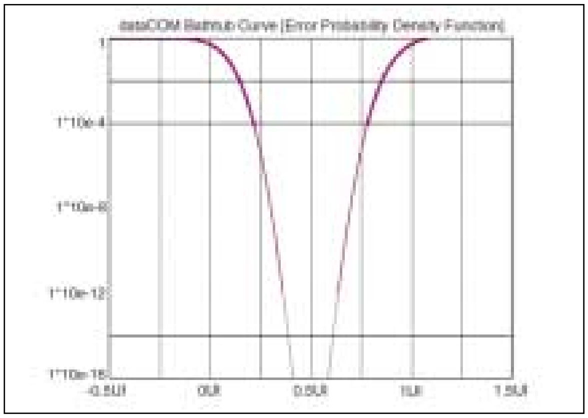


Figure 11. *Error probability versus eye closure.*

Analyze electrical or optical signals

*The **WAVECREST** OE-2 — used together with the SIA-3000 — allows you to measure jitter on optical signals. It converts optical signals to electrical signals and has built-in filters for serial datacom applications. The OE-2 also accepts single-mode and multimode fiber.*

Databus Applications

Applications that require low-cost, intra-system (or "inside-the-box") data transfer frequently use a bus type architecture such as LVDS, Rapid I/O, PCI, PCI-X, DDR SRAM, Rambus® DRAM or DVI. Common to all these applications is the requirement to measure jitter on the clock and data, measure skew between data lanes and between the clock and all data lanes, measure pulse widths, rise times, and determine if there are any setup-and-hold violations.

The need to characterize and quantify these parameters becomes increasingly important as bus speeds surpass 100 MHz, which reduces timing margins. As timing margins decrease, designers and engineers must maintain smaller skew values across PCB traces and cables to ensure a constant phase relationship between the data and clock signals.

From a testing perspective, users want a multichannel measurement solution that can measure the critical test parameters accurately and quickly.

Determining clock-data skew and jitter

Analysis of a typical databus device starts with an examination of the jitter on the data, the skew between the data lanes, and the setup-and-hold times. For example, Figure 12 shows a typical data set with two data channels of an LVDS device. (You can measure up to 10 channels on the SIA-3000.)

For each data lane there are two histograms: one showing the transitions before a clock edge, and one showing the transitions after the clock edge. The data indicate that lane 4 is closest to the mean of the clock edge (see Fig. 12) and the setup time is 314 ps — well within the device specification of 150 ps. The shaded portion of the screen is the user-defined setup-and-hold specification (in this example, 300 ps). The data-data skew is 177 ps — with a device specification of 100 ps.

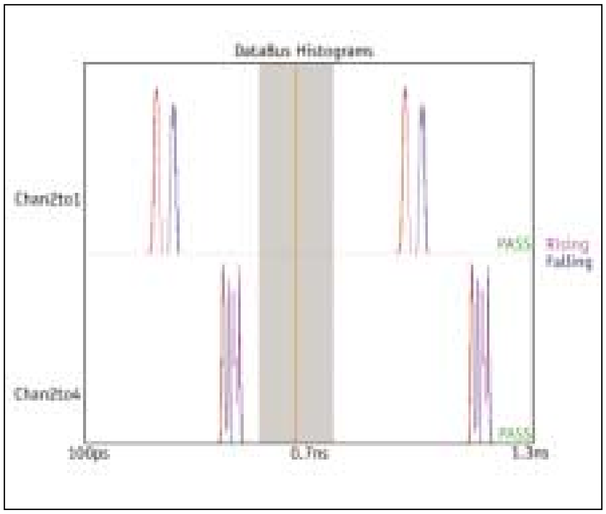


Figure 12. *Histogram of data edge transitions before and after the clock edge. Here we see two data lanes of a typical LVDS device.*

Databus metrics

The SIA-3000, with the Databus software module, can fully characterize signal integrity on data and clock signals on up to 10 channels simultaneously. In fact, the SIA-3000 can characterize and quantify any of the following:

- *TJ, DJ and RJ on the clock and data signals*
- *System reliability to 10^{-16} BER*
- *Channel-channel and clock-data skew*
- *Setup-and-hold times*
- *Periodic modulation(s) on reference clocks*
- *Rise and fall times*

DJ and RJ components

The DJ and RJ components for each lane — as well as the jitter on the clock signal — are shown in Table 2. In this instance, the 1.5 GHz clock contributes 41 ps of TJ at 10^{-12} BER. A clock signal with excessive jitter can be further analyzed with the clock analysis tools to provide quantitative information on any periodic noise components.

