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The Benefits of and Considerations for the Embedded CDR in the Agilent N5980A Manufacturing Serial BERT

Technical Overview

Optical Transceiver Test in Manufacturing

An optical transceiver module consists of a transmitter (TX) and a receiver (RX). The TX is tested for optical power and signal quality. The RX is tested for sensitivity, which is based on a bit error ratio (BER) test.

For such a test an optical data signal is connected via a variable optical attenuator to the optical input of the transceiver under test (DUT). The differential electrical output of the transceiver is connected to the error detector input of a Bit Error Ratio Tester (BERT), as shown in Figure 1. Typically such a DUT does not provide a clock.

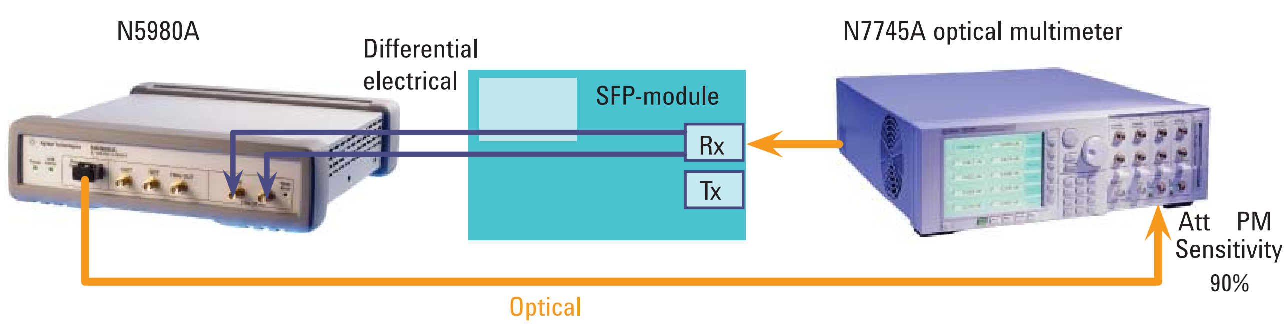

Figure 1. N5980A used in receiver (RX) test of an optical transceiver

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The Agilent N5980A Manufacturing Serial BERT Used for Manufacturing Test of Optical Transceivers

The Agilent N5980A 3.125 Gb/s Serial BERT is ideal for manual or automated manufacturing testing of electrical and optical devices running at speeds between 125 Mb/s and 3.125 Gb/s. By using both the electrical and optical (SFP) interfaces concurrently, one can double the measurement throughput (electrical in/optical out and vice versa).

The error detector provides differential inputs with a built-in clock-data recovery (CDR) according to Figure 3.

Scope of this Document

The N5980A Manufacturing Serial BERT is recommended for optical transceiver testing in manufacturing.

The N5980A comes with a clock-data recovery (CDR) in the input of the error detector/analyzer. The benefits of this implementation are:

- Shorter test times
- Reduced hardware costs

Both are key goals in a manufacturing line. On the other hand, such timing systems may affect test results.

The document describes:

- the benefits between sampling based on a CDR vs. conventional auto-alignment of the sampling point
- the behavior of optical transceivers while varying optical power

the potential difference of the sensitivity measurement and a proposal for how to deal with potential differences in the results.

Figure 2. Example of an optical transceiver implemented as SFP module

CDR vs. Manual or Semi-Automatic Auto-Align Routine

A conventional BERT needs a clock. A conventional BERT provides a manual or semi-automatic auto-align software routine which takes care of the adjustment of the sampling point within the eye. These routines work together with variable delay circuits in the hardware implementation. Such routines may run for several seconds to adjust properly.

Using a CDR provides several benefits:

- Extraction of the missing clock
- Automatic adjustment of the sampling point
- Fast adjustment of the sampling point
- Elimination of any manual or semi-automatic auto-align routine
- Suppression of low frequency jitter

The CDR eliminates the need for any clock . This makes test setup easier and independent from the clock availability (or lack thereof) by the DUT. The clocking of the error detector is performed with the help of the recovered clock from the incoming data stream.

