Keysight Technologies
Analyzing Jitter Using EZJIT Plus Software

Application Note
# Table of Contents

Introduction .............................................................................................................. 3  
Time Interval Error ................................................................................................. 4  
The Dual-Dirac Model of Jitter .............................................................................. 5  
Jitter Decomposition Model ................................................................................. 6  
Jitter Decomposition Methodology ...................................................................... 7  
  - Periodic versus arbitrary data pattern analysis ............................................ 7  
  - Separating DDJ from RJ and PJ ................................................................. 7  
  - Separating PJ from RJ .............................................................................. 9  
  - Applying the dual-Dirac model to PJ and DJ ............................................. 10  
Performing a Jitter Measurement ....................................................................... 11  
  - General setup .......................................................................................... 11  
  - Source type ............................................................................................. 12  
  - Measurement setup .................................................................................. 12  
  - Clock recovery ......................................................................................... 13  
  - Thresholds ............................................................................................... 13  
  - Other setup options .................................................................................. 14  
Analyzing the Graphs ......................................................................................... 15  
  - DDJ versus bit (periodic data mode only) ................................................. 15  
  - ISI filter (arbitrary data mode only) ............................................................ 16  
  - DDJ histogram .......................................................................................... 17  
  - RJ,PJ histogram ....................................................................................... 17  
  - TJ histogram ............................................................................................. 18  
  - RJ,PJ spectrum .......................................................................................... 18  
  - BER bathtub .............................................................................................. 19  
Analyzing the Measurement Results .................................................................. 20  
  - RJ(rms), DJ(6-d) and TJ(p-p) ................................................................. 20  
  - DDJ(p-p), ISI(p-p) and DCD ................................................................. 20  
  - PJ(6-d) and PJ(rms) ................................................................................ 20  
Conclusion ............................................................................................................. 21  
Related Literature ................................................................................................. 21  
Support, Services, and Assistance ...................................................................... 22
Introduction

RJ/DJ analysis separates a signal’s aggregate total jitter into random jitter (RJ) and deterministic jitter (DJ) components. When you separate the components, you can estimate peak-to-peak jitter values at very low bit error rate levels that would otherwise take too much time to measure directly. An additional benefit of this technique is that it helps you diagnose and understand the jitter’s underlying causes.

You can perform RJ/DJ jitter analysis using various products presently on the market. Some of these products perform their analysis on jitter measurements from time interval analyzers. Others use sampling oscilloscope jitter measurements or real-time oscilloscope jitter measurements. Unfortunately, this wide variety of RJ/DJ analysis products also provides a wide variety of reported results.

EZJIT Plus is an optional jitter analysis software package that supports Infinium real-time oscilloscopes from Keysight Technologies, Inc., and it performs RJ/DJ analysis. EZJIT Plus software leverages the fast, accurate analysis methodology and familiar graphical interface of the Keysight’s DCA-J, which operates only on Keysight equivalent-time sampling oscilloscopes. This application note describes the use and theory of operation of the EZJIT Plus software.
Time Interval Error

EZJIT Plus software’s RJ/DJ analysis is based on variations in time-displacement of voltage transitions of a serial data waveform relative to a specified time reference. More simply, EZJIT Plus software analyzes time interval error (TIE). TIE (also called phase jitter) is a discrete-time function of time error versus time.

The time reference (clock reference) used for TIE measurements can be defined many different ways. One time reference commonly used for TIE measurements is a constant-frequency squarewave with frequency and phase that has been best-fit to the measurement’s source waveform. Sometimes the voltage transitions of a second source waveform are used as the time reference.

It’s important to choose the appropriate time reference for each application so the measurement reports the information that you really want to know. If you use a software PLL (phase-locked loop) clock recovery reference, for example, the measurement will report only the residual PLL jitter delivered to your receiver’s decision circuit.