The summary table contains a considerable amount of useful information. It can be exported to a separate application (such as Microsoft® Excel) for further analysis with cut-and-paste simplicity. Because data acquisition times take only seconds, other tests can be performed, such as switching adjacent channels of the device on and off to see the effects of channel-to-channel crosstalk or the relationship between device temperature and jitter.

Databus Summary

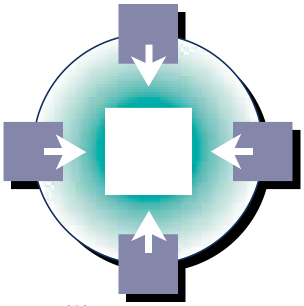
	RefChan2	Chan2to1	Chan2to4
DJ(pk-pk)	2.851ps	51.322ps	42.912ps
Ave-rmsJ	2.964ps	4.285ps	3.159ps
TJ	40.781ps	109.231ps	84.951ps
1-Sigma	2.777ps	23.126ps	16.449ps
Maximum	0.67881ns	353.274ps	0.527506ns
Minimum	0.652704ns	271.441ps	458.735ps
Pk-Pk	26.107ps	81.833ps	68.771ps
Unit Interval		0.666646ns	0.666644ns
Skew		313.894ps	490.328ps
Duty Cycle	51.494324%		
Hits	90000	512302	512686

Table 2. *Shows a representative table of reference clock jitter, data jitter and clock-data skew. The SIA-3000 can measure up to 10 channels simultaneously.*

Triggerless architecture

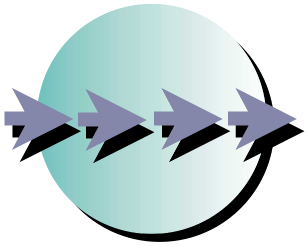
The SIA-3000 takes measurements based on data or clock timing events, eliminating the risk of errors typically associated with trigger-based instruments.

SIA-3000: The complete solution for signal integrity analysis



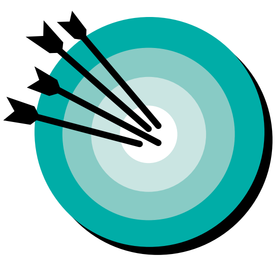
Versatility

Multi-instrument functionality
Lab or production
Electrical or optical



Speed

3 GHz or 4.5 Gb/s
10 parallel channels
Higher throughput



Accuracy

Repeatable measurements
200 fs resolution
Triggerless architecture

The ***WAVECREST*** SIA-3000 is the reference standard for signal integrity analysis. It is the only instrument that can perform the functions of an oscilloscope, BER tester, time interval analyzer and spectrum analyzer. What's more, it is the only test and measurement solution available today that allows design and test engineers to:

- Measure jitter in seconds
- Separate jitter into random and deterministic components
- Quantify each jitter component individually
- Analyze jitter in a wide range of applications

When you're designing and manufacturing today's most advanced systems and components, these exclusive capabilities are absolutely critical. They provide a more precise, detailed representation of signal integrity — which enables you to optimize device design in the lab, and guarantee flawless device operation during production.

What's more, the SIA-3000 allows you to accomplish all this in record time. Tests that used to consume hours can be finished in seconds. Which means you can test more devices in less time, increase total throughput, and get new solutions in your customers' hands faster than ever before. To find out more about the SIA-3000, please contact ***WAVECREST*** today at 1-800-733-7128, or visit www.wavecrest.com.

Based on the same high-performance time measurement technologies as our award-winning DTS instruments, the SIA-3000 delivers the results you need for a wide range of applications.

Ongoing education and support

WAVECREST *takes an active role in the education of engineers and technicians about timing, jitter and signal integrity analysis. By providing developers and manufacturers with this knowledge, we can help users realize the full value of the SIA-3000. That's why we created this brochure. If you have any questions about this piece, the SIA-3000, or any other technical issue, please do not hesitate to call our Technical Support team at 952-646-0111.*

Contact *WAVECREST* today

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