The CDR uses the transition within the data stream as reference for the recovered clock. So any jitter up to the loop bandwidth of the CDR can be tracked.

The main advantage of this is the elimination of any delay circuits and auto-alignment routines.
The CDR recovers the clock with the help of the transitions within the data signal. The recovered clock has a fixed phase shift of .5 UI in relation to the average position of the transitions. This is achieved by design without the need for further delay elements, see figure 4. This settles within milliseconds after applying the data signal to the error detector input.

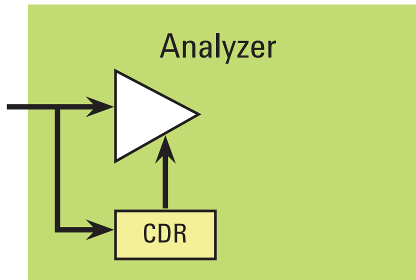

Figure 3. Sampling based on a CDR, the clock is recovered from the data stream

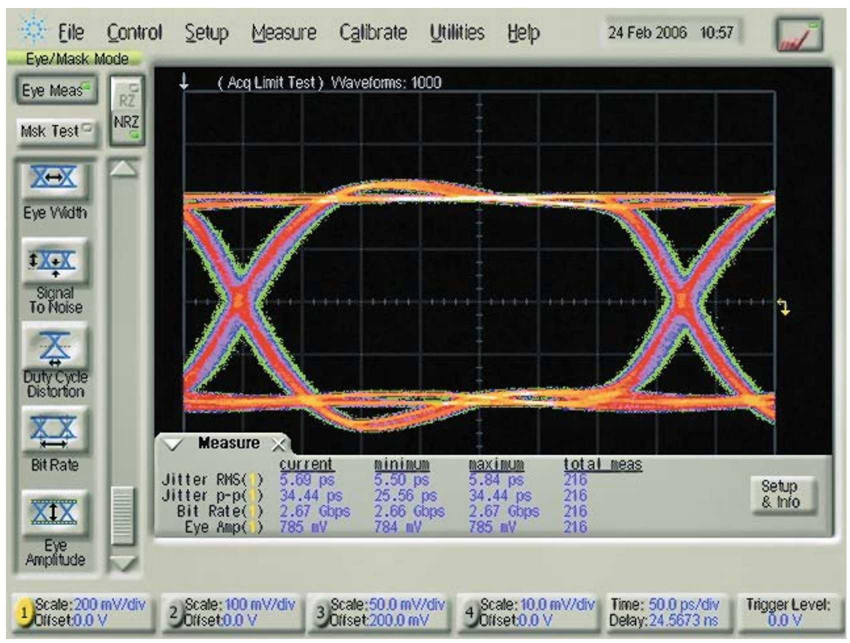

Figure 4. Sampling point is fixed to the middle of the eye with help of a CDR

There is no need for any programming of the input parameters, the embedded CDR adjusts automatically.

Compared to a conventional BERT, there is no need for any manual or semi-automatic routine to adjust the sampling point. This is a huge benefit in manufacturing, saving the time for such adjustment. The sampling point is adjusted in a couple of milliseconds after an input signal is detected. There is no need for variable delay circuits which reduces hardware costs.

Also worth mentioning is that the transceivers RX output connects to an ASIC which has the same CDR input as the BERT input. So the operating conditions during measurement match real life.

Measuring a 1 Gb/s optical transceiver

Figures 5 to 8 are screen shots taken from the RX electrical output of an optical transceiver for 1 GbE. The data rate is at 1 Gb/s, the pattern used is PRBS 2^7-1. The test setup is the same as shown in figure 1, except the RX electrical outputs are connected to a 86100C Infiniium DCA-J oscilloscope.

