Jitter Fundamentals: Agilent 81250 ParBERT Jitter Injection and Analysis Capabilities

Application Note

Introduction

In digital communications, a sequence of 0's and 1's flows from a transmitter to a receiver. The transmission media is copper, fiber or air. Communication systems are maximized for bandwidth and minimized for errors. These errors are counted as Bit Error Ratio (BER).

Digital communication systems transmit the pure bit stream in terms of a NRZ data stream only, and then regenerate the bit clock at the receiver through the use of a clock and data recovery (CDR) circuit. Timing aberrations of the incoming signal causes malfunction of the CDR circuit resulting in bad sampling of the data causing bit errors. These timing aberrations are called jitter.

Jitter Fundamentals

- What is Jitter?
- Jitter Components
- Jitter Challenges
- Jitter in SONET and Ethernet
- Stressed Eye
- Jitter Measurement in Time/Frequency Domain

81250 ParBERT Jitter Capabilities

- Delay Control / Clock Modulation
- Bandwidth Control
- Bath Tub Measurement with RJ / DJ Separation
- Spectral Decomposition of Jitter

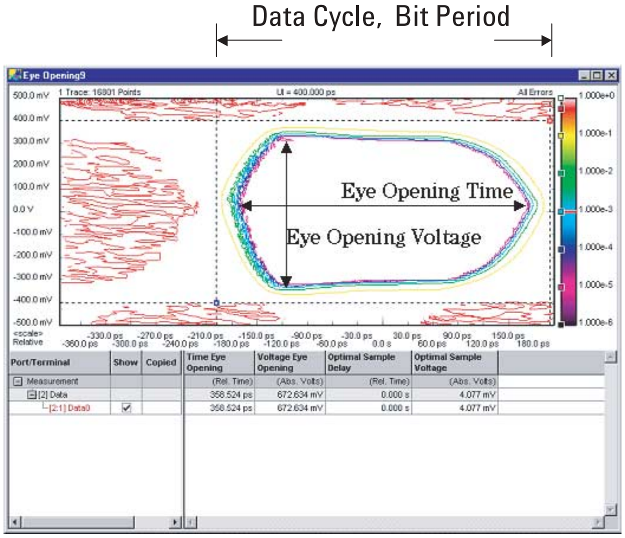
Figure 1: Jitter Fundamentals

Agilent Technologies

Why is jitter an important issue?

Jitter is significant because it is one of the major potential causes for data being received in error. For example, if a long string of bits is on the short side, eventually a receiver will make a decision at the edge of the bit rather than the center (if the clock rate is held constant). This will result in errored bits. Another perspective is to view the eye diagram. As the jitter increases, eventually the eye will close horizontally. In the eye opening display, one can see how the eye closes the higher the BER figure gets. The representation here defines so called ISO-BERs. In the original Graphical User Interface (GUI), this diagram would be in color, and the color coding on the right defines the BER figure for each line. If the clock is derived from the data (CDR), the sampling point can then follow the jitter and allow the system to tolerate jitter. A clock recovery process is limited by the loop bandwidth of the clock recovery circuitry.

It causes bit errors!



Port/Terminal	Show	Copied	Time Eye Opening	Voltage Eye Opening	Optimal Sample Delay	Optimal Sample Voltage
Measurement			(Rel. Time)	(Abs. Volts)	(Rel. Time)	(Abs. Volts)
[2] Data			358.524 ps	672.634 mV	0.000 s	4.077 mV
[2:1] Data0	☑		358.524 ps	672.634 mV	0.000 s	4.077 mV

Figure 2: Why Jitter is an important issue

There are many challenges to today's jitter measurements:

- Huge problems on complex ASICs to avoid ground bounce and clock crosstalk induced jitter.

- New high speed IO standards require DJ, RJ specified separately.

- SONET based jitter transfer specs only make sense when there is no other (intrinsic) jitter source than the artificially injected jitter.

- New defect types in production: process variation affects gross yield through different influences on DJ and RJ.

- Design goal for maturing high speed interfaces: Generate robustness with circuits that show more margin against process influence on DJ and RJ.

- Increasing difficulties for design validation and debugging.

- A better analysis of jitter mechanisms is required.

- Probabilistic view (histogram) is no longer sufficient.

By examining the edges of a digital communications bit stream, we can better illustrate our definition. Figure 3 shows an oscilloscope display of a data stream with the system clock waveform. If the timing of this bit stream is jitter free, the period for all of the bits will always be precisely identical. Thus the time between any two rising or two falling edges will always be a precise integer multiple of the nominal bit period.

Another way to look at this is to look at the data stream relative to an ideal clock source. The time between a data edge and the closest clock edge should always be the same. If the data signal is jitter free, then the 50% amplitude points on the data waveform should consistently align with points on the clock waveform. However, if the bit period fluctuates for any reason, the bit stream will no longer be jitter free.

- ***Significant instants*** **can usually be defined as edges**
- **The system clock can be used to define what the** ***ideal positions*** **in time are**
- **Edge position of the data should consistently align with the same relative points on the reference clock waveform**

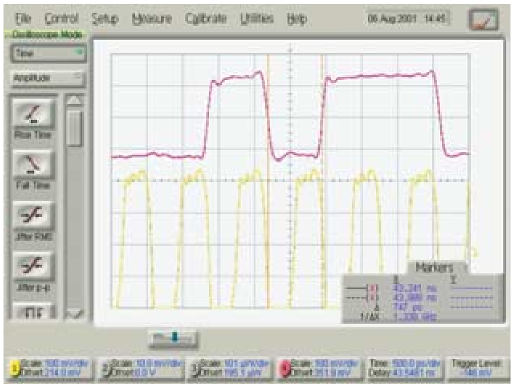


Figure 3: Ideal signal = constant bit period

Although there are differences in the many definitions of jitter, the fundamental similarity is that jitter has to do with the time difference between the ideal and actual occurrence of an event. A simple definition is:

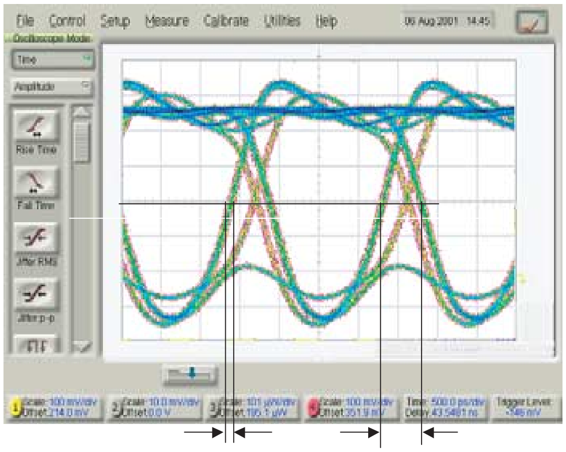
"Jitter is the time difference between when a pre-defined event should have occurred and when it actually did occur. The time difference is expressed in unit interval (UI), 1 UI is the value of the bit period of the ideal clock signal. This time difference can be treated as phase modulation, there are one (or more) signals modulating the ideal position of the data signal."

A more sophisticated definition from the viewpoint of the SONET standard [1] is: *"Jitter is the short term phase variation of the significant instants of a digital signal from their ideal positions in time. It is primarily concerned with non-cumulative variations above 10 Hz. Cumulative phase variations below 10 Hz are referred to as wander."*

The Fibre Channel community defined it thus: *"Jitter is the deviation from the ideal timing of an event. The reference is the differential zero crossing for electrical signals and the nominal receiver threshold power level for optical systems."* [2]

Jitter Components (1)

Jitter consists of two fundamental components called Random Jitter (RJ) and Deterministic Jitter (DJ). Figure 4 illustrates an example of a signal with an extremely large amount of DJ. Random Jitter is unbounded and is usually best described by a Gaussian probability density function. Deterministic jitter is bounded, ie it has definite amplitude limits from an earliest to a latest trace. The Random Jitter (RJ) is defined by an rms value which in this case equals the 's' (sigma) of the Gaussian distribution. The total jitter is a function of 'n' times the rms value, depending on what BER limit a system is specified, plus the Deterministic Jitter (DJ) which is by nature a peak-to-peak value.



Random Jitter (RJ):
Defined by RMS value which
equals s (sigma) of the
Gaussian distribution

Deterministic Jitter (DJ):
spacing between mean values of
"earliest" and "latest" trace

Figure 4: A real signal

Total Jitter (pp) :
Data jitter
plus
n(BER) xs

s :sigma

BER	n
10^{-6}	9.8
10^{-9}	12.2
10^{-10}	12.7
10^{-12}	14.1
10^{-14}	15.3

Jitter Components (2)

This is the whole picture of the jitter components:

The Deterministic Jitter (DJ) has several faces, e.g. it is caused by bandwidth limitations and component interaction (crosstalk). The diagram shown here separates the individual components and pins the nature of the origin.

The first layer separates the DJ into:

- Periodic Jitter (PJ), which displaces the timing of rising and falling edges with a periodic pattern (or as the origin of this type of jitter is sinusoidal modulation, it is also called SJ).

- Data Dependent Jitter (DDJ) (which is a function of bit patterns).

- Bounded Uncorrelated Jitter (BUJ) which is caused by interference with asynchronous signals: cross-talk between sub-circuits, power supply noise and electro-magnetic interference (EMI).

In the next layer the Data Dependent Jitter can be separated into:

- Duty Cycle Distortion (DCD), which is caused by voltage offsets between differential inputs and differences between transition times within a system.

- Inter-Symbol Interference (ISI), which is caused by the different symbols (long and short bit cycles).

