NEW FOCUS

Application Note 12

Jitter and Jitter Testing For Modulator Drivers

Introduction

In digital systems, a critical parameter that must be controlled to within specified limits is "jitter". The SONET specification defines jitter as,

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

The Fibre Channel specification defines jitter as,

"the deviation from the ideal timing of an event".

For the purposes of this discussion, jitter will be defined as,

"the time difference between the ideal and actual occurrence of an event".

This application note will explain the different types of jitter and discuss the proper methods to measure jitter.

Types of Jitter

Jitter is typically specified as being either **random (RJ)** or **deterministic (DJ)**. **RJ** is caused by random noise and has a Gaussian probability distribution function (PDF). Since RJ has a probability distribution function that is infinite in extent, RJ is specified in terms of its root-mean -squared (RMS) average. **DJ** is non-random and is bounded. The four types of DJ are:

1) duty-cycle distortion (DCD) & pulse-width distortion (PWD)
2) data-dependent ditter (DDJ) & inter--symbol interference (ISI)
3) sinusoidal jitter (SJ)
4) uncorrelated bounded jitter (UBJ)

Since DJ is bounded, and not specified in terms of a PDF, it is usually specified in terms of its peak-to-peak value.

In the next two sections both RJ and DJ will be considered in more detail.

Random Jitter

The Gaussian PDF associated with RJ is the classic bell-shaped curve shown in Figure 1. Mathematically, this can be represented as,

$$P[v(t)] = \frac{1}{\sqrt{2\pi}} \bullet \frac{1}{\sigma} \bullet exp\left\{ \frac{-1}{2\left[\frac{v(t)-v_S}{\sigma}\right]^2} \right\} \ldots(1)$$

where v_s is the mean value of the density function, $v(t)$ is the measured signal at time t, and σ is the standard deviation.

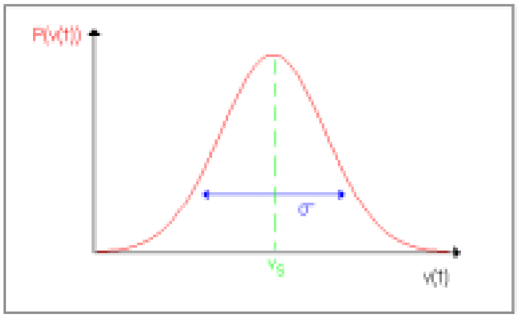

Figure 1. Gaussian probability distribution function (PDF)

RJ is easily seen in the eye diagrams produced by virtually all commercially-available modulator drivers and clock amplifiers. An example of RJ in a modulator-driver eye diagram is shown in Figure 2.

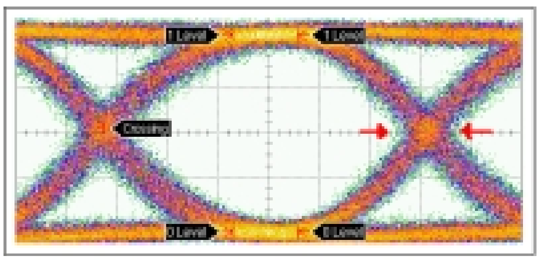

Figure 2. Eye diagram of OC-192 modulator driver displaying random jitter

To measure the amount of RJ attributable to the modulator driver, one must first know the amount of RJ attributable to the test instrumentation being used to evaluate the modulator driver. This is done by measuring the eye being provided by the test instrumentation, without the modulator driver in the circuit. The RMS value of the RJ of the test instrumentation, σ_{Test} is measured and is subtracted from the total jitter measured when the modulator driver is present in the circuit in an RMS fashion,

$$\sigma_{Driver} = \sqrt{\sigma^2_{Test+Driver} - \sigma^2_{Test}} \cdots RMS \cdots (2)$$

Deterministic Jitter

As discussed earlier, DJ has four primary causes. Each will be discussed in the following four sections. It is important to remember that DJ is not random and thus is not described by a PDF. Instead, because it is bounded, it can be described by its peak-to-peak magnitude.

