Fast Total Jitter Test Solution

Application Note

Introduction

As data rates get faster, jitter becomes a more and more important factor. Many standards for transmitters, receivers or transmission lines define limits for jitter or a minimum eye-opening at a certain bit error ratio (BER). Traditionally, measuring the eye-opening or the total jitter (TJ) for a given BER is straightforward using a Bit Error Ratio Tester (BERT). However, the measurements take a long time. Agilent has a new, optimized measurement technique on its BERTs that uses statistics and probability methods to reduce the measurement time to around a fortieth, at a confidence level comparable with full, traditional BERT measurements. This application note compares the results, measurement times and other considerations for the new Agilent Fast Total Jitter measurement with the traditional measurement, and with the functions available on BERTs and 'scopes to extrapolate eye-opening or TJ.

Eye-Opening and Total Jitter

The eye-opening, or phase margin, for a given bit error ratio (BER) defines how much of the bit period (T_B) or unit interval (UI) has a BER less than or equal to the BER threshold. The total jitter (TJ) is what remains, and is defined as the amount of T_B or UI greater than the given threshold. That is, the sum of eye-opening and TJ equals T_B, or (normalized) 1 UI. The relationship between the size of the eye-opening and the TJ depends on the BER threshold. Many standards define the eye-opening numerically or by Eye Timing and Voltage specifications. Figure 1 shows such a specification for PCI Express. In this case an eye-opening of 0.75 UI (75% of the UI) is required. The maximum TJ is therefore 0.25 UI (25% of the UI). The PCI Express standard, like many standards, defines such eye specifications for a BER threshold of 10^{-12}.

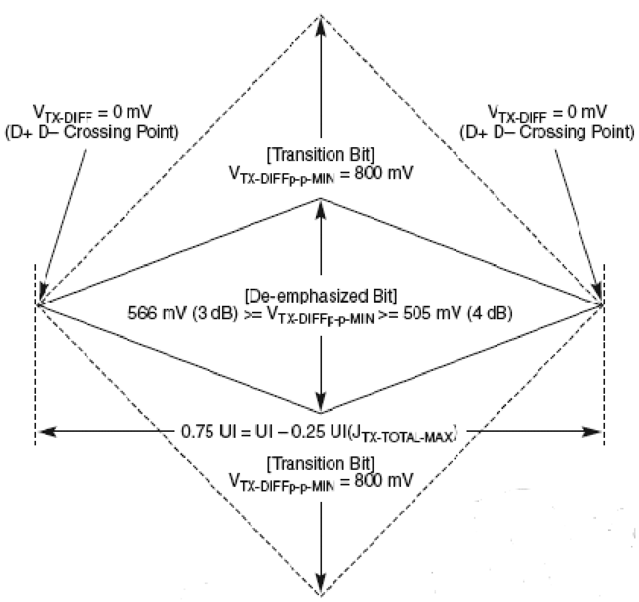

Figure 1: PCI Express Eye Specification @ BER 10^{-12}

Measuring TJ(BER)

The common way to measure TJ(BER) is the BERTScan or "bathtub" measurement. To do this, a BERT steps a sampling point through the eye along the time-delay axis. At each measuring point, the BERT compares bits until it reaches a defined number of bits or a defined number of errors. It then calculates the BER by dividing the measured errors by the number of compared bits. Figure 2 shows such a BERTScan.

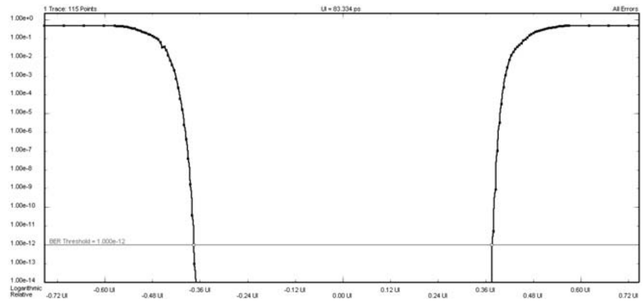

Figure 2: BERTScan

This straightforward approach can be extremely time-consuming, especially for low BER threshold like the 10^{-12} defined by PCI Express. To verify a BER of 10^{-12} with a high confidence level, the BERT compares up to 10^{13} bits for each measurement point before creating a BERTScan as shown in figure 2. The BERTScan between two measured points is interpolated. The eye-opening is considered as the distance between the points where the BERTScan crosses over the desired BER threshold, which in this example is 10^{-12}. For a resolution of 0.005 UI, the measurement for a PCI Express device at a data rate of 2.5 Gb/s takes 2.5 days.