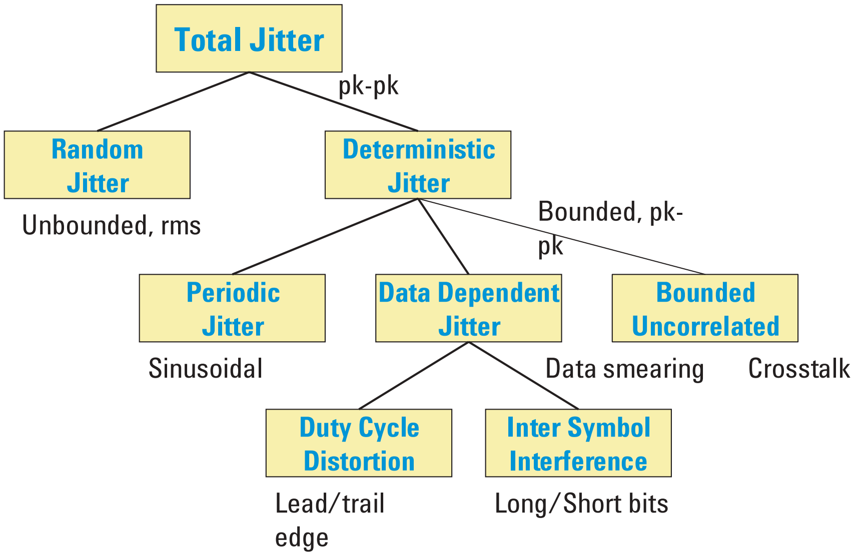


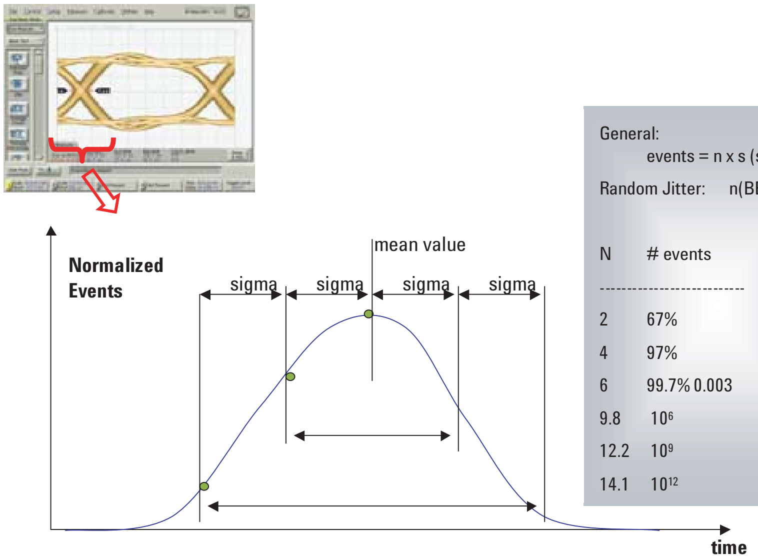
Figure 5: Jitter Component Segmentation

This can also be explaind from Bandwidth limitations which occur from AC coupling (low frequency cut-off) or from high frequency roll-off. However, this is from filters with non-linear phase characteristic only. Linear filters, such as Bessel filters, do not cause jitter. DCD and ISI jitter are a function of the pattern. The jitter appears when changing the pattern from a clock-like pattern to real data. PRBS type patterns are good for testing as they contain many variants of frequency component.

Random Jitter (RJ)

RJ is caused by thermal and noise effects. These effects are statistical by nature. So the Random Jitter (RJ) is unbounded and is modeled by a probability density function and is quantified by the rms value of the density function. In most cases the Gaussian distribution is used for the characterization of Random Jitter. In this case the rms value equals the ‘s’ (sigma) of the Gaussian distribution. There is a fixed relation between ‘s’ (sigma) and the number of events. While a range of 6 sigma already defines a high number of events (99.7%), this is a small number for BER. Typically a BER is required to be as low as 10^{-12}, this needs a range of 14.1 sigma to be included for the total jitter budget.

In the past the common model was to fit the actual jitter histogram into the Gaussian curve and the rms value was extracted. For a signal with significant DJ this resulted in a value way too high for the rms figure. This led to the RJ/DJ separation model. So first any DJ jitter component is isolated and only the ‘remaining’ jitter is then treated as RJ. DJ would broaden the Gaussian curve, while the tail portions of the histogram represent the RJ jitter component [3]. However, it is not necessary to perform histogram measurements to isolate RJ/DJ components. Later in this Note it will be shown that the BERT Scan Measurement allows Random/Deterministic Jitter to be separated directly. This eliminates the need for specific jitter test sets, because the jitter measurements can be obtained from BER test equipment.



General: # events = n x s (sigma)
Random Jitter: n(BER) xs

N	# events	BER
2	67%	0.33
4	97%	0.03
6	99.7% 0.003	
9.8	10^6	10^{-6}
12.2	10^9	10^{-9}
14.1	10^{12}	10^{-12}

Figure 6: Random Jitter: The Gaussian Distribution

Inter-Symbol Interference

Inter-Symbol Interference describes the amount of jitter occuring through data content. Here the issue is the transmission of long and short bits. Within the data stream the data cycles most affected are those which contain a single bit state which is opposite to the surrounding bits. In Figure 7 this is represented by the trace which shows a data bit being one cycle a ‘1’ while it is surrounded by ‘0’s.

This type of jitter results from bandwidth limitations which are low/high pass filters with non-linear phase characteristic, or from loss within transmission lines. Loss in cables/microstrips causes droop which again limits signal settling before the next transition occurs. Both bandwidth limitation and cable loss lead to a shortening of this bit as this is insufficient time to settle the signal to 100% before the opposite state starts. This leads to an early start of the transition with the disadvantage that 50% is too early and within random data, the eye will start to close.

A lot of jitter tests use specific filters which incorporate jitter as inter-symbol interference. These filters are called JIMs (Jitter Injection Modules), and are built as L-C chains, which resulting in a higher order. Here, Phase Shift occurs not only for a single bit but also for 2,3 or more consecutive bits. This is applied in the so called “Stressed Eye Tests”, which will be covered later in this Note. [4]

caused by bandwidth limitation / loss

- low/(high) pass filter
- cable droop

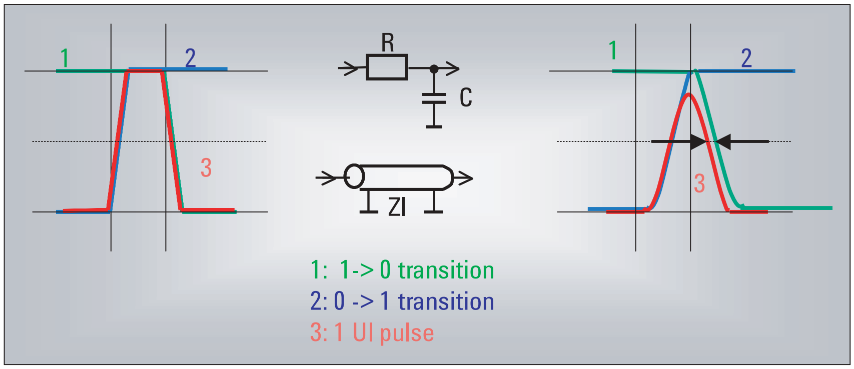


Figure 7: ISI: Inter-Symbol Interference

Periodic Jitter (PJ)

Periodic Jitter provides sinusoidal varying jitter, where a sinusoidal signal modulates the phase of the ideal clock or data signal. The sinusoidal signal may be asynchronous or synchronous to the clock / data signal. Synchronous clock sub-rates cause every ‘n’th cycle to be shorter/longer than the others.

Often this type of jitter is used in jitter testing. In this case a sinusoidal signal is used to displace the data edges. This helps to characterize the bandwidth of CDR circuits. SONET Jitter testing is standardized for all jitter components to be sinusoidal.

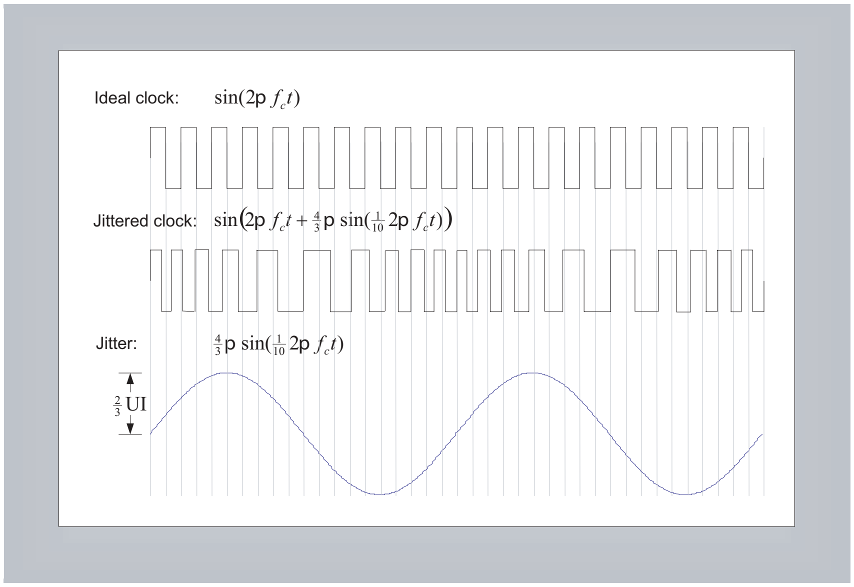
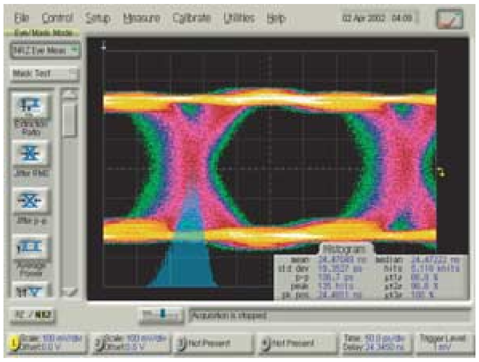


Figure 8: Periodic Jitter

Figure 9 shows the traditional eye measurement taken from a sampling scope. This allows the jitter to be viewed as rms and peak-to-peak values and a histogram is generated. The histogram can tell us some details about the jitter distribution. But the histogram is not able to get insight on what lies beneath this. In this case there is a mix of Random and Sinusoidal jitter. As mentioned earlier, with help of some DSP (Digital Signal Processing) tools it would be possible to do a RJ/DJ separation from the Histogram for gaining the rms/peak-to-peak value of the jitter components. But it is impossible from the histogram to gain the bandwidth of the noise or the frequency of the sinusoidal interference. This requires another approach.

