Electromagnetic Field Analysis for Next-Generation Optical Transceivers

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The demand for high-speed data communication systems has been increasing to accommodate huge data communication traffic resulting from the growth of smartphone and cloud computing services via data centers. This trend has generated a strong demand for high-speed optical transceivers. To transmit electric signals without distortion, transmission lines are designed with a due consideration of characteristic impedance. Nevertheless, electric signals tend to be distorted by unexpected factors on actual circuit boards. These factors often consist of signal integrity, power integrity, and electro-magnetic interference/electro-magnetic susceptibility, which are correlative to each other. For these problems, electromagnetic field analysis plays an extremely important role. This paper describes typical contributing factors, as well as problem examples and their solutions extracted by electromagnetic field analysis.

Keywords: high-speed signal, signal integrity (SI), power integrity (PI), electro-magnetic interference (EMI) / electro-magnetic susceptibility (EMS), electromagnetic field analysis

1. Introduction

In recent years, data communications equipment has started to handle rapidly increasing volumes of data due to the widespread use of smartphones, video streaming services in high-definition (HD) and 4K formats, and communications for the Internet of Things (IoT). Data centers that manage these data are required to provide higher-capacity and faster data communications. In tandem with these advances in data communications, optical transceivers are required to support high-speed data communications. An optical transceiver is a module that converts optical signals transmitted over an optical fiber line to electrical signals or vice versa. It is an indispensable component in optical networks. As with many other electronic devices, optical transceivers are subject to problems such as electromagnetic interference (EMI) by unwanted radiation from incorporated electronic components and electromagnetic susceptibility (EMS) to EMI. Electromagnetic field analysis is an effective method of addressing these problems, and the need for this analysis increases when dealing with faster transmission signals.

2. Relationships between Signal Integrity, Power Integrity, and EMI/EMS

Signal integrity (SI) is a term indicating the quality of a signal to ensure proper transmission of digital signal waveforms (generally, pulse waves) from the driver to the receiver in a digital circuit. Power integrity (PI) is a term used to express the quality of the power supplied to working devices in a digital circuit. The following is a discussion of the relationship between SI, PI, and EMI/EMS.

To ensure SI with an ideal transmission line, the designer needs to simply focus on whether the transmission line will give the required characteristic impedance. However, in practice, when the device that transmits digital signals (hereinafter, the "driver") is mounted on a printed circuit board (PCB) and connected to a signal receiver by a transmission line, the matter is not as simple as this. For example, there are three driver states: low, high, and the transition from low to high (or vice versa). An electric charge is carried from the power source to the driver in a high state or when shifting to a high state. This implies that the power source is switching ON and OFF at the same speed as the signal transmission. This process is not problematic as long as the power source supplies a large enough electric charge to the driver. However, the driver may become unstable if it is separated from the power supply by some distance or is connected by thin lines. This is because of the time required for the power supply to electrically charge the driver. For example, assume that the driver is separated from the power supply by some distance. When the driver is turned ON, the electric charge present in the power line is carried to the driver at once. Subsequently, when the driver is turned OFF and then ON, if the power line connected to the driver does not carry a sufficient electric charge, the driver may fail to operate. These variations in the power supplied are termed power supply voltage fluctuations, and they increase with the number of signal channels through which the driver transmits signals. Use of thin lines for fast switching power supply results in an increase in the inductance of the power line. This inductance generates a counter electromotive force with the switching of the power supply when the electric charge being carried to the driver is turned ON/OFF. As a result, the power line does not carry a sufficient electric charge for the driver to operate properly.

The two causes of this failure to carry a sufficient electric charge to the driver lead to a decrease in the SI because the rise of the leading edge of the waveform transmitted by the driver is delayed. In this condition, the driver fails to output the input signal, producing a distorted signal (jitter) or a suppressed signal amplitude. In this way, SI is correlated with PI.

