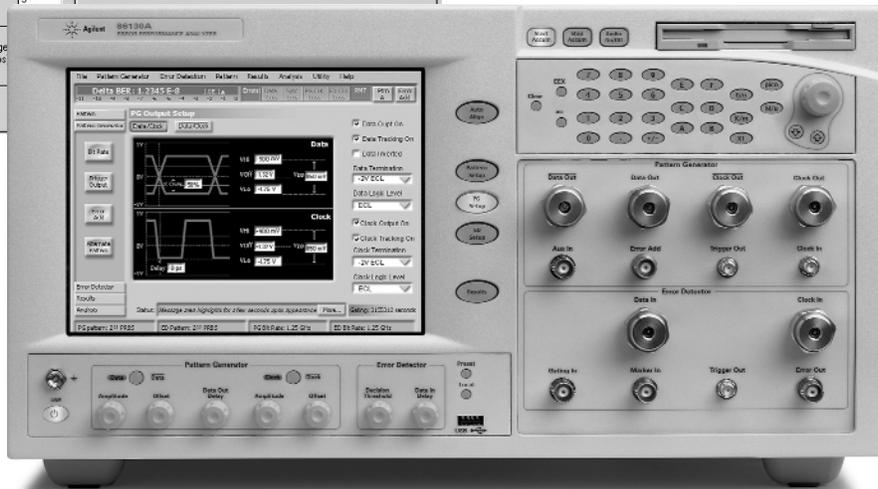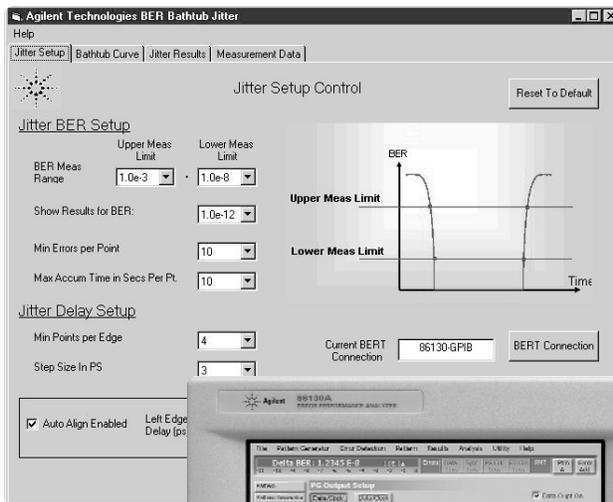# Using Bathtub Jitter Software with the Agilent 86130A and 71612C Error Performance Analyzers

Application Note 1550-12


Agilent Technologies

Introduction

This application note describes the use of the BER bathtub software with the 86130A and 71612C error performance analyzers to determine Random Jitter (RJ), Deterministic Jitter (DJ) and Total Jitter (TJ) according to the ANSI NCITS T11.2 Fibre Channel Methods for Jitter Specification (FC-MJS.)

Jitter

Jitter is a condition in which the clock rate of a data signal is not stable, but has small, rapid variations in frequency. The TJ of a signal consists of RJ plus DJ. Jitter is often measured as a fraction of the unit interval (UI), or bit period.

In an eye diagram, the data-logic-level transitions occur at specific points in time. For a jitter-free signal, the transitions always occur at the same points in time. For signals with jitter, the transitions are distributed over certain time intervals, thus reducing the inside opening of the eye.
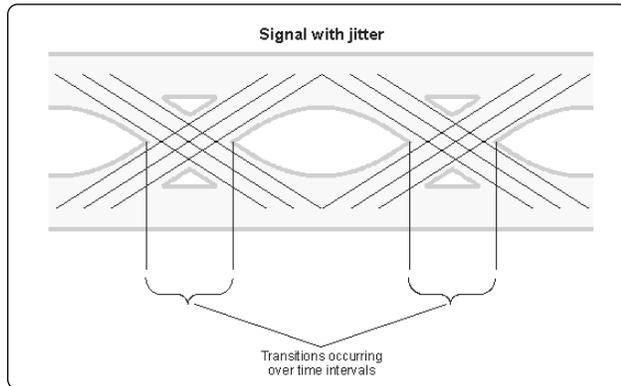