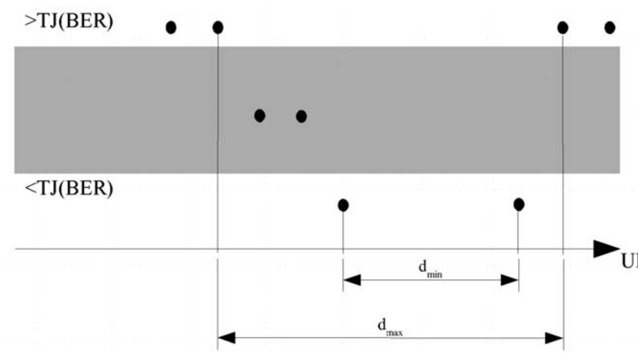

Figure 3: Sketch Fast TJ

Agilent has implemented a new measurement technique for TJ(BER): the Fast Total Jitter Measurement. This measurement is based on probability and statistics theory, and was presented at DesignCon 2005 [1].Instead of comparing bits until the BERT reaches a defined number of bits or errors, it compares bits until it can decide with a 95% confidence level whether the actual BER is above or below the desired threshold.The algorithm steps from the left until it reaches the first point with a BER below the desired threshold. It then repeats this procedure for the right side. The distance of the inner points with a BER above the desired threshold, d_{max}, is the upper limit for the eye-opening (figure 3). The distance of the inner points with a BER below the desired threshold, d_{min}, is the lower limit for the eye-opening (figure 3). The eye-opening τ(BER) is then calculated as$\tau(BER) = (d_{max} + d_{min})/2$ and $TJ(BER) = 1\ UI - \tau(BER)$.

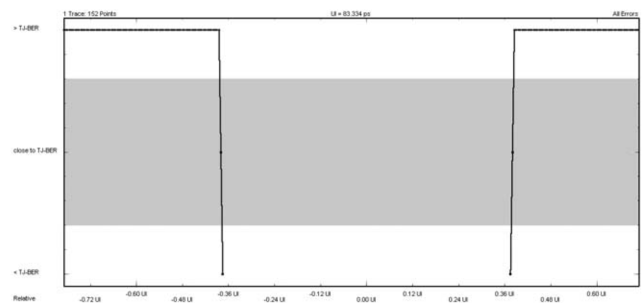

Figure 4: Fast Total Jitter Measurement

The difference between d_{max} and d_{min} describes the uncertainty of the TJ(BER). Using this method, for a resolution of 0.005 UI the measurement for a PCI Express device at a data rate of 2.5 Gb/s is as short as 50 minutes.Even faster results for TJ(BER) are available usingextrapolation methods, as is done on some BERTs. After performing a BERTScan with a few compared bits, TJ(BER) is estimated by extrapolating the BERTScan to the desired BER. However, getting reliable results from this very fast method means properly selecting the thresholds for the extrapolation. This takes much experience.
The DSO80000 Series oscilloscopes and the 86100 DCA- j sampling scopes measure the deterministic jitter (DJ) and random jitter (RJ), then use these values to extra-polate the TJ(BER) based on mathematical and statis-tical models.

Table 1: Measurement time for TJ(10^{-12})

	BERTScan 10^{13}	Fast TJ	BERTScan 10^{09} TJ estimated	BERTScan 10^{06} TJ estimated	DCA-j TJ estimated
Sinusoidal Jitter data rate 12 Gb/s	13 hours	15 minutes	<1 minute	<1 minute	(10–15 minutes)
Bounded Gaussian RJ data rate 10 Gb/s	14 hours	12 minutes	<1 minute	<1 minute	Not possible
ISI data rate 5 Gb/s	1.8 days	25 minutes	<1 minute	<1 minute	(15 minutes)
Optical Transceiver data rate 5.2 Gb/s	1 day	30 minutes	<1 minute	<1 minute	(10 minutes)
PCI Express graphics device data rate 2.5 Gb/s	2.5 days	50 minutes	2 minutes	<1 minute	(10–15 minutes)

Comparison of the different methods

This section compares the results for the different techniques of measuring and extrapolating TJ(BER) for different kinds of jitter and devices, at different data rates. The kinds of jitter and devices measured are:

- Sinusoidal jitter
- Bounded Gaussian random jitter
- Inter- symbol interference (ISI) on a backplane
- An optical transceiver
- A PCI Express graphics device

The techniques compared are:

- Agilent's new Fast Total Jitter Measurement
- A BERTScan with edge optimization comparing 10^{13} bits
- A BERTScan with edge optimization comparing 10^{9} bits and extrapolating
- A BERTScan with edge optimization comparing 10^{6} bits and extrapolating
- TJ on an Agilent 86100C DCA- j 'scope

All measurements and extrapolations are done for a BER of 10^{-12} and a resolution of 0.005 UI. Table 1 provides an overview of the time needed to perform the different techniques on the different devices for the different kinds of jitter. The DCA- j sampling scope provides results for jitter within seconds. It also updates these results continuously. To ensure stable results all measurements on the DCA- j are based on 5 to 10 million samples. All BERTScan measurements were done by ParBERT 81250 with separate 13.5 Gb/s clock groups for data generation and analyses. Except for the PCI Express graphics device, the data signal was a PRBS 2^{15}- 1.
The accuracy of a measured BER of 10^{-12} after comparing 10^{13} bits is around $\pm 7*10^{-13}$ at a confidence level 95%. The effects of this uncertainty on the TJ(BER) are low. Therefore the BERTScan with 10^{13} compared bits is considered as the most accurate TJ(BER) measurement. All deviations in the following sections are related to this measurement.

