MEASUREMENT THEORY

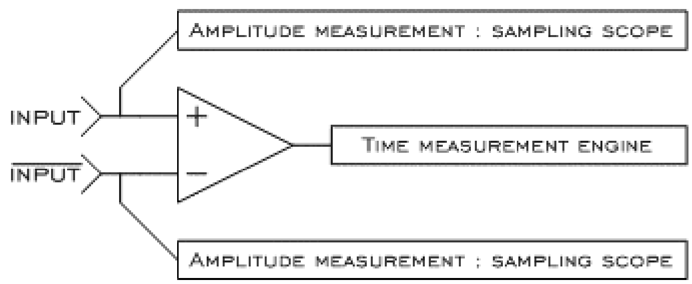
For the SIA with Amplitude and Timing Measurement Engines

Introduction

The focus of this note is to quickly familiarize the user with *SIA* measurement fundamentals. This information will help the user understand the sampling methodology and help them to more comfortably utilize all of the *SIA*'s capabilities. Refer to the User's Manual or other Quick Reference Guides for a more detailed description of all possible tool configurations.

The SIA dual-engine measurement architecture provides the best, optimized hardware for the type of measurement to be made. Each input contains both amplitude and timing circuitry so there is no need to disconnect the signal to run different types of analysis.

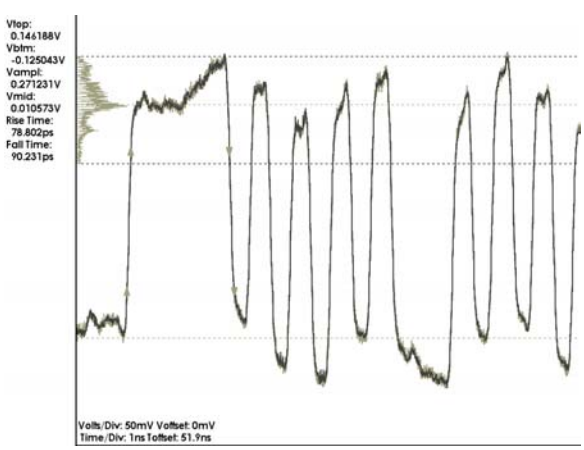
The block diagram shown below illustrates the two sampling oscilloscopes and the timing circuits for each input pair. A pair of SMA connectors is defined as a single channel because of the differential receiver in the time measurement path.



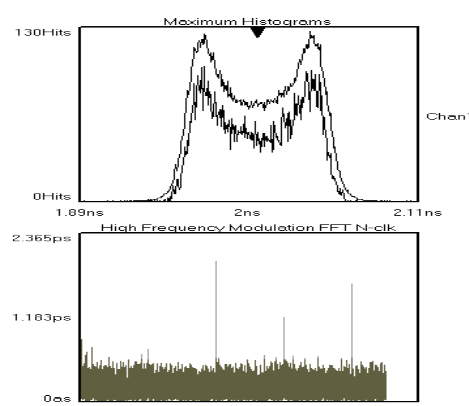
Simplified block diagram of input structure

The two types of measurement engines utilize two distinctly different measurement methodologies. The amplitude engine primarily measures voltages at specified times while the timing engine measures times at specified voltages. Another very distinct difference is the amplitude engine uses a trigger signal to which all measurements are referenced. The timing engine does not require a trigger, but utilizes an arm signal that is not used as a time reference. This allows all timing measurements to be made between the edges of concern only and not to other unrelated signals.

Amplitude Engine



Timing Engine



Amplitude Engine

Measures voltage at specified times.
Common voltage parameters including voltage histograms, eye diagrams and eye masks