Signal with jitter

BER Bathtub Curve

A BER bathtub curve is the plot of BER vs. sample time from the left edge to the right edge of a data eye. This plot resembles a "bathtub" and is also referred to as a "BERT scan."
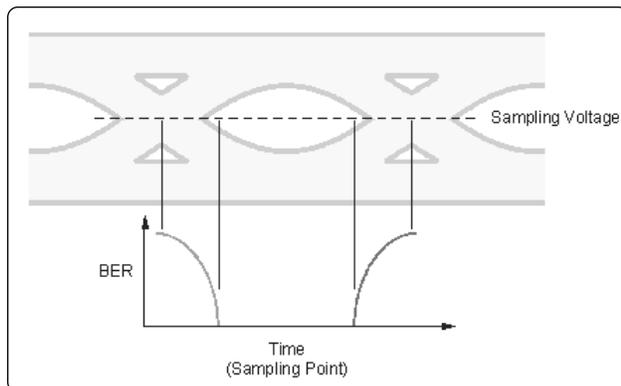
BER bathtub curve

BER Bathtub Jitter

This jitter test methodology applies to enterprise standards such as Fiber Channel and Gigabit Ethernet. Refer to ANSI X3.230-1994 Annex A, sub clause A.4.2. BER measurements across the regions where data transitions occur (the left and right eye edges) provide the necessary information to calculate TJ. TJ is quantified by noting the points where the BER reduces to $1E^{-12}$ at both eye edges, and subtracting that interval from the bit period. For example, if the data rate is 1.25 Gb/s, the corresponding bit period is 800 ps. If a BER of $1E^{-12}$ occurs at 10 ps and 790 ps, then the total jitter is 800 – (790 – 10), or 20 ps.
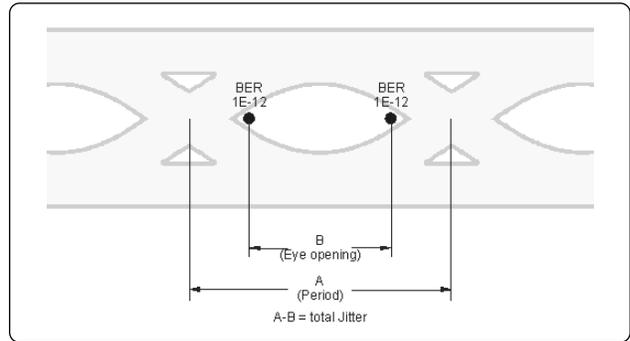
BER bathtub jitter

Bathtub Jitter Software

The software controls and receives information from a BERT. First, the s/w uses BER information to characterize the input eye and determine where the eye crossings occur. Once that information is obtained, the s/w proceeds to extract BER values as the sampling point is moved in time increments of 1 ps or more from the eye crossings. By default, data points are measured from BER $1E^{-3}$ to BER $1E^{-8}$, and then extrapolated to BER $1E^{-12}$.

The mathematical model for random jitter is based on a Gaussian distribution. The measurement data within the region of RJ is used to calculate Gaussian curves. These curves are then used to extrapolate data to BER $1E^{-12}$ and calculate RJ. The DJ and RJ are determined by a mathematical best fit of a complementary error function to the BER data plotted as a function of the decision time. All deterministic jitter sources, including data-dependent jitter (DDJ), duty-cycle distortion (DCD), and periodic jitter (PJ) are included in the DJ measurement.

How does the BER scan technique compare to other techniques for measuring jitter?

The BER scan technique is the reference standard method for measuring jitter for Fibre Channel and Gigabit Ethernet standards, among others. It directly employs actual bit error rate measurements. Other FC-MJS-compatible techniques, such as real-time oscilloscope jitter software or time-interval analyzer methods, generally measure fewer data points and depend more on extrapolation to low probability values. Other techniques may separate the jitter into more sub-types.

The details of the mathematical extraction of deterministic jitter differ between these techniques, possibly resulting in some minor differences in the reported values of deterministic jitter. However, the reported TJ should closely agree.

Standard oscilloscope jitter measurements are not necessarily designed to conform to the FC-MJS methodology.