Sinusoidal Jitter

Method

The N4872A 13.5 Gb/s generator module of the ParBERT 81250 System uses an integrated delay line for injecting jitter. This delays the data signal with respect to the clock corresponding to the voltage applied to the delay control input. For our comparison, we applied a sine wave generated by an arbitrary waveform generator (an Agilent 33250A) to the delay control input. The sine wave had a frequency of 30 MHz and an amplitude 10 mV. We routed the data signal and the clock directly to the analyser clock group. The data rate was 12 Gb/s.

Results

All measurements and extrapolations show roughly same results.

Table 2: TJ(10^{-12}) results for SJ

	TJ (10^{-12})	deviation	duration
Fast TJ	0.25 UI	0	15 minutes
BERTScan 10^{13}	0.25 UI	–	13 hours
BERTScan 10^{09} TJ estimated	0.25 UI	0	< 1 minute
BERTScan 10^{06} TJ estimated	0.28 UI	+0.03	< 1 minute
DCA-j TJ estimated	0.27 UI	+0.02	(10 – 15 minutes)

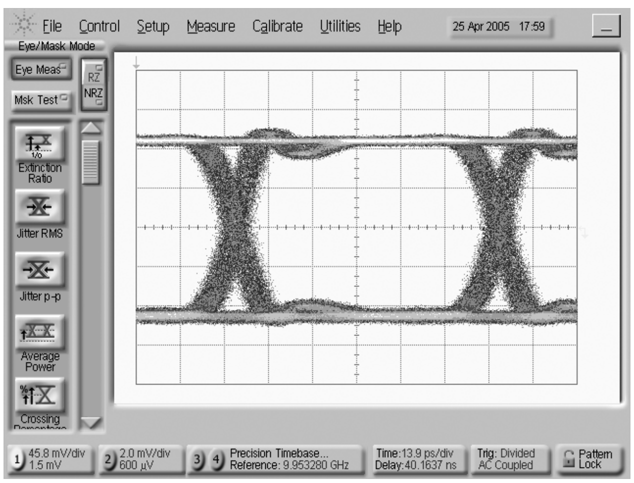

Figure 5: Waveform on DCA-j for SJ

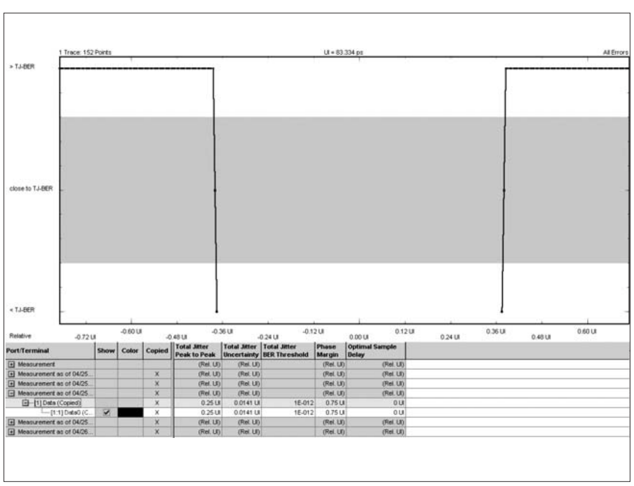

Figure 6: Fast TJ measurement for SJ

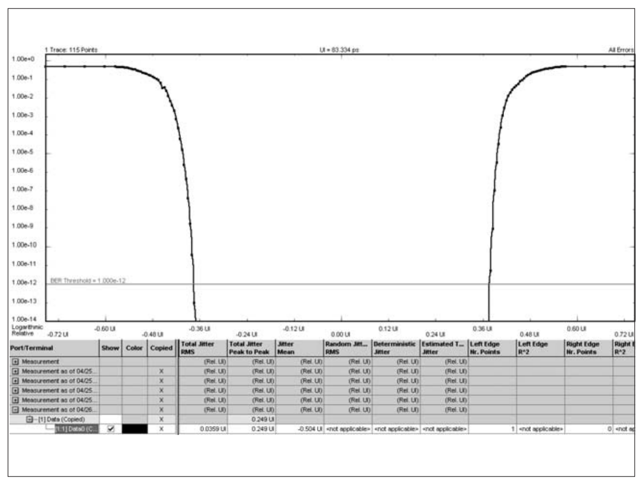

Figure 7: BERTScan 10^{13} for SJ

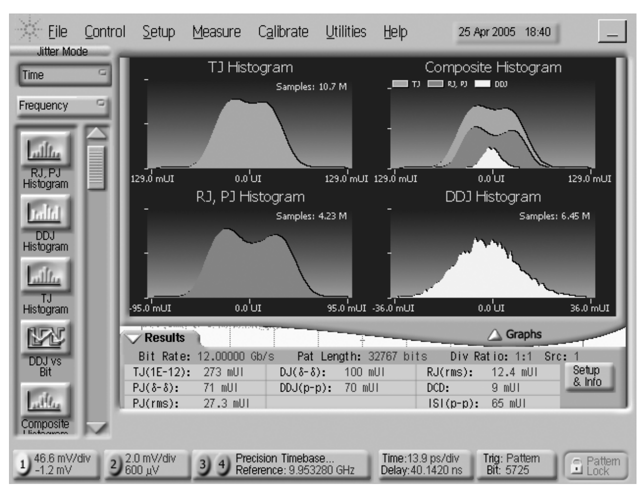

Figure 8: Jitter Analysis on DCA-j for SJ

Bounded Gaussian Random Jitter

Method

For this measurement, we applied a Bounded Gaussian Noise signal to the delay control input of the N4872A generator module. We generated this signal by routing a PRBS data signal through a low pass filter. The histogram of the voltage signal is shown in figure 9. We routed the data signal and clock directly to the analyser clock group. The data rate was 10 Gb/s. The DCA-j could not extrapolate the TJ(10^{-12}).

Results

The BERTScan, figure 10, shows that for on low bit counts (such as 10^6 compared bits) it is difficult to separate RJ_{rms} and $DJ_{\delta\delta}$. This leads to imprecise results.

Table 3: TJ(10^{-12}) results for bounded gaussian RJ

	TJ (10^{-12})	deviation	duration
Fast TJ	0.64 UI	+0.01	12 minutes
BERTScan 10^{13}	0.63 UI	–	14 hours
BERTScan 10^{09} TJ estimated	0.64 UI	+0.01	<1 minute
BERTScan 10^{06} TJ estimated	0.70 UI	+0.07	<1 minute
DCA-j TJ estimated	Not possible	–	–