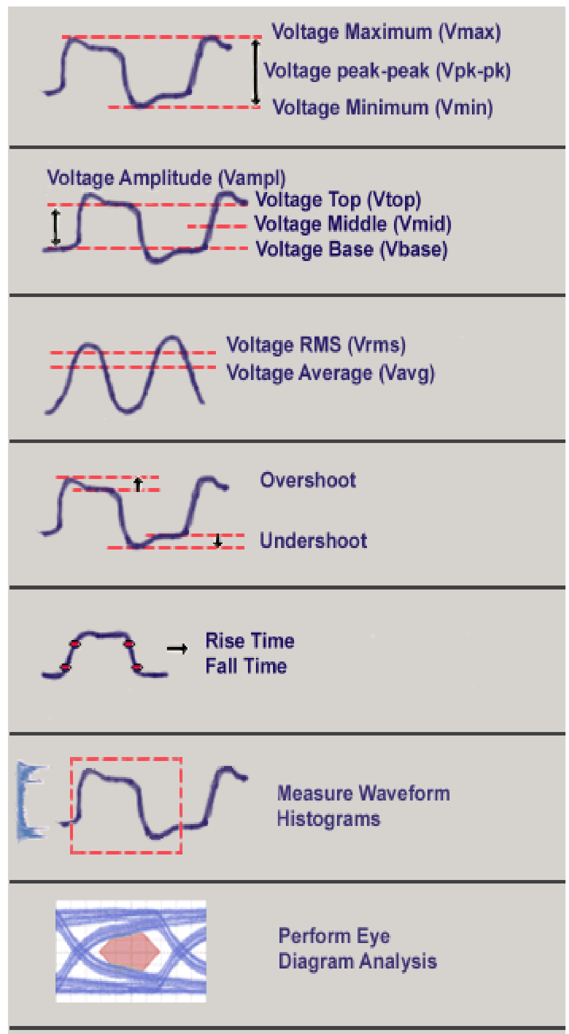
Timing Engine

Measures time at specified voltage.
Basic timing measurements such as period, pulse width, frequency, skew, etc. Jitter, RJ, DJ, TJ, DCD+ISI, PJ & jitter spectral content

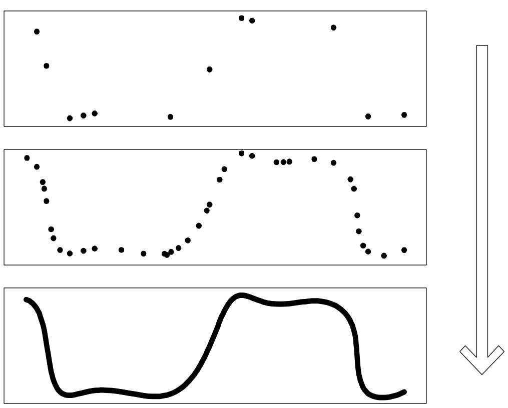
Amplitude engine

Every differential input channel has two connectors; each of these connectors has its own 6GHz-sampling oscilloscope. These two scopes per channel allow for viewing of amplitude characteristics on both phases of the differential pair at the same time with no need to disconnect the signals.

The amplitude engine is used to measure all voltage related aspects of the signal. The figure above shows an example of the oscilloscope view looking at a data signal that shows an amount of degradation. Very good detail can be examined with its 300uV vertical resolution. The figure to the right illustrates the types of measurements made using the oscilloscope. Because this is a random sampling oscilloscope, the picture is drawn one point for every trigger event as shown in the figure below.



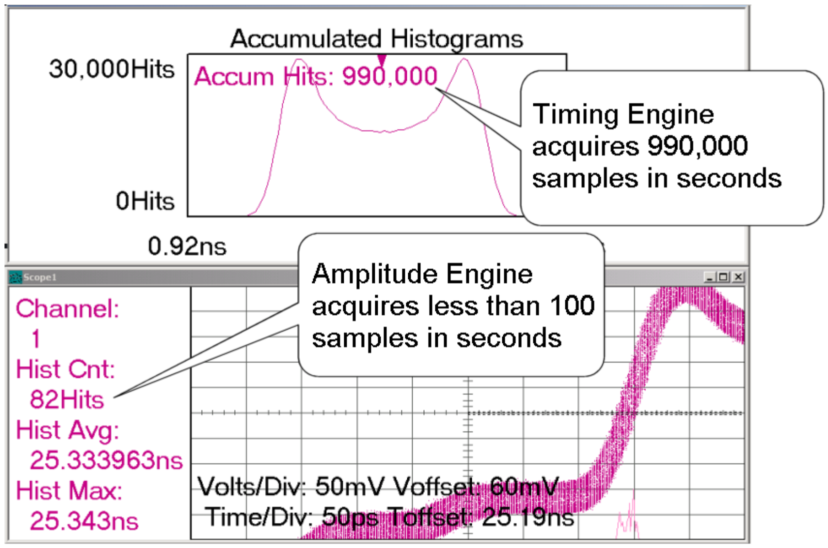
Random sampling results in a dot for each trigger event appearing on the scope, this process will fill in a more complete picture as more samples are taken



The amplitude engine is not used to measure jitter. There are many reasons for this; one is that the timing engine is better suited to making time measurements. Also, because the oscilloscope needs a trigger, this can affect the jitter results. Use of a trigger with jitter on it could mask out a jitter contributor if this jitter is related to the jitter on the measured signal. This happens as the jitter on the two signals synchronize, the picture on the scope will not show the effect as it shows the difference between the trigger timing and the measured signal timing. For example, if jitter from the same source (like power supply noise) is on both the trigger signal and the signal to be measured, both signals would move from their ideal position in a similar way causing the oscilloscope to not see this movement because it plots the difference between the two signals.