Figures 5 to 7 show a series of eye openings and histograms while the optical modulation amplitude (OMA) varies. In Figure 5 the OMA is adjusted for a large eye opening. The histogram is narrow. In Figure 6 the OMA is reduced by roughly 2 dB. The device reacts by reducing the eye opening and widening the histogram. As the shape looks Gaussian, it is random jitter which closes the eye. In Figure 7 the optical power is reduced by a further 2 dB. The eye diagram looks like there isn´t any eye opening anymore. The histogram is still Gaussian. So the random jitter totally closes the eye. An area with a bit error ratio of zero (BER = 0) does not exist anymore.

Looking closer at the histograms in Figure 6 and especially in Figure 7, it is clear that the histogram is not symmetric: the left slope is steeper than the right one. This observation tells us that the eye closure is different on both sides of the eye. There is more uncertainty on the entry side (left side of the eye) than on the exit side (right side) of the eye.

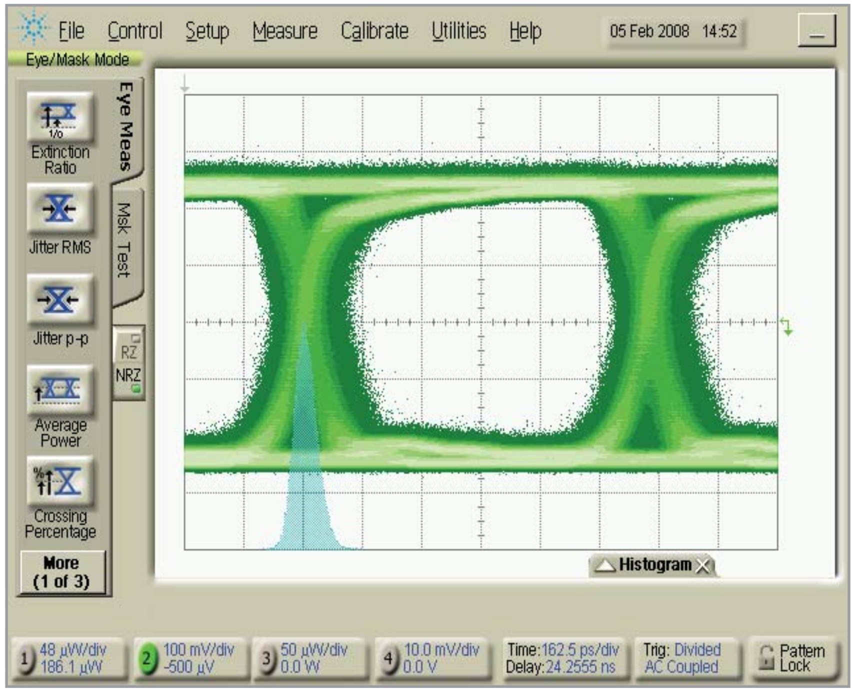

Figure 5. Eye Diagram and histogram of the electrical RX output while the optical input is supplied with an OMA above the compliance requirements