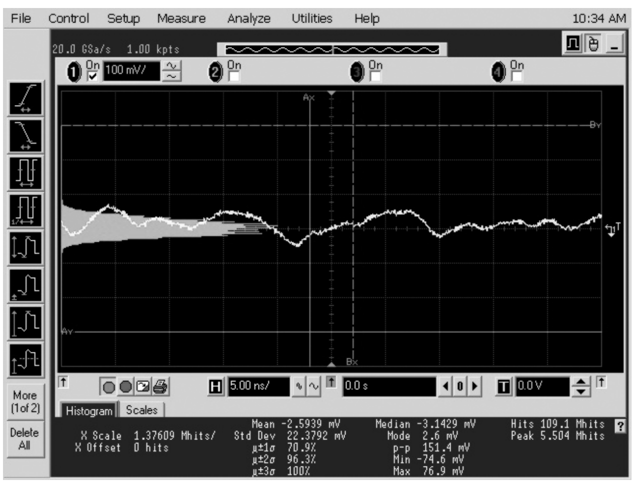

Figure 9: Histogram of voltage signal

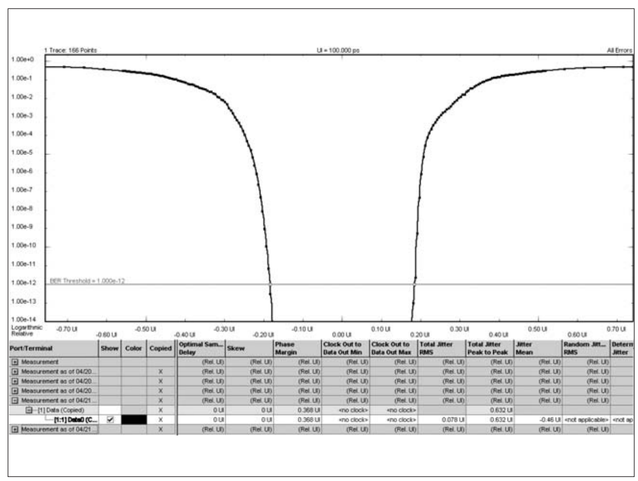

Figure 11: BERTScan 10^{13} for bounded gaussian RJ

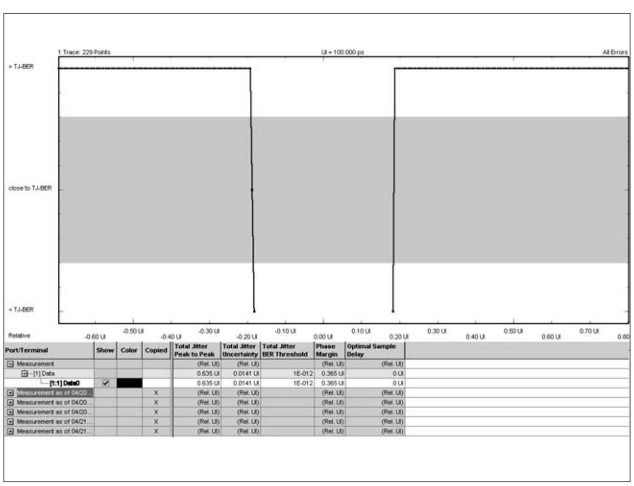

Figure 10: Fast TJ for bounded gaussian RJ

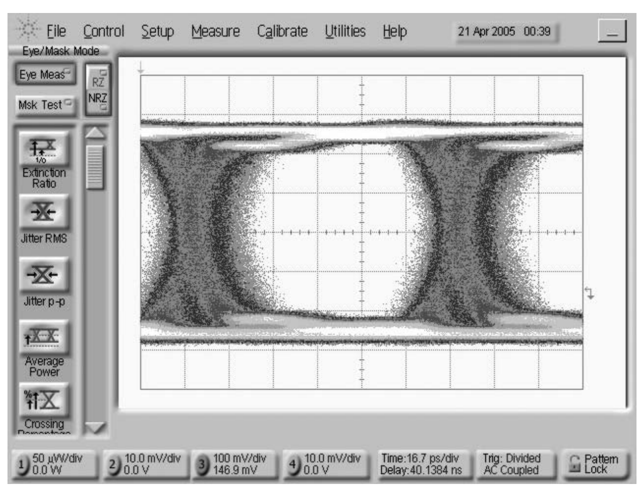

Figure 12: Waveform for bounded gaussian RJ

Inter-Symbol Interference (ISI) on a backplane

Method

Attenuation and bandwidth limitations on transmissionlines generate jitter called inter-symbol interference (ISI) [1]. For our comparison we transmitted the data signal over a backplane. We routed the clock directly to the analyser clock group. The data rate was 5 Gb/s.

Results

Table 4: TJ (10^{-12}) results for ISI

	TJ (10^{-12})	deviation	duration
Fast TJ	0.30 UI	+0.01	25 minutes
BERTScan 10^{13}	0.29 UI	–	1.8 days
BERTScan 10^{09} TJ estimated	0.29 UI	0	<1 minute
BERTScan 10^{06} TJ estimated	0.31 UI	+0.02	<1 minute
DCA-j TJ estimated	0.37 UI	+0.08	15 minutes