## Should I use a clock recovery circuit in the measurement?

The need for a clock recovery unit (CRU) depends on what device is being tested. The FC-MJS methodology is written to test transmitters that include an autonomous bit clock source. In these cases, a CRU with the prescribed jitter transfer bandwidth (usually Fclock/1667) should be used. A data splitter may be require to feed the signal under test both to the CRU and error detector (ED) data inputs. The CRU output is connected to the ED clock input. The resulting measurement filters out clock and data jitter below the CRU jitter transfer bandwidth.

A CRU may not be required to measure the jitter contribution from a transmission medium connection such as a PC board transmission line or E/O and O/E optical link. In these cases, the pattern generator (PG) clock is connected to the ED clock input. The PG clock jitter is not measured in this common-mode clock connection. The jitter added by the transmission line or E/O O/E combination is likely measured correctly because very little of this jitter would have been rejected by use of the CRU.

What data patterns should I use to measure jitter?

FC-MJS jitter testing is done with short to medium length (<10,000 bit) coded repeating patterns, e.g. Fibre Channel CJPAT and CRPAT. The limited pattern length assures that the DJ probability distribution is tightly bounded, affecting the shape of the BER versus time curves only at the higher BER values. The BER scan technique separates RJ from DJ by fitting the distribution at lower BER values, where the shape is solely a function of RJ.

What settings should I use in the Bathtub jitter program?
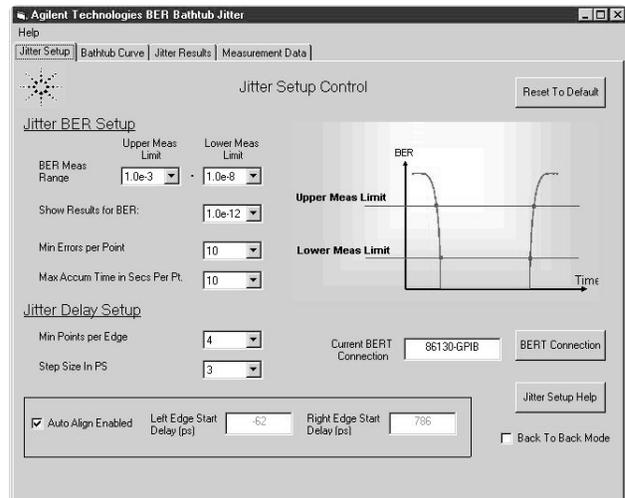
The following settings are recommended for best results:

Back-to-Back Mode: OFF

Upper Meas Limit BER: set no higher than 0.1 times the inverse of the pattern length (e.g. $1E^{-4}$ for a 1,000 bit pattern.)

Lower Limit BER: Set less than Upper Limit BER times 1E, even lower is fine.

Max Accumulation Time in Secs Per Pt: This setting (combined with the clock rate and Min Errors per point) will set an effective limit to the lowest BER measurement point. Set enough time to get at least 4 decades of valid BER values.

Time = Min Errors per point / min BER / Clock Rate.

Step size in ps: Start by using 1 ps. If there are many more than 4 valid points per edge, try increasing the step size to reduce the measurement time.

Min points per edge: 4 is the usual setting. If you are not able to obtain at least 3 points in the valid range on each side even after setting step size to 1 ps, follow hints in "back-to-back" settings.

Min errors per point: 10.

What is a "back-to-back" connection?

The "back-to-back" (or looped-back) connection can be used to verify and estimate the "baseline" performance of the measurement system, including the PG, ED and CRU (if used.) The jitter measured in this configuration will be the TJ of the PG, ED, and the relevant clock and CRU jitter if a CRU is used.

Connections (without CRU)
PG data OUT ≥ED data IN
PG clock OUT ≥ED clock IN
Connections (with CRU)
PG data OUT ≥ED data IN
PG databar OUT ≥CRU ≥ED clock IN

A dual output amplifier or data signal splitter can be used if only one data signal output is available.

What settings should I use for a back-to-back measurement?