Figure 1. EZJIT Plus software analyzes the TIE (time interval error) of serial data waveforms and clock waveforms. (c) TIE is the time error between (b) the source waveform’s transitions and (a) the specified time reference.
The Dual-Dirac Model of Jitter

The dual-Dirac model of jitter models the PDF (probability density function) of TIE. The dual-Dirac model separates the total TIE, called TJ (total jitter) into two components, RJ (random jitter) and DJ (deterministic jitter). RJ is defined to have a Gaussian PDF and DJ is defined to have a bimodal PDF such that when the two are convolved together, they form a new PDF that closely matches the TJ's PDF at low probability. Figure-2 shows how the dual-Dirac model matches the measured TJ histogram at the low-probability “tails” of the TJ histogram.

The terms random and deterministic are arguably poor names for these two jitter components. Jitter that falls into the RJ category is not necessarily random. By definition, it is jitter that exhibits a Gaussian PDF. Likewise, DJ is not necessarily deterministic. By definition, DJ is jitter that does not exhibit a Gaussian PDF.

1. The term dual-Dirac comes from the two Dirac delta functions that form the bimodal PDF of DJ.
2. A histogram is a small-sample measure of the jitter's actual PDF.
3. TJ is technically the cross-correlation of RJ and DJ, but convolution works because RJ and DJ are symmetrical.

Figure 2. EZJIT Plus uses the dual-Dirac model to extrapolate measured jitter histograms to very low probabilities.
Jitter Decomposition Model

The dual-Dirac model of jitter is useful because it allows us to estimate the impact of jitter on system reliability by estimating peak-to-peak jitter at probabilities that would otherwise take too much time to measure directly. In addition to estimating TJ quickly, EZJIT Plus also helps identify the possible causes of jitter.

In this more complex jitter model, DJ is further broken down into PJ (periodic jitter), DDJ (data-dependent jitter), ISI (inter-symbol interference) and DCD (duty-cycle distortion). This model also distinguishes between jitter that is correlated to the data pattern (DDJ, ISI and DCD) and jitter that is uncorrelated to the data pattern (RJ and PJ). Each of these sub-components of jitter is best understood by understanding how EZJIT Plus software separates them from one another, as described in the next section Jitter Decomposition Methodology.
Jitter Decomposition Methodology

Periodic versus arbitrary data pattern analysis

EZJIT Plus software can analyze the jitter on any clock waveform or NRZ serial data waveform, no matter what binary sequence is present in the data. EZJIT Plus software analyzes clock waveforms by treating them as data waveforms with alternating 1/0 data patterns. EZJIT Plus software uses two different analysis techniques depending on whether you specify that the data pattern is periodic or non-periodic. The periodic method is usually preferable for periodic data applications because it runs considerably faster than the arbitrary method. Note, however, that there is a maximum pattern length limitation when you use the periodic analysis method.

Separating DDJ from RJ and PJ

Periodic data mode

To isolate the component of jitter that is correlated to the data pattern, EZJIT Plus software must first calculate the TIE function of the jitter and associate each TIE value with a specific bit in the source waveform's logical bit sequence. This is done by extracting the logical bit sequence from the source waveform and determining the length in bits of its periodic pattern. Next, the original TIE function is decimated into sub-sampled TIE functions, where all of the values in each sub-sampled function correspond to a specific bit within the pattern. The number of original samples that are skipped when decimating depends on the RJ bandwidth mode setting that you choose. The narrow-band (pink) RJ bandwidth mode setting maximizes the decimation ratio, while the wide-band (white) setting minimizes it. Refer to the discussion in the Performing a Jitter Measurement section.

Figure 4. EZJIT Plus software decimates (b) the original TJ TIE into (c-e) separate TIEs that correspond to each bit in (a) the source waveform's repeating bit pattern.
Jitter Decomposition Methodology (continued)

Each of these sub-sampled TIE functions is then transformed into the frequency domain using an FFT (fast Fourier transform). DDJ is now easily separated from the rest of the jitter because the first value of each jitter spectrum (DC component) is equal to the DDJ for that particular bit of the repeating bit pattern.