Meanwhile, repeated supply voltage fluctuations resulting from switching during signal waveform transmission cause various high-frequency signals to be propagated through the power lines. These supply voltage fluctuations are one of the factors that affect EMI, and so EMI is also correlated with PI. Additionally, in some cases, unwanted electromagnetic noise radiated as EMI disturbs other power lines and may cause supply voltage fluctuations, resulting in the described phenomenon associated with PI and SI. Consequently, complex correlations are present between PI, SI, and EMI/EMS, as shown in Fig. 1. When investigating the causes and looking for solutions, it is important to identify the problems and their locations.(1)-(3)

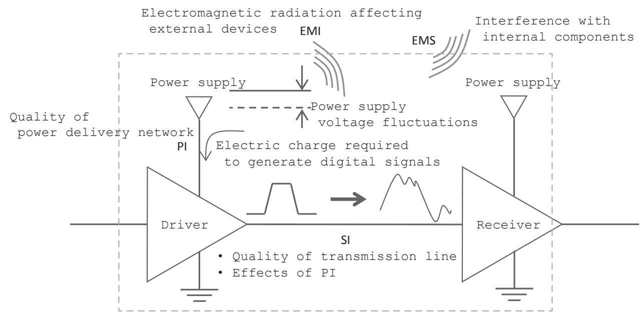


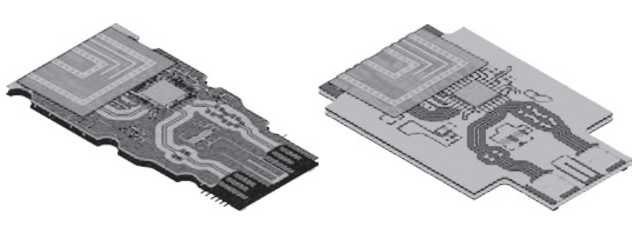
Fig. 1. Schematic diagram of SI, PI, and EMI/EMS

3. Using Electromagnetic Field Analysis to Improve Signal Quality

Electromagnetic field analysis is a highly effective way of solving the problems described above. The following three examples use the analysis to improve the signal quality.

3-1 Applying electromagnetic field analysis to EMI

To control these EMI effects in PI design, one effective way is to reduce the impedance of the power supply. This is because of the same electric charge carried to the device (the same electric current flows), according to Ohm's Law, reducing the impedance will reduce the supply voltage fluctuations. One typical method of reducing the power supply impedance is to insert a capacitance between the power line and the ground near the device. However, for the high-frequency components, the inductance present in the actual capacitor reduces the effect of this technique. As a solution, to reduce the EMI, the power line is run between large conductive areas at ground potential (ground planes) on the PCB to generate a pseudocapacitance between the power supply and ground planes and thus reduce the power supply impedance. Figure 2 shows the electromagnetic field analysis model used to analyze and test this technique. Model (a) is an unimproved model in which the power lines are not run between ground planes. Model (b) is an improved model with the power lines running between ground planes. Although in this analysis model, the device power supply and grounding are represented as short-circuited. The frequency characteristics of

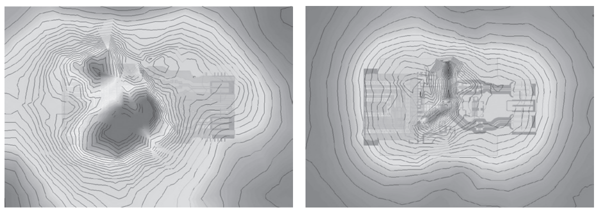


(a) unimproved model (b) Improved model

Fig. 2. Electromagnetic field analysis model

the other mounted components are incorporated into the circuit analysis and then transferred to the electromagnetic field analysis.

Figure 3 shows the electric field distribution 4 mm above the two PCBs. The power lines in model (a) are not trace between ground planes. In this case, the electric field distribution is strong at the center of the PCB, with strong radiation spreading outwards to the edges of and upwards from the PCB. In comparison, in model (b), in which the power lines are trace between ground planes, the electric field is weaker than in model (a), demonstrating the effectiveness of this technique.



(a) unimproved model (b) Improved model

Fig. 3. Analysis results

3-2 Applying electromagnetic field analysis to EMS

Figure 4 shows the layout of an optical transceiver. The metal case contains a control PCB, a transmitter optical subassembly (TOSA) that converts electrical signals to optical signals, and a receiver optical subassembly (ROSA) that converts optical signals to electrical signals. These components are closely housed together in the same case, meaning that electromagnetic emissions from the subassembly or the PCB will affect other power supplies or other devices on subassemblies or PCBs in more than a few cases. Technically, there are two ways of dealing with EMS in such cases. One is to address the problem at the source of the electromagnetic emissions (OSA or PCB), while the other is to focus on the affected components. In general, it is simpler to solve the problem at the source, as with the EMI considerations discussed in 3-1. However, some components may be affected by weak electromagnetic emissions that are not caused by EMI. In these cases, it is necessary to devise solutions after clarifying how the external electromagnetic waves reach the affected device.