The RJ in a back-to-back measurement can be very small (Rj sigma <1 ps), particularly in the case of the Agilent 71612C PG/ED. This makes the slope of the BER curves very steep, making special settings necessary to obtain enough data points for a fit (a minimum of 2 valid points at least 3 decades apart are required). A special "back-to-back" mode in the software applies these settings. The back-to-back mode can also be used for measuring DUTs with extremely low RJ.

Back-to-back Mode: ON
Step Size in PS to 1
Min errors per point 10
Set Min Points/edge to 2
Lower Meas BER: $1E^{-11}$
Accumulation time per point: 10 seconds

Upper Meas BER: start with 0.1 times the inverse of the pattern length (e.g. $1E^{-4}$ for a 1,000 bit pattern.) If there are not at least 2 valid points on each side, spanning at least 3 decades on each side, increase MEAS BER by 10x and measure again. Try not to allow several points to bunch up near the high BER limit (this may happen at $1E^{-3}$ or $1E^{-2}$ BER); RJ may be overestimated. If no setting is found to be satisfactory, these extra points at high BER can be eliminated by turning off the autoalign option and modifying the Left and Right edge Start delays.

What jitter results should I expect when I run my BERT back to back?

The baseline performance of the bathtub jitter measurement depends on the level of the jitter generated by the PG, the intrinsic jitter and clock delay accuracy of the ED, and the jitter generation in the CRU (if used.) These performance levels will vary from unit-to-unit and also depend on the pattern used (particularly the CRU performance.) It is important that the BERT factory calibration be current in order to achieve the best results.

It is important to note that the back-to-back results (and actual DUT results) can vary somewhat if the clock to data delay is varied. In back-to-back mode, this effect can be tested by changing the PG data out delay.

Note that the back-to-back measurement includes PG jitter, which might be as much as half of the measured jitter.

For clock frequency >1 Gb/s, patterns less than 10,000 bits and no CRU, the jitter can be expected to fall into the following ranges (ref BER = $1E^{-12}$):

86130A: 10 <DJ <30 ps, 7 ps <RJ <28 ps (0.5 ps <RJ sigma <2 ps)

71612C: 10 <DJ <30 ps, 2.8 ps <RJ <14 ps (0.2 ps <RJ sigma <1 ps)

How does the back-to-back performance compare to other jitter measurement techniques?

The following is the published typical performance of a transition interval analyzer:

RJ sigma <2 ps, ISI+DCD (compare to DJ) <25 ps.

Are the back-to-back results sufficiently below what is required by the Infiniband, Fibre Channel and Gigabit Ethernet standards to be useful?

Yes, in many cases. The level of jitter required by these standards can be from 100 ps to 300 ps for both RJ and DJ, depending on the specific interface being tested. For 1.062 Gb/s Fibre Channel, the back-to-back results are a small percentage of the DUT requirement. At higher frequencies, the absolute measurement requirements are more stringent. The actual back-to-back performance results of your unit might be near the upper or lower end of the typical performance range given, and can be compared to your particular requirements.

What is the relationship between BERT clock-data align eye opening result and the bathtub jitter eye opening result?

The bathtub total jitter eye opening is normally calculated for $1E^{-12}$ BER TJ = DJ + (14)(RJ sigma), whereas the BERT clock-data align result is measured for BER between $1E^{-7}$ and $1E^{-2}$. The bathtub jitter eye opening can be re-calculated for a higher BER value by resetting the BER results value on the "Bathtub Curve" page. The result should be comparable to the eye opening reported by the BERT.

Why does the bathtub jitter give me a different answer from my oscilloscope?

The FC-MJS jitter methodology is designed to estimate the jitter at the $1E^{-12}$ probability level and to specifically extract RJ and DJ components. Standard oscilloscopes directly measure jitter to approximately the $1E^{-4}$ probability level and generally measure the rms and peak-peak jitter deviation without regard to the type of component. While jitter measurements from an oscilloscope are valid, the raw results are generally not reported in a way that can be directly applied to the FC-MJS methodology.

Intrinsic performance: Compared to an ED, an oscilloscope generally will contribute less DJ and more RJ to the measurement.

How can I correlate oscilloscope results to BT jitter results?

Interpretation of jitter on oscilloscope eye diagram:

The peak-to-peak jitter measured on an eye diagram on an oscilloscope is essentially a TJ measurement at a probability level of about $1E^{-4}$ (depending on the number of data points in the measurement.) This is equivalent to TJ at BER $1E^{-4}$.