Arbitrary data mode

In arbitrary data mode, EZJIT Plus software cannot simply average the TIE values associated with specific locations within the bit sequence. Instead, it determines a formula for calculating the DDJ from the surrounding data bits. EZJIT Plus’s formula is a transitional ISI (inter-symbol interference) filter. This filter works like a conventional FIR (finite impulse response) digital filter, except that it calculates the DDJ value of each transition from the polarity of the transitions that surround it. The assumption in ISI is that energy contained in “aggressor” transitions (edges) affects the timing of “victim” edges. The ISI filter in EZJIT Plus software actually consists of four separate sets of weighted-coefficients; rising victim-rising aggressor, rising victim-falling aggressor, falling victim-rising aggressor, and falling victim-falling aggressor. The four different sets of coefficients enable EZJIT Plus software to accommodate non-linear effects in the DDJ.

You can specify how many leading and lagging coefficients are contained in the ISI filter. Then EZJIT Plus software calculates the filter coefficient values that minimize the squared-error between the measured TJ and the calculated DDJ. An example of a 26-coefficient ISI filter is shown in Figure-9.

(a) Spectrum of Bit 0

(b) Spectrum of Bit 1

(c) Spectrum of Bit 3

Figure 5. The first value of each jitter spectrum is equal to the DDJ for each particular bit of the source waveform’s repeating bit pattern.
Jitter Decomposition Methodology (continued)

Separating PJ from RJ

Periodic data mode

Once the DDJ has been subtracted from all of the TJ spectrums, the remaining jitter spectrums are entirely comprised of RJ and PJ. The first step in separating PJ from RJ is to calculate the PSD (power spectral density) of all the remaining RJ/PJ spectrums. All of the individual RJ/PJ spectrums are averaged together (as well as averaged with spectrums from previous acquisitions) to form an APSD (averaged PSD).

At this point, all of the APSD’s frequency components that have significantly large magnitudes are removed, because they could potentially contain PJ. The remaining frequency components of the APSD are then combined to obtain the rms (root-mean-square) value of RJ.

Arbitrary data mode

As with periodic data mode, the DDJ is subtracted from the TJ. In arbitrary data mode, this is done in the time-domain in order to produce a TIE function that is entirely comprised of RJ and PJ. This RJ,PJ TIE function is then segmented or decimated, depending on the RJ bandwidth mode setting prior to calculating the PSD of the RJ,PJ TIE function. The narrow-band (pink) RJ Bandwidth mode setting decimates the TIE function, while the wide-band (white) setting segments it.

Arbitrary data mode also separates PJ from RJ by identifying narrow spikes in the RJ,PJ spectrum as potential PJ frequency components. In arbitrary data mode, however, a single PJ frequency component will appear as multiple spikes in the RJ,PJ spectrum. This happens because the underlying PJ is modulated by the “holes” (see the description of holes in RJ,PJ spectrum, below) in the measured TJ TIE function. Since these modulation spurs of the underlying PJ can be too small to distinguish from RJ by simple comparison to threshold, arbitrary data mode calculates their values from knowledge of the serial data pattern and then subtracts them from the original RJ,PJ spectrum. This subtraction is performed in an iterative process until all of the remaining PSD’s frequency components that have significantly large magnitudes are removed. The remaining frequency components of the PSD are then combined to obtain the rms (root-mean-square) value of RJ.

Figure 6. Spectral components that extend significantly above the mean PSD are removed from the TJ spectral components. RJ rms is then calculated from the remaining spectral components.
Jitter Decomposition Methodology (continued)

Applying the dual-Dirac model to PJ and DJ

DJ(\(d - d\)) and PJ(\(d - d\)) are both determined by fitting the dual-Dirac model described above to measured histograms. The dual-Dirac model can be fitted to a PDF using various methods, many of which solve for the Gaussian component and the bimodal component simultaneously. EZJIT Plus, already knows the Gaussian component (RJ) so it needs only to solve for the width of the bimodal component. EZJIT Plus solves for this width by finding the width of the bimodal PDF where the nth percentiles of the dual-Dirac model match the nth percentiles of the measured histogram.

The percentiles used to find PJ are progressive. They start at about 0.1% and decrease as the total number of accumulated acquisitions increases. The percentiles used to find DJ also are progressive, but start between about 0.1% and 0.1% divided by the number of edges per pattern, depending on how much the variance of the RJ,PJ histogram was reduced by the cross-correlation with the DDJ histogram to form the TJ histogram.

