Selecting RJ Bandwidth in EZJIT Plus Software

Application Note 1577

Introduction

Separating jitter into its random and deterministic components (called "RJ/DJ separation") is a relatively new technique for analyzing a signal's aggregate total jitter. The primary purpose of this task is to estimate peak-to-peak jitter values at very low bit error rate levels that would otherwise take too much time to measure directly. An added benefit of this technique is that it gives you a basic understanding of the jitter's underlying cause.

EZJIT Plus is an optional jitter analysis package that runs on Infiniium real-time oscilloscopes from Agilent Technologies, Inc. and performs RJ/DJ analysis. EZJIT Plus software uses different analysis techniques depending on whether you specify that the data pattern is periodic or non-periodic. Further, the RJ bandwidth modifies parameters for these techniques, and these modifications can yield different results depending on the nature of the signal being applied. The pattern length selection (periodic/arbitrary) allows for analysis of data patterns that are periodic, or for data patterns that are either not periodic, or their pattern length is too long to be analyzed using the periodic data mode. (See Figure 1.) The RJ bandwidth selection (wide/narrow) enables you to tailor the analysis based on your knowledge of the noise model of the signal. This document provides a detailed explanation of the RJ bandwidth control and helps you determine how to set it.

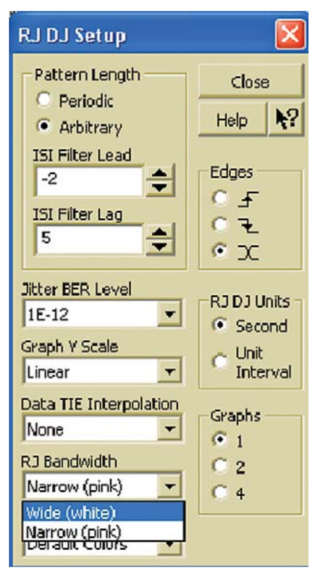

Figure 1. EZJit Plus GUI with RJ bandwidth selection shown

Why a Wide/Narrow Noise Model Selection?

One of the steps in the RJ/DJ separation process is to separate PJ from RJ. EZJIT Plus performs this separation in the frequency domain by removing all the excessively tall frequency components in the jitter spectrum, as shown in Figure 2. The remaining frequency components are then combined to determine the RJrms value.

The ultimate purpose of separating random jitter from the deterministic jitter components is to separate the jitter that has a Gaussian distribution (RJ) from the jitter that has a bounded or finite distribution (PJ and DDJ). For the spectral method of RJ/PJ separation to satisfy its ultimate purpose, all of the tall spikes in the spectrum need to correspond to bounded jitter components, and the noisy baseline of the spectrum needs to correspond to the Gaussian components. Indeed, this is generally the case because most RJ is caused by additive white Gaussian noise. Situations can arise however, where this is not the case. Consider a signal with a raised noise floor in its low-frequency region. Should this be considered as RJ or DJ? Without a priori knowledge of what this jitter source is, we may interpret this as RJ, or we may interpret it as DJ. If we interpret it as RJ, our estimate for total jitter will increase because the RJ value is multiplied by the BER multiplier (for 10^{-12} BER, the multiplier is about 14). What if this noise is not RJ, but some bounded uncorrelated noise type (such as low Q spurious)? In this case, you don't want the answer to be subject to this RJ penalty and yield an overestimate of total jitter. Figure 3 shows the jitter spectrum of such a signal.

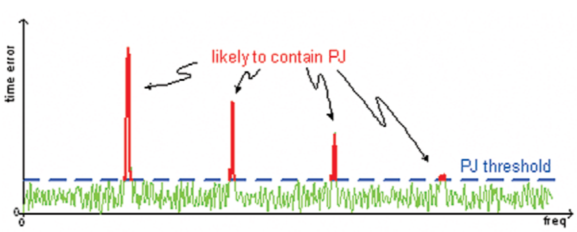

Figure 2. Portrayal of RJ/PJ spectrum after removal of DDJ

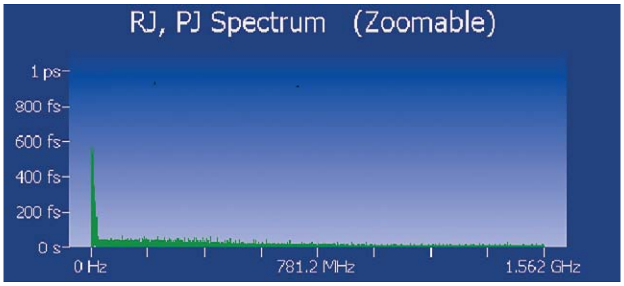

Figure 3. Jitter spectrum of signal to be analyzed. Note rather large low-frequency content.