What you see today...



...What is behind

(RJ=0.2UIrms 80MHz bandwidth , DJ=0.05UIpkpk, 10MHz)

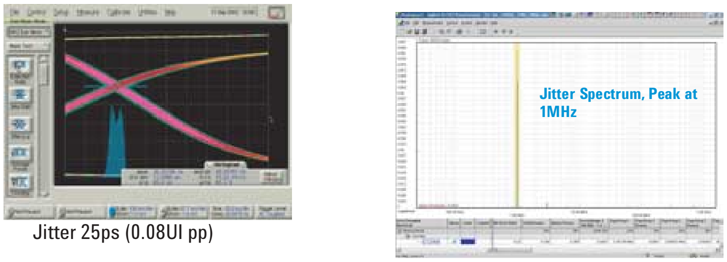
Figure 9: Jitter Measurement Situation

Jitter in the Frequency Domain

Figure 10 introduces jitter in the frequency domain. This shows a diagram with frequency on the x-axis and power (or power factor) on the y-axis. The graphs show the two jitter components separated for sinusoidal and random. In the histogram there is only a slight difference between the Sinusoidal (DJ) and the Gaussian (RJ) jitter. In the frequency decomposition the sinusoidal jitter is represented as a single line occurring at a single frequency. The random noise shows a wide frequency spectrum up to the bandwidth of the random spectrum (in this case 80 MHz). Above this value, the power decreases down to the noise floor.
This kind of representation is possible using a Spectrum Analyzer with a Phase Discriminator. The Phase Discriminator (or Demodulator) de-modulates the signal to obtain the phase modulation signal which is what we see in the figures above. This type of measurement is very common to jitter measurements on SONET devices. However, one has to be aware that this is practical for jitter on a clock signal, but cannot be used for true data signals.

There is a new tool usable on BER test equipment, which can perform these Spectral Decomposition Measurements eliminating the need of Spectrum Analyzer equipment and the capability to do these measurements on true data signals. This will be explained later in this Note.

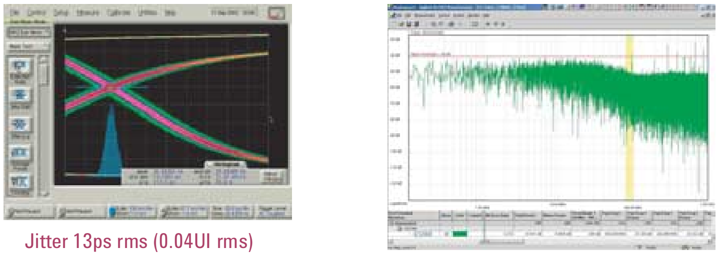
Clock with 1MHz Sinusoidal Jitter



Jitter 25ps (0.08UI pp)

Jitter Spectrum, Peak at 1MHz

Clk with 80MHz Broadband Gaussian Jitter



Jitter 13ps rms (0.04UI rms)

Figure 10: Spectral Decomposition of Jitter

The BERT Scan Measurement

The Gigabit Ethernet approach to measuring something that is unbounded is through a Bit-Error-Ratio measurement, specifically through a "Bath Tub plot":

Data Jitter will result in the signal edges moving toward the center of the eye diagram. Extreme excursions will occur less frequently than minor excursions. If the transmit signal is fed to an error detector and the sampling point is optimized in both time and amplitude, the error rate should be well below 10E-12 (as close to zero as can be measured). As the sampling point is continually moved into the edges of the eye, the BER will get steadily worse.

The important element for doing characterization is the ability to move timing edges around. On an analyzer this allows to move the sampling point around.

It is important to state: this measurement can be performed on differential signals! Moving the sampling point over one cycle and plotting the error rate, results in a graph called 'Bath Tub'. The x-axis of this graph is time, the y-axis is the BER figure. The name 'Bath Tub' results from the specific shape of the curve. This specific shape results from the fact that the lower the BER figure gets, the more test vectors have to be processed. The longer the test runs, the wider the jitter band of a real world signal will be. So the lower the BER threshold is specified, the less the resulting phase margin will be.

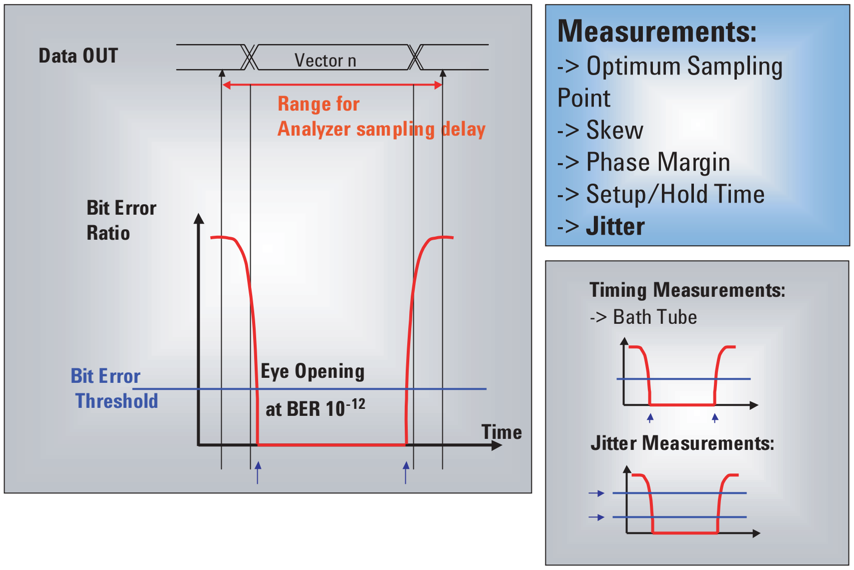


Figure 11: BERT Scan

The IEEE 802.3ae standard sets the allowable jitter magnitude at the 10E-12 BER level. Thus the "eye" must have a specified opening at this BER.

Bath Tub measurements are the basis for all measurements listed above including jitter measurements. For the jitter measurement (especially the RJ/DJ separation) the transitional behavior of the left and the right slope between two points specified as BER figures will be extrapolated.

Jitter within the Standards

Jitter is described differently within the various standards within the communication industry. The SONET as a synchronous architecture deals with Jitter Generation, Jitter Tolerance and Jitter Transfer. Jitter Generation is the jitter coming from the device, Jitter Tolerance is the jitter which the device can handle, and Jitter Transfer is the jitter which moves through the device from input to output. The jitter used for the measurements is sinusoidal only.

The more modern standards are dominated by the Ethernet community dealing with asynchronous architecture. Here the jitter is a mixture of random and deterministic content. And the 10GbE community has established new concepts of measuring: Transmitter Dispersion Penalty (TDP) and Stressed Eye Test.

The difference between SONET and Ethernet is the clocking system:

SONET/SDH – ITU-T0.172, GR-253-CORE

Synchronous Architecture

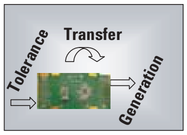
Transceiver timing derived from received signal therefore jitter propagation **critical**

- **Jitter Generation**

  Characterizes transmitter jitter performance
- **Jitter Transfer**

  Characterizes clock recovery performance against jitter
- **Jitter Tolerance**

  Characterizes receiver's tolerance to jitter



Gigabit Ethernet and 10 Gigabit Ethernet – IEEE 802.3z and 802.3ae

Asynchronous Architecture

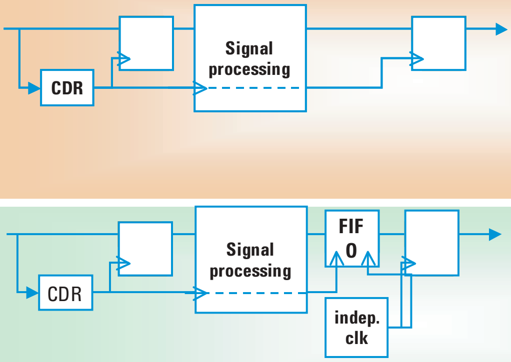
Transceiver timing not derived from received signal therefore jitter propagation **less critical**

- **1 Gb En**

  Bathtub plots to measure jitter generation
- **10 Gb En: Serial** **TDP** (Transmitter dispersion Penalty) for transmitters **Stressed Eye** receiver test – similar to Jitter Tolerance

  XAUI **Bathtub, Stressed Eye**

Figure 12: Jitter: the Standards



SONET/SDH = Synchronous clocking

- Important spec is Jitter Transfer
- Outgoing signal is retimed with recovered clock of incoming signal so that clock propagates through the system
- Disadvantage: imparities can accumulate until clean-up PLL is used
- Advantage: as data rate is identical everywhere number of data bits on both sides of DUT is identical, too

(10Gb)Ethernet

- No such spec as Jitter Transfer
- Outgoing signal is retimed with independent DUT clock which may have a slightly different rate (+/- 100ppm)
- Advantage: no accumulation of clock disparities / jitter
- Disadvantage: as number of data bits on both sides of DUT is not identical, bit-stuffing/discarding scheme is required

Figure 13: The difference in clocking of SONET/SDH and Ethernet

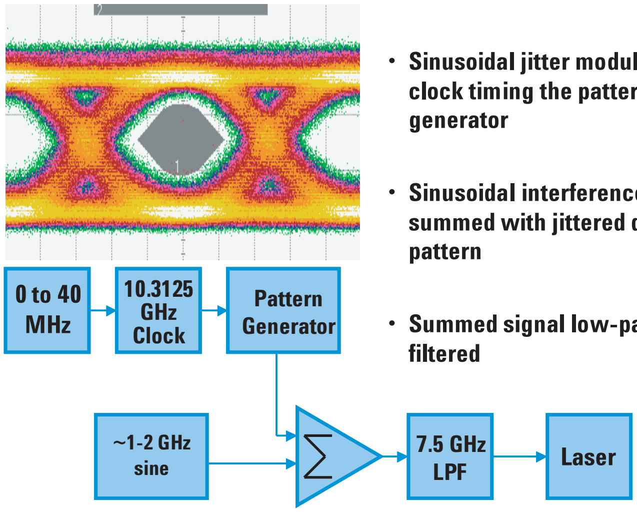
SONET/SDH uses a common system frequency which is recovered by CDR within each receiver, and then used within the whole circuity. Therefore it is called synchronous or a-synchronous clocking. The outgoing signal is retimed with the recovered clock of the incoming signal so that the clock propagates through the system. An important specification therefore is Jitter Transfer. A disadvantage is that the imparities can accumulate, as from sub-system to sub-system jitter can add up until a very specific clean-up PLL is used. An advantage (especially for testing) is that the data rate is identical everywhere in the system, and the number of data bits on each sides of the DUT is identical, too.