Figure 7. EZJIT Plus software matches the nth percentiles of the dual-Dirac model to the nth percentiles of the measured histograms.
Performing a Jitter Measurement

Jitter analysis is a relatively sophisticated analysis process, making the setup of jitter measurements confusing or even intimidating. EZJIT Plus software provides a setup wizard to aid you through the five major steps of the setup process: general setup, source type, measurement setup, clock recovery, and thresholds.

General setup

The first step in setting up a jitter measurement is to configure the oscilloscope’s sample rate, memory depth, and vertical channel scaling for proper waveform acquisition.

Sample rate

In general, the higher the sample rate, the more accurate the jitter measurement will be. The measurement bandwidth required for jitter measurements is typically about twice the serial bit rate, which implies a sample rate of eight times the serial bit rate. However, over-sampling with a higher sample rate than is needed and then reducing the measurement bandwidth using digital filtering (waveform math or software bandwidth limit) improves the scope’s jitter measurement floor.

In some applications, increasing the source waveform’s acquired time range is more important than lowering the jitter measurement floor. In these cases, reducing the sample rate is an effective alternative to increasing the memory depth.

Memory depth

Jitter analysis is performed on individual waveform records, one acquisition (trigger cycle) at a time. The statistics of measurements from multiple acquisitions are then combined until a significant oscilloscope setting is changed (e.g. vertical scale change) which resets the accumulated statistics. You can set the time range of source waveforms acquired on each trigger cycle by changing the acquisition memory depth.

The EZJIT Plus software’s analysis methodology requires each individual waveform acquisition to include a minimum number of instances of the source waveform’s repeating logical bit pattern, when you use the periodic method. This limits the maximum pattern length of source waveform test patterns that can be analyzed using a particular memory depth with the periodic method.

In general, lower-frequency components of jitter are analyzed using longer time ranges of source waveforms. You must be careful, however, when using very long memory depths and constant frequency clock recovery methods. The clock sources of many serial communication systems are not as stable as the scope’s timebase reference and can wander relative to the scope’s timebase during the time range of an individual acquisition.

Vertical scale

The vertical scale (Volts/div) of source waveforms used for jitter measurements should always be chosen such the displayed waveform is as large as will still fit within the oscilloscope’s full scale display range (eight divisions). This maximizes the measurement signal-to-noise ratio (SNR) without introducing waveform distortions caused by clipping the oscilloscope ADC’s input voltage range. Maximizing voltage SNR is critical when performing low-jitter measurements on source waveforms with slow risetimes because voltage noise is converted to timing jitter through the slope of the source waveform.
Performing a Jitter Measurement (continued)

Source type

The source type step of the RJ/DJ setup wizard not only allows you to select the source channel for the RJ/DJ measurement, but it also allows you to select whether the analysis is to be performed using the periodic data method or arbitrary data method. The periodic data method is generally preferred if the serial data waveform that you’re testing is periodic and if the pattern length is short enough for the waveform memory depth you are using.

In periodic mode, the pattern length can be set manually, or can be determined automatically by the EZJIT Plus software. The automatic pattern length setting is generally preferred. You may wish to choose a manual setting if there are occasional bit errors in the serial data waveform, because in automatic pattern length mode, bit errors will reset the accumulated measurement statistics, but not in manual mode.

Arbitrary data mode requires you to specify the number of coefficients used in the ISI filter. “ISI Filter Lead” refers to the number of leading coefficients in the filter, while “ISI Filter Lag” refers to the number of lagging coefficients in the filter. The best size of ISI filter for an application depends on the DDJ that’s in the source waveform. Choosing more coefficients than you need will cause EZJIT Plus software to run more slowly than necessary. Choosing fewer coefficients than you need will cause some of the DDJ to be interpreted as RJ.

Prior knowledge about the origin of the source waveform’s DDJ can help you choose the proper number of filter coefficients for your application. Leading coefficients, for example, are only necessary if the DDJ at a particular transition is affected by other transitions that occur later in time. One way to determine the minimum necessary size for the ISI filter is to perform a measurement with a large number of coefficients, and then gradually reduce the number of coefficients as much as possible without affecting the measurement results.