To illustrate the differences in answers you can get, this signal is analyzed in periodic and arbitrary modes with both the wide and narrow settings. The results of these four analyses are shown in the screen captures, Figures 4, 5, 6 and 7.

Note that in these screen captures the total jitter (TJ) is approximately 106 pseconds with the narrow setting, while in the wide setting it is approximately 81 ps. The reason for this difference is easily seen when you examine the RJ and PJ components. With the narrow setting, the low-frequency content is considered to be all RJ, and so a value of approximately 7 ps rms is measured, which (with the 10^{-12} BER multiplying factor of 14) yields the high value of TJ we observe. With the wide setting, the noise is seen as pure PJ, its rms value more than doubling while the RJ rms value is commensurately reduced. The result is a total jitter estimate that is less because there is no peak-to-peak jitter extrapolation multiplier for periodic jitter. Total jitter is estimated at 81 pseconds, which is much lower than the narrow setting estimate.

Observe further that the RJ/PJ histogram is the same in each. The appearance of the DDJ histogram is different when you operate in the periodic and arbitrary modes, but this can be explained by the differences between the signal processing used in arbitrary mode versus periodic mode.

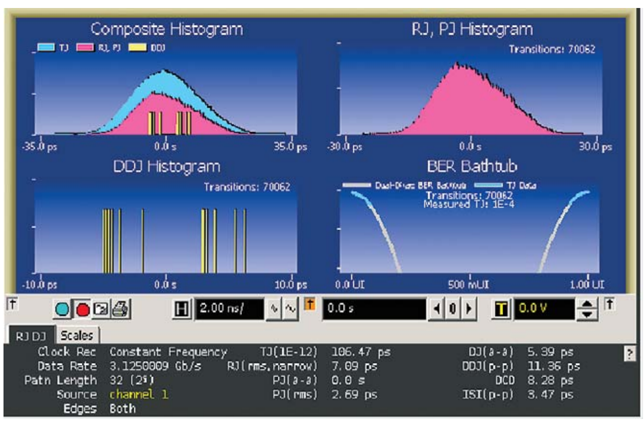

Figure 4. Periodic mode with narrow setting

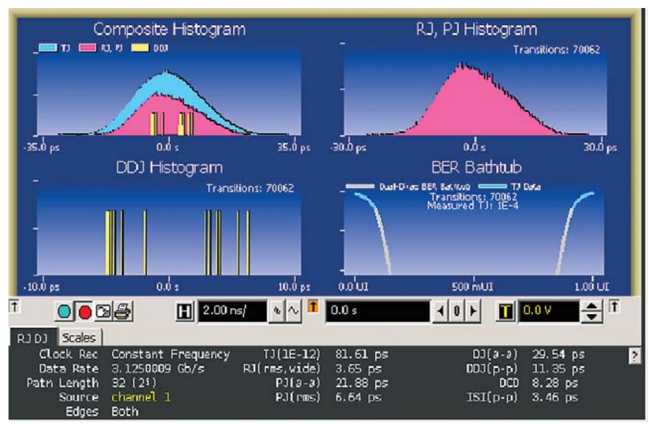

Figure 5. Periodic mode with wide setting

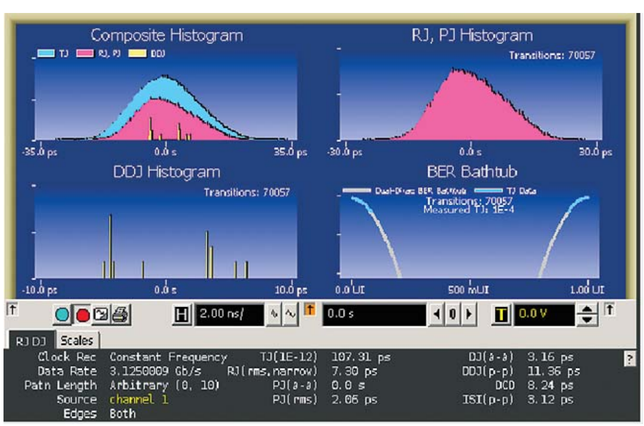

Figure 6. Arbitrary mode with narrow setting

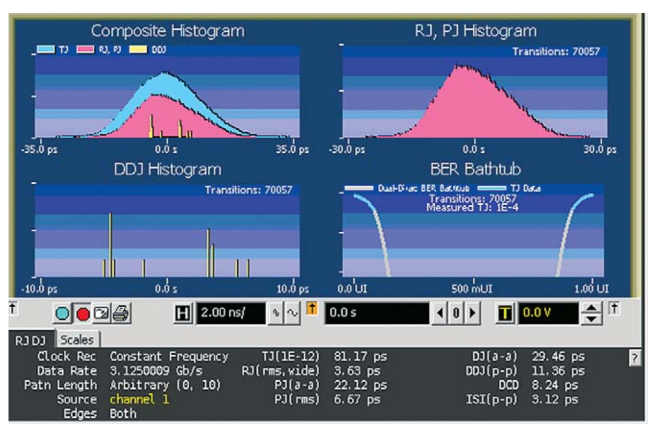

Figure 7. Arbitrary mode with wide setting

Signal Processing Details

EZJIT Plus provides the wide/narrow RJ bandwidth control to allow you to specify how you would like EZJIT Plus to model RJ. In the wide setting, EZJIT Plus assumes that all of the RJ is constant with respect to frequency (white), such that a raised band in the jitter spectrum will be considered to be PJ. In the narrow setting, EZJIT Plus assumes that some of the RJ can be narrow-band (pink), such that only spikes in the jitter spectrum will be considered to be PJ.

The specific affect that the RJ bandwidth control has on EZJIT Plus's RJ/PJ separation algorithm, lies in the trade-off between the jitter spectrum's Nyquist frequency and its resolution.