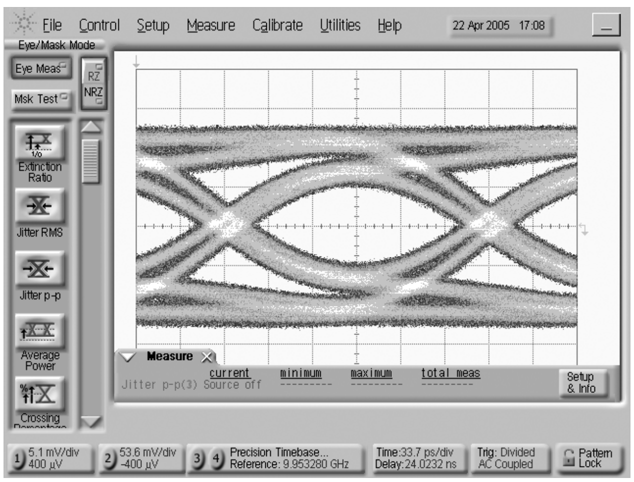

Figure 13: Waveform for ISI on backplane

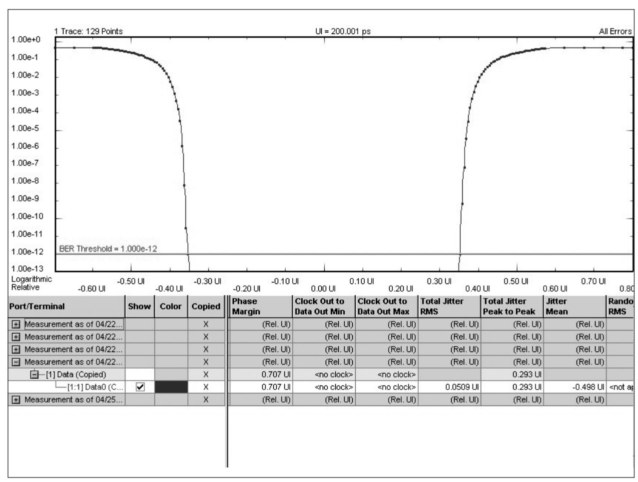

Figure 15: BERTScan 10^{13} for ISI on backplane

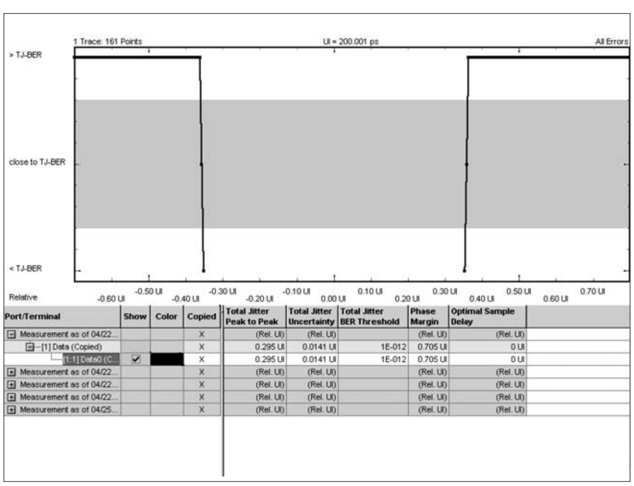

Figure 14: Fast TJ for ISI on backplane

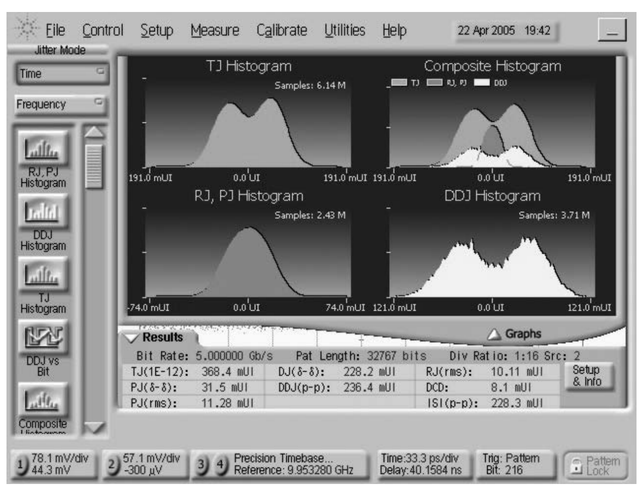

Figure 16: Waveform for ISI on backplane

Optical Transceiver

Method

We generated the data signal by looping back between two optical transceivers designed for 2.5 Gb/s and stressing the optical transceivers with a data rate of
5.2 Gb/s. We routed the clock directly to the analyser clock group.

Results

Figure 19 shows the asymmetric behaviour of the left and right side in the BERTScan plot. This behaviour does not fit in most models. Therefore most extra-polation methods create imprecise results with this kind of signal.

Table 5: TJ(10^{-12}) results for an optical transceiver

	TJ (10^{-12})	deviation	duration
Fast TJ	0.52 UI	0	30 minutes
BERTScan 10^{13}	0.52 UI	–	1 day
BERTScan 10^{09} TJ estimated	0.47 UI	– 0.05	<1 minute
BERTScan 10^{06} TJ estimated	0.56 UI	+ 0.04	<1 minute
DCA-j TJ estimated	0.48 UI	– 0.04	10 minutes