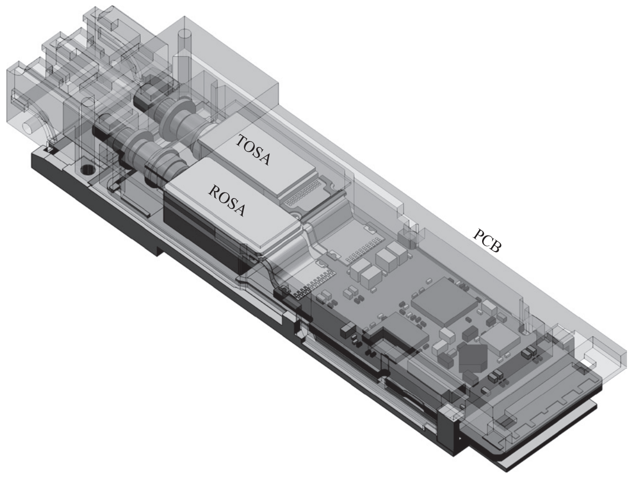


Fig. 4. Structure of optical transceiver

This paper describes an example in which emissions from the TOSA affected the ROSA. The effect of the emissions and the solution were both determined by electromagnetic field analysis.

Figure 5 shows an analysis model. After determining by experiment that electromagnetic emission noise (hereinafter, "noise") from the TOSA affected the ROSA, we substituted the TOSA with a simple antenna to simplify the analysis model. A simplified analysis model reduces the time taken for the initial analysis. It is also expected to reduce the analysis time when seeking solutions. Although our preliminary assumption was that the noise was entering through the non-metalized opening at the side of the ROSA, the initial analysis results revealed that the noise was actually coming from the direction of the mounting pad on the ROSA package (the direction indicated by the arrow with the dashed line in Fig. 5). The mounting pad comprises a high-speed signal line block and a power line block. The high-speed signal lines were fully shielded by ground planes to protect them from noise and to avoid any induced noise. In contrast, the power lines were not being shielded effectively by the ground planes. As a result, noise was induced in the power line and entered the ROSA.

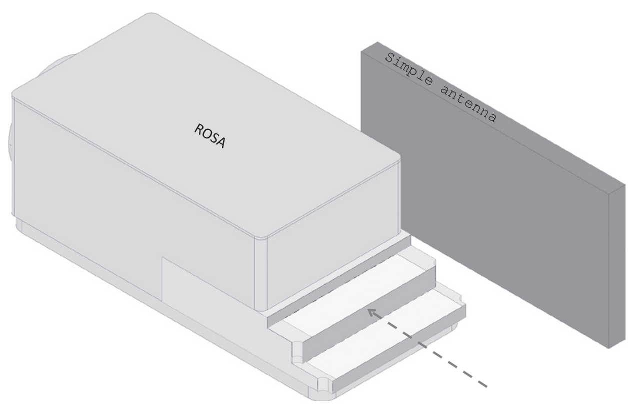


Fig. 5. EMS analysis model

Next, it was necessary to devise a technique to prevent the noise from propagating to the ROSA. We added a circuit constructed to prevent noise entering the ROSA package.

3-3 Applying electromagnetic field analysis to the SI

Optical transceivers transmit pulse amplitude modulation 4 (PAM4) signals in addition to non-return-to-zero (NRZ) signals to meet the need for faster transmission of electrical signals. There is a reason for this. When transmitting a high-speed NRZ signal on a PCB, as the signal rate increases, the signal contains a wider band of frequency components. This implies the need to be able to transmit faster signals with higher-frequency components without any problems. However, the signal suffers increasing attenuation with frequency due to dielectric loss and losses associated with the surface roughness involved in achieving a close bond between the conductors and the PCB. One possible solution is to raise the data transmission rate by adding transmission channels, while maintaining a constant transmission speed for the NRZ signals. This technique requires space for additional components on the PCB and a suitable layout for the high-speed signal line. This brings the PAM4 signal into focus, which uses amplitude thresholds other than 0 and 1. The PAM4 signal incorporates four voltage levels to double the data rate without altering the signal transmission speed. In a simple comparison, the lowest voltage in PAM4 is one-third of that in NRZ. For this reason, it is necessary to first estimate the effects of losses on the SI through an electromagnetic field analysis.

