



Understanding Jitter

Getting Started

Introduction

The focus of this document is to give the user a basic understanding of what jitter is and what causes jitter to occur. Quotes sub-noted 1 to 7 are definitions taken from the MJS document. Refer to the Fibre Channel MJS document (T11.2/Project 1230/Rev 10 Located at ftp:ftp.t11.org/t11/member/fc/jitter_meth/99-151v2.pdf) for more information.

Jitter Definition

“The deviation from the ideal timing of an event. The reference event is the differential zero crossing for electrical events and the nominal receiver threshold power level for optical systems. Jitter is composed of both deterministic and Gaussian (random) content.”₁

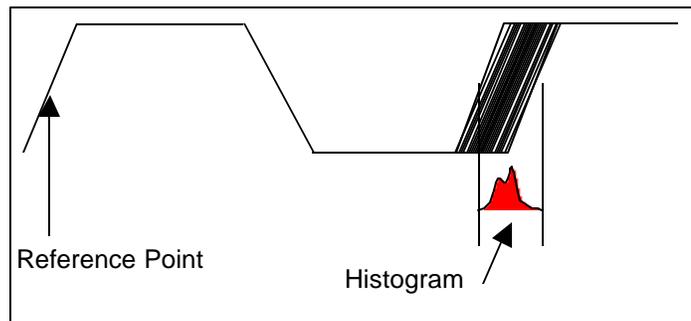


Figure 1. Definition of jitter.

The following sections explain each element and where they come from.

Deterministic Jitter (DJ) Definition

“Jitter with a non-Gaussian probability density function. Deterministic jitter is always bounded in amplitude and has specific causes. Four kinds of deterministic jitter are identified: Duty Cycle Distortion, Data Dependant, Sinusoidal, and Uncorrelated (to the data) bounded. DJ is characterized by its bounded, peak-to-peak value.”₂

There are several forms of DJ. Clock signals are typically susceptible to Duty Cycle Distortion (DCD) and Periodic Jitter (PJ). Data signals are also susceptible to DCD and PJ as well as Inter-Symbol Interference (ISI) and Data Dependant Jitter (DDJ). The total amount of DJ will remain constant regardless of a change in sample size as long as a sufficient data points are taken to complete at least one complete cycle of each periodic element.

Where Does DJ Come From?

DJ is typically caused by cross talk, EMI, simultaneous switching outputs (SSO), device function dependency (pattern dependant jitter) and other regularly occurring interference signals. Cross talk occurs when a victim line (a trace on a circuit board or 2 adjacent wires in a cable) is affected by the magnetic field from a driver line. (Figure 2) The incremental inductance of a victim conductor converts induced magnetic field into induced current. The induced current adds (positively or negatively) to a victim lines current increasing or decreasing potential. This decreased potential causes jitter on the victim line.

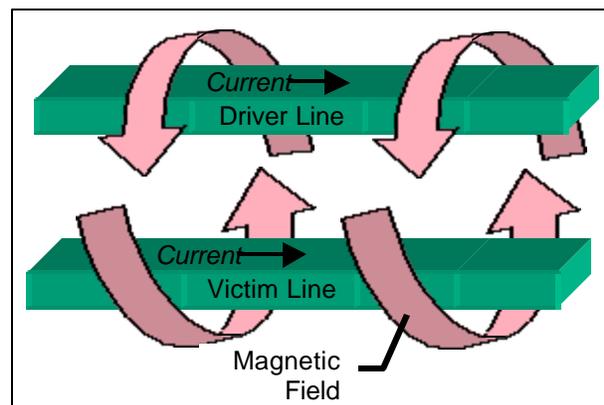


Figure 2. Crosstalk example.

A diagram of EMI radiation is shown in Figure 3. Here a victim line is affected by a magnetic field from an EMI source (Switching power supply, AC Power Line, RF Signal Source, etc.). This is similar to cross talk induced jitter in which a magnetic field induces a current that is added (positively or negatively) to the victim line current thereby adding jitter to the signal on the victim line.

