BER Simulator Development for Link Compliance Analysis

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***Abstract*—This paper is related to developing new Bit Error Rate (BER) simulator, Samsung BER simulator (SBERS), in order to evaluate the link compliance and all kinds of effects of link compliance in a real environment. SBERS allows to generate transmit pulse accurately by using the various parameters, and obtain the eye diagram and bathtub curve, which represents the performance of link, by calculating the transmit pulse and the measured frequency response characteristics. SBERS give results as same as real environment after taking account of distribution and value of noise. To verify the accuracy of simulator, we derive the simulated and measured result and compare eye opening. The difference came out to be within 5% error. It is possible to estimate the real environment and design the transmitter and receiver circuit effectively using new BER simulator, SBERS.**

***Index Terms*—BER simulator, SBERS, link compliance, eye diagram, bathtub curve**

I. INTRODUCTION

Nowadays, the demand for efficient data transmission and reception is growing as the operating frequency of memory chip is increasing. However, it becomes more difficult to overcome the noise, attenuation, and the timing uncertainties caused by channel skew and jitter with high-price channel which has high bandwidth and the power improvement of transceiver circuit.

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In particular, it becomes even more difficult to predict the aspect of errors in data transmission and reception since the effect of noise factors has characteristics of the statistical distribution, in a situation to transmit data within a short period of time of less than 1ns. In other words, it is very important work to guarantee link compliance for the high degree of accuracy.

There are many technologies to overcome the noise and timing uncertainties (Fig. 1). These technologies are applied someday, but no one knows "when" is most appropriate time since there exit cost, reliability issues. Therefore, BER simulator is developed to set up the trade-off relation of the performance, cost, and time issues, effectively.

Link consists of transmitter circuit (Tx), channel, and receiver circuit (Rx). One of the methods to evaluate the link performance is to simulate eye diagram of the incoming