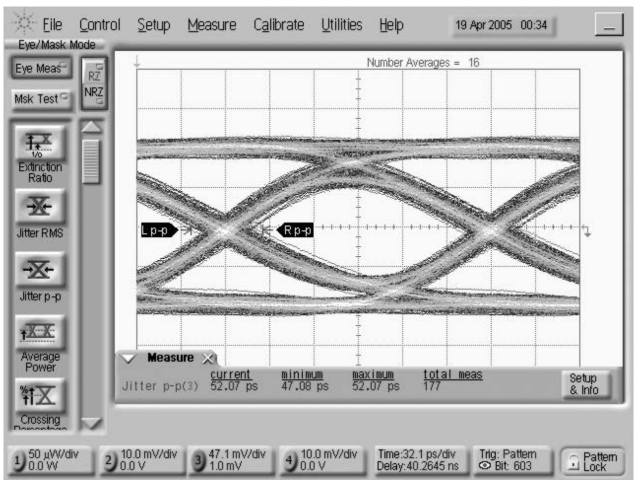

Figure 17: Waveform for an optical transceiver

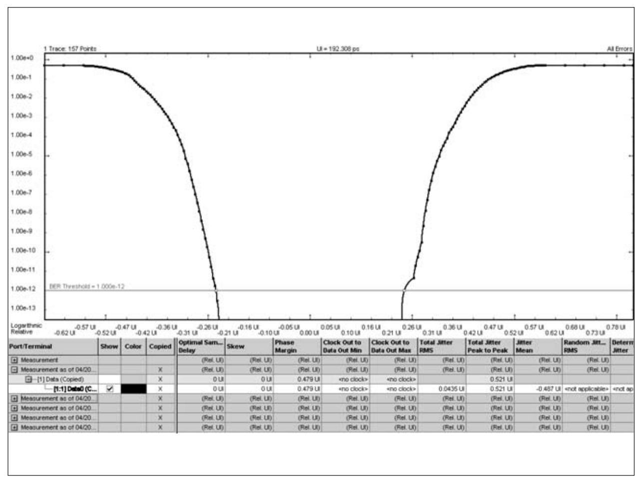

Figure 19: BERTScan 10^{13} for an optical transceiver

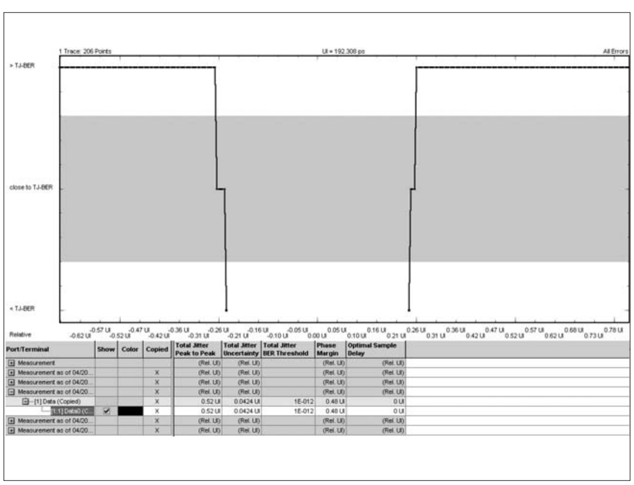

Figure 18: Fast TJ for an optical transceiver

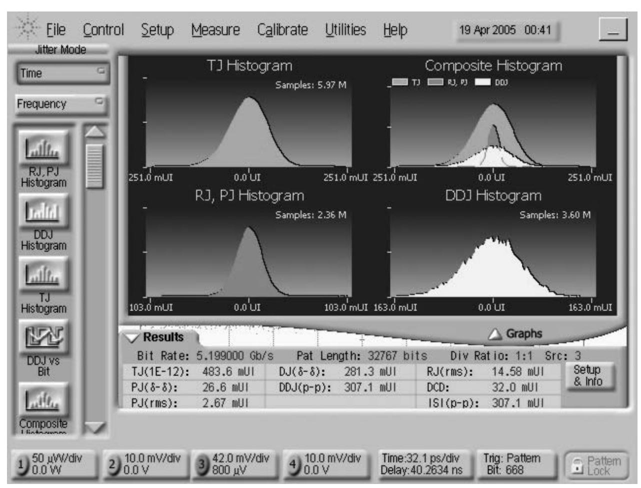

Figure 20: Waveform for an optical transceiver

PCI Express video card

Method

We measured the PCI Express graphics device with a memory based data pattern instead of a PRBS. The data rate was 2.5 Gb/s.

Results

Table 6: TJ (10^{-12}) results for PCI Express video card

	TJ (10^{-12})	deviation	duration
Fast TJ	0.19 UI	+0.02	50 minutes
BERTScan 10^{13}	0.17 UI	–	2.5 days
BERTScan 10^{09} TJ estimated	0.18 UI	+0.01	2 minutes
BERTScan 10^{06} TJ estimated	0.20 UI	+0.03	<1 minute
DCA-j TJ estimated	0.22 UI	+0.05	10–15 minutes