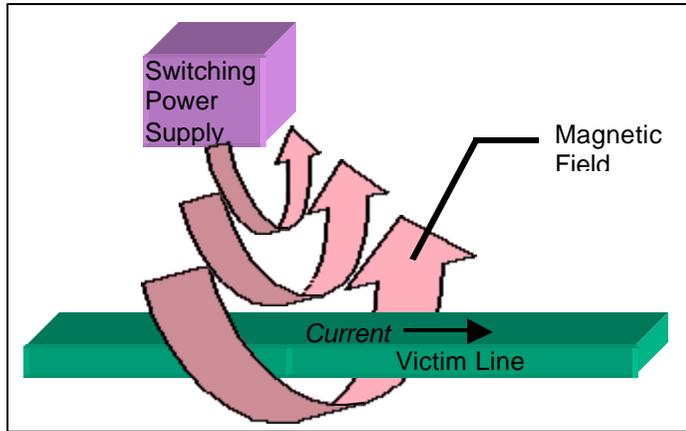


Figure 3. EMI example.

Figure 4 shows an example of a noisy reference plane. This form of DJ occurs when noise in a power plane causes a reference shift in the threshold voltages of downstream logic gates. This shift is proportional to the slew rate of the input signal. The output transistor will switch when V_t is exceeded at the gate. When there is a change in the ground reference at V_t , there will be a shift in the voltage required to switch the gate thereby delaying or advancing the switch. The resulting timing error causes jitter.

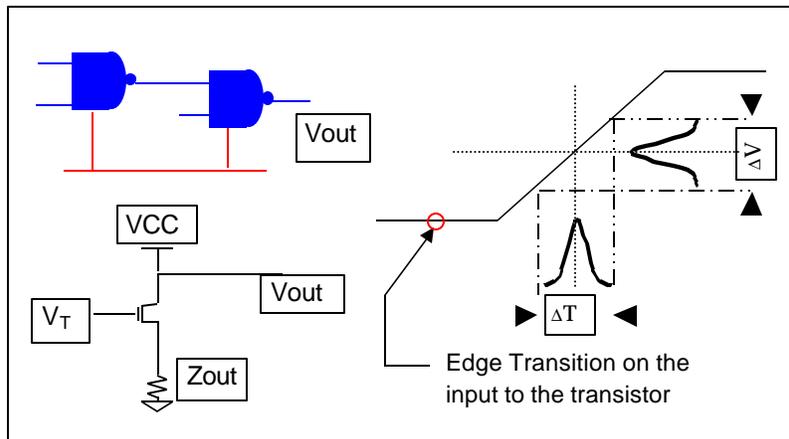


Figure 4. Noisy reference plane Diagram.

Simultaneous switching outputs (SSO) is another source of DJ. A diagram for SSO is shown in Figure 5. If several output pins switch to the same state, a current spike occurs which is induced on the V_{cc} and GND planes. These current spikes can cause the threshold voltage sense point to shift. Due to the pattern sensitivity and the bounded amplitude of edge jitter due to SSO, this is considered DJ.

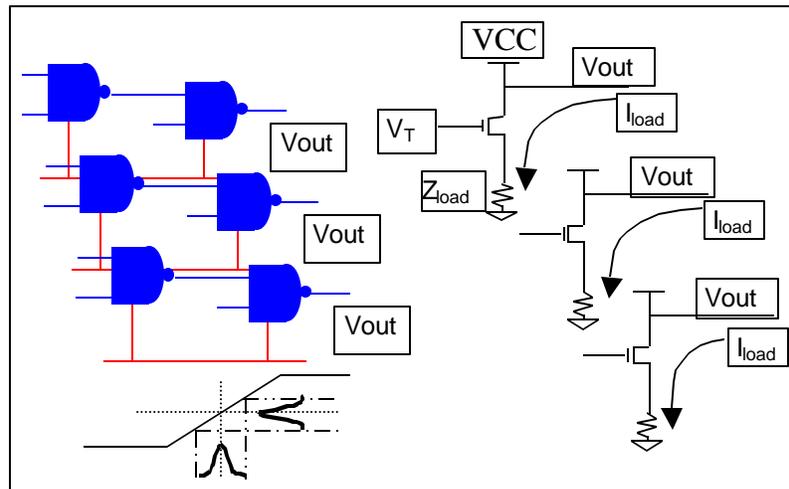


Figure 5. Diagram of Simultaneous Switching Outputs (SSO).

