Application of Electromagnetic Field Simulation to 40Gbps Optical Receiver Module Development

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As the signal processing speed of electronic devices increases, transmission capability over 10Gbps has been required for printed wiring boards (PWBs). In designing these PWBs capable of Giga-speed signal transmission, traditional MHz-based signal integrity simulation does not always ensure signal integrity. In 2008, SimDesign Techno-center, a business unite of Sumitomo Electric System Solution Co., Ltd., developed a new method to overcome this problem by combining 3-D electromagnetic simulation and several GHz signal integrity simulations. Since then, this method has enabled us to obtain accurate simulation results even for over 10 Gbps signals.
In this study, this method is applied to 40Gbps optical receiver modules to optimize signal routing with the aim of improving transmission characteristics at over 10Gbps. Firstly, simulation results and measured values are compared to verify the conformity of simulation models. Next, simulation using a 40Gbps optical receiver module model is conducted to consider optimum signal routing. The result shows that this method reduces calculation time without compromising simulation accuracy, and thus increases simulation trial cycles.
Although some differences are found between simulation results and actual measurements, similar transmission characteristics are obtained by changing model shapes and improving the modeling method of the adjacent area of a source injection point. Thus, we have succeeded in eliminating unnecessary design and trial routines by feeding back these simulation results to the actual PWB design process.
This paper describes mainly challenges in the development of this design method using electromagnetic simulations and explains the advantages of the method.

Keywords: 3-D electromagnetic simulation, signal transmission, transimpedance, optical receiver, TIA, signal integrity, 10Gbps, simulation based design, electronics device

1. Introduction

As the signal processing capability of electronic equipment has increased in recent years, printed wiring boards (PWBs) used for the electronic equipment have required increasingly high transmission capability over 10Gbps. For designing these PWBs, traditional simulation methods cannot always ensure signal integrity. To solve this problem, three-dimensional (3-D) electromagnetic field simulation technique has been developed in the SimDesign Techno-center.

In this study, the simulation technique was applied to the design of a 40Gbps optical receiver module to optimize its wiring pattern shape for characteristic improvement. The simulation results and actual measurements were compared to verify the correspondence of the simulation model to the actual signals. The number of trial cycles was increased by shortening simulation time without sacrificing accuracy. Results obtained by the simulation using a 40Gbps optical receiver module were applied to the actual design to achieve excellent characteristic improvement.

In this paper, we introduce our approach to problem solving, and report on the effectiveness of the electromagnetic field simulation in concurrent design development.

2. Electronic Equipment Design Using Simulation

SimDesign Techno-center, a business unit of Sumitomo Electric System Solutions Co., Ltd., specializes in concurrent design including circuit design, FPGA (field-programmable gate array) design, mechanical design and PWB design. Our simulation-based design method consists of the structural simulation, thermal analysis, transmission line simulation and EMC (electromagnetic compatibility) simulation, conducted at each stage of the design process (**Fig. 1**). We have consol-

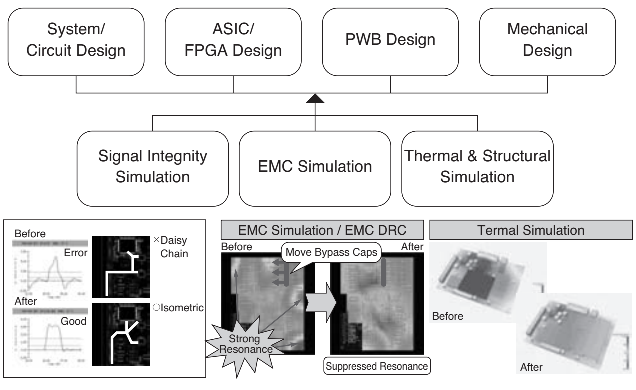

Fig. 1. The Simulation-based design method

idated the design techniques of each stage with the best simulation technique to complete the design. This method contributes to efficient product design improvement by saving on costs and time for building many sample products.

3. Approach on Electromagnetic Field Simulation

As the processing speed of electronic equipment rapidly increases, PWBs which are capable of transmitting signals at 10Gbps or more are increasingly required. Therefore, we have developed 3-D electromagnetic field simulation technology to improve the simulation accuracy in Gbps high-speed signal transmission. This simulation technology was achieved by using Simulation Technology Research Center's license and simulation environment. Thus, technical advice and know-how about simulation techniques were shared between us.