Duty-Cycle Distortion (DCD) & Pulse-Width Distortion (PWD)

DCD and PWD are essentially different names for the same phenomena. This type of deterministic jitter can result when the modulator driver has rise and fall times which are not equal or when DC voltage offsets are present. These two situations are depicted in Figure 3. As shown in Figure 3, the rising and falling edges of the eye diagram do not intersect each other at the half-maximum of the eye (indicated by the horizontal black line).

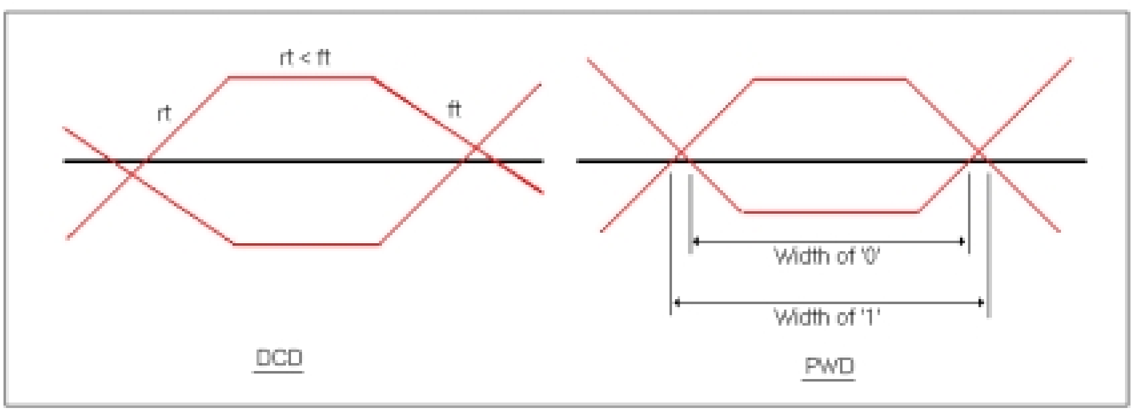

Figure 3. Examples of DCD and PWD

Data-Dependent Jitter (DDJ) & Inter-Symbol Interference (ISI)

DataDDJ (also known as pattern-dependent jitter) and ISI are typically a result of bandwidth limitations of the modulator driver. DDJ is usually the name used when relating time-domain effects and ISI is the name used when relating frequency-domain effects. This type of jitter can be the result of the output-coupling capacitor that causes excess voltage droop when long strings of "1"s or "0"s are present in the data stream or from amplifier frequency-response issues that result in "ringing" in the response. Because each different data sequence has different frequency content, the response of the modulator driver can be slightly different for different data sequences. This results in eye diagrams that display different "rails" (tops and bottoms of the eyes) and different transition trajectories (rising and falling edges) for different data patterns. Examples of this are shown in Figure 4. Note that the patterns shown in Figure 4 exhibit clearly different characteristics than the eye in Figure 2, which displayed RJ. In Figure 4, there is no probabilistic relationship between the multiple traces seen. They are independent of each other but are dependent on the exact nature of the data stream.

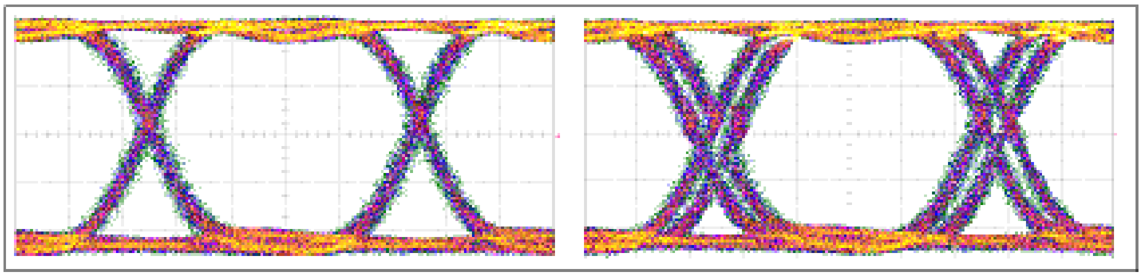

Figure 4. Eye diagrams showing DDJ

Sinusoidal Jitter (SJ)