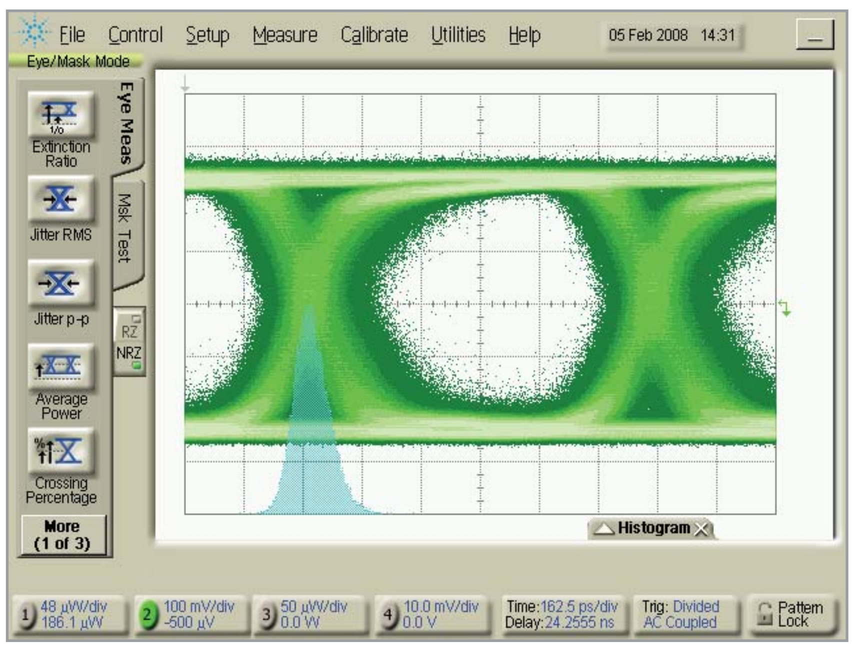

Figure 6. Eye Diagram and histogram of the electrical RX output while the optical input is supplied with an OMA reduced by roughly 2 dB compared to figure 5

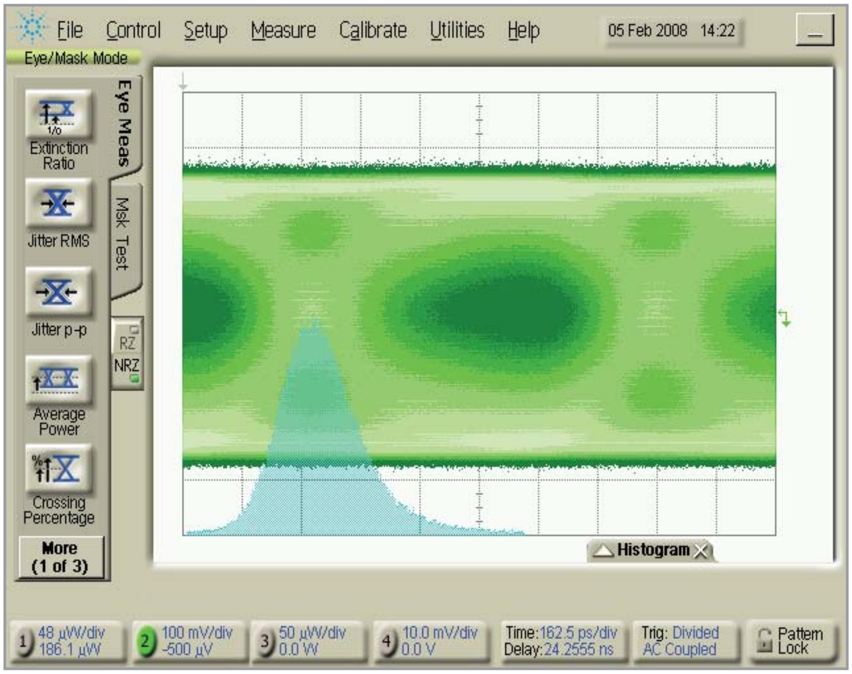

Figure 7. Eye diagram and histogram of the electrical RX output while the optical input is supplied with an OMA reduced by roughly 4 dB compared to figure 5