3-1 Simulation Flow and Features

① Two-dimensional information of drawings and DXF (Drawing Exchange Format) data are converted into 3-D models by using 3-D CAD (computer-aided design) technology.

② The 3-D models are imported by simulation tools, and various conditions, including the physical property, frequency range and convergence condition of dielectric materials, are set to the model.

③ Electromagnetic field simulation is conducted to calculate the frequency response. Resultant characteristics are checked to find the optimal structure and wiring pattern.

④ Eye-diagrams are computed based on the results of the electromagnetic field simulation if required.

The features of this simulation flow are as follows:

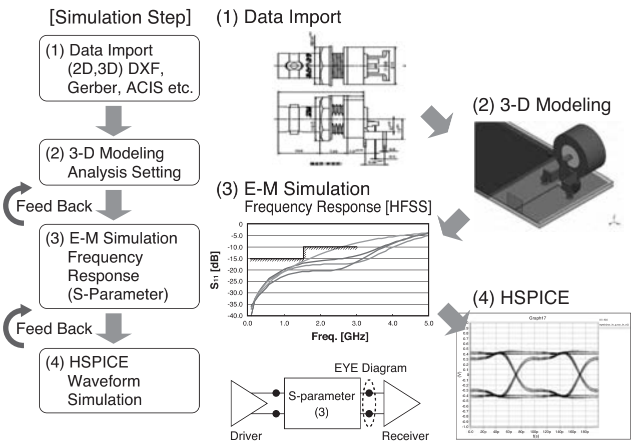

Fig. 2. Flow of the electromagnetic field simulation

① Accurate modeling of 3-D structure

Model input is necessary for the electromagnetic field simulation. The 3-D CAD using the mechanical design technology enables fast and accurate modeling.

② Eye-diagram simulation using transmission line simulation tools

The accuracy of the eye-diagram simulation is improved by the use of the frequency response obtained by the 3-D electromagnetic field simulation.

In this report, we introduce an example of the electromagnetic field simulation where these features are fully demonstrated. The 3-D electromagnetic field simulation is applied to a 40Gbps optical receiver module.

4. Applications of Electromagnetic Field Simulation to Optical Receivers

Optical receivers are important components that convert optical signals into electric signals and used in optical communication systems which connect network devices. The optical receiver used in this study employs a transimpedance amplifier (TIA). **Figure 3** shows a simplified configuration diagram of the receiver. Optical signals are received with a photodiode (PD) and converted into minute current signals, and further converted into voltage signals after amplified by the TIA.

Figure 4 shows the arrangement image of each part.

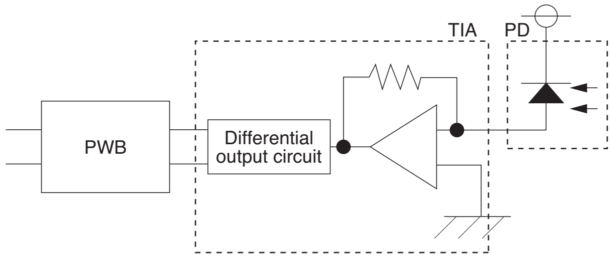

Fig. 3. Simplified configuration diagram of the optical receiver

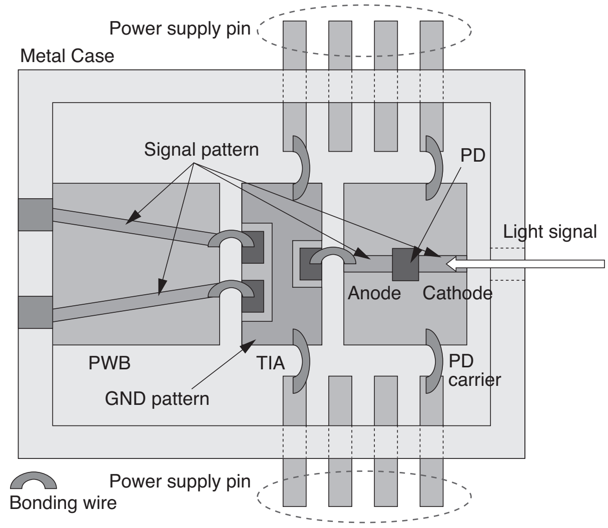

Fig. 4. Arrangement image of each part

These parts are connected to each other with bonding wire. Power supply pins penetrate the case to the inside of the module and are also connected to respective parts with bonding wire. A PD is placed on the substrate called PD carrier.