SJ is rarely seen in real systems but is used in jitter-testing systems. Here, the timing of the rising and falling edges of the eye is displaced by an amount that is defined by a sinusoidal function of time. We include it here for completeness sake.

Uncorrelated Bounded Jitter (UBJ)

UBJ is a "catch all" category that covers all other deterministic jitter that does not fall into the other three categories. Causes of this jitter include power supply issues and crosstalk.

To measure the amount of DJ attributable to the modulator driver, one must first know the amount of DJ attributable to the test instrumentation being used to evaluate the modulator driver. This is done by measuring the eye being provided by the test instrumentation without the modulator driver in the circuit. The peak-to-peak value of the DJ of the test instrumentation, DJ_{Test} is measured and is subtracted from the total peak-to-peak jitter measured when the modulator driver is present in the circuit in a simple linear fashion,

$$DJ_{Driver} = DJ_{Test+Driver} - DJ_{Test} \cdots peak - to - peak \cdots (3)$$

Mixed Jitter Measurements

In practice, situations will arise where both RJ and DJ are present in the test system and the modulator driver. In this case, the RJ must first be converted to DJ before the jitter value can be specified. In order to convert RJ to DJ, the desired bit-error rate (BER) of the system must be taken into consideration. Suppose we define the BER of the system to be 10^{-10}. Then using the PDF shown in Figure 1, the Gaussian function can be bounded so that the probability of being outside the bounds is $< 10^{-10}$. The width of the bounded region will be defined as the peak-to-peak value of the equivalent DJ. A simple conversion factor can be defined which does this calculation, so

$$DJ = \alpha \bullet RJ \cdots (4)$$

where α is defined in Table 1.

TABLE 1

Bit Error Rate (BER)	α
10^{-9}	11.996
10^{-10}	12.723
10^{-11}	13.412
10^{-12}	14.069
10^{-13}	14.698
10^{-14}	15.301
10^{-15}	15.883
10^{-16}	16.444

Once the RJ is converted to DJ, the DJ of the modulator driver can be calculated using equation (3). It is important to note that the conversion from RJ to DJ is not reversible since there is no functional relationship between DJ, which is multi-valued, and an equivalent RJ.

Notes on Jitter Measurements Using the Agilent 86100A Oscilloscope

One industry standard for measuring jitter in eye diagrams is the Agilent 86100A oscilloscope. This unit measures either RMS or peak-to-peak jitter, regardless of whether it is RJ or DJ. The oscilloscope first finds the eye-crossing point and places a vertically thin horizontal window through the crossing point and generates a time histogram. This histogram determines the center of the crossing point. The window is kept narrow enough so that the measurement is not influenced by the rise/fall time of the waveform. The histogram is then analyzed to determine the amount of jitter present. When an RMS measurement is selected, one standard deviation of the histogram is calculated and an RMS jitter value is returned. When a peak-to-peak measurement is selected, the extremes of the histogram are given as a peak-to-peak value. Hence it is left to the operator to decide the type of jitter present, RJ or DJ, and select the appropriate result to be returned.

References

Jitter in Digital Communication Systems Part 1 --- Maxim Integrated Products Application Note HFAN- 4.0.3

Converting Between RMS and Peak-to-Peak Jitter at a Specified BER --- Maxim Integrated Products Application Note HFAN- 4.0.2

A Brief Introduction to Jitter in Optical Receivers --- Maxim Integrated Products Application Note HFAN- 4.0.1

Fibre Channel – Methodologies for Jitter Specification --- INCITS TR-25-1999