Measurement setup

The measurement setup step of the RJ/DJ setup wizard configures various options related to displaying results. These options are specific to RJ/DJ analysis and include settings such as the BER (bit error rate) level for reported TJ and the time versus unit interval scaling of jitter results. This step also includes the data TIE interpolation control, which selects whether the TIE function is interpolated across holes before calculating the jitter spectrum graph (see RJ,PJ spectrum, on page 16, Figuer 12).
Performing a Jitter Measurement (continued)

Clock recovery

All TIE measurements (including RJ/DJ analysis) measure the time position of waveform transitions relative to a specified clock reference. The choice of this clock reference is critically important to measuring the particular characteristic of jitter that you intended to measure. You select the clock reference used for jitter measurements from EZJIT Plus software’s clock recovery setup menu. The clock recovery setup menu provides the following clock recovery choices.

- Intel PCI Express (1.0a)
- Intel PCI Express (1.1)
- Fibre Channel
- First-Order PLL
- Second-Order PLL
- Constant Frequency
- Explicit Clock
- Explicit First Order

Of these clock recovery methods, the two explicit clock methods measure the jitter between voltage transitions on one signal relative to transitions on a second signal. The other methods measure jitter between a waveform’s voltage transitions and transitions of a reference clock that is extracted from the waveform.

Some of these clock recovery methods employ PLL techniques that have a high-pass filtering effect on the measured jitter. The constant frequency clock recovery with automatic frequency extraction measures jitter relative to the oscilloscope’s internal timebase. You must be careful when using this method with deep acquisition memory depths because these jitter measurements will include any differential low-frequency phase noise (wander) between the source waveform’s clock reference and the oscilloscope’s internal timebase.

Typical RJ/DJ analysis measurements are limited to the higher-frequency content of jitter because PLLs employed in most serial data systems correct for lower-frequency jitter and wander. However, EZJIT Plus software can also measure arbitrarily low-frequency jitter when used with explicit clock or manual constant clock recovery, limited only by memory depth and sampling rate.

Thresholds

All jitter measurements are based on the times of voltage threshold crossings, but the oscilloscope can be configured to use different thresholds for its measurements. Typically, you will want to use a fixed voltage threshold that is chosen to be close to the 50% level of the source. The hysteresis value should typically be set to about 5% of the source waveforms amplitude. However, the hysteresis should be increased if the source waveform has inflections on its transitions. The hysteresis may need to be decreased if the vertical eye opening of the source waveform is significantly reduced by excessive ISI or voltage noise.

If the intended receiver is DC coupled and has a fixed threshold, you may want to use that threshold so the jitter you measure is the jitter that the receiver would experience. Many high-speed data signals are differential. In this case the crossover, or zero volts differential, is often the switching threshold for receivers.
Other setup options

There are two setup options that are not exposed in the RJ/DJ setup wizard. One of these options is the default color scheme used by the graphs. The other is the RJ bandwidth mode.

RJ bandwidth mode

As described above, EZJIT Plus software uses a spectral technique to separate RJ from PJ. Narrow bandwidth spikes that extend above the jitter spectrum’s baseline are considered to contain PJ, while the remaining baseline is assumed to contain only RJ. This technique works very well for wide-bandwidth or “white” random jitter. Wide bandwidth RJ has a uniform PSD across the entire jitter spectrum. Sometimes however, the RJ being measured does not have a uniform PSD. Although this is not as common in practical communication system applications, it does occur frequently in jitter sources generated using laboratory test equipment. Conversely, the jitter spectrum of some PJ components appears much broader than the narrow spikes of a highly periodic jitter component. These broad-bandwidth PJ components are also uncommon, but can be difficult to distinguish from RJ by inspection of the jitter spectrum alone.

For these reasons, EZJIT Plus software allows you to specify whether you want to treat “broad lumps” in the jitter spectrum as RJ or PJ. Setting the RJ Bandwidth mode to wide (white) assumes that the RJ is flat, and that all broad lumps in the jitter spectrum are considered to be PJ. By default, the RJ bandwidth mode is set to narrow (pink). This mode acknowledges that the RJ may or may not be flat, and that all broad lumps in the jitter spectrum are considered to be RJ.
Analyzing the Graphs

DDJ versus bit (periodic data mode only)

The DDJ versus bit graph (see Figure-8) displays the average time error associated with each bit of the source waveform’s repeating bit pattern. A positive value of DDJ indicates that the transitions preceding those bits arrive later than they should. Examination of this graph shows which patterns and which bits within a pattern are most likely to cause transmission errors.