The PD carrier has a pattern connected to the anode side and the cathode side of the PD. The anode side is connected to the input pad of TIA via bonding wire, whereas the cathode side is connected to the ground via a capacitor. Transimpedance (Zt) is used as a parameter which evaluates the characteristic of this optical receiver. Zt means the ratio at which the input current to TIA is output as a voltage. The goal of the analysis is to obtain an ideal Zt for characteristic improvement.

An optical receiver to which the electromagnetic field simulation was applied showed unfavorable peaks in Zt characteristics. We built a simulation model based on the measurement result, and then examined improvement ideas by using the model.

4-1 Problem with actual sample

Figure 5 shows measured Zt characteristics of an actual sample. Unfavorable peaks observed in the frequency band from 17GHz to 22GHz. We first reproduced these peaks in simulation.

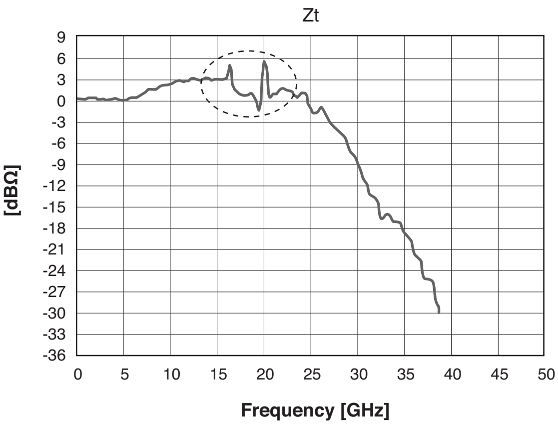

Fig. 5. Zt measurement result with an actual sample

4-2 Confirmation of simulation method

(1) Building a simulation model and calculating the frequency response

To build a simulation model, DXF data was converted into 3-D data by using 3-D CAD technology. The simulation model was made to resemble the actual structure. We analyzed the electromagnetic field by using this model as an initial model and obtained the frequency response.

In this study, we used a 3-D electromagnetic high frequency structure simulator (HFSS), adopting the finite element method (FEM). Generally in FEM, simulation time increases according to the number of elements. We made changes with regard to the following two points to shorten the simulation time.

① The shapes of both the cross-section of bonding wire and a via hole were changed from round to square.
The number of elements increases when round-shaped portions are included. To reduce the number of elements, every round-shaped portion, including the bonding wire cross-section and via hole, was changed to square shaped.

② The thickness of a conductor is ignored, and only skin effects are considered.
The thickness of the thinnest conductor used in this model is 2.3um, which is very thin compared with the whole model dimension. The number of the elements around the conductor increases when such a thin conductor is used for modeling as it is. Therefore, we considered using the model which allows us to ignore the thickness of the conductor.
Generally, skin effects are generated, as high frequency current passes the conductor. That is, the current passes only the surface of the conductor, and hardly passes the inside. When it comes to the conductor with the skin depth of 1/2 or less of the conductor thickness, the conductivity is obtained only by the skin effect. Therefore, conductivity can be realized in the seat form without considering the thickness. In this simulation, the skin depth is equal to 1/2 of the thickness of the conductor when the frequency is at 5GHz, and therefore the thickness of the conductor can be ignored.
In this model, because the frequency band to be considered is 17GHz or higher, the conductor thickness also can be ignored. Thus, the number of the elements was remarkably reduced.

As shown in **Table 1**, simulation time was shortened by 90% due to the improvements described above.

Table 1. Shortening simulation time

	Number of meshes	Memory Used [GB]	Simulation time ratio (*1)
Before applying ①, ②	500k	11.4	1.0
After applying ①, ②	100k	1.1	0.1

(*1) The simulation time ratio refers to the ratio in comparison with the simulation time before and are applied.