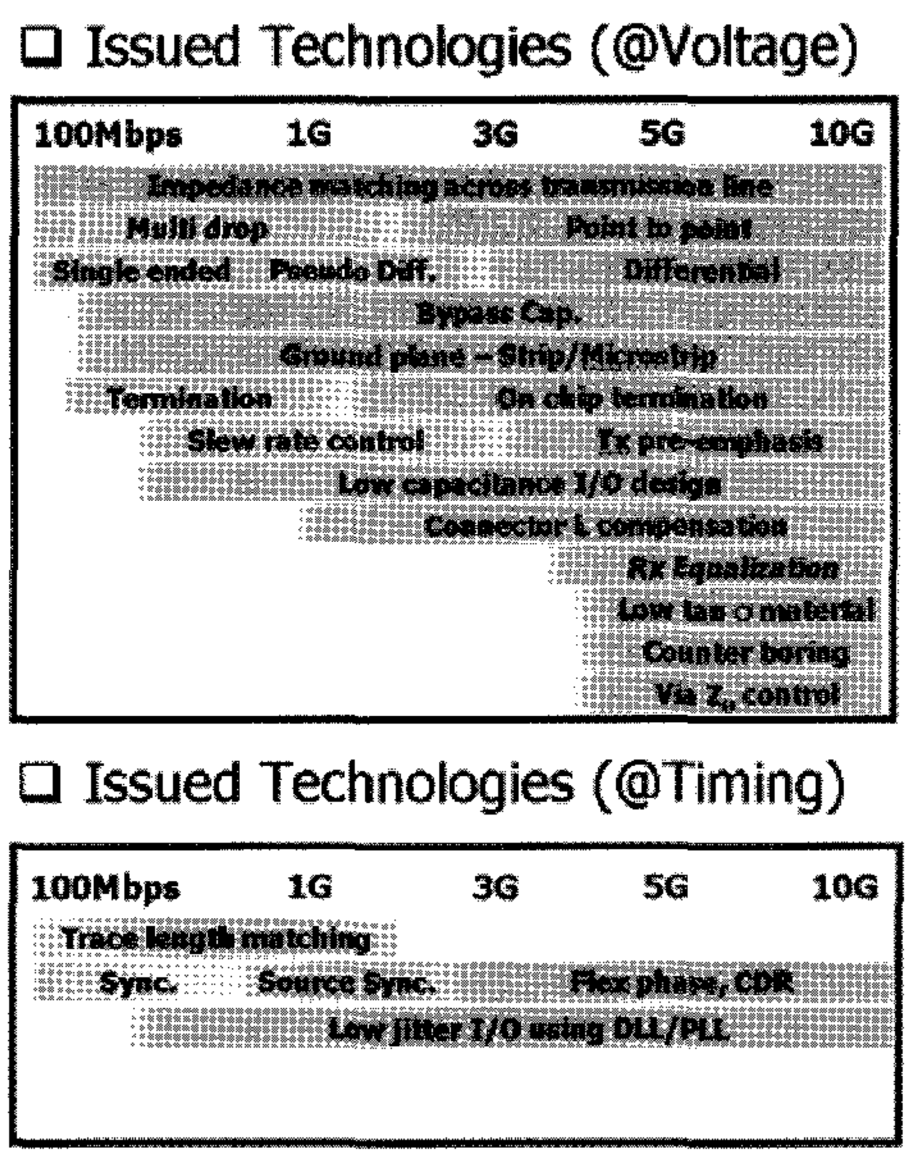

Fig. 1. High-speed technology issues.

signal appearing on the input side of receiver circuit by modeling the link.

There are two kinds of simulators using this method.

At first, the SPICE-based circuit simulator can model the transceiver circuit and channel somehow accurately. But simulation takes too long, and it could not show the effect caused by the distribution of noise factors.

Secondly, impulse response and statistical calculation is used to estimate eye diagram [1,5]. This approach is being given a relatively fast time simulation, and reflects the effect from the distribution of noise factors well. However it is difficult to show the effect of transceiver circuit because this simulator evaluates only channel,

In this research, SBERS is developed to apply all the effect of each components of link in data transmission and reception, with fast simulation time. In this way, it estimates the exact results.

Matlab based SBERS is configured to estimate the BER and eye diagram of target link. It applies a lot of noise factors and evaluates the effects of transceiver circuit which influence the link performance but are not adopted by the previous method.

The following Section introduces the configurations and operation principles of SBERS. In Section 3, the comparison, verification and analysis of simulation result and measurement result are described. The last section concludes research.

II. FUNDAMENTAL CONCEPTS

1. Configuration and Function of SBERS

As shown in Fig. 2, SBERS includes the link components such as Tx, channel, Rx and input parameters that affect BER.

There are many parameters to set up and generate a

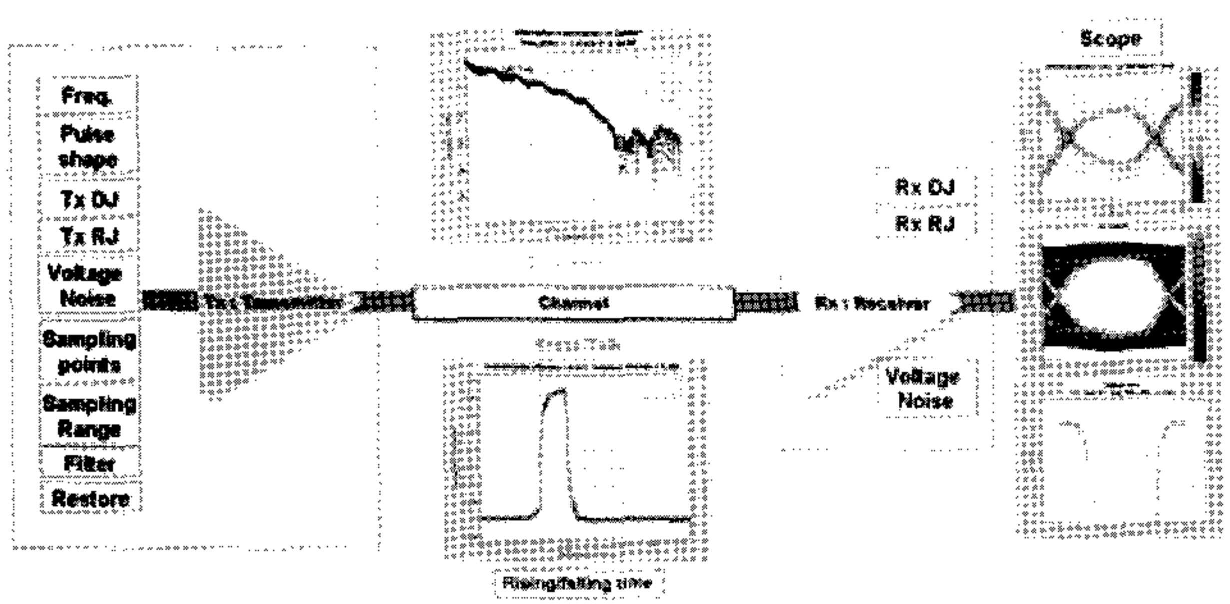

Fig. 2. Configuration of SBERS.

pulse similar to the actual one in Tx. If it is difficult to define Tx pulse using these parameters, measured data can be applied directly.