Building histograms to generate jitter information

When jitter information is the desired measurement, a histogram of a waveform section needs to be created. This histogram, or dataset, is the basis for statistical analysis that becomes the simplest of jitter measurements. This first analysis of a simple histogram can give such results as 1-sigma, peak-to-peak, RJ, DJ, and TJ. More complex analysis requires that many histograms worth of results be acquired and analyzed, which would be a very time consuming effort using the amplitude engine.



The sampler builds a histogram very slowly because it is drawing the entire waveform picture even though the desired voltage area to create the histogram is very small. As samples slowly occur in this small box, it is able to build the histogram. Only after a sufficient number of samples have been captured can any meaningful statistics be generated from that histogram. The timing engine however does not draw the entire waveform, but only looks at signals that cross a particular voltage threshold or the crossing point of a differential pair. This and the optimized timing measurement circuits are why the timing engine can create a histogram many times faster than the amplitude engine.

Timing engine

A channel is defined by the differential receiver between the two SMA connectors. This receiver leads to the time measurement circuits. At its most basic level, the Time Measurement Engine is a very accurate and repeatable time measurement device. It measures the time between edge events. Inside the instrument, many time measurements (samples) are taken and compiled into a histogram. Histograms are the most basic level of information provided by the *SIA*. The basic statistics from a histogram include sample size, mean, peak-to-peak, 1-sigma, maximum and minimum values. Most of the analysis tools plot statistics from many histograms.

The Histogram Tool provides the capability to analyze the histogram itself. If the histogram is non-Gaussian, the Tail-Fit algorithm will separate the Random Jitter (RJ) and Deterministic Jitter (DJ) to provide an estimation of Total Jitter (TJ) at a particular bit error rate.

No trigger needed

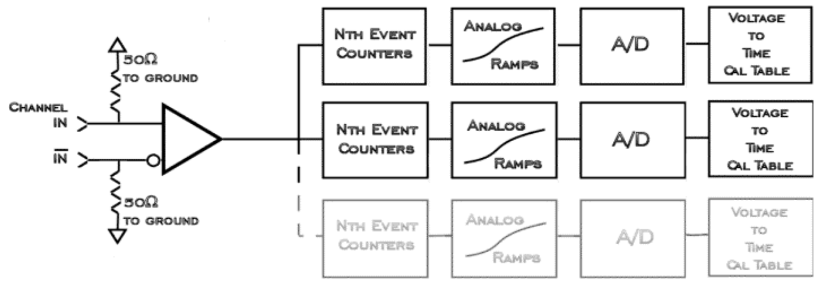
The timing engine does ***not*** reconstruct waveforms and does ***not*** use a trigger. This is very important to understand and remember. The *SIA* measures the time between "events" which are threshold crossings. This differs from an oscilloscope, which measures the voltages with respect to time relative to a time-base synchronized to a trigger. Not using a trigger ensures that there is no possibility of synchronizing a measurement to a jitter source. Use of a trigger with jitter on it could mask out a jitter contributor.

The *SIA* uses asynchronous random sampling of events to derive a solid statistical distribution of the event times and will not mask out any jitter contributors.

How does the SIA make a single time measurement?

The timing engine measures the time between events. The events to be measured are determined by the Nth Event counters. The precise time between events is determined by the analog interpolators (ramps). See figure below.

The Input



Simplified Block Diagram of Timing Engine

The figure to the right shows only one channel. All other measurement channels function similarly. The inputs are each 50ohms to ground. Impedance matching modules are available for LVDS/CML to provide 100ohms between the differential inputs. The input signal can be single-ended or differential. If the signal is single-ended, the non-inverting input is used.

The Receiver/Comparator

The differential receiver produces the "event" which, for a single ended signal, is a threshold crossing. For a differential signal the event is the crossing point of the differential signals. The differential receiver output is split to pass the events to the Nth Event counters.

The n^{th} Event Counters

The counters allow a specified number of edges to be skipped providing the capability to perform modulation analysis or analyze the time between specific edge relationships. Most measurements use only two counters and associated paths. Some measurements, such as "Adjacent Cycle", use a third counter and path. So, for a period measurement, the counters would be set to one and two. When an Nth event counter has registered a specified number of events, the ramp following that counter will start.