(2) Calculation of Zt

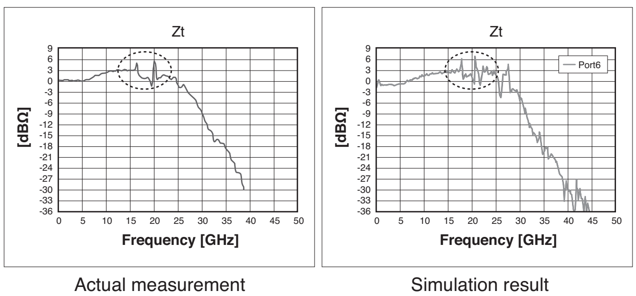

Fig. 6. Zt characteristics of the initial model

The frequency response obtained by the process described in (1) is regarded as an S parameter model, and Zt is calculated by using a transmission line simulation tool. **Figure 6** shows the results. In the simulation, the unwanted peaks and dips seen with the actual sample in the frequency band of 17-22GHz was reproduced. We examined the improvement idea based on this initial model.

4-3 Examination of Zt improvement plan

To investigate the cause of the unwanted peaks and dips in Zt characteristics, the electromagnetic field distribution and the current density of each part were examined. However, remarkable disorder was not found. Therefore, we carried out the investigation by comparing changes in Zt characteristics associated with changing model shapes. The results show that when the shape of the cathode side pattern of the PD carrier is changed, the characteristic disorder in the area of 17-22GHz is improved. The simulation result of Zt characteristics using the improved model is shown in **Fig. 7**.

Small dips are still observed in **Fig. 7**. We conclude that this small dips are due to the resonance caused by the parasitic inductance and the equivalent series resistance of the capacitors which were added to the model to improve the Zt characteristics. The parasitic inductance and the equivalent series resistance were generated because of the single-layer structure of the simulation model. These factors are suppressed with the actual capacitor which has a multi- (not single) layer structure, and therefore the small dips observed in **Fig. 7** should not occur in the actual sample. We reviewed all the above-mentioned results with the members in the Transmission Devices R&D Laboratories to design an improved model.

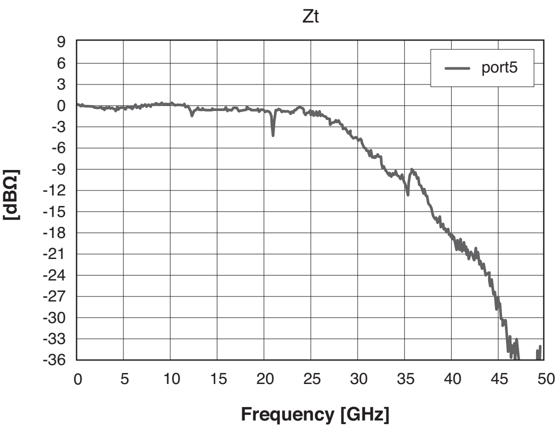

Fig. 7. The simulation result of Zt characteristics of the improved model

4-4 Result

Figure 8 shows the measurement result of the improved actual sample. The unwanted peaks and dips seen in the frequency band of 17-22GHz have been decreased to the similar level seen in the simulation result. As the improvement of TIA has been promoted at the same time, Zt characteristics have also been improved at 25GHz or higher frequency compared with the result shown in **Fig. 7**.

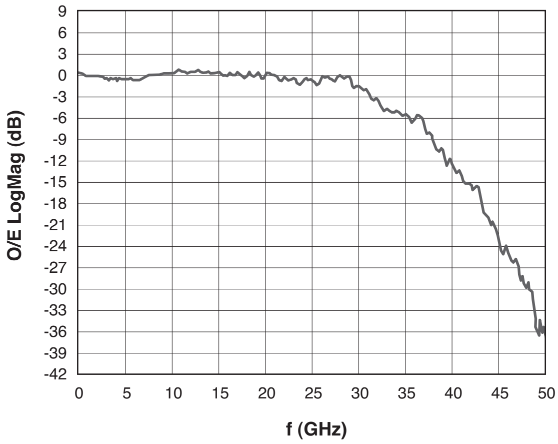

Fig. 8. Measurement result of the improved actual sample

In this study, we investigated the cause of the unwanted peaks and dips seen in Zt characteristics, and carried out simulations by using a revised design to improve the characteristics of the actual sample. As a result, we have established a simulation method of applying the electromagnetic field simulation to optical receiver design. This simulation method has advantages in considering improvement models, particularly in verifying characteristics of various structures by combining several kinds of analyses.

5. Conclusion

In this paper, we reported on the effectiveness of the electromagnetic field simulation technology for the design of PWBs over 10Gbps. We are planning to study the correlation between Zt characteristics and signal waveforms through the computation of eye diagrams by using this simulation method. We are also working to develop further accurate, high-quality design technique based on this result so as to contribute to the development of telecommunication and other electronic equipment.

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