Channel characteristics is estimated by applying S-parameter measured using Network Analyzer or calculated directly. Also, the effect of the neighbor channels can be evaluated by cross-talk function.

In Rx, it is possible to apply the noise factors that affect link performance, and the outputs are plots such as Eye Diagram, bathtub curve.

There are noises, Tx pulse shape, and channel characteristics in parameters. These parameters influence BER, which is link performance.

At first, noises are separated by timing noise (jitter) and voltage noise largely.

Jitter is the deviation of a transition from ideal time. It is divided by Deterministic Jitter (DJ) and Random Jitter (RJ) [2]. There are clock tree DJ, Driver/Receiver DJ in DJ, and PLL RJ, Driver/Receiver RJ in RJ. And there are Common Mode Noise, Power Supply Noise, Comparator Offset, and Thermal Noise Offset in voltage noise, each can be applied as parameters.

Effects of jitter and voltage noise can be estimated more specifically through itemized Tx, Rx noise parameters in SBERS.

Secondly, Tx pulse shape such as Pattern length, rising/falling time can be entered as important factors which affect the link performance, and the effects of parameters of Tx pulse shape to BER can be estimate.

Finally, the characteristics of the channel like the characteristics of channel substances, noise factors can be evaluated through S-parameter.

Previous simulator used either timing or voltage side approach to analyze the BER, however it can't reflect the actual environment.

While, to solve all these shortcomings, SBERS is improved to evaluate the link performance in both timing and voltage sides and implemented to analyze BER more accurately.

2. Methodology of SBERS

SBERS is BER simulator to evaluate whether the noise factors of the link affect BER or not.

Tx pulse is entered and takes superposition to draw eye diagram, a bathtub curve for BER evaluation. The flow is shown in Fig. 3. When Tx pulse is inputted, it is calculated with channel S-parameter, and the result is Rx signal. Using this Rx signal, output the Eye Diagram, the bathtub curve are outputted and the final goal is to.

If it is difficult to generate one pulse shape using Tx parameters, the result from measuring the pulse response characteristics of Tx except channel can be applied to simulator.

Eye Diagram is obtained by applying Statistical Analysis to Rx Signal [1].

After specifying the arbitrary sample points (Cursor) in Rx signal, amplitudes located at the neighbor of the cursors are nested by adding or subtracting each other.

As the result of the superposition of amplitude, the probability distribution, which is conditional Probability Distribution Function (PDF), is obtained.

This action will continue as long as the number of cursors, and PDFs corresponding to cursors. Therefore, the more accurate distribution is obtained as the number of cursor is getting more,

With 1/2 probability, the number of cases as many as 2^{Cursor} is operated with the superposition of amplitude as many as the number of cursors such as adding or subtracting. [3].

Here, the operation of timing side is needed because conditional PDF considers only amplitudes that is, voltage side.

Using the input jitter, Dual-Dirac plot is obtained [4], signal PDF is acquired by operating from Dual-Dirac plot and conditional PDF.

At last, eye diagram is obtained by connecting the points that have the same value of BER in each signal PDF.