For (10Gb) Ethernet there is no such specification as Jitter Transfer. The reason for this is that the outgoing signal is retimed with an independent Reference Clock within the Receiver. This new Reference Clock is allowed for a slightly different rate (typically +/-100 ppm). The resulting disadvantage is that the number of data bits on each side of DUT is not identical. So an Idle scheme with bit-stuffing/discarding is required. The major advantage is that no accumulation of clock disparities/jitter occur throughout the device, so no jitter transfer happens and therefore no such specification or measurement is necessary.

Stressed Eye

Stressed Eye for Ethernet [5] is similar to Jitter Tolerance for SONET/SDH. While SONET/SDH deals with sinusoidal jitter only, here the stressed eye is a well defined mix of periodic jitter in time and amplitude.

An arbitrary Waveform Generator is used to modulate a Signal Generator which sends the jitter modulated clock into the Pattern Generator. The data stream is added with a sinousoidal interference signal and finally is low-pass filtered for a specific shape supplied to optical converters. Often there are additional filters to the Pattern Generator output to include Data Dependent Jitter (ISI) with the data pattern.



- **Sinusoidal jitter modulates the clock timing the pattern generator**
- **Sinusoidal interference signal summed with jittered data pattern**
- **Summed signal low-pass filtered**

Figure 14: Stressed Eye Example

ParBERT 81250 Jitter Capabilities

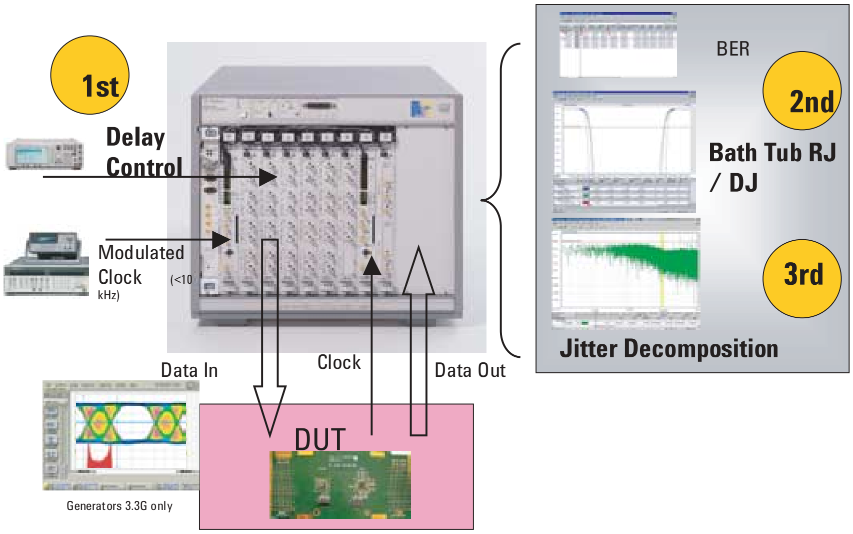
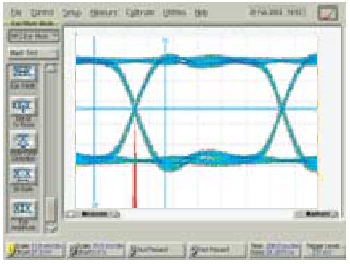
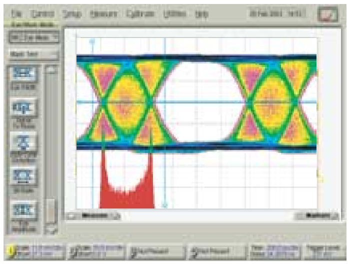


Figure 15: 81250 ParBERT Jitter Capabilities

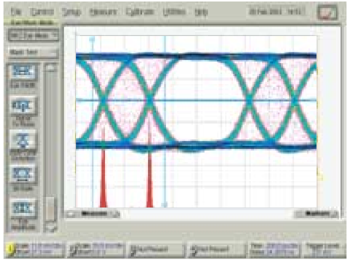
"Clean Eye"



Jitter modulated with Sine - Wave



Jitter modulated with Rectangle - Wave



Jitter modulated with Noise

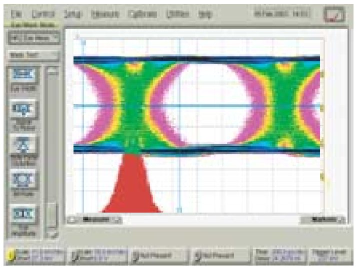


Figure 16: Jitter Injection

The 81250 ParBERT can emulate (1) and measure (2+3) jitter. For Jitter Tolerance type testing, the ParBERT allows either a modulated clock to be worked with and/or the delay of the generator output to be controlled (by 3.3 Gb/s generator E4862B and 13.5 Gb/s generator N4872A).

The modulation of the external clock can be done to achieve multiple Unit Intervals (UI's) as jitter, but this is limited to a certain bandwidth as there are PLLs within the internal clock distribution path. The PLLs will filter the higher frequency contents of the modulation signal. With the delay control input each generator can be controlled individually up to a modulation frequency of 200 MHz and a peak-to-peak modulation of 500 ps. At 3 Gb/s speed this allows a jitter budget exceeding the eye totally. The modulation signal type controls the distribution of the jitter. With a mix of random and square wave signal one can emulate a mix of RJ and DJ.

The measure capability of the 81250 ParBERT is BER, Bath Tub, Eye Opening and Fast Eye Mask. With the Bath Tub it is possible to read the jitter separated for RJ and DJ.

The ParBERT generators (3.3 Gb/s E4862B & 13.5 Gb/s N4872A) provide a Control Input for modulating the Delay with help of an external signal. This modulation can be used to emulate jitter. Figure 16 shows this jitter emulation as a scope view for three different types of control voltage: sinusoidal, rectangle and random. This Jitter Modulation can be used to test a DUT for Jitter Tolerance or to built a

As a source for these modulation voltages Agilent offers the 3325A Function/Arbitrary Waveform Generator. This type of instrument can generate any mentioned type of signal, but one at a time. By combining two of them with help of a power splitter (11667B), a mix of two signals is possible. So mixing random and Sine/rectangle emulates jitter with RJ and DJ components.

The control inputs of the different ParBERT generators work similarly but differ in parameters: the 3.3 Gb/s generator (E4862B) allows a delay modulation of +/- 250 ps up to 200 MHz modulation bandwidth, the 13.5 Gb/s generator (N4872A) allows a range of +/- 100 ps up to 1 GHz bandwidth.

The ParBERT can run on an external Clock. For Jitter Emulation where multiple UI jitter is required (what the delay control cannot offer) an externally modulated Clock can be fed to the ext. Clk Input of the clock module. But there are PLLs in the clock path between the ext. Clk input and the channels. There are some specific restriction depending on the specific speed class of ParBERT data clock and data modules.

- *675 MHz data modules used with E4805 /E4808A clock module:* In regular operation there is a PLL inside the clock module with a cut-off frequency of around 10 kHz. So one can generate a modulated jitter covering multiple UIs (linear transfer range) only up to this cut-off frequency. There is a specific procedure to bypass the PLL, in this case the cut-off can be avoided. For details of operation contact ParBERT technical support.

- *1.65 Gb/s, 2.7 Gb/s, 3.3 Gb/s and 10.8 Gb/s with any clock module:* There are always multiplying PLL‘s in the clock path inside the data modules which cannot be bypassed. These have a bandwidth limit of 10 kHz.

- *13.5 Gb/s data modules together with E4809A clock:* This module offer a clock path at speed, so there are no multiplying PLL‘s. This achieves an unlimited bandwidth of the clock path, so a modulation of multiple UIs is possible up to clock speed.

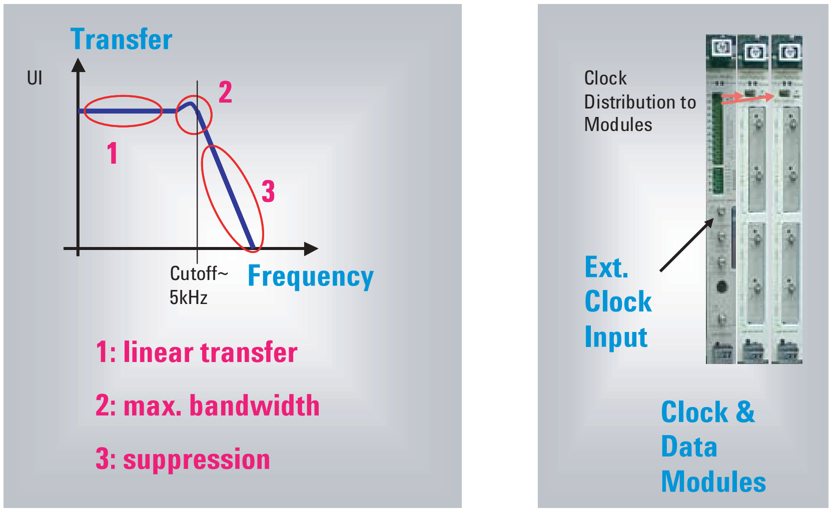


Figure 17: ParBERT 81250 Jitter Emulation with a modulated Ext. Clock

A modulated clock is achieved by modulation of a signal generator. Agilent offers various signal generators. A signal generator provides a sinusoidal signal, which is fine for the ext. Clk input of the ParBERT clock module. The power level is also sufficient. To establish a modulation, the signal generator again needs a function generator or another signal generator as its modulation input.