Figure 8. This DDJ versus bit graph shows how much jitter is contributed by each bit of a 27-1 data pattern.
Analyzing the Graphs (continued)

ISI filter (arbitrary data mode only)

The ISI filter graph (see Figure 9) displays the ISI filter coefficients in a graphical form that is similar to the impulse response of an FIR digital filter. This graph contains four separate traces; one for each combination of aggressor polarity and victim polarity. A positive coefficient value for the rising victim–rising aggressor and falling victim-falling aggressor traces indicates that transitions at those relative bit positions add positive delay to the total DDJ. A positive coefficient value for the other two traces indicates that transitions at those relative bit positions subtract positive delay from the total DDJ.

Comparing the differences between the four traces provides insight into the origins of the DDJ. For example, trailing positive exponential pulse shapes, located at position 0 indicate low-pass filtering of the data waveform. Abrupt discontinuities in the filter shape, displaced away from position 0, can be caused by transmission line reflections in the transmission channel. Separation between the four traces shows that rising and falling transitions affect DDJ differently. In fact, the separation between the rising and falling traces at position 0 is equal to the DCD (duty-cycle distortion). Non-zero leading coefficients imply that the DDJ at a particular transition in the pattern is being affected by other transitions that follow it in the serial data pattern. Non-zero leading coefficients are rare in practice, but they can occur in systems that employ buffering or pipelining.

Note that although the ISI filter is always effective at modeling DDJ in the measured signal, the above-mentioned interpretations of the ISI filter graph depend on the randomness of the source waveform’s serial data pattern. The serial data pattern needs to be random (not just arbitrary) in order for the ISI filter graph to display the true correlation between the DDJ at a particular transition and the transition that produced the DDJ. If a short periodic pattern (e.g., 27-1 PRBS) is used, for example, then certain combinations of transitions will never occur in the test waveform, causing the resultant ISI filter to show zero values for those coefficients, even though they may contribute to the DDJ if they were present. Conversely, two different transitions may always occur together, causing the actual DDJ of one transition to appear at both positions on the ISI filter graph.

Figure 9. This ISI filter graph shows how the transitions surrounding each bit affect that bit’s data-dependent jitter.
Analyzing the Graphs (continued)

**DDJ histogram**

EZJIT Plus software calculates and displays three different DDJ histograms; one for rising transitions, one for falling transitions, and one for both rising and falling edges. All of these histograms are calculated directly from the DDJ versus bit function. These histograms provide a graphical representation of the ISI and DCD within the total measured jitter.

![Composite DDJ Histogram](image)

Figure 10. The composite DDJ histogram simultaneously displays the DDJ histograms of rising transitions, falling transitions, and both transitions.

**RJ,PJ histogram**

The RJ,PJ histogram is a histogram of the measured TIE function with the DDJ removed. It comprises RJ cross-correlated with PJ. A Gaussian-shaped RJ,PJ histogram would indicate that there is negligible PJ in the source waveform. The composite histogram graph shown in Figure-11 includes the RJ,PJ histogram.

![Composite Histogram](image)

Figure 11. The composite histogram graph allows you to compare the relative contributions of the DDJ and RJ,PJ histogram to the total TJ histogram.
Analyzing the Graphs (continued)

TJ histogram

The EZJIT Plus software’s TJ histogram is a measure of the TJ’s PDF. It is very similar to a histogram of the source waveform’s TIE function, but it is not exactly the same. EZJIT Plus software calculates the TJ histogram by cross-correlating the DDJ histogram with the RJ,PJ histogram. This technique reduces the variance in the histogram function relative to that produced by accumulating the histogram directly from the TIE function.

RJ,PJ spectrum

The RJ,PJ spectrum graph shows the DFT (discrete Fourier transform) of the combined RJ and PJ. The displayed magnitude spectrum is calculated independently for each acquired waveform and then averaged with magnitude spectra from previous acquisitions. The RJ,PJ spectrum can be used to identify the PJ components of jitter in the source waveform. PJ components of jitter appear as discrete impulses of jitter extending above the noisy RJ baseline.