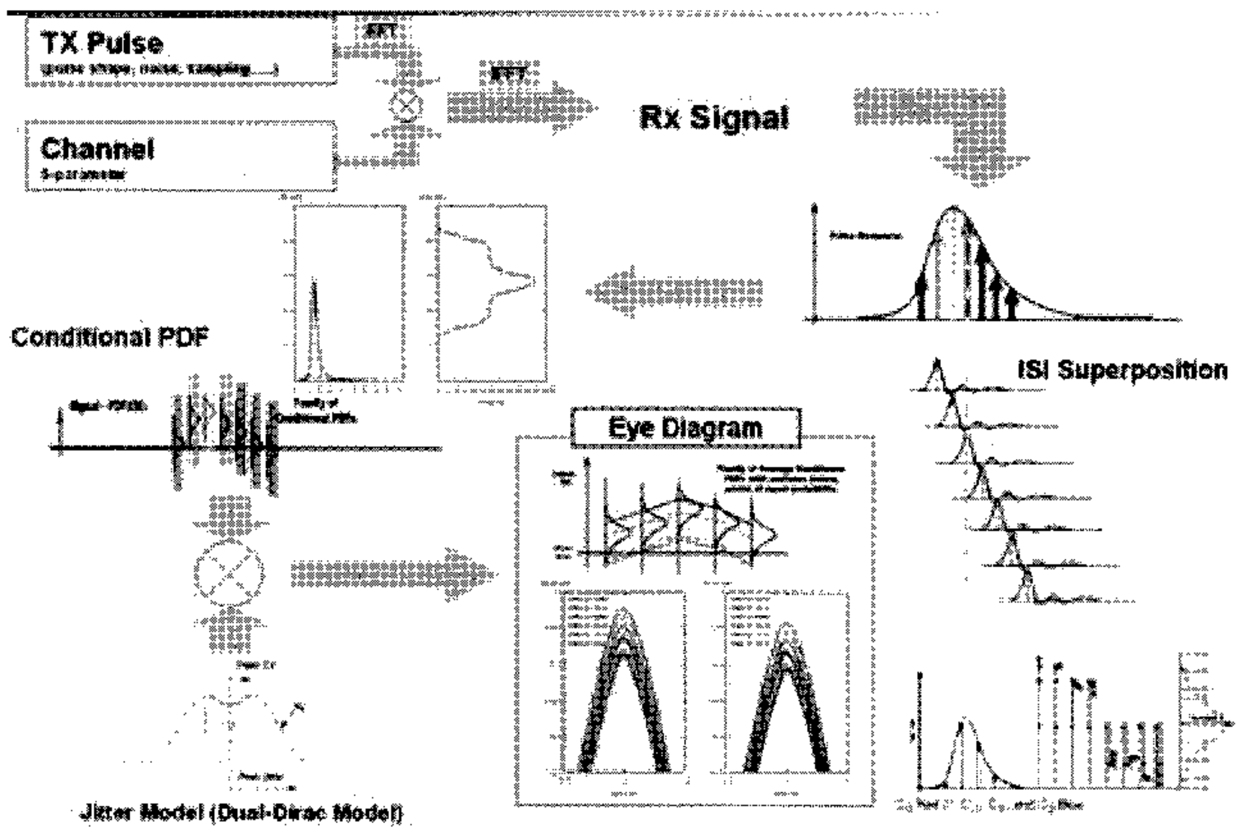

Fig. 3. Methodology of SBERS.

III. Experiment Results

1. Simulation Results

As described previously, several various parameters have effects on the link performance.

To estimate the link performance, Eye Opening and Height is verified with the some parameters such as DJ, RJ, voltage noise, frequency, changing in comparison with the typical condition like Table 1.

In Fig. 4, when DJ increases from 0 UI ~ 0.3 UI, Eye Opening and Height decreases about the value of 0.3UI and 0.03 V, respectively. Eye Opening is linearly proportional to the value of DJ but Eye Height is not.

Fig. 5 is the result of changing RJ. As RJ increases from 0.5 ps(0.0338 UI) ~ 3.5 ps(0.236 UI), Eye Opening and Height also decreases about the value of 0.2 UI and 0.02 V, respectively. The trend is same as that of DJ.

The simulation result for DJ/RJ is that Eye Opening is linear to the value of DJ/RJ but Eye Height is not linear. This seems that the influence of voltage noise is weak because jitter is timing noise. In other words, jitter affects Eye Opening directly and Eye Height indirectly.

Table. 1. Simulation condition.

Target BER	Freq	DJ/RJ	PRBS	Tx voltage	Voltage Noise
10^{-12}	4.8Gbps	0.2UI/ 2.5ps	2^{15}-1	0.2V	0.025V