The Analog Interpolators/Ramps

The ramps are the main timing circuitry used to measure time between events. The following descriptions will discuss "start events" and "stop events". This terminology relates to a *measurement*, so a period measurement "start event" would be a rising edge, the "stop event" would be the next rising edge. This is to distinguish from the start and stop of a *ramp*. A "start event" and "stop event" will each start individual ramps that will then be stopped by the internal time base (Figure 1).

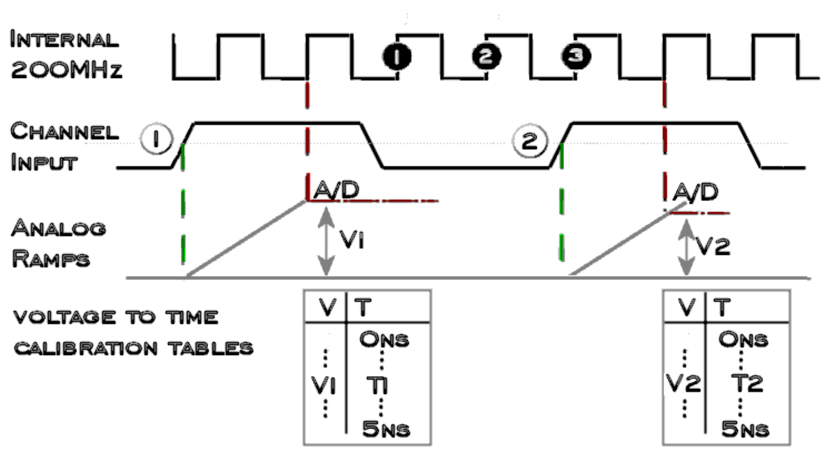


Figure 1 - Time measurement example (measured signal is slower than internal 200MHz oscillator)

The ramps can be thought of as the fine-count (vernier) part of the measurement. The ramps and calibration method are patented *WAVECREST* technology. In the previous figure, two counters and ramps are used. The *nth* event counters are set to one and two to capture the first and second edge respectively of the period. While the ramps are initiated by the signal being measured on the input channel, they are stopped by the internal 200MHz time-base. Once a ramp stops, the voltage is read by an analog-to-digital converter (ADC). The rule for stopping the ramp is that the ramp must charge over more than one full period of the 200MHz clock but less than two. In other words, the ramp is stopped by the second rising edge of the 200MHz clock. This ensures that the ramp stops in a linear region. The voltage measurement is then used to find a time from the "voltage-to-time" lookup table.

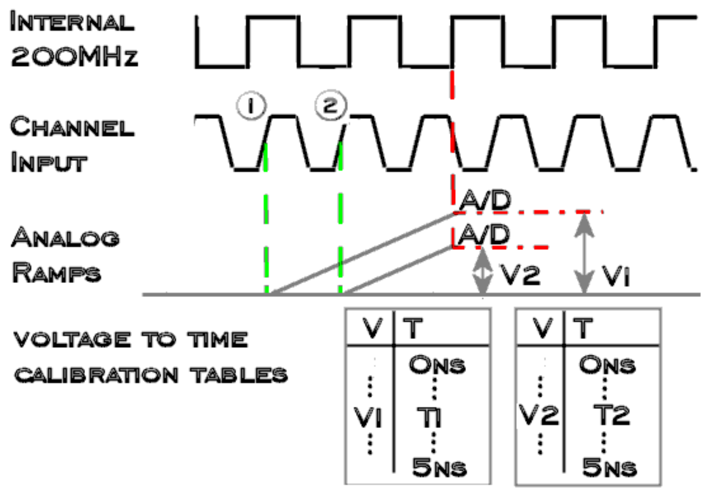


Figure 2 - Time measurement example (measured signal is faster than internal 200MHz)

The "Timer Calibration" builds this lookup table (and characterizes the ramps). The table is created by dividing the usable 5ns portion of each ramp into more than 41000 increments or bins. Each bin is less than 100 femtoseconds (fs) from its neighbor giving the SIA an overall hardware resolution of ~200fs per measurement.