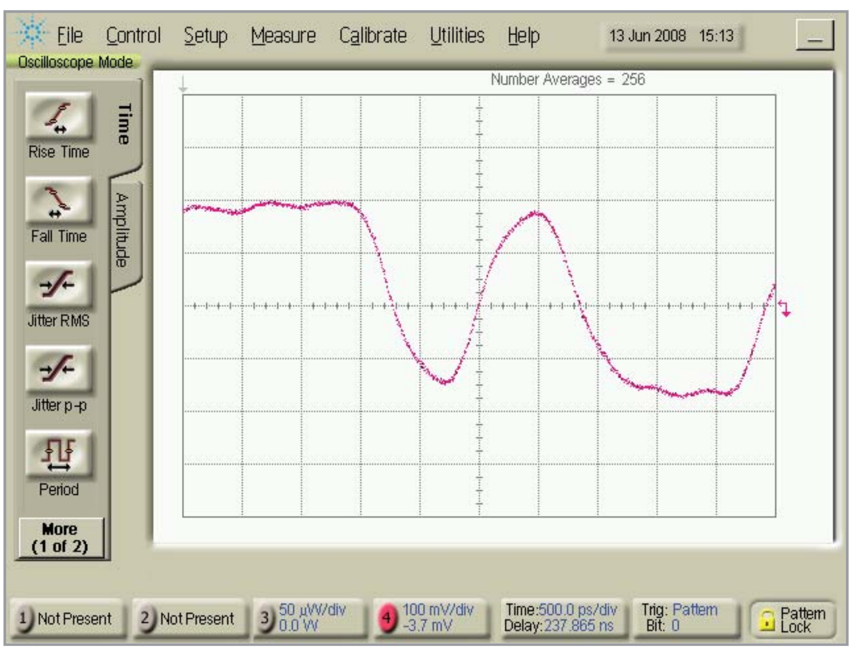

Figure 8. Single valued waveform of the electrical RX output while the optical input is supplied with an OMA reduced by roughly 4 dB against figure 5

So what is the cause of this unexpected behaviour? The answer can be found with the help of the single valued waveform which is represented in figure 8. The 86100C Infiniium DCA-J oscilloscope provides the ‚Pattern Lock' feature, which provides a view of what the individual bits look like within the pattern . Random jitter is removed in this view.

The following conclusion can be taken from this view::
The cause of the asymmetric histogram/eye closure comes from the fact that the transition of the electrical RX signal is not equally straight from start to settle; the slope of the signal is bent, similar to a hockey stick. The signal starts to rise fast. Somewhere at the 50 % point is gets slower and from the 75% point there is some drooping which takes a long time to settle.
When we match this behavior to the entry and exit of the eye we can see the following: the first half of the slope (0 % to 50 %, left side of the histogram) is responsible for the exit side of the eye, as we can see on the right side of the eye diagram. The second part of the slope (50 % to 100 %, right side of the histogram) is responsible for the entry side of the eye we can see this on the left side of the eye diagram. This accurately explains the asymmetry in the eye diagram observed before.

As another consequence of this behavior, the middle point of the remaining eye opening is shifted against the middle of the data cycle defined by the points where the average transitions occur. This average is expressed by the peak point in the histogram. This is analyzed in detail on the following page.

More Measurements on the 1 GbE Optical Transceiver

For the screen shots on this page the electrical output of the optical receiver is connected to the J-BERT N4903A High-Performance Serial BERT.

Using the output timing measurement and varying the optical power gives a set of curves, as shown in Figure 9. From top to bottom (red curve to blue curve) the OMA is reduced in steps of 1 dB. Again the result is the smoother entry into the eye: the left branches of the BERT scan traces are less steep than the right ones. From a certain OMA level the curve does not hit the bottom, so there is no longer an opening with BER = 0.

The output timing measurement allows for specification of the BER Threshold, which is shown as a red line. The intersection between the BER Threshold (set to 1e-3 in this example) and the BERT scans, are indicated with red dots. So the pair of red dots on each BERT scan define the window of eye opening, the value of which can be read in the phase margin column. As can be seen, this window does not stay centric within the eye; the window shifts to the right with the lowering of the OMA.

Figure 10 shows the Eye Opening measurement for the same OMA condition used in Figure 7. The lines with different colors in figure 10 are the contour lines of the same BER value, coded to the legend on the right side. The horizontal markers are spaced by .5 UI. As a result the contour lines have a much wider spacing on the left side than on the right side. This is equivalent to the histogram with the asymmetric slopes in Figure 7. The point with the lowest BER is roughly at .65 UI from the left averaged transition point.