For clock-type signals, the DFT is calculated from the uniformly spaced RJ,PJ time record, where each value in the RJ,PJ time record corresponds to a voltage transition in the clock-type waveform. For NRZ data-type signals, the RJ,PJ time record is not composed of uniformly spaced jitter values. For these signals, the RJ,PJ time record contains “holes” caused by consecutive logical ones or zeros. The lack of information about the jitter at times corresponding to these holes makes it impossible to determine the true RJ,PJ spectrum.

EZJIT Plus software provides two options for displaying the RJ,PJ spectrum. If the data TIE interpolation mode in the RJ/DJ setup menu is set to none, then the spectrum is calculated as if the holes were all set to a value of zero. In this case, the resulting spectrum appears to be modulated (convolved in the frequency domain) by the data pattern. If the data TIE interpolation mode in the RJ/DJ setup menu is set to linear, then the spectrum is calculated as if holes were determined using linear interpolation. In this second case, the resulting spectrum appears as though filtered by a time-variant, low-pass filter. Figure-12 shows how the RJ,PJ spectrum graph is affected by interpolating the holes in the TIE function.

![Figure 12. EZJIT Plus software displays the RJ,PJ spectrum with and without TIE hole interpolation.](image-url)
Analyzing the Graphs (continued)

BER bathtub

The BER bathtub graph (see Figure-13) plots the width of the data valid window of a serial data signal (horizontal axis) versus bit error rate (vertical axis). The two sides of the bathtub plot each consist of a measured section and an extrapolated section. The top section (high BER) is calculated directly from the measured TJ TIE. The lower section (low BER) is calculated by extrapolation of the EZJIT Plus software’s dual-Dirac model for the TJ.

The BER bathtub graph is useful in visualizing how the desired BER affects the data valid widow, or conversely, what BER can be expected from a desired data valid window. Examination of the intersection between the upper and lower sections of the plotted curves indicates how well the dual-Dirac model fits the measured jitter data.

![BER Bathtub Graph](image)

Figure 13. The BER bathtub graph shows how the estimated TJ value is extrapolated from the measured TJ using the dual-Dirac jitter model.
Analyzing the Measurement Results

RJ(rms), DJ(δ-δ) and TJ(p-p)

Random jitter, RJ(rms) is the rms value of the random portion of jitter in the source waveform. It is uncorrelated to the source waveform’s serial data pattern and is generally believed to exhibit a Gaussian PDF. Deterministic jitter, DJ(δ-δ) is the width of the bimodal-PDF component of the dual-Dirac model of the source waveform’s total jitter. Total Jitter, TJ(p-p) is the estimated peak-to-peak range of total jitter in the source waveform at a specified BER level as calculated from RJ(rms) and DJ(δ-δ) using the dual-Dirac jitter model.

DDJ(p-p), ISI(p-p) and DCD

Data-dependent jitter, DDJ(p-p) is equal to the peak-to-peak range of time errors that are correlated to the source waveform’s serial data pattern. Inter-symbol interference, ISI(p-p), is the range of DDJ from rising edges or the range of DDJ from falling edges, whichever is greater. Duty cycle distortion, DCD is defined as the absolute value of the difference of the mean of the DDJ from rising edges and the DDJ from the falling edges.

You must be careful in interpreting DDJ and DCD values because although DDJ is comprised of both ISI and DCD, ISI and DCD are not mutually exclusive. In fact, because DCD is an unsigned difference, they don’t always add linearly. In addition, DCD depends heavily on your choice of measurement threshold. ISI is generally more useful in understanding the underlying causes of jitter than is DDJ because it is desensitized from the complex characteristics of DCD.