Measurements longer than a period of the internal clock are covered by a course counter. Figure 1 shows the course counter adding three edges of the internal clock to the measurement. The course counter counts cycles of the 200MHz time base between the ramps. In this way, events separated by up to 2 seconds are measured with the same 200fs hardware resolution. The time base is very stable over this amount of time. In the case where Course counters are used, it is then important to note that the 200MHz clock is actually synchronized to an ovenized 10MHz oscillator. This provides the best of short-term stability of the 200MHz clock and long-term stability of the 10MHz clock. The equation used to calculate one time measurement between events is

Equation 1 - $(T_2-T_1)+5ns*\text{Course Count}$

Notice that in Figure 2, the course counters are not necessary. This case shows a period measurement for any signal faster than 200MHz.

Using three ramps in the *SIA* allows the measurement of three consecutive edges. "Cycle-to-cycle" can be displayed by measuring three adjacent edges. The difference between the two periods is then displayed. For this type of measurement, the three ramps are used and the counters are then set to one, two and three.

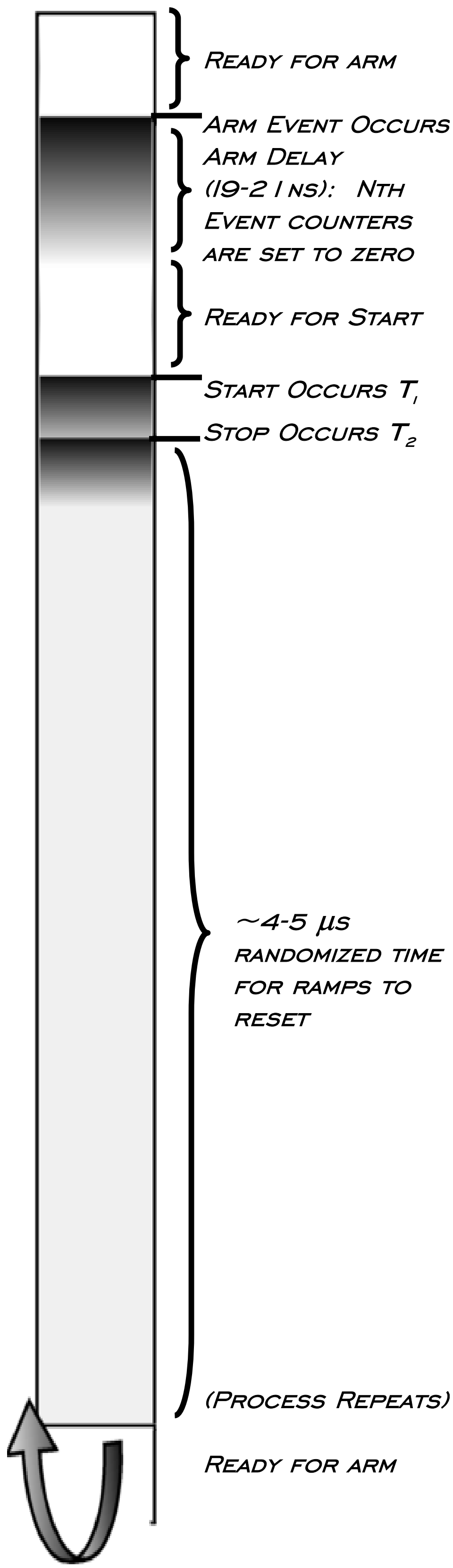


Figure 3 - Measurement Timeline

Having made a single measurement, how does the SIA derive information about the waveform?

The SIA continues to compile a large number of measurements (set by "Hits per Edge" in most tools). It gathers samples asynchronously (without a trigger) in a randomized window of between 4μs to 5μs. This randomized sampling time provides a sound statistical population of randomly sampled events and ensures there is no chance of masking out a jitter component that could match a sampling rate. These measurements are all compiled into a histogram.

The SIA uses an Arm event to determine when a measurement can be made. This is not a trigger because the measurements are not relative to it. Rather, it is a "get-ready", or enable signal, which tells the ramps and CPU that a measurement is about to be made. In doing this, the counters are set to zero, thus the next edge is 1. Arming Mode defaults to Arm on Stop. For a detailed description of arming, see the "Understanding Arming" quick reference guide. A channel other than the measurement channel may arm a measurement; arming mode would be set to "External". There is an adjustable arm delay of between 19 and 21ns before the system is ready for a "Start Event".

Note that an arm must occur for each measurement, whether the arm is derived from the signal itself or a signal on another channel.

The time between a "Start Event" and a "Stop Event" can now be measured. Following the measurement, the ramp circuitry resets and the system is ready for an arm in 4 to 5μs.