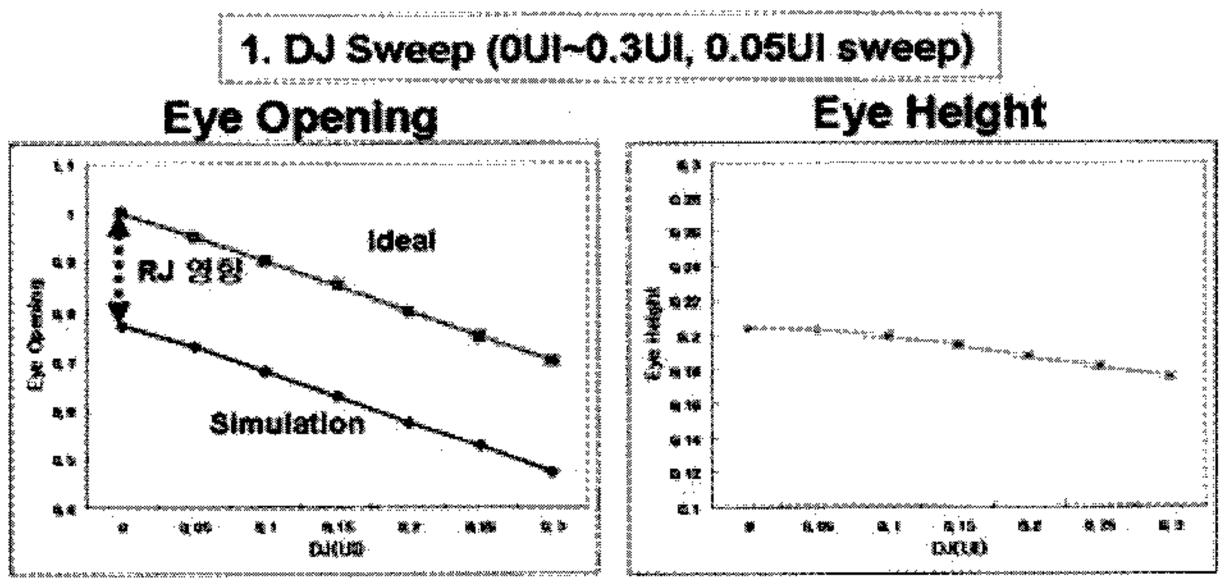

Fig. 4. Simulation result (DJ change).

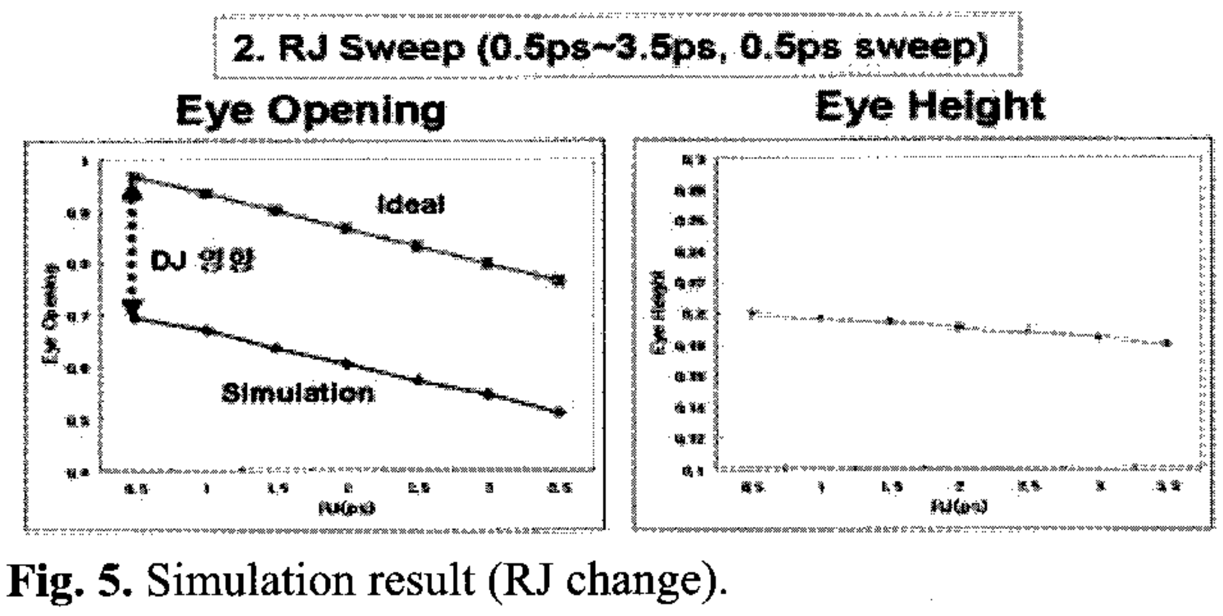

Fig. 5. Simulation result (RJ change).

Finally, Fig. 6 is the result with the frequency changing. Eye Opening and Height is decreased as the frequency increases. The reason is that the Unit Interval (UI) is getting smaller as frequency increases, so Eye Opening and Height both are relatively more affected.