Interpretation of jitter measured with oscilloscope using a pattern trigger:

In some cases, but not all, an oscilloscope can be used to estimate RJ. If the oscilloscope is triggered on a particular bit of the pattern, the jitter of a particular edge can be measured. This eliminates DDJ and DCD. Only if there are no other sources of DJ, then the random jitter (RJ sigma) can be measured. It is fairly common that other sources of deterministic jitter are present, such as MUX patterning jitter or sinusoidal jitter. In these cases, the raw jitter number will include the effect of the remaining DJ.

Can I use "long" data patterns (e.g. PRBS23,31) with the Bathtub jitter software?

Yes, but the FC-MJS BER scan Dual-dirac delta function jitter extraction methodology is not valid for these long data patterns, and the RJ/DJ extraction should not be taken literally.

For long patterns (e.g. PRBS23, 31), the measured BER data is correct, but the DJ probability distribution is no longer necessarily tightly bounded. In other words, the DJ affects the shape of the BER curve below $1E^{-7}$ (For PRBS23) or even below $1E^{-9}$ (PRBS31). Thus, it is practically difficult or impossible to measure a large enough portion of the BER curve that reflects only RJ. The result is a (too large) "RJ" number that reflects a combination of both the true RJ and the DJ, and a "DJ" number that may be too small compared to results with a short data pattern. This can happen even if the bathtub jitter complementary error function fits the data very well.

Nevertheless, some users may want to use the BER scan capability with long PRBS sequences or other long stressful patterns. The RJ and DJ separation should not be taken literally at face value, but the TJ and BER results can be very useful for comparison purposes.

How do I interpret back-to-back results with long patterns (PRBS23,31):

Long patterns (PRBS23,31) have significant low frequency content. Although the 86130A and 71612C BERTs are wideband, DC-coupled designs, this low frequency content can interact with the residual non-flatness in the low frequency response to create some low frequency pattern-dependent jitter (also referred to as "baseline wander".) This will add low probability "tails" to the DJ distribution. As a result, the Bathtub jitter software program will report a greater TJ and RJ value and possibly a smaller DJ value. The RJ and DJ values obtained with long patterns do not reflect the "true" RJ and DJ, but these baseline results can be a basis for long pattern testing on a DUT.

Agilent 71612C Back-to-Back Example

Clock frequency: 9.95328 Gb/s
Pattern : PRBS7
Jitter Software Settings:
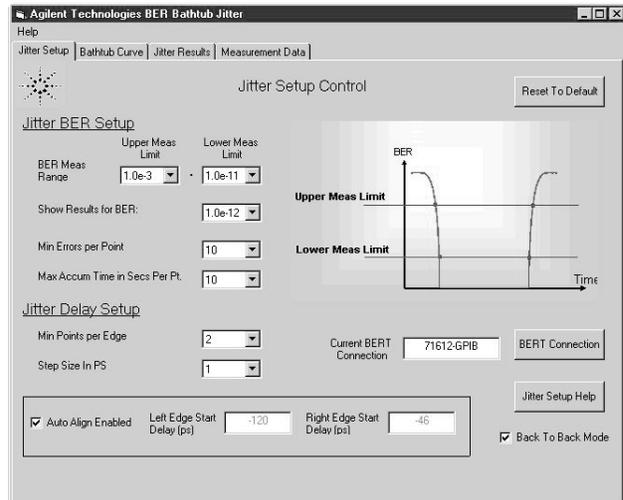 Turn Back to Back mode ON—do this first
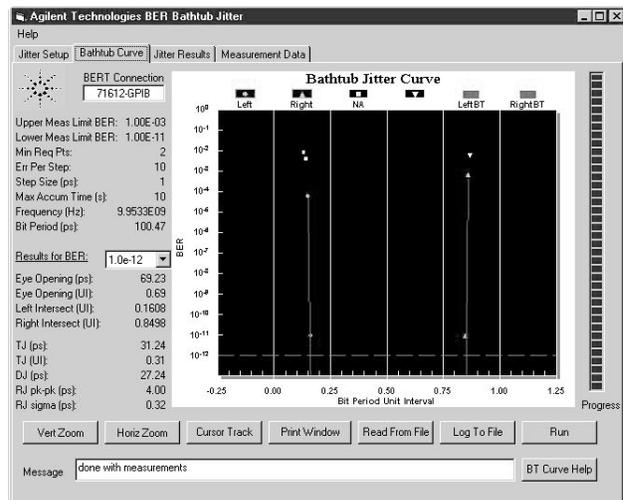 Step Size in PS to 1
  Min errors per point 10
  Set Min Points/edge to 2
  Lower Meas BER $1E^{-11}$
  Upper Meas BER $1E^{-3}$ ($1E^{-2}$ if necessary to get at least 2 valid (green) points on each side)