The next four DJ elements are specific to Data.

InterSymbol Interference (ISI) Definition

“Data dependant deterministic jitter caused by the time differences required for the signal to arrive at the receiver threshold when starting from different places in bit sequences (symbols). For example when using media that attenuates the peak amplitude of the bit sequence consisting of alternating 0,1,0,1... more than peak amplitude of the bit sequence consisting of 0,0,0,0,1,1,1,1... the time required to reach the receiver threshold with the 0,1,0,1... is less than required from the 0,0,0,0,1,1,1,1... The run length of 4 produces a higher amplitude which takes more time to overcome when changing bit values and therefore produces a time difference compared to the run length of 1 bit sequence. When different run lengths are mixed in the same transmission the different bit sequences (symbols) therefore interfere with each other. ISI is expected whenever any bit sequence has frequency components that are propagated at different rates by the transmission media.”³



Figure 6. Example of DDJ/ISI.

Data Dependent Jitter (DDJ) Definition

“Jitter which is added when the transmission pattern is changed from a clock like to a non-clock like pattern. Includes ISI.”⁴ Figure 6 shows an example of DDJ/ISI affecting a Fibre Channel K285 pattern. There is a 1,0,1,0,1,1 transition followed by 5 zeros. The 5 consecutive zeros transition to a lower voltage than the 2 zeros that go immediately back to ones during the 1,0,1,0,1,1 section.

Duty Cycle Distortion (DCD) Definition

“Difference in the mean pulse width of a ‘1’ pulse compared to the mean pulse width of a ‘0’ pulse in a clock-like(repeating 0,1,0,1,...) bit sequence. DCD is the part of the DJ distribution and is measured at the ideal receiver threshold point.”⁵

Bounded-Uncorrelated Jitter Definition

“Deterministic jitter that is caused by other than the data on the signal under test.”⁶

Periodic Jitter (PJ) Definition

PJ can quantify crosstalk effects from EMI sources. (adjacent lines, power supply noise, etc.)

RMS Jitter (RMSJ) or Random Jitter (RJ) Definition

Jitter that is characterized by a Gaussian distribution. Random jitter is defined to be the peak-to-peak value which is given to be 14 times the standard deviation of the Gaussian distribution for a Bit Error Rate (BER) of 10^{-12} .” RMS jitter is “The root mean squared value or standard deviation of jitter. For a Gaussian distribution, the RMS value is 1/14 of the peak-to-peak value for BER 10^{-12} .”

Random (Gaussian) jitter is stochastic in nature. It is typically characterized by a Gaussian distribution. RJ will continue to increase with time. This is reason why Random jitter is referred to as unbounded.

Where does RJ come from?

Like all physical phenomena, the edge deviation which occurs in electronic signals will contain some level of random behavior. This component is probabilistic in nature and is best modeled by a Gaussian function. Random jitter is unbounded and therefore directly affects long term reliability.

Random jitter comes from thermal vibrations of semiconductor crystal structures, material boundaries having less than perfect valence electron mapping due to semi-regular doping density and process anomalies, thermal vibrations of conductor atoms, and many minor contributors. (cosmic radiation, etc.)

Because RMS jitter is characterized by a Gaussian distribution, the next section will describe the Gaussian model and how it applies to jitter.