The jitter separation algorithm in EZJIT Plus uses a spectral approach where spectral lines are examined and compared relative to the noise floor. If above a given threshold, the spectral lines are considered PJ and are removed before making the RJ rms calculation. If the noise floor is raised in a given frequency band, this distinction is difficult to make and the result is that the spectral components will be considered as PJ. A pathological case has already been proposed that shows that the jitter spectrum has a band significantly raised above the noise floor. An assumption will be made by the measurement software about the nature of this spectrum peaking. If examined in a wide spectrum sense, this peaking will occur over a relatively narrow frequency band and will be above the threshold derived for the signal's whole jitter spectrum. If examined in a narrow sense, the peaking may either be seen as a truly raised noise floor as a group of spurs all closely bunched together; in the former case it would be interpreted correctly as PJ, and in the latter as RJ. This wide/narrow viewpoint is accomplished by segmenting our sampled dataset for the wide case or decimating our sampled dataset for the narrow case.

After clock recovery of the acquisition and data edge comparison to the clock, the oscilloscope has sampled jitter values at the bit rate. Any high frequency jitter (higher than 1/2 the bit rate) is aliased back down to lower frequencies. Without further processing, an FFT of this data (number of points, M) will exhibit the Nyquist bandwidth of BitRate/2 Hertz and a resolution bandwidth of BitRate/M. If decimation (resampling the time record at every nth point) is included in the processing, then the Nyquist bandwidth decreases by the decimation ratio and, therefore, the degree of aliasing is increased as well. Note: we do not worry about aliasing as the energy content of the signal is preserved.

Periodic mode

In periodic mode, the data is decimated by the pattern length. This is done to evaluate the ISI of every bit in the pattern by taking the first element in the FFT of each array representing samples of every bit in the pattern. By so doing, the decimation factor is the pattern length. This is the process for the white noise model. For the pink noise model, further decimation is applied that is *dependent* on the data pattern length and acquisition memory depth used. If the time arrays for each bit exceed 512 elements, they are decimated a factor equal to FLOOR($N_{Elements}$/512), where FLOOR(x) = INT(x).

An example will clarify.