Figure 18 shows three measurements of a Bath Tub curve with three signals of different jitter content. As a stimulus to the ParBERT analyzer a ParBERT generator is used:

Low RJ: This is the most ideal signal (clean data signal, no modulation) from a ParBERT 3.3 Gb/s generator.

High RJ: This is the modulated signal using noise applied to the control input. As the noise closes the eye, it reduces the phase margin. The slopes of the Bath Tub curves get less steep as in the case of no modulation.

RJ + DJ: This is a modulated signal using noise and sinusoidal modulation. The amount of modulation is set for obtaining the same phase margin as the High RJ signalat the BER threshold of 10^{-3}. But the shape is different especially for the ‘shoulder‘ at BER = .25, which is characteristic for the DJ jitter component.

The visualisation of the Bath Tub Measurement includes a tabular format under the graph, which represents the measured values. Each signal reads for Phase Margin (out of the viewable range), Jitter Mean, Random Jitter (RMS) = RJ, Deterministic Jitter = DJ, Estimated Total Jitter (which is an extrapolation value for total jitter at a very low BER threshold, much lower than measured), and finally there are 4 colums for representing the quality of fit for the RJ/DJ separation.

All the values can be read either in time (ps) or in UI (Unit Interval) by configurating the Window View.

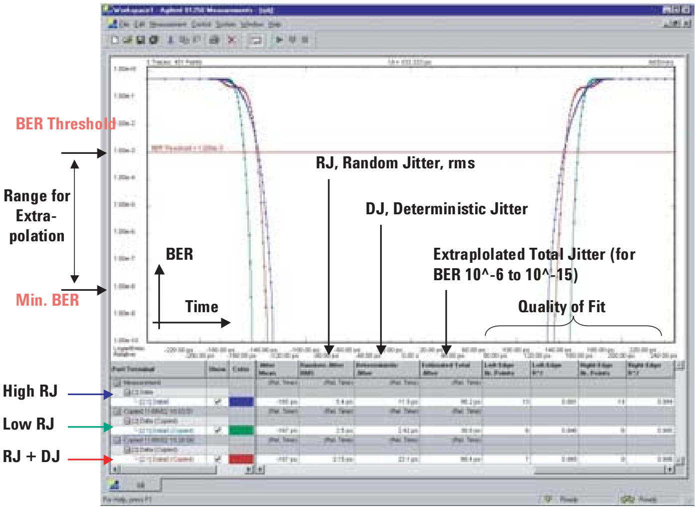


Figure 18: 81250 Bath Tub with RJ / DJ

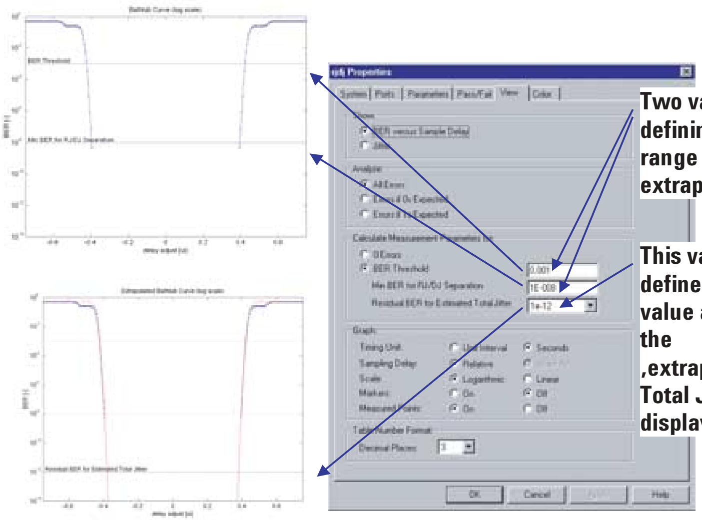
The RJ extrapolation is done within the Bath Tub from a range specified by two points for BER: one is the BER threshold, the other as a Min BER figure (see Figure 18). In the table below the graph, there a 4 colums dealing with the quality of fit obtained, the R*2 value is the appropriate indicator, this value should be between .75 and 1 for good extrapolation.

Figure 19 shows the so called Property Window for the parameters defining of the RJ/DJ separation.

Two values of the Bath Tub properties define the range for the RJ extrapolation: the BER Threshold defines the upper value, the Min BER for RJ/DJ seperation defines the lower value. In practice, the values should be set to the lower region of the Bath Tub curve where the slope of the curves is defined by the random jitter only. However, the range needs be wide enough for a couple of measurement points to be included. Otherwise the fit will be marginal due to insufficient number of points.

The Residual BER for Estimated Total Jitter defines the BER value at which the extrapolated Total Jitter is calculated and displayed. This extrapolation method saves measurement time, as it eliminates the need for measurements, which at a BER threshold of 10^{-12} or lower the measurement time is very large. So the extrapolation method is as fast as the measurement for a BER down to 10^{-6} which can be done within a few seconds of measurement time.

With help of the Bath Tub measurement and the property settings, it is also possible to extract the value for the Duty Cycle Distortion (DCD) Jitter Component. The duty cycle distortion is the difference of the phase margin (horizontal eye opening) for the Bath Tub curves of separating between Errors on ‘0‘s only and Errors on ‘1‘s only. The parameter setup allows the selection for this settings, indicated in Figure 20. It is not necessary to take the measurement twice.



BER Threshold 0.001
Min BER for RJ/DJ Separation 1E-008
Residual BER for Estimated Total Jitter 1e-12

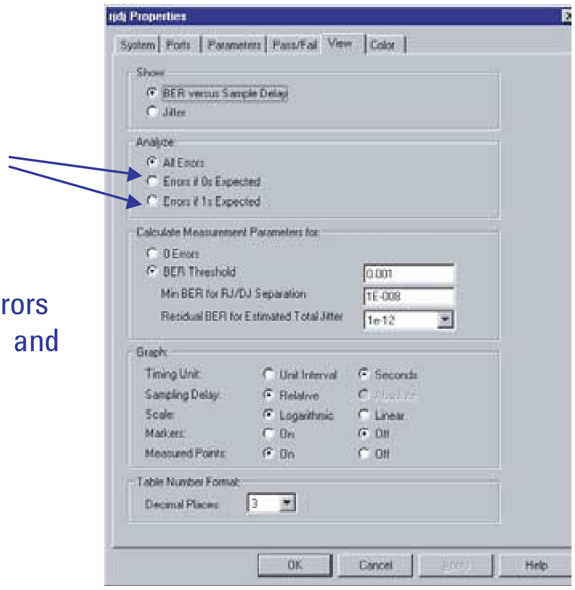
Two values defining the range for RJ extrapolation

This value defines the BER value at which the ‚extrapolated‘ Total Jitter is displayed

Figure 19: Bath Tub Properties for RJ / DJ

- DCD is

- Difference of horizontal eye opening for ‘Errors if 0’s Expected and Errors if 1’s Expected



Show:
● BER versus Sample Delay
○ Jitter

Analyze:
● All Errors
○ Errors if 0s Expected
○ Errors if 1s Expected

Calculate Measurement Parameters for:
○ 0 Errors
● BER Threshold 0.001
Min BER for RJ/DJ Separation 1E-008
Residual BER for Estimated Total Jitter 1e-12

Graph:
Timing Unit: ○ Unit Interval ● Seconds
Sampling Delay: ● Relative ○ Absolute
Scale: ● Logarithmic ○ Linear
Markers: ○ On ● Off
Measured Points: ● On ○ Off

Table Number Format:
Decimal Places: 3

Figure 20: Jitter Measurement, DCD extraction

Simply perform the measurement once for ‘All Errors’ and after the measurement, check the values for the phase margin once for ‘Errors if ‘0‘s Expected’, and once for ‘Errors if ‘1‘s Expected’. The difference of the two phase margin values is the DCD value.

Spectral Decomposition of Jitter

Deterministic Jitter can be analysed for its spectral contents. This is a complimentary view in the frequency domain, while the BERT Scan method analyses jitter in the time domain.

The Jitter Decomposition is gained from a specific measurement, which uses an Error Function obtained from the real-time compare of incoming data against expected data. The error function is the pass-fail information over a certain number of data bits. The content of the error function is processed with Digital Signal Processing Tools (DSP) to visualize the spectral information. The DSP tools used are the Autocorrelation, the Furrier Transformation and the power density calculation. The DSP processing delivers a power factor as a function of frequency which is visualized in an x-y graph. The algorithm works in a wide frequency range: from DC up to half of the signal's data rate.

There are two principles to gain Spectral Jitter information:

Firstly, there is the Phase Noise Measurement. SONET/SDH does all jitter testing according this principle. This uses a Spectrum Analyzer together with a phase discriminator. A discriminator or demodulator extracts a signal which is proportional to the phase deviation in the running signal, and the Spectrum Analyser visualizes the power factor versus frequency. This type of measurement is possible on clock signals only. So for a data signal a CDR (Clock Data Recovery) is needed to convert it into a clock signal.