Introduction to Gaussian Distributions

To understand jitter measurement, it is important to understand Gaussian Distributions as it relates to probability. Figure 7 shows an ideal Gaussian distribution. The three basic elements that describe a Gaussian distribution are the mean, standard deviation (1σ), and the Peak-to-Peak. The mean is the average of all samples taken. The Peak-to-Peak is the largest measurement made minus the smallest measurement made. The 1σ is the window in which 68.26% of all measurements to one side of the mean are contained. Similarly, 2σ is the window in which 95.4% of all measurements to one side of the mean are contained. 3σ is 99.73% of measurements, 4σ is 99.99366%, etc up to 10σ which is $(100-1.973 \times 10^{-21})\%$ of measurements. The standard deviation or 1σ is used to predict the occurrence of outlying measurements from the mean. In electronics, it is important to know the frequency that edges deviate from their ideal/intended positions. For example, if your system cannot tolerate clock periods that are less than 900ps on a 1 GHz clock (1,000ps), you would like to know what the probability of a period of less than 900ps will be. Knowledge of the short period tail can tell you exactly how often a 900ps period occurs.

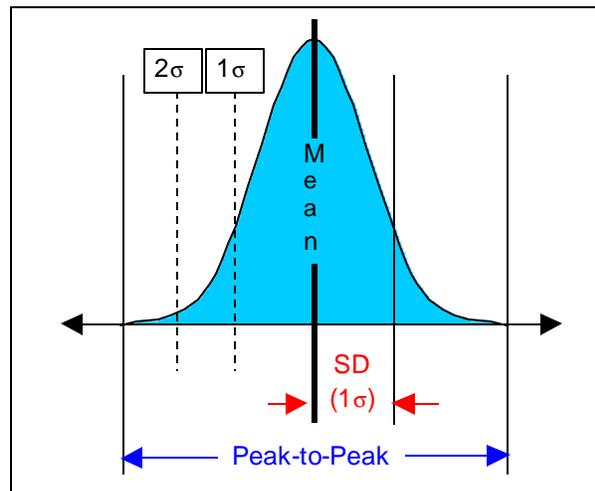


Figure 7. Ideal Gaussian Distribution.

There are a couple things to note about this model. First and foremost, the use of standard deviation or 1σ as the RMS jitter component is only valid for purely Gaussian distributions. If there are any deterministic components in your distribution, the use of 1σ based on the entire jitter histogram for the estimate of probability of occurrence is invalid.

Second, in pure Gaussian mathematics, all possible measurements are assumed to be possible. However, for all practical purposes, the Gaussian model holds true in electronics for measurement populations not exceeding 10^{21} . This is equivalent to 20σ (single sided). After 20σ the Gaussian model begins to break down to the predictability of the measurement. 20σ reliability corresponds to compliant operation for at least 32,150.2 years for a 1 GHz clock. And third, the Peak-to-Peak is dependant on the sample size. Larger samples of the same distribution will likely yield a larger Peak-to-Peak measurement. Thus, Peak-to-Peak must be discussed in context of the number of samples and the total time over which the measurements were made. If 100 measurements of a 1 GHz clock are made by taking a period measurement every $25\mu\text{s}$ the statistical value of those samples is better than 100 consecutive period measurements of the same 1GHz clock. The 100 $25\mu\text{s}$ sample are taken over 2.5ms where the 100 consecutive measurements are made over 100ns. The larger total time window of the $25\mu\text{s}$ samples gives a better statistical view of the signal integrity.

Calculating Standard Deviation (1s)

Below is the calculation for standard deviation.

$$\sqrt{\frac{1}{n-1} \sum_{i=1}^n (X_i - \bar{X})^2} \quad \text{Where } \bar{X} = \frac{1}{n} \sum_{i=1}^n X_i$$

For example, if I have 8 measurements whose values are 2.00, 2.02, 2.10, 2.20, 1.99, 1.98, 1.99, and 2.00 ns the standard deviation would be....