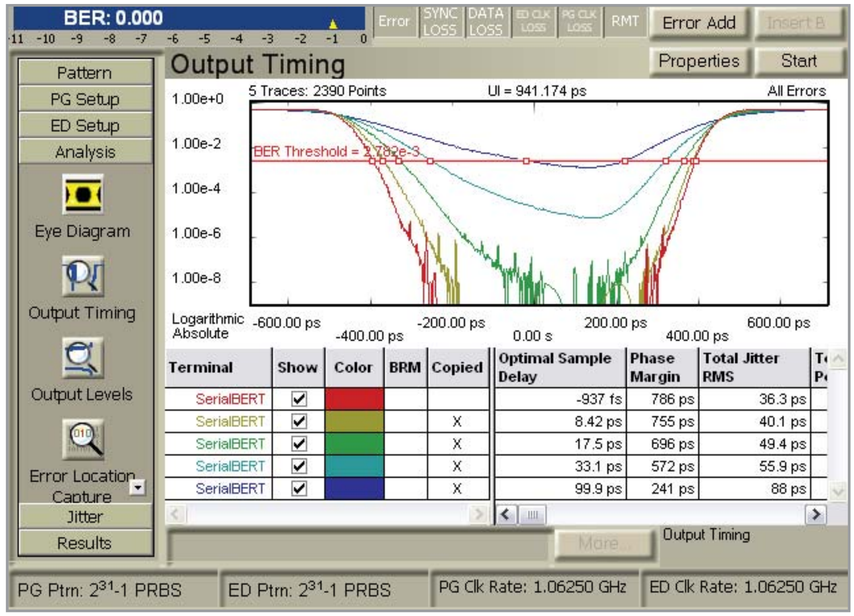

Figure 9. Output timing measurement of the optical transceiver with the help of the N4903A serial BERT while the OMA is varied in steps of 1 dB

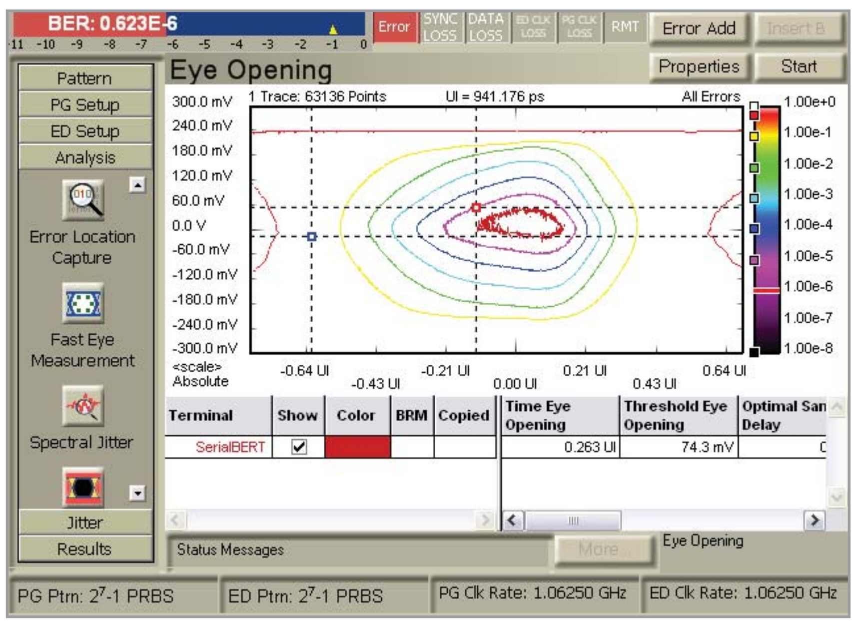

Figure 10. Eye Opening (ISO BER) measurement of the optical transceiver with help of the N4903A serial BERT while the OMA is set to the same value as used in Figure 7

Considerations with the CDR-Based Sampling of the N5980A Manufacturing BERT

The CDR of the N5980A manufacturing BERT will sample the data in the middle of the data cycle as indicated in figure 10 with the right marker. This is not the point of lowest BER in the case of lowering the OMA for non-error free operation.