2. Comparison and Verification

To verify the accuracy, the simulation and measurement results near actual environment are compared.

The setups are Tx without channel and with channel. As shown in Fig. 7, pulse generator for jitter injection is J-BERT (N4903A), Sampling Oscilloscope (DCA-J 86100C) is used to measure Eye Diagram.

In addition, like Fig. 8, the channel is configured with coaxial cable and PCB pattern designed to have 50 Ω impedance. The measured 3dB Bandwidth is 1.95 GHz.

Measurement and the simulation results for two criteria are shown in Fig. 9 and Fig. 10.

The left side of Fig. 9 is simulation result of Tx without channel and the right side of Fig. 9 is measurement result. In the same manner, the left side of Fig. 10 is simulation result of Tx with channel and the right side of Fig. 10 is measurement result.

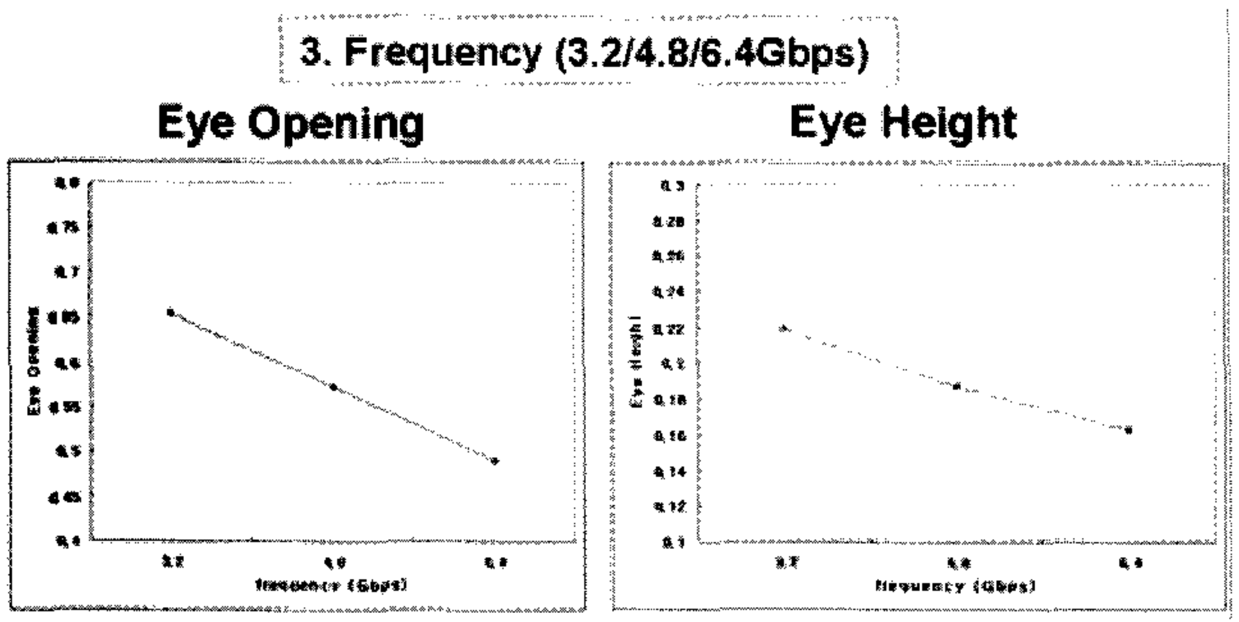

Fig. 6. Simulation result (frequency change).