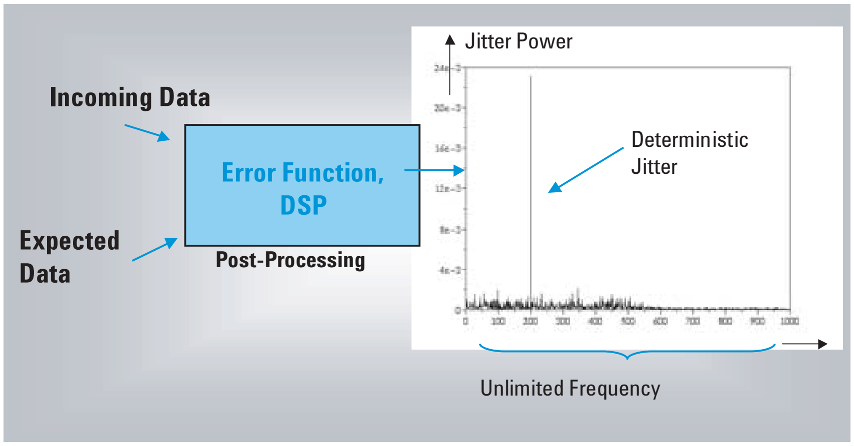


Figure 21: Jitter Decomposition by Spectrum Analysis

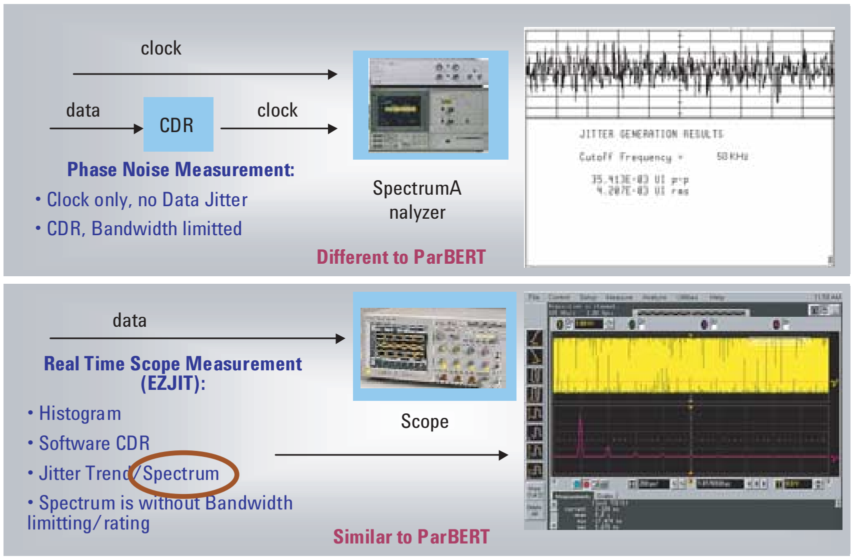


Figure 22: Existing Spectral Jitter Solutions

Any CDR has its characteristic in terms of bandwidth, so part of the jitter is removed, especially the high frequency part. So SONET/SDH looks at the jitter only within a specified bandwidth range. The phase noise measurement is different from the Spectral Decomposition offered on the ParBERT.

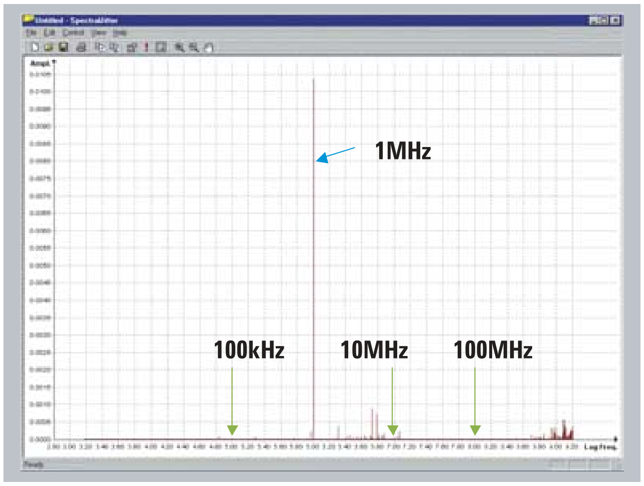
Another solution is the Jitter Measurement Software (EZJIT) on the Agilent Infiniium 54850 series oscilloscopes. This solution samples a portion of the data stream. Out of this it runs a software based CDR, and with further help of DSP technology, it gains the spectral information. This is a similar methodology to the ParBERT implementation.

Use of Jitter Decomposition Measurement:

This type of measurement is embedded within the ParBERT measurement suite, as a new measurement in the software measurement package. As it is providing qualitative information on the frequencies within the Deterministic Jitter budget, it is a DEBUG Tool. So for any kind of design verification/characterization it can help the designer to identify the root cause of Jitter Injection and sources, which are impossible to simulate even with todays sophisticated tools. The final implementation of high integrated ASICS with all kind of analog circuitry (PLL, CDR, ...) within large digital cores will always give unexpected results

Another use model is the charactertization for CDR devices. Assuming the device is stimulated with a data signal incorporated with Jitter Modulation consisting of wide band noise (white noise), a CDR will filter this noise according to the bandwidth of its feedback loop design. The feedbacks have a certain bandwith, so a jitter supression will occur beyond this point. Figure 24 gives such an example. Also one can see if there is some peaking at the roll-off point.

- **DEBUG:**

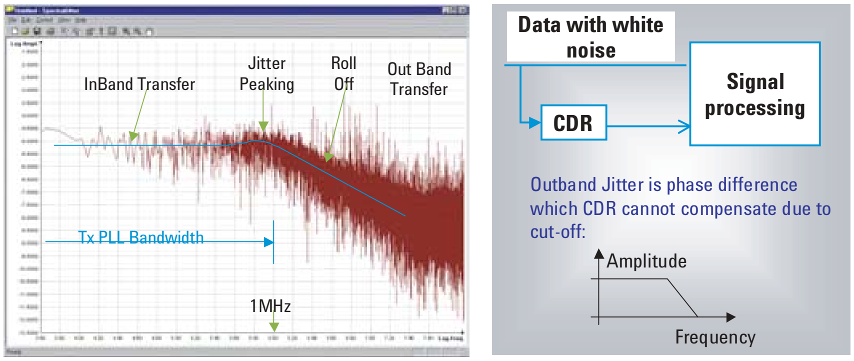


Qualitative information on frequency components within jitter budget

Example: interference of 1 MHz signal

Figure 23: What ParBERT's Jitter Decomposition is good for (1)

- **Frequency Range of Jitter components not limited by bandwidth -> Inband and Outband frequency spectrum**
- **CDR can be characterized for all parameters:**



Outband Jitter is phase difference which CDR cannot compensate due to cut-off:

Figure 24: What ParBERT's Jitter Decomposition is good for (2)

Basics of the Jitter Decomposition Method

The Jitter Modulation on a data signal (in this case a sinusoidal modulation is assumed) causes the data signal to toggle around the ideal sampling point within the eye (on the right in Figure 25). For this measurement the comparator strobe will be displaced by 0.5 UI from the normal sampling point within the centre of the eye. So the sampling occurs within the transition (left in figure). Now when sampling and comparing against expected data, there will be errors for those data cycles where the data is 'late' due to jitter. If the data is 'early', the sampling and comparing deliver no errors. Now this stream of errors and no errors is called the 'Error Density Variation or Error Function'. Within the ParBERT this Error Function is gained for a configurable block length and stored in a memory.

Figure 26 explains the creation of the Error Function: At the top is a sinusoidal jitter modulation signal applied to a clock signal (middle). The edge position of the ideal positions of this clock signal is dotted, and the position is straight due to the modulating signal. Analyzing the modulated signal with strobing at the ideal position and comparing against '1', create the errors as shown in the bottom row of the table. As long as the modulating signal delays the data cycles, there are errors; as long as the modulation accelerates the data signal, there are no errors.

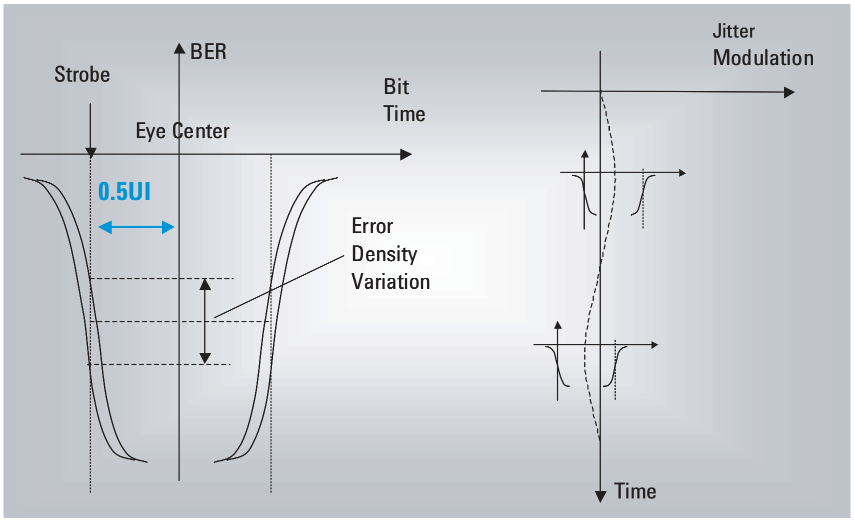
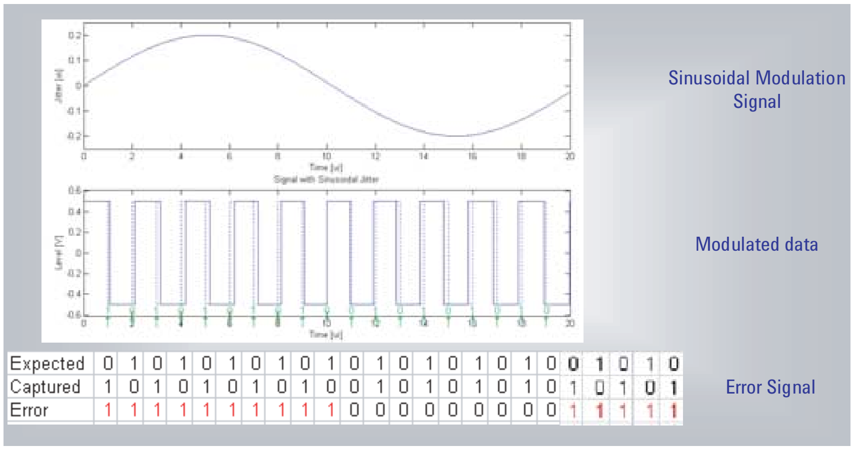


Figure 25: Basics of Method (1): Modulated Signal at Comparator



Expected	0	1	0	1	0	1	0	1	0	1	0	1	0	1	0	1	0	1	0	0	1	0	1	0
Captured	1	0	1	0	1	0	1	0	1	0	0	1	0	1	0	1	0	1	0	1	0	1	0	1
Error	1	1	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	1	1	1	1	1

Figure 26: Basics of Method (2): Error Density Variation

So far it would make no difference if the modulating signal were sinusoidal, triangle or rectangle. Within this ideal description the period/frequency of the modulating signal is recorded, but the shape would be lost.