You may get a message about a low fit correlation coefficient. This is to be expected, but the absolute error is very small because the random jitter is so small.
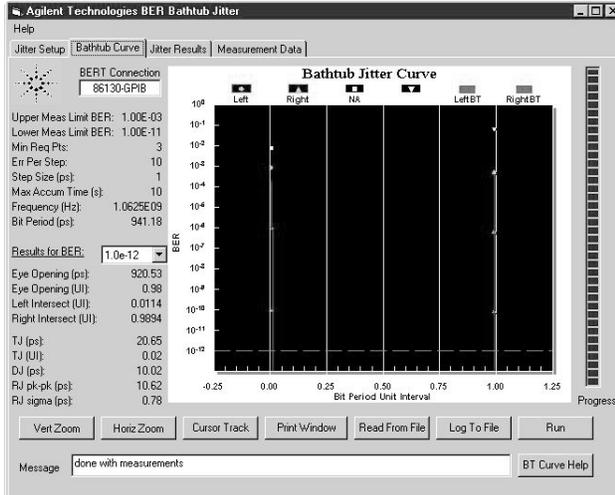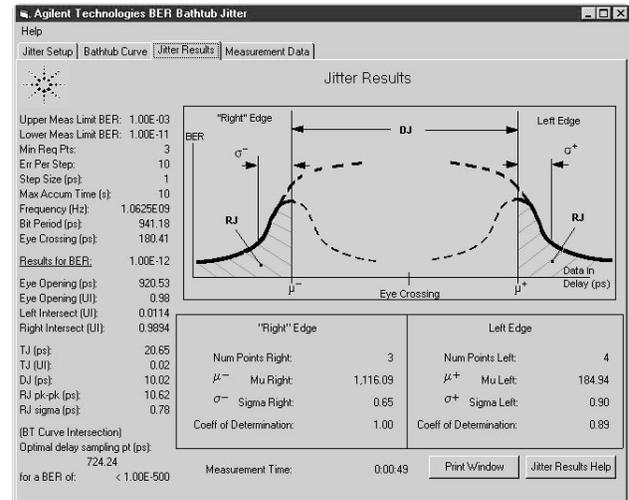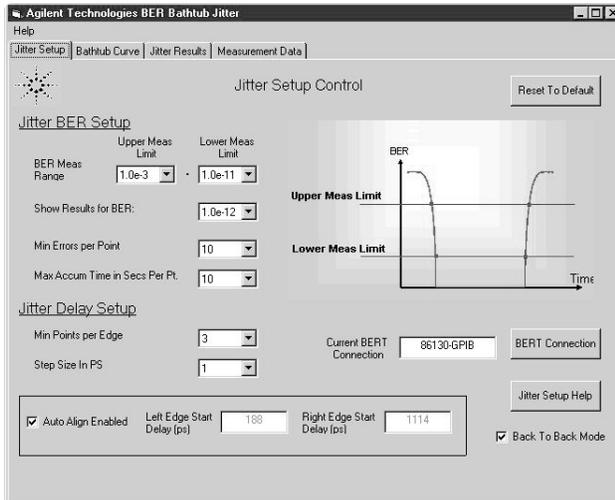
Agilent 86130A
Back-to-Back Example

