Signal Integrity Improvement Method and Its Robustness Evaluation for VLSI and VLSI-packaging

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Abstract: Recently, GHz frequency signal is required to be propagated in the PCB (printed circuit board) with low distortions. And the higher frequency-signal of 10 GHz or more will be also required to be propagated with low distortion in the VLSI in the future. The signal-propagation with low distortion, however, is getting difficult more and more as the frequency increases.

In order to solve this problem and to ensure the signal integrity, we have proposed a novel transmission line called "Segmental transmission Line (STL)" already. In the STL, a transmission line is divided into multiple segments of individual characteristic impedance. The multiple segments are designed to fix the waveform distortion on the transmission line by solving a combinatorial explosion problem using the genetic algorithms.

In our previous paper, we have shown effectiveness of the STL designed to GHz-clock-signal on the computer simulations. And, we have fabricated two scale-up STL prototypes for clock-signal using real PCBs.

In this paper, we input random-signal changing its frequency to the scale-up STL prototype designed to 150MHz clock-signal. And, we show that the STL has high robustness to the random-signals and the frequency fluctuation, which indicates generality of the STL technique.

Keywords: Signal Integrity, Transmission Line, Random Signal, Genetic Algorithms

Ⅰ. INTRODUCTION

Signals of GHz frequency, the wavelengths of which are less than 15cm and are shorter than the PCB, are terribly distorted at the impedance mismatching points in the PCB traces. And this problem will also occur in the VLSIs in the future at the frequency more than 10 GHz.

They have used conventional impedance-matching techniques [1][2] to fix the distorted waveforms. These techniques works well up to hundreds MHz, but will not work well at more than GHz.

In order to overcome this problem and ensure the signal integrity we have proposed a novel transmission line called "Segmental Transmission Line (STL)" [3] .

In the STL, a transmission line is divided into multiple segments of individual characteristic impedance. In this structure, noises are generated purposely at the segments boundaries to cancel the target noises, which occur due to the impedance mismatching between the transmission line and the devices connected to the transmission line. We have shown the effectiveness of the STL to GHz-clock signals on the computer simulation already. Furthermore, we have fabricated two scale-up STL prototypes designed to clock-signals using real PCBs [4][5]. In the scale-up prototypes, the STL for GHz-frequency is designed to be measured in the MHz-frequency domain by lengthening the wire or trace length in proportion to the ratio between the GHz and MHz.

The robustness of the STL designed to the clock-signals, however, has not been evaluated yet in terms of random-signal and frequency-fluctuation, and the purpose of this paper is to evaluate the robustness using the scale-up prototypes. We thus input random-signals to the scale-up STL prototype designed to 150MHz-clock-signal changing the random-signal-frequency and measure the distortion of the waveforms to evaluate the robustness.

Ⅱ. SEGMENTAL TRANSMISSION LINE

The idea of STL is completely different from the conventional methods such as [1][2], in which the impedance mismatching points are tried to be fixed.

In the STL, we use noises that are generated purposely a t segment boundaries to cancel the target noises, which are reflection and transmission-waves that occur due to the impedance mismatching bet ween the transmission line and device-inputs connected to the transmission line. And the target noises are the sources of the waveform distortion at the point where the device-inputs are connected to the transmission line.

To generate these noises purposely, a transmission line is divided into multiple segments of individual characteristic impedance, which can be implemented with adjustment of segment-widths.

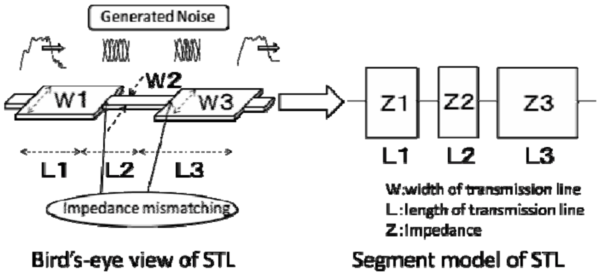

Figure 1: Overview of STL

Figure 1: shows an overview of the STL and its segment-model.

In the STL, it is necessary to obtain the best combination of segment-widths and segment-lengths. It is however next to impossible to find the best combination because of the combinatorial explosion.

For example, 10 widths and 100 lengths for each of 10 segments results in the combination of $(10*100)^{10} = 1.0*10^{30}$. We thus use the genetic algorithms [6] to solve the combinatorial explosion problem and to find semi-optimized combination quickly.

In the GA coding, the chromosome consists of two kinds of loci i.e., one is for the segment-width and the other is for the segment-length. Each chromosome thus represents each STL of multiples segments of individual characteristic impedances and individual lengths. Figure 2 shows the STL design system named STL-Designer, which is composed of a newly developed GA calculation-loop specialized for the STL and the circuit simulator SPICE.