Histogram of measurements

The burst of measurements taken, form a histogram from which more meaningful statistical information can be derived (such as mean, peak-to-peak and 1-sigma). The Tail-Fit™ algorithm also allows separation of Random and Deterministic Jitter. These components can be used to calculate Total Jitter. See "Histogram Quick Reference Guides".

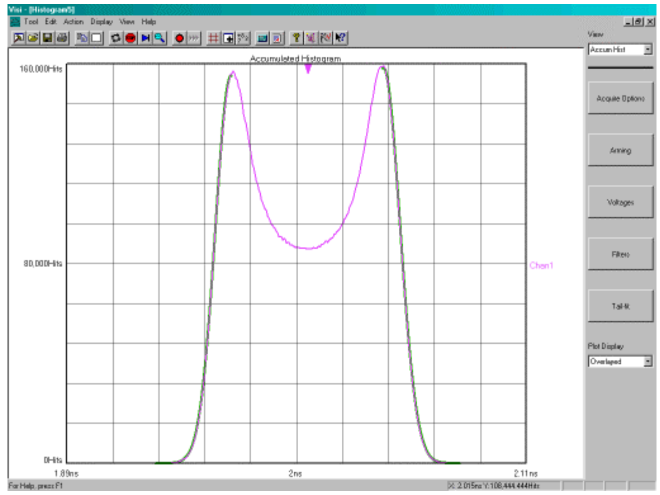


Figure 4 - Typical display of histogram.

Jitter Accumulation and Periodic Jitter—Viewing the modulation domain

Other tools in the *GigaView* software make use of the *n*th event counters. By skipping a number of edges, the *n*th event counters give the *SIA* the ability to derive information about the long-term timing characteristics of the signal. The spectral content of the jitter can also be determined. This is periodic jitter (PJ)

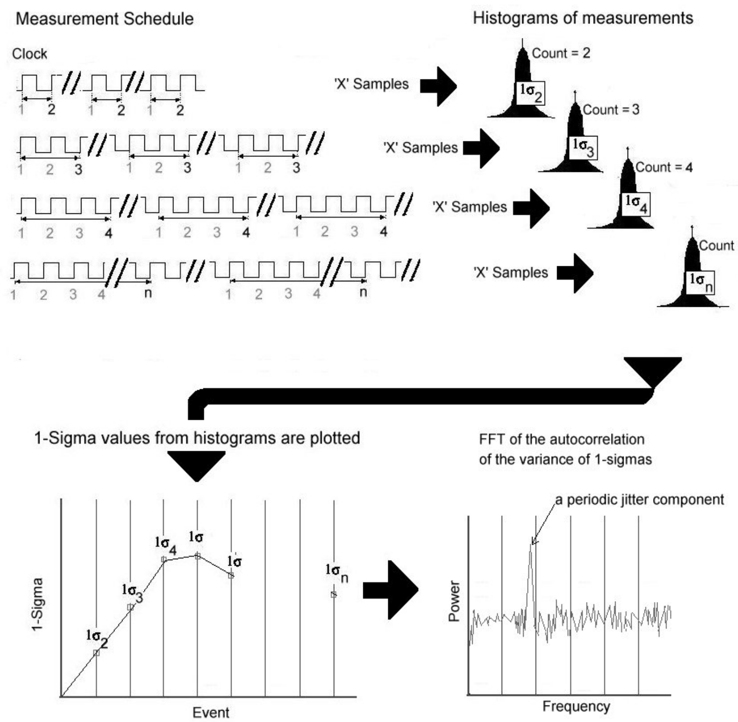


Figure 5 - Measuring Periodic Jitter

The High Frequency Modulation Analysis tool automatically increments the stop counter. This allows the *SIA* to make a histogram, for instance, over one period, then two periods and on to a designated stop point. Data from the histograms can then be plotted relative to number of events, allowing the user to see any jitter modulation. Performing an FFT of the autocorrelation of the variance from the 1-sigma information will give a frequency vs. power plot. This shows the frequency components of the jitter modulation. Figure 5, Measuring Periodic Jitter, shows the measurement theory.

Conclusion

The *SIA* and *GigaView* software tools provide the ability to accurately measure different components of jitter. Histograms of measurements provide statistical information such as mean, 1-sigma, peak-to-peak, maximum and minimum values. Using the Tail-Fit algorithm, Random, Deterministic and Total Jitter can be measured. Other software modules allow similar types of measurements on Serial Data Signals

Refer to the Getting Started for each tool for a better understanding of how each one makes its measurement and displays the data.

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