PJ(δ-δ) and PJ(rms)

EZJIT Plus software reports periodic jitter as both a delta-delta value, PJ(δ-δ), and an rms value, PJ(rms). PJ(δ-δ) corresponds to the deterministic component of the dual-Dirac model fitted to the RJ,PJ histogram. Although it is valuable in comparing the relative contribution of PJ to the total jitter, it is difficult to verify experimentally. PJ(rms) is less useful for comparing the relative contribution of PJ to the total jitter, but it is much easier to verify experimentally.
Conclusion

Keysight’s EZJIT Plus software provides a fast, accurate and effective solution for separating a signal’s aggregate total jitter into random jitter and deterministic jitter components, allowing for faster estimation of TJ at very low bit error rate levels that would take too long to measure directly. EZJIT Plus combines the proven analysis methodology and familiar graphical interface of the Keysight DCA-J with the versatility of software-based clock recovery, covering a wider array of applications and PLL-based jitter measurements. Additionally, the powerful troubleshooting capability of real-time oscilloscope acquisition helps you diagnose and understand the underlying causes of individual jitter sources.

Related Literature

<table>
<thead>
<tr>
<th>Publication Title</th>
<th>Publication Type</th>
<th>Publication Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>EZJIT and EZJIT Plus Jitter Analysis Software for Infinium Series Oscilloscopes</td>
<td>Data Sheet</td>
<td>5989-0109EN</td>
</tr>
<tr>
<td>Infinium 90000 Series Oscilloscopes and InfiniiMax II Series Probes</td>
<td>Data Sheet</td>
<td>5989-7819EN</td>
</tr>
<tr>
<td>Precision Jitter Analysis Using the Keysight 86100C DCA-J</td>
<td>Product Note</td>
<td>5989-1146EN</td>
</tr>
<tr>
<td>Comparison of Different Jitter Analysis Techniques With a Precision Jitter Transmitter</td>
<td>White Paper</td>
<td>5989-3205EN</td>
</tr>
</tbody>
</table>
Evolving Since 1939

Our unique combination of hardware, software, services, and people can help you reach your next breakthrough. We are unlocking the future of technology.
From Hewlett-Packard to Agilent to Keysight.

For more information on Keysight Technologies’ products, applications or services, please contact your local Keysight office. The complete list is available at: www.keysight.com/find/contactus

Americas
Canada (877) 894 4414
Brazil 55 11 3351 7010
Mexico 001 800 254 2440
United States (800) 829 4444

Asia Pacific
Australia 1 800 629 485
China 800 810 0189
Hong Kong 800 938 693
India 1 800 11 2626
Japan 0120 (421) 345
Korea 080 769 0800
Malaysia 1 800 888 848
Singapore 1 800 375 8100
Taiwan 0800 047 866
Other AP Countries (65) 6375 8100

Europe & Middle East
Austria 0800 001122
Belgium 0800 58580
Finland 0800 523252
France 0805 980333
Germany 0800 6270999
Ireland 1800 832700
Israel 1 809 343051
Italy 800 599100
Luxembourg +32 800 58580
Netherlands 0800 0233200
Russia 8800 509286
Spain 800 000154
Sweden 0200 892255
Switzerland 0800 805363
Opt. 1 (DE)
Opt. 2 (FR)
Opt. 3 (IT)
United Kingdom 0800 0260637

For other unlisted countries: www.keysight.com/find/contactus
(BP-9-7-17)

DEKRA Certified
ISO 9001:2015
Quality Management System

www.keysight.com/go/quality
Keysight Technologies, Inc.
DEKRA Certified ISO 9001:2015
Quality Management System

myKeysight
www.keysight.com/find/mykeysight
A personalized view into the information most relevant to you.

www.keysight.com/find/emt_product_registration
Register your products to get up-to-date product information and find warranty information.

KEYSIGHT SERVICES
Accelerate Technology Adoption, Lower Costs.

Keysight Services
www.keysight.com/find/service
Keysight Services can help from acquisition to renewal across your instrument’s lifecycle. Our comprehensive service offerings—one-stop calibration, repair, asset management, technology refresh, consulting, training and more—helps you improve product quality and lower costs.

Keysight Assurance Plans
www.keysight.com/find/AssurancePlans
Up to ten years of protection and no budgetary surprises to ensure your instruments are operating to specification, so you can rely on accurate measurements.

Keysight Channel Partners
www.keysight.com/find/channelpartners
Get the best of both worlds: Keysight’s measurement expertise and product breadth, combined with channel partner convenience.