And in the fitness evaluation, each chromosome is translated to the transmission-line net-list for the circuit simulator SPICE and the waveform, which is the result from the simulator, is evaluated compared with the ideal waveform as shown in Fig. 3 . The STL prototypes are fabricated based on the design results from the STL-Designer

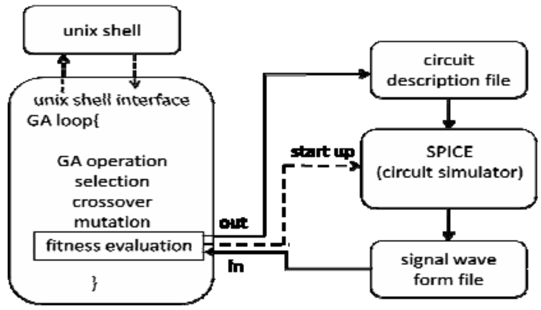

Figure 2: STL design system

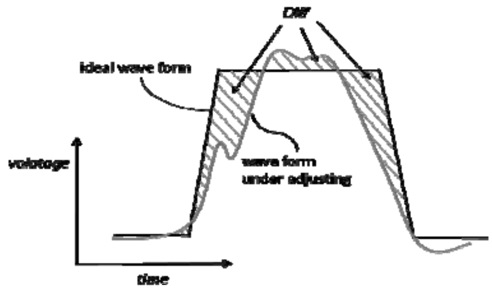

Figure3: Difference between the wave form under adjusting and the ideal wave form

Ⅲ. 150MHz SCALE-UP STL PROTOTYPE

Figure 4 shows the circuit-diagram of the scale-up STL prototype for 150MHz clock-signal [5]. The transmission line of 1m long is divided into 15 segments. Two capacitors of 24pF each represent two device-inputs, e.g., VLSI inputs connected to the transmission line.

Figure 5 shows a distorted waveform observed in the conventional transmission line (left) and a improved waveform observed in the STL prototype (right) at 150MHz clock-signal.

The logical margin is improved to about 0.8 – 1.0[V] in the STL while it in the distorted wave is reduced to about 0.5 – 0.5[V] in the conventional transmission line.

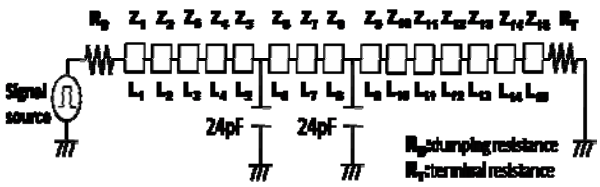

Figure 4: Circuit-diagram of the scale-up STL Prototype for 150MHz clock-signal

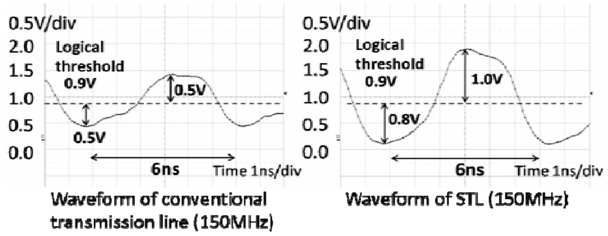

Figure 5: Waveforms at 150MHz clock-signal

Ⅳ. ROBUSTNESS EVALUATION

In this paper, we evaluate the robustness of the 150 MHz scale-up STL prototype designed for clock signal to the random-signal-input and base-clock frequency-fluctuation. We input the random signals generated from 150 MHz base-clock, and we also change the base-clock frequency from 150 MHz.

1. Signal-Generation and Measurement

We made a pseudorandom number generation circuit by using the linear feedback shift register (LFSR), which is one of the famous random number-generation methods.

The LFSR mainly consists of a n-bit shift-register circuit and an exclusive-OR of a feed-back-loop from the shift-register, which generates random cycle length of 2^{n-1}.

In this paper, we used a 7-bit LFSR of 127-bit random-cycle-length as shown in Fig. 6 . We implemented it onto the FPGA in the Virtex5-ML505-board provided by Xilinx Co. and used it as the random-signal-generator.

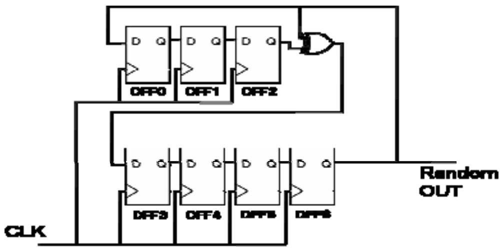

Figure 6: 7bit linear feedback shift register

In the measurements, waveforms are probed with a probe from a digital sampling oscilloscope of 2 GHz band-width and 10

GS/s sample-rate contacted t-o the trace in the prototype.