$$\bar{X} = \frac{1}{8} (2.00 + 2.02 + 2.10 + 2.20 + 1.99 + 1.98 + 1.99 + 2.00) = 2.035 \text{ ns}$$

$$1\sigma = \sqrt{\frac{1}{8} \left((2.00 - 2.035)^2 + (2.02 - 2.035)^2 + (2.10 - 2.035)^2 + (2.20 - 2.035)^2 + (1.99 - 2.035)^2 + (1.98 - 2.035)^2 + (1.99 - 2.035)^2 + (2.00 - 2.035)^2 \right)} = 0.0738 \text{ ns}$$

In most cases, time measurement distributions are not purely Gaussian. Typically, some DJ occurs to make a distribution Non-Gaussian. Figure 8 shows an example of a distribution that has DJ and is not a purely Gaussian distribution. But, the tail regions Ltail (solid Red area) and Rtail (solid Blue area) still appear Gaussian in nature. Gaussian assumptions can still apply to the tail regions if and only if the equivalent 1σ of the tail regions can be calculated.

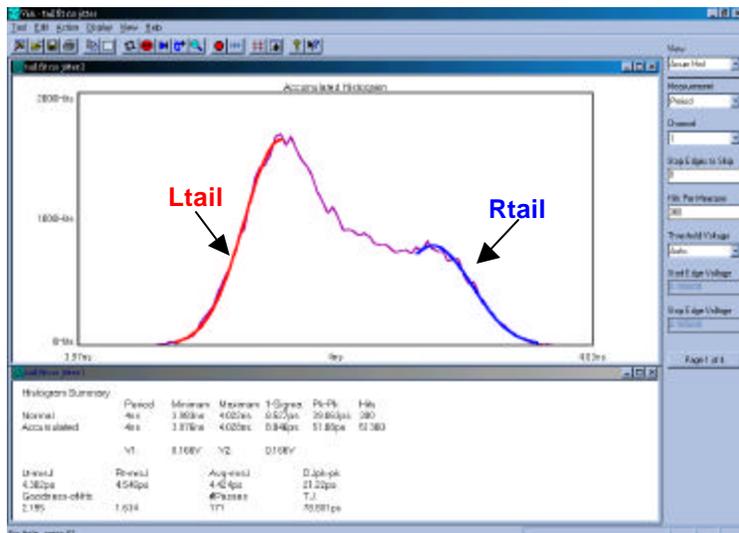


Figure 8. Non-Gaussian Distribution

TailFit™ Algorithm

The Patent Pending TailFit™ algorithm enables the user to identify a Gaussian curve with a symmetrical tail region to that of the non-Gaussian distribution under evaluation. Various Gaussian curves are fitted against the tail region of the distribution until an optimal match is found. Then, the 1σ ($1\sigma_L$ for the left side) of the matched curve is used as the standard deviation multiplier for that particular tail. This is repeated for both sides of the distribution. Note that the matched Gaussian distributions are not necessarily the same for each tail. Figure 9 shows an example where the Right tail had a larger 1σ (Rt-rmsJ) than the Left tail (Lt-rmsJ). Once the left and right 1σ values are found, the total DJ is the difference of the means of the 2 Gaussian curves that were fit to the distribution. From this DJ value and the Right and Left 1σ values, we can calculate total jitter over time. In Figure 9 a total jitter of 231.953ps was calculated at 10^{-12} Bit Error Rate (BER) or after 10^{12} cycles of this clock.