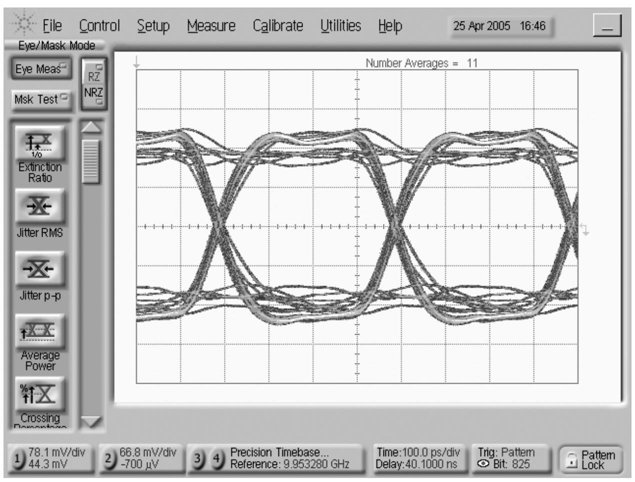

Figure 21: Waveform for a PCI Express video card

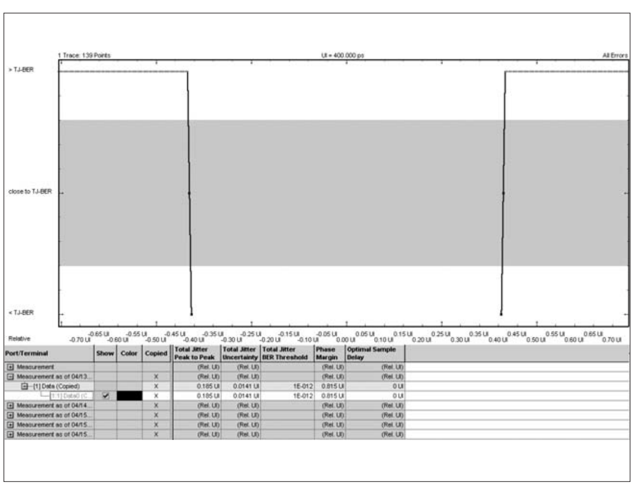

Figure 22: Fast TJ for a PCI Express video card

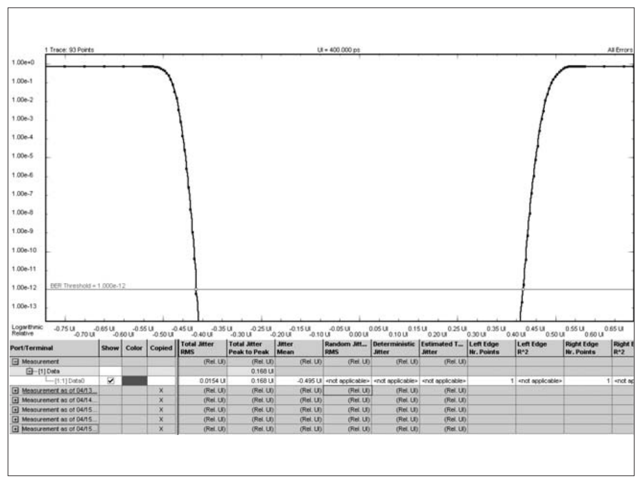

Figure 23: BERTScan 10^{13} for a PCI Express video card

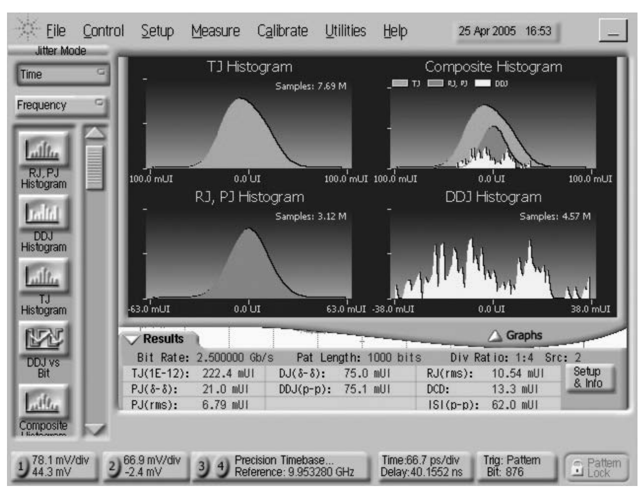

Figure 24: Waveform for a PCI Express video card

Conclusions

Diagram 1 shows, in UI, the absolute difference between the BERTScan comparing 10^{13} bits and the various measurements and extrapolations. Mostly, the extrapolated results of the 10^{06} BERTScan and the DCA-j are higher than the measured values. Considering the 0.005 UI resolution applied for the measurements, the low difference between the 10^{13} BERTScan and the Fast Total Jitter measurement is negligible.The accuracy of extrapolations is dependent on the fit of the signal under test to the underlying model. This explains why the stressed optical TX-RX loop and the Bounded Gaussian RJ injection show larger deviations. Therefore using these extrapolation methods on either BERTs or scopes needs experience and knowledge both of the signal and the underlying jitter model of the extrapolation method. The time taken by the traditional BERTScan for measurements at a high-confidence level is considerable, which is also a challenge for keeping the test environment stable.Agilent's new Fast Total Jitter measurement is the fastest and easiest way to measure TJ(BER) for low BER independently of any underlying jitter model. It also provides the uncertainty of the measured result, showing the quality of the measurement. The great time reduction makes measuring TJ(BER) feasible where often a BERTScan would not be considered. This makes it easier to use TJ(BER) for better understanding of all kind of designs.