2. Eye-pattern measurement

Signal integrity of the random signals is usually evaluated in the eye-pattern, or eye-diagram, in which waveforms are overwritten at the clock-frequency interval period (e.g., inverse of the frequency). Its name comes from the fact that the observed patterns look like human-eye, and the eye opens more clearly as the waveform distortion decreases.

In this paper, we define the quality of the signal with the eye-height at 1/4 clock-period after the starting point of the signal switching and with the eye-width at the threshold voltage.

3. Robustness to random-signal

Figure 7 shows eye-patterns to 150MHz random-signal-input observed in the conventional transmission-line (left) and in the STL (right).

In the conventional transmission-line, the eye-height at 1.65 ns (1/4 clock-period) from the switching point is 0.2 [V]. On the other hand, it in the STL is improved to 0.55 [V], which is larger than it in the conventional one by 2.75 times. The eye-width of 2.1 [ns] ns in the conventional transmission line is also improved to 2.6 [ns], which is longer than it in the conventional one by 1.23 times (results are summarized in Tab. 1).

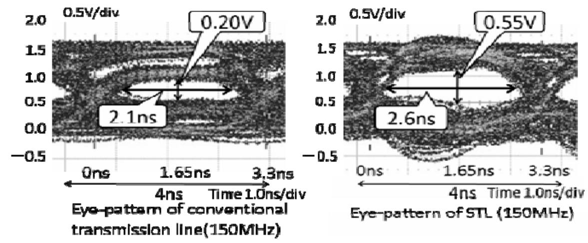

Figure 7: Eye-patterns to 150MHz random-signal

Table 1: Signal integrity improvement at 150 MHz random-signal

	Conventional Transmission Line	STL	Improvement Ratio
Eye-height	0.2[V]	0.55[V]	2.75
Eye-width	2.1[ns]	2.6[ns]	1.23

4. Robustness to Frequency-fluctuation

We change the base-clock-frequency from 150 MHz to 130MHz, 140MHz, 160MHz, and 170MHz in the above experiments. Eye-patterns observed at 130 MHz and 170 MHz are shown in Figs. 8 and 9, respectively, and the signal-integrity-improvements measured at the same points as in the previous section are summarized in Tabs. 2 and 3, respectively.

High robustness in the eye-height, the improvement-ratio of which is 2.25, is still maintained even at 130 MHz. An eye-height improvement-ratio of 1.50, which is not so high as at 150MHz and 130MHz, is also observed at 170 MHz. On the contrary, remarkable improvement is not observed in the eye-width.

In the measurements in this paper, we clearly showed that the STL designed to clock-signal waveform had high robustness to the random-signals and the frequency fluctuation. The results thus indicate generality of the STL technique.

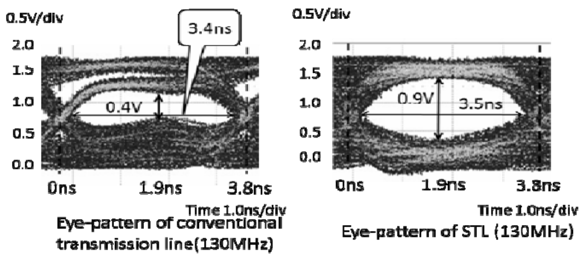

Figure 8: Eye-patterns to 130MHz random-signal

Table 2: Signal integrity improvement at 130 MHz random-signal

	Conventional Transmission Line	STL	Improvement Ratio
Eye-height	0.4[V]	0.9[V]	2.25
Eye-width	3.4[ns]	3.5[ns]	1.03

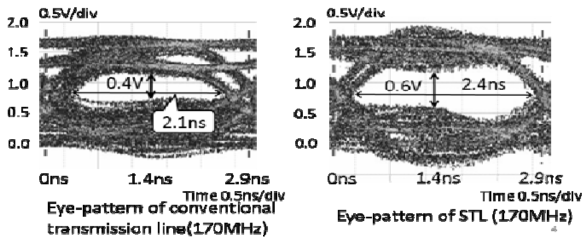

Figure 9: Eye-patterns to 170MHz random-signal

Table 3: Signal integrity improvement at 170 MHz random-signal

	Conventional Transmission Line	STL	Improvement ratio
Eye-height	0.4[V]	0.6[V]	1.50
Eye-width	2.1[ns]	2.4[ns]	1.14

Ⅴ. CONCLUSIONS and FURTHER WORK

We carried out the random and frequency-fluctuated signal-injection-tests to the STL scale-up prototype designed at 150MHz clock-signal. The measured eye-patterns showed high improvement ratio from 1.50 to 2.75 in the eye-height and small ones in the eye-width. The results as a whole indicate high robustness of the signal-integrity improvement-capability in the STL against the random and frequency-fluctuated signals.

The reason of the high robustness, however, is not cleared yet. We will analyze its mechanism in terms of the impulse-response in the frequency domain.

Ⅵ. ACKNOWLEDGMENTS

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