Best practices

Single ended connection between transceiver and N5980A input should be avoided. Unused inputs should be terminated with the help of a 50 Ohm termination.

Compared with a conventional BERT, where there is a programmable sampling delay, there are two scenarios:

Scenario 1: The AutoAlignment is performed once, when the optical receiver is supplied with a large OMA. This case corresponds to the red BERT scan curve in figure 9. The AutoAlign routine will find the corner points which intersect with the BER threshold and place the sampling point in the middle. This is very much the same point where the CDR does sample.

Scenario 2: The AutoAlignment is performed each time the OMA is changed. The alignment will follow the shift that occurs, by reducing the OMA and the sampling will take place close to the point of lowest BER.

A common measurement for optical receivers is the Sensitivity Measurement. This measurement shows the BER vs. OMA. Figure 11 is an example of such a measurement. Figure 11 compares the sensitivity curve obtained from the two scenarios: ‘BERT CDR‘ is scenario 1, ’BERT AutoAlign’ is scenario 2. One might argue that the curve resulting from scenario 2 is the ‘better‘ curve, but as both curves result from the same device, this is a matter of the testing method.

Conclusions

- On a conventional BERT the sensitivity chart may be obtained by scenario 1 or 2. Depending on the scenario used, there might be a difference of roughly .2 dB of OMA or roughly a magnitude in BER.
- With the N5980A manufacturing BERT the sensitivity measurement can only be scenario 1.
- If this difference is recognized then scenario 1 measurement data could be corrected to match that of scenario 2.
- The BERT with CDR based sampling works in the same way as the environment where the optical module has to operate.

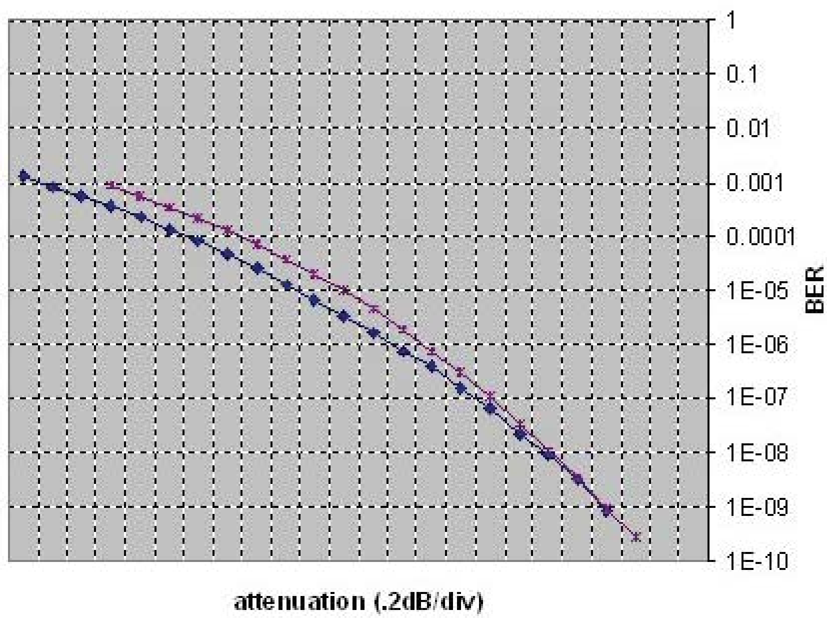

Figure 11. Sensitivity measurement performed with BERT error detector sampling with CDR (fix timing at .5 UI) and timing aligned with help of AutoAlignment before each measurement

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