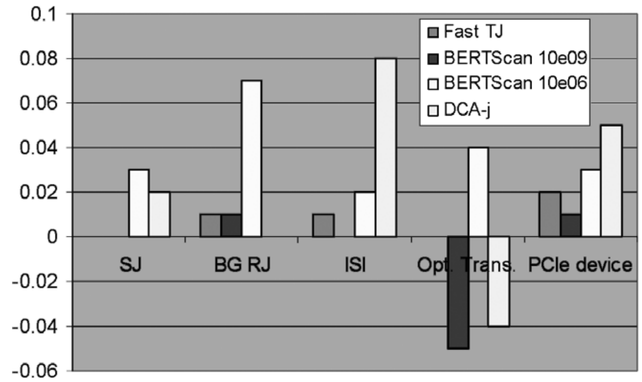

Diagram 1: Abs. delta to 10^{13} bit BERTScan in UI

Summary

The new Fast Total Jitter Measurement:

- Fast and feasible: around 40 times faster than a common BERTScan with comparable confidence level
- Easy to use: all you need to do is select the desired BER and resolution
- Reports one measured value for TJ(BER) and the according uncertainty
- Independent of jitter model, works on any distri bution, such as asymmetric BERTScans

References

[1] Marcus Müller, Ransom Stephens, and Russ McHugh, "Total Jitter Measurement at Low Probability Levels, Using optimized BERT Scan Method – DesignCon 2005"; http://www.designcon.com/pdf/7-ta4_mueller.pdf

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Related Literature

Related Literature	Publication Number
Agilent Physical Layer Test Brochure	5988-9514EN
Agilent ParBERT 81250 Parallel Bit Error Ratio Tester Product Overview	5968-9188EN
N4901B Datasheet	5989-0398EN
N4902B Datasheet	5989-0399EN
Jitter Fundamentals: Agilent N4900 Serial BERT Series Jitter Injection and Analysis Capabilities Application Note	5989-0089EN
Jitter Solutions for Telecom, Enterprise, and Digital Design Brochure	5988-9592EN
Jitter Fundamentals: Jitter Tolerance Testing with Agilent 81250 ParBERT Application Note	5989-0223EN
Jitter Fundamentals: Agilent 81250 ParBERT Jitter Injection and Analysis Capabilities Application Note	5988-9756EN

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