Test Pattern: PRBS7
Clock rate: 1.0625 Gb/s
Back-To-Back Mode: ON
Step size in PS: 1
Set BER Meas lower limit $1E^{-11}$
Set min points/edge 3
Set BER meas upper limit $1E^{-4}$ (<1/(10x pattern length))
Acquire at least 3 valid (green) points on both left and right sides (increase BER meas upper limit if necessary)
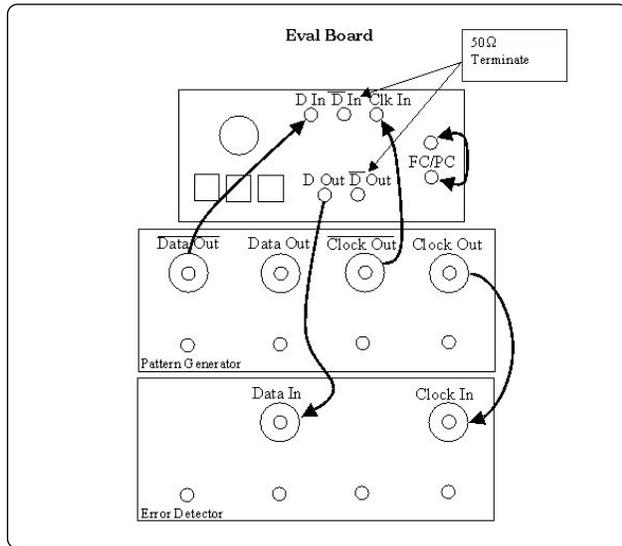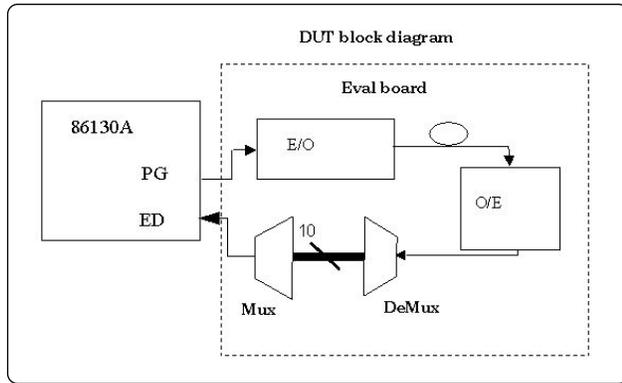
The results are for BER=$1E^{-12}$ according to the FC-MJS methodology:

TJ= 20.65 ps
DJ= 10 ps
RJ= 10.6 ps.
RJ sigma= 0.78 ps

The Jitter Results page shows data from the perspective of the jitter histogram (the left and right sides are flipped compared to the BER eye results page). There is more detail about the curve fits. In particular, the RJsigma equals average (sigma- , sigma +) = 0.78 ps. RJ = 14 (RJsigma).

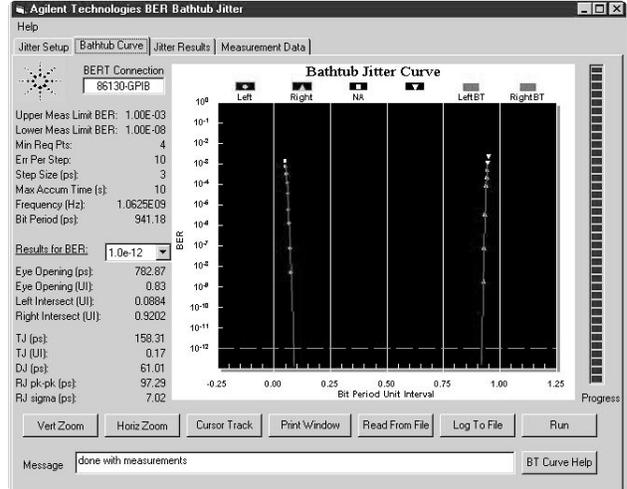# Fibre Channel transceiver test example using Agilent 86130A

DUT block diagram

Fibre Channel Transceiver Test with the Agilent 86130A

Pattern: PRBS7
Bit Rate: 1.0625 Gb/s

Note step size increased to 3 ps to reduce number of points and speed up measurement time.

TJ= 158 ps
DJ= 61 ps
RJ = 97 ps
RJ sigma= 97.02 ps

Detailed test connection

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