Figure 27 is a similar way of looking at the method of sampling. This assumes that the incoming datastream runs from bottom to top. The sampling is set to strobe within the transitional area. The process is not ideal because there is always some noise within the sampling. Either this noise is incorporated with the incoming signal or the there is noise (jitter) on the sampling edge itself. In reality both will occur. Normally a test system is designed to reduce this noise to a minimum. Noise can actually very helpful for this type of measurement. When looking into the Error Function, the noise will displace the positions of the errors according to the shape of the modulating signal. So over the longer time, a sinusoidal signal can be recognised as sinusoidal, as long as the Error Function is recorded long enough. So the full spectral information is embedded and the later DSP processing will identify the whole spectral content. The digitizing does not change the spectral content.

The ParBERT Waveform Viewer allows the Error Function to be visualized. Errors appear in red in the GUI. They appear as a lighter grey in Figure 28. In this case a 1 MHz sinusoidal modulation generates jitter on a data signal running at 3.125 Gb/s. One can clearly see that the error distribution occurs with the period of the modulating signal. The random noise involved generates some displacement.

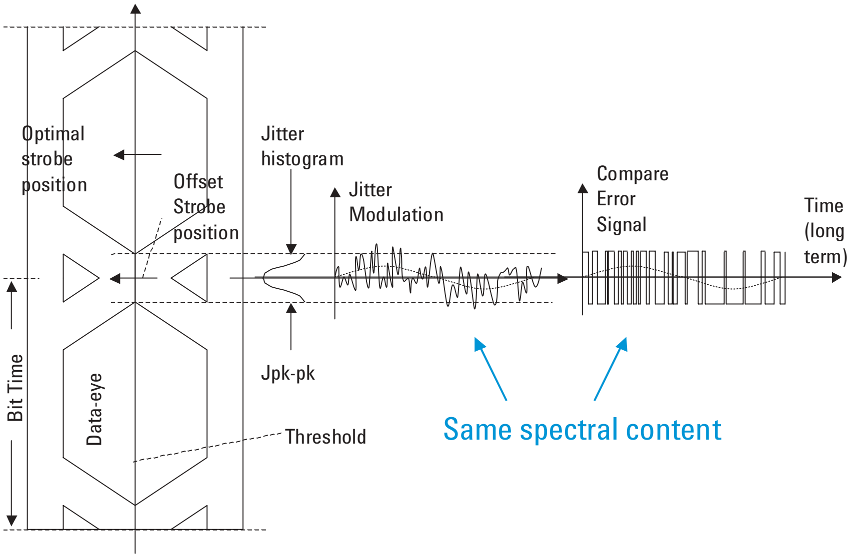


Figure 27: Basics of Method (3): The Noise is important

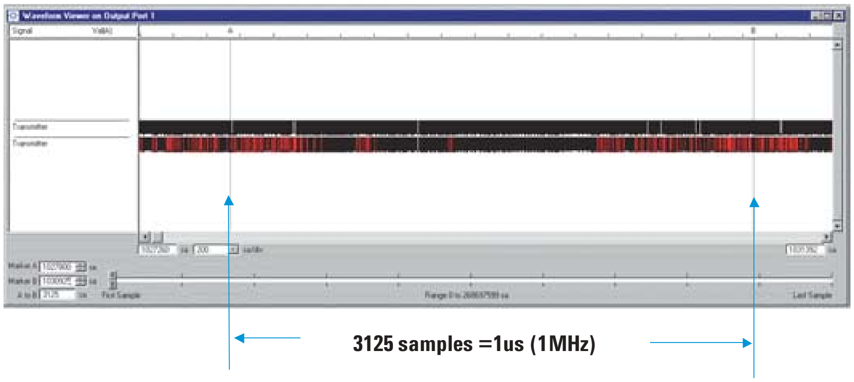


Figure 28: Error Density Modulation (1MHz Sinusoidal Jitter)

Already mentioned is that the noise is important for this type of measurement. As long as the noise is of similar magnitude to the Deterministic Jitter, this will operate as a linear method So the spectrum of the Deterministic Jitter is linear in the error function and the DSP algorithm operates cleanly. If there is more Deterministic Jitter than random jitter, the error function gets clipped and operates in the ideal way (as described earlier). Therefore the shape of the modulation gets lost, which causes the DSP processing to generate Harmonics, which occur if there is a modulation with rectangular signals. Within the spectral view one would see the Harmonics as a rectangular waveform.

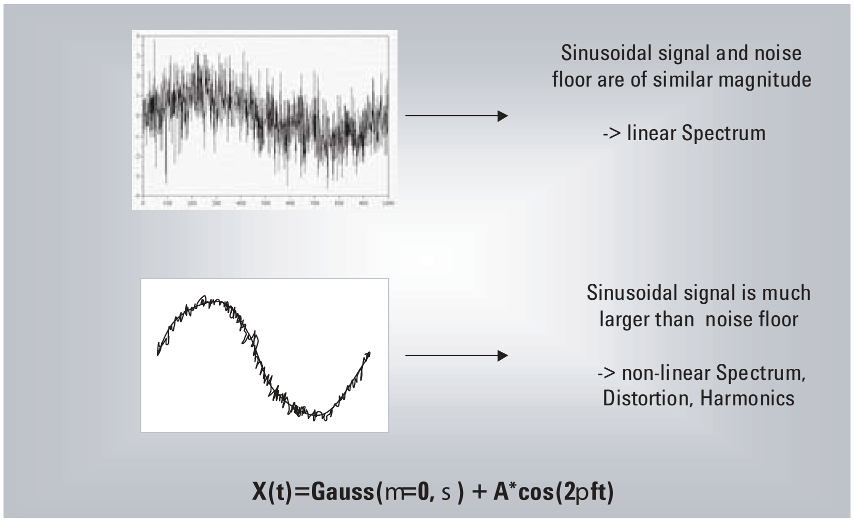


Figure 29: Sinusoidal Signal and Noise, Harmonic Distortion

Some examples

This is the setup for some examples: A ParBERT generator (3.3 Gb/s, E4862B or 13.5 Gb/s, N4872A) is modulated via the ‘Control Input’. We use three different signals for jitter modulation: sine wave (1 MHz), Pulse with 10 MHz and 10% Duty Cycle (Width 1 us) and Noise with 80 MHz bandwidth. All these signals can be achieved with an Agilent 33250A Arbitrary Waveform Generator.

The generator output connects by loop-back cable to an analyzer. Any ParBERT analyzer can be used with the Spectral Decomposition Measurement as long as the data rate is within its operating limits.

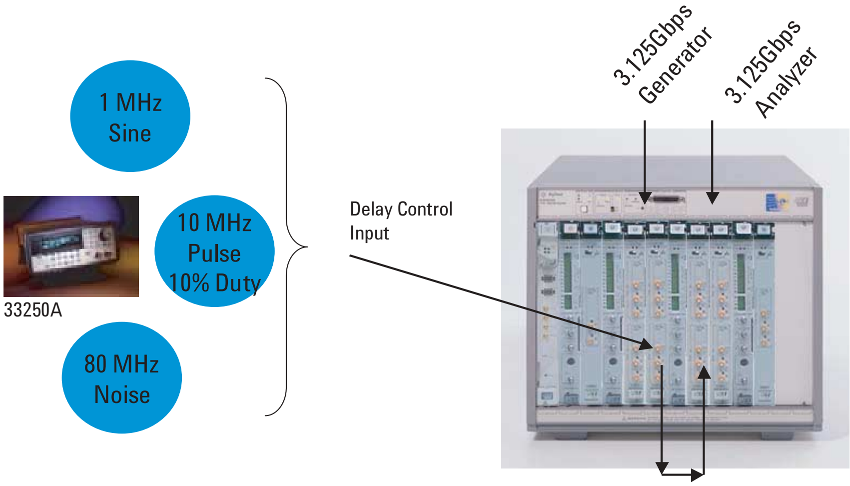


Figure 30: Simple Loop-back Measurements with help of Generator’s Delay Control

Jitter Decomposition Examples

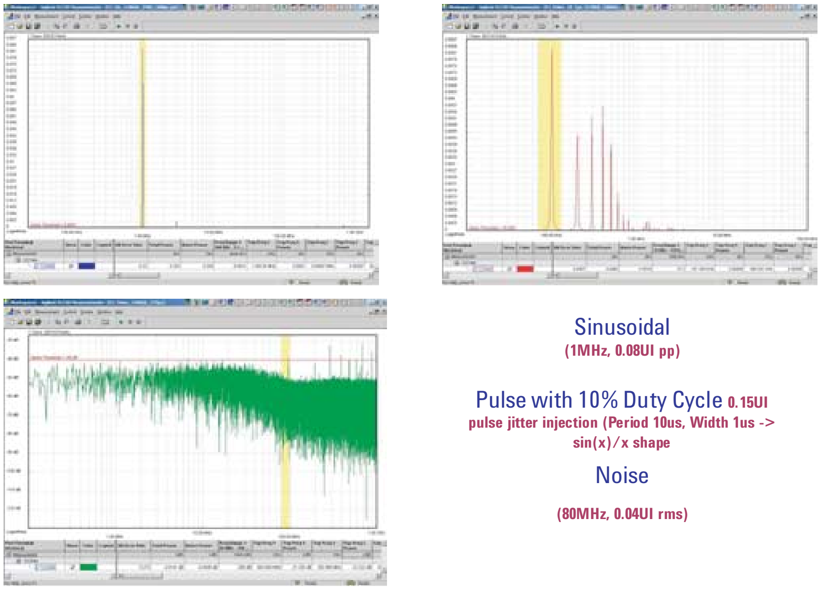
Sine Wave: The graph represents a single line at a single frequency (top left on Figure 31).