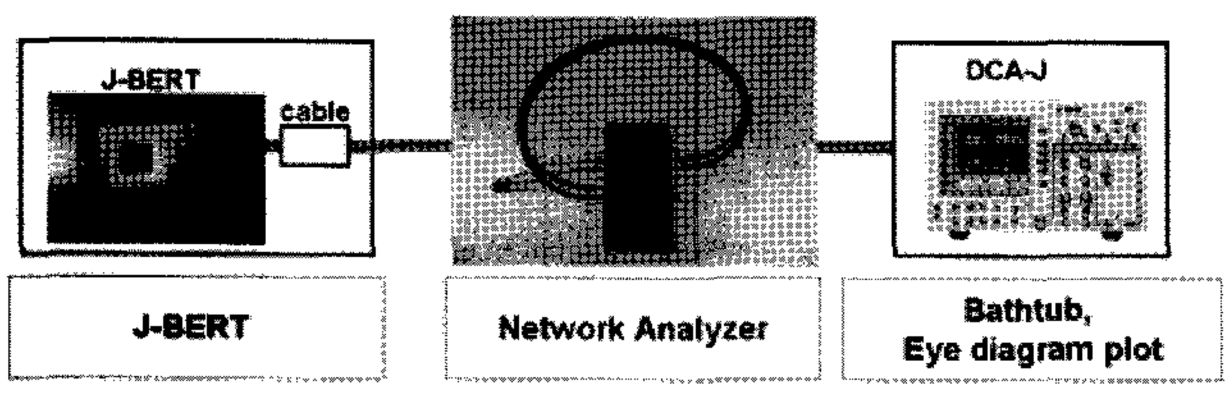

Fig. 7. Measurement set up.

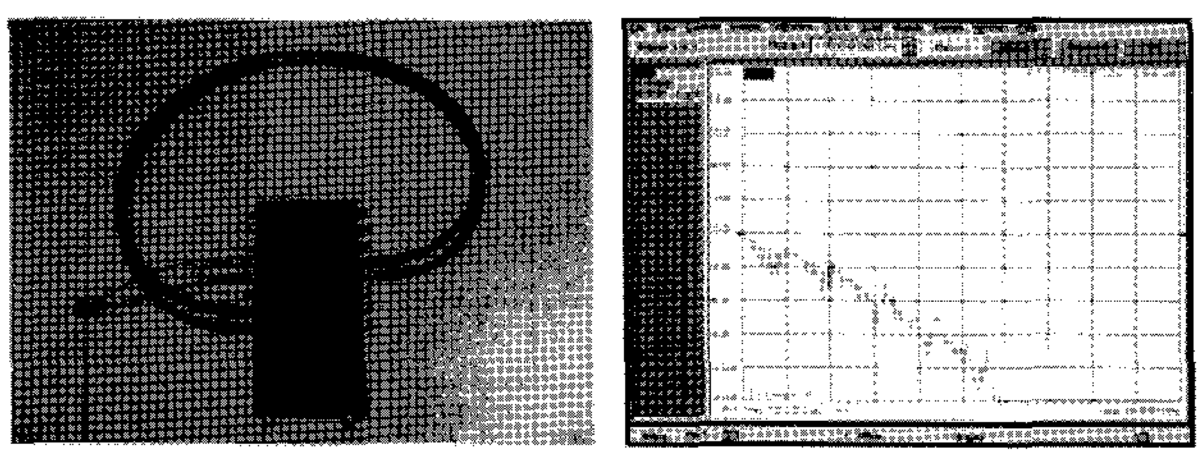

Fig. 8. Channel used in measurement.

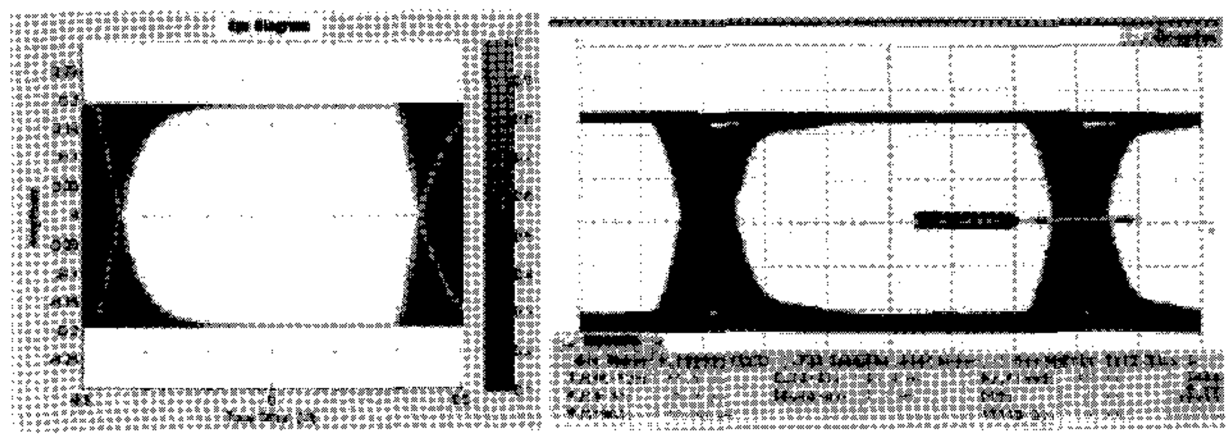

Fig. 9. Simulation vs. measurement result (Tx without Ch.).