Suppose we sample at 20 GSa/s a 3.125 Gb/s signal with a 32-bit pattern and use 1 M of memory:

Jitter sample rate = 3.125 GHz

Number of bits sampled
1 M/[20 G/3.125 G] = 160,000

Number of pattern repetitions covered = 160,000/32 = 5000

We will have 32 time arrays of 5000 values:

Time array length = 5000 points

Effective sampling = 3.125 G/32 = 98 MSa/s

Evaluate time array length/512... we get 9.8 so we take the integer of 9.

Wide RJ bandwidth setting
The 5000 point arrays are segmented into 9 sections which yields nine 556-point arrays that are then power spectral averaged. The resolution bandwidth is equal to 98/556 = 176 KHz and the Nyquist frequency is 98/2 = 49 MHz. This is shown in Figure 8.

Narrow RJ bandwidth setting
We decimate the 5000 point arrays by a factor of 9 again, which yields nine 556-point arrays for each and power spectral average the result. The resolution bandwidth is equal to 98/5000 = 20 KHz and the Nyquist frequency is 49/9 = 5.4 MHz. This is shown in Figure 9.

Notice that Figure 8 appears to have a large number frequency components that protrude from the noisy baseline and exceed the PJ threshold. This causes a large portion of the jitter to be identified as PJ. Figure 9 however, shows how the aliasing of narrow mode causes the entire spectrum to appear as a noisy baseline, where very little of the jitter exceeds the PJ threshold and is placed into the PJ category.

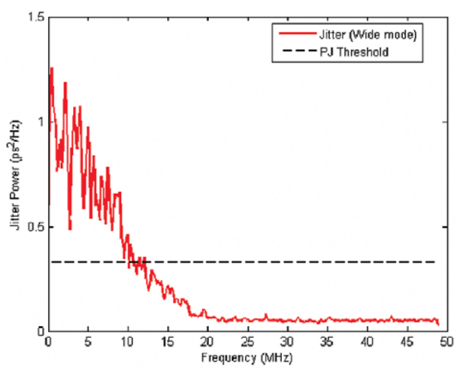

Figure 8. Plot of jitter spectrum of this example with RJ bandwidth=Wide

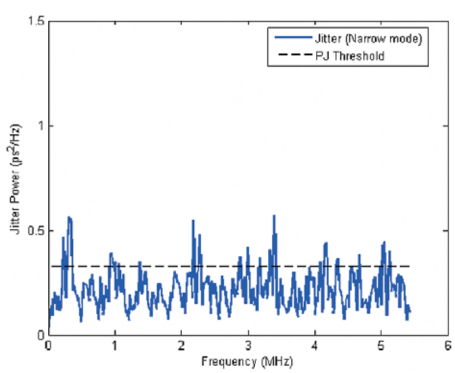

Figure 9. Plot of jitter spectrum of this example with RJ bandwidth=Narrow

Arbitrary mode

In the arbitrary mode, there is no pattern so the initial decimation by pattern length seen in the periodic mode does not occur. (The ISI per bit is calculated through the ISI filter). Again, we evaluate using decimation and segmentation. The acquisition array is divided by 512 to find the number of segments and/or the decimation factor.

Using the same example as above:

Acquisition array is 160,000 in length.

Number of segments = Decimation factor = Acquisition Length/512 [rounded up] = 313 (implies actual segment length = 512).

Wide noise model
313 512-point arrays are created by segmenting the acquisition array, and they are power spectral averaged. The resolution bandwidth is 3.125 G/512 = 6.1 MHz and a Nyquist frequency of 3.125/2 = 1.625 GHz.

Narrow noise model
Decimation by 313 is performed, creating 3013 512-point arrays which are then power spectral averaged. In this case, our sampling frequency is 3.125 GSa/313 = 10 MHz, so the crossover frequency is 5 MHz. Our resolution frequency then is 10 MHz/512 = 20 kHz.

Measurement Summary

Table 1 compares EZJIT Plus's reported measurement results for four configurations described above. You can see from these results that EZJIT is quite effective at separating the RJ from PJ no matter which type of RJ is present in the signal. However, it is up to the user to select the appropriate configuration of the RJ bandwidth control.