Pulse: This delivers a spectrum according the sin x/x shape (top right on Figure 31).

Noise: There is a spectrum of constant energy level up to the bandwidth of the noise source (80 MHz). Then the power decreases to the noise floor of the system (bottom left on Figure 31).

The Spectral Decomposition offers a couple of parameters for setup and configuring the results. Figure 32 shows the Viewing parameters. First of all one specifies the Power Scaling. This allows a setup for calibrating the jitter power scale with a pilot tone. The measured jitter spectrum will be referenced power wise to this reference signal.

Then it allows the Frequency Ranges to be specified. These will be highlighted as shown in the figure before. Further choices are on scaling of axis, markers and range of x-axis.

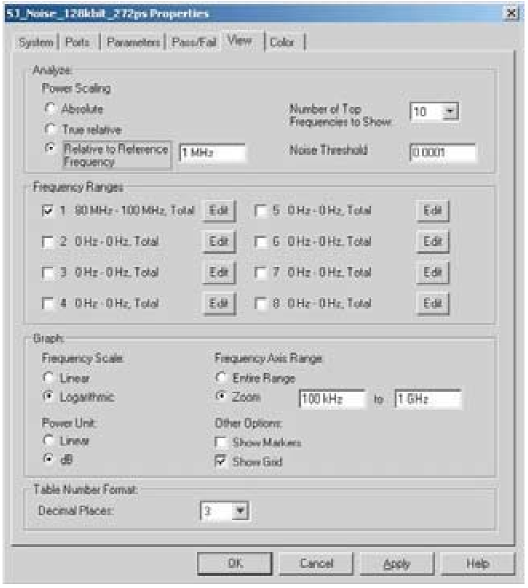

Sinusoidal
(1MHz, 0.08UI pp)

Pulse with 10% Duty Cycle 0.15UI
pulse jitter injection (Period 10us, Width 1us -> sin(x)/x shape

Noise

(80MHz, 0.04UI rms)

Figure 31: Jitter Decomposition Examples



S1_Noise_128kbit_272ps Properties

Analyze:

Power Scaling
○ Absolute
○ True relative
● Relative to Reference Frequency: 1 MHz

Number of Top Frequencies to Show: 10

Noise Threshold: 0.0001

Frequency Ranges

☑ 1 80 MHz - 100 MHz, Total
☐ 2 0 Hz - 0 Hz, Total
☐ 3 0 Hz - 0 Hz, Total
☐ 4 0 Hz - 0 Hz, Total
☐ 5 0 Hz - 0 Hz, Total
☐ 6 0 Hz - 0 Hz, Total
☐ 7 0 Hz - 0 Hz, Total
☐ 8 0 Hz - 0 Hz, Total

Graph:

Frequency Scale
○ Linear
● Logarithmic

Frequency Axis Range
○ Entire Range
● Zoom 100 kHz to 1 GHz

Power Unit
○ Linear
● dB

Other Options:
☐ Show Markers
☑ Show Grid

Table Number Format:

Decimal Places: 3

Snapshot of the Parameters affecting the measurement

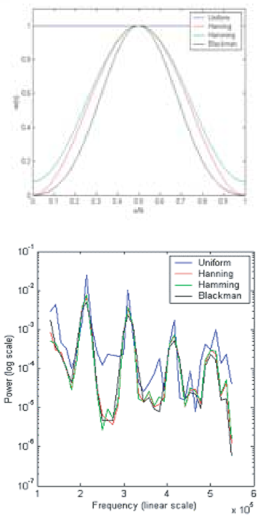
Figure 32: Calibration and Pilot Tone

Windowing

Windowing reduces the effects of unwanted frequency components by the Furrier Transformation due to the finite length of acquired bits. Some literature references are given in Figure 33 with the primary recommendation for ‘The Fundamentals of Signal Analysis (AN243)’ available as: 5952-8898E from Agilent Lit-station or from the web (www.agilent.com). [7]

There are three predefined filters selectable from the configuration: Hanning, Hamming and Blackman. Uniform is not a filter, but uses the data as measured. The filters reduce the amount of energy in the unwanted signal areas much larger than in the areas of interest.

There is a dependency between frequencey resolution and acquisition depth. The longer the segment of the Error function, the lower the frequency. But this is also a matter of the data rate. This is of course a function of measurement time. Using a segment below 1 MBit, let the measurement run within a few seconds. Larger Acquisition Depth will slow down the measurement time. Frequency Resolution also defines also the minimum frequency. Therefore if the resolution is 1 kHz, then the first energy line is available at 1 kHz, the next is at 2 kHz and so on.



Windowing reduces the effects of unwanted frequency components by the Fourier Transformation due to finite length of acquired bits

Some more literature:

- The Fundamentals of Signal Analysis 5952-8898E
- On then Use of Windows for Harmonic Analysis with the Discrete Fourier Transform, IEEE, Vol. 66, No. 1
- A Refresher Course on Windowing and Measurements, Real-Time Update, Hewlett-Packard
- The Fundamentals of FFT-Based Signal Analysis and Measurement, AN041, National Instruments, is Source for:

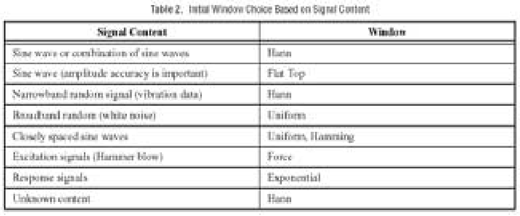


Table 2. Initial Window Choice Based on Signal Content

Signal Content	Window
Sine wave or combination of sine waves	Hann
Sine wave (amplitude accuracy is important)	Flat Top
Narrowband random signal (vibration data)	Hann
Broadband random (white noise)	Uniform
Closely spaced sine waves	Uniform, Hamming
Excitation signals (Hammer blow)	Force
Response signals	Exponential
Unknown content	Hann

Figure 33: FFT Windowing

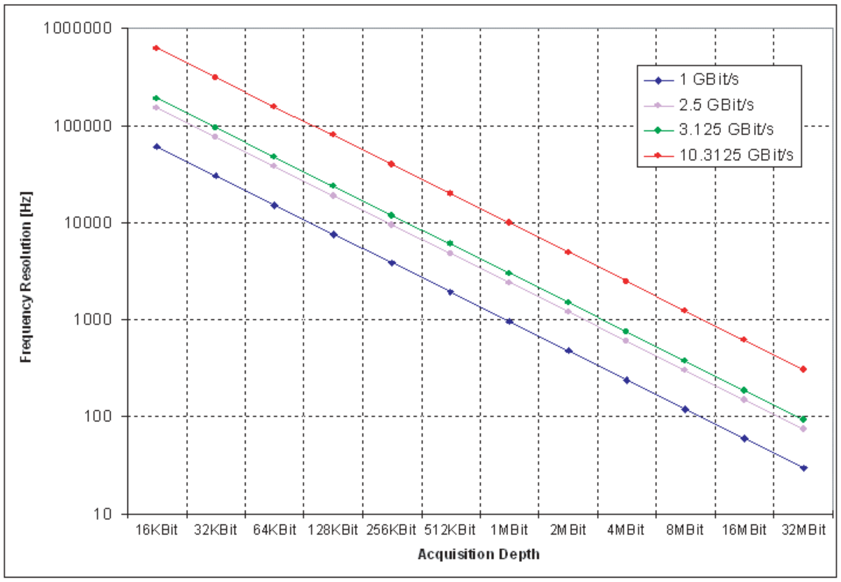


Figure 34: Frequency Resolution vs. Data

References

[1]: NIST Technical Note 1337, "Characterization of Clocks and Oscillators," edited by D.B. Sullivan, D.W. Allan, D.A. Howe, F.L. Walls, 1990

[2]: National Committee for Information Technology Standardization (NCITS) T11.2/Project 1230-DT "Fibre Channel – Methodologies for Jitter and Signal Quality Specification" Rev. 5.0, February 21, 2002

[3]: Jan B. Wilstrup: A new method for jitter decomposition through its distribution tail fitting, ITC 1999

[4] Agilent Jitter Injection Module (JIM), 5988-3583EN

[5] 10GbE Standard IEEE 802.3ae

[6] Infiniium 54850 Series Oscilloscopes, 5988-7976EN

[7]: The Fundamentals of Signal Analysis, Agilent AN243, 5952-8898E

Related Literature	**Pub. Number**
Need to Test BER?, Brochure	5968-9250E
Agilent ParBERT 81250, Mux/Demux Application, Application Note	5968-9695E
Agilent ParBERT 81250 Parallel Bit Error Ratio Tester, Photo Card	5980-0830E
Agilent Productivity Assistance	5980-2160E
Agilent ParBERT 81250 43.2/45G Product Overview	5988-3020EN
Agilent ParBERT 81250 Paralel Bit Error Ratio Test Platform	5988-5901EN
Agilent 81250 ParBERT Product Note (The influence of Generator Transition times on Characterization Measurements)	5988-5948EN
Agilent ParBERT 81250 Automatic Phase Margin Measurements at 43.2 Gb/s	5988-5654EN
Agilent ParBERT 81250 Product Overview	5968-9188E

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