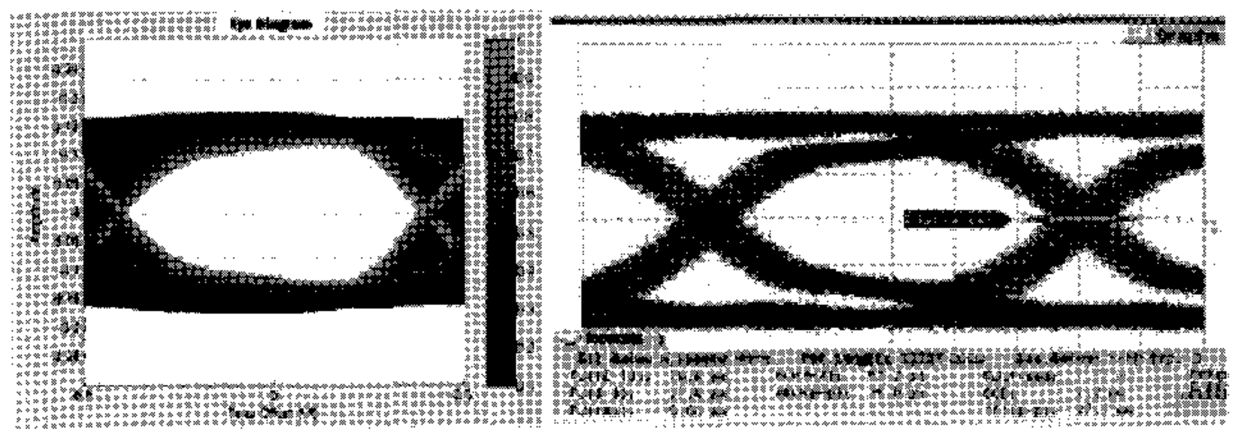

Fig. 10. Simulation vs. measurement result (Tx with Ch.).

Table. 2. Simulation vs. measurement condition & result.

Condition				
Target BER	Freq	PRBS	Tx voltage	Total Jitter (Tx)/ DJ (Tx)/RJ (Tx)
10^{-9}	4.8Gbps	2^{15}-1	0.2V	55.9ps (0.268UI)/ 43.4ps(0.208UI)/ 0.9ps (0.0043UI)
Result				
	Simulation	Measurement	Error	
Fig. 9	0.8200UI	0.8040UI	0.0160UI	
Fig. 10	0.7001UI	0.703UI	0.0029UI	

Table 2 summarizes the results and the conditions in each case.

As a result of comparing the simulation and measurement result, the error between the results is within 1% in the point of Eye Opening, maximum is 5% in other conditions.

IV. CONCLUSIONS

In this paper, BER simulator to analyze the link compliance is developed.

Using various parameters and noise factors, all the effect of transceiver circuit and channel occurring in the real environment can be applied and the accuracy is verified that the simulation result is within 5% in comparison with measurement result.

For better application of the actual environment in simulator implementation, there are some factors to be improved to reduce error. In simulator, there are Tx modeling issues such as limited RJ, uncertainty of DJ, exact pattern, and methodology improvement to calculate Eye Opening and Height accurately and more accurate reflection thermal noise, which is random elements of voltage axis. In measuring equipment, the factors is considered such as primary Jitter raised from J-BERT to DCA-J, measurement error S-parameter extraction from channel Network Analyzer.

For improvement, researches to enhance the accuracy of methodology and ongoing correlation progress through measuring real device cases are indispensable condition. It is required much effort for BER simulator to be same as real environment.

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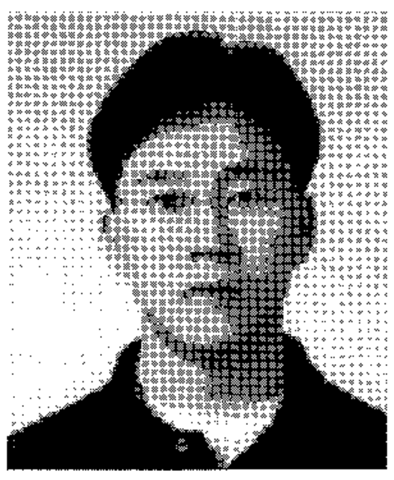

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