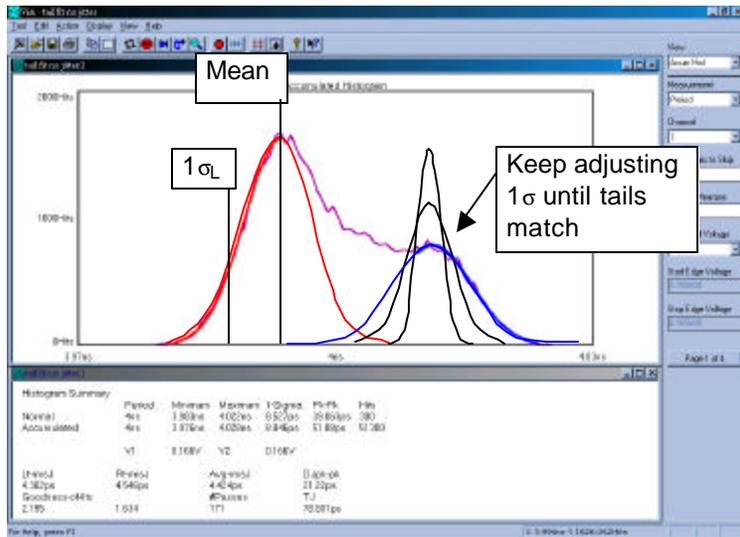


Figure 9. TailFit™ algorithm.

Jitter Modulation

Figure 10 shows the effect of jitter modulation on a synchronous system. There are 3 signals shown in this diagram. The first signal is an ideal clock that has no jitter. The second signal is a clock that is being modulated the third signal which is the jitter modulation function. When the modulation signal is high, it is adding to the period length of the victim clock. When the modulation signal is low, it is subtracting from the period length of the victim clock. Notice that if you measure across 11 periods (the period of the modulation) you get the same measurement for both the ideal clock and the jittered clocks. This is an example of Periodic Jitter (PJ).

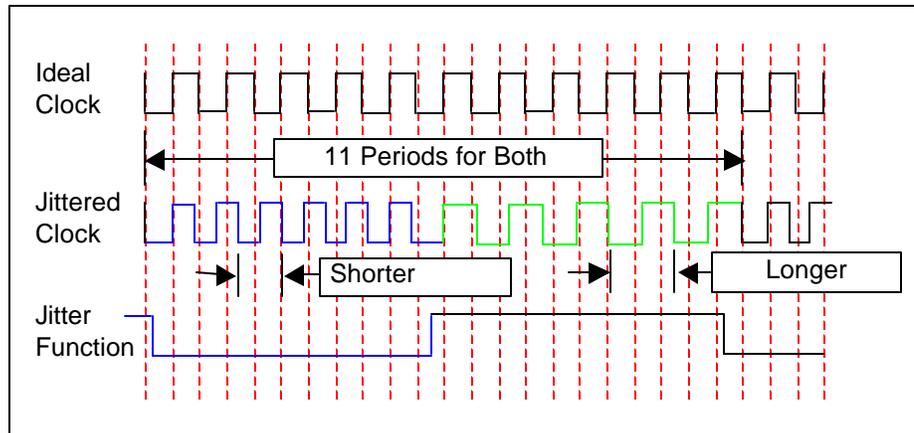


Figure 10. Jitter Modulation effect.

Figure 11 shows a breakdown of the components of jitter that are outlined in this paper.

SUMMARY:

Jitter is composed of many elements. Because random jitter is unbounded you must quantify your jitter specifications. By breaking down the total jitter into its basic elements of deterministic jitter and random jitter using our TailFit™ algorithm, we are able to project out in time and get a total jitter number at a desired BER or time and thus quantifying the jitter.

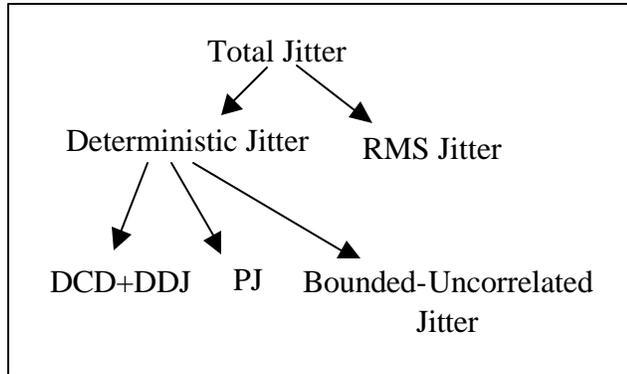


Figure 11. Diagram of the breakdown of jitter components.

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