Jitter measurement mode	Reported RJrms	Reported PJrms	Resolution bandwidth	Nyquist frequency
Periodic				
Wide: White	3.7 ps	6.6 ps	176 KHz	49 MHz
Narrow: Pink	7.1 ps	2.7 ps	20 KHz	5.4 MHz
Arbitrary				
Wide: White	3.6 ps	6.7 ps	6.1 MHz	1.625 GHz
Narrow: Pink	7.3 ps	2.1 ps	20 KHs	5 MHz

Table 1. Summary for wide and narrow settings for periodic and arbitrary modes for a 3.12-5 Gb/s, PRBS7 signal with 2-M acquisition memory.

Examining the Bathtub Curve

Sometimes it is possible to determine which RJ bandwidth mode to use by examining the BER bathtub curve. Figure 10 provides an exaggerated example of a BER bathtub curve when the RJ is underestimated.

Notice the sharp bend or inflection between the measured portion of the curve (blue) and the extrapolated portion (white). In this example, the bathtub curve should transition smoothly between the measured and extrapolated portions of the curve, as shown in Figure 11.

Examining the BER bathtub curve can often be helpful, but it is not always guaranteed to work. Sometimes, as seen in our previous example (Figures 4-7), the inflection may be too subtle and difficult to recognize. Other times, there really is an inflection in the bathtub curve that just happens to fall on the intersection of the measured and extrapolated portions of the graph. If this happens, extending the measured portion of the curve by accumulating more acquisitions can often expose a true inflection in the curve. The good news is that when the difference in measurements results between the two RJ bandwidth mode settings is large, so is the erroneous inflection in the bathtub curve.

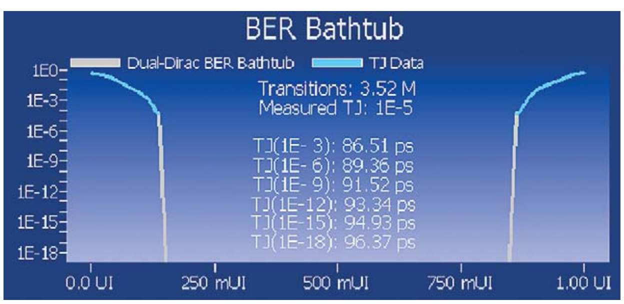

Figure 10. Erroneous inflection in BER bathtub curve caused by underestimation of RJ

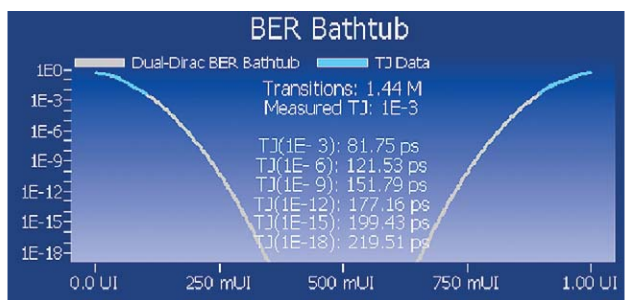

Figure 11. Correct extrapolation of BER bathtub curve when RJ is not underestimated

Conclusion

The model for understanding jitter by decomposing it into RJ and DJ components is an abstraction that though useful, has its flaws. Using a spectral noise floor analysis, as EZJit Plus does, requires assumptions to be made regarding the spectral model for RJ. Unless you have prior knowledge of the jitter generation mechanisms within your signal, it can be difficult, if not impossible, to determine which RJ model applies to your application. If you obtain very different answers when you use wide and narrow settings, your signal needs to be understood further. One thing you can do is measure the signal in both RJ bandwidth modes and compare the resultant TJ values against a direct TJ measurement using a BERT. Another alternative, if the unknown jitter component dominates the RJ+PJ, is to examine the RJ+PJ histogram to see if the unknown jitter has a Gaussian distribution. If neither of these options is available to you, then at least you can measure the signal in both modes and know that the true answer probably lies somewhere between them.

Related Literature

Publication Title	Publication Type	Publication Number
EZJIT and EZJIT Plus Jitter Analysis Software for Infiniium Series Oscilloscopes	Data sheet	5989-0109EN
Analyzing Jitter Using Agilent EZJIT Plus Software	Application note	5989-3776EN

Product Web site

For the most up-to-date and complete application and product information, please visit our product Web site at:
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Product specifications and descriptions in this document subject to change without notice.

Printed in USA, April 30, 2006
5989-5056EN

Agilent Technologies