Figure 6 shows an example of the SI analysis model. This model has various transmission lines that differ in length, with some parts of lines passing into the inner layer. This analysis model was created by adding thickness data to two-dimensional computer-aided design PCB data. The trace incorporated in the model comprised transmission lines and part of the ground pattern, because the SI analysis requires a signal transmission line and a ground that carries the return current. The part of the ground pattern that was determined by experience to be unnecessary was removed.

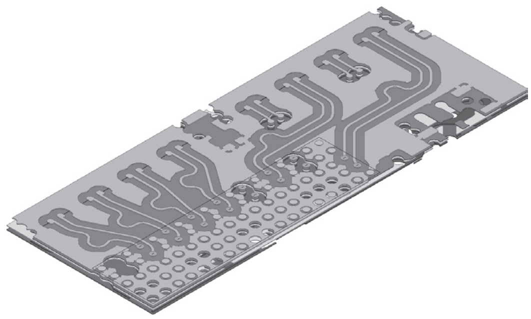


Fig. 6. SI analysis model

Figure 7 shows the frequency-domain analysis results for the transmission characteristics of the various lines shown in Fig. 6, where the insertion loss was closer to zero and signals were transmitted with reduced losses. Some lines required vias*1 and lands*2 to pass from the outer layer into the inner layer and pass through the inner layer. Even with this design, the lines did not exhibit any significant difference in characteristics and performed favorably. Lines that showed different peak-to-peak intervals are accounted for by differences in the line lengths. How the PAM4 signals represented as time-domain waveforms will be distorted cannot be determined by the frequency-domain transmission characteristics shown in Fig. 7, and so the electromagnetic field analysis results were transferred to a circuit analysis process to carry out a time-domain analysis. The results are shown in Fig. 8.

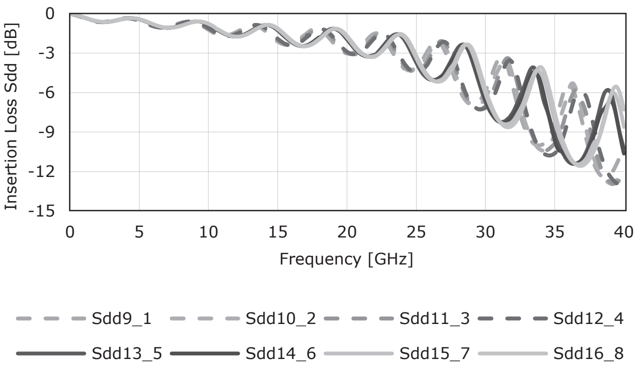


Fig. 7. Transmission characteristics

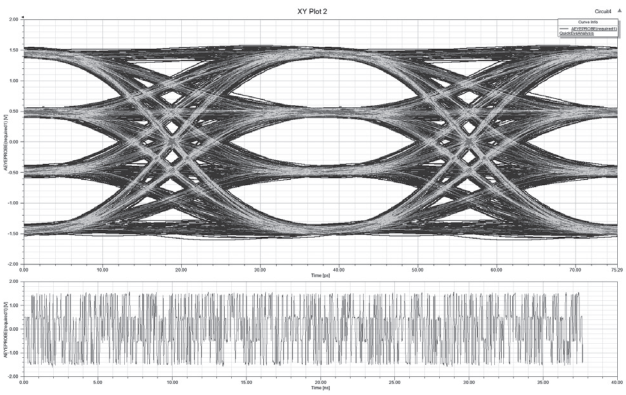


Fig. 8. Results of PAM4 signal waveform analysis

The solid lines at the bottom of Fig. 8 represent random PAM4 signals for the circuit analysis. The solid lines at the top indicate the results of overlaying sections of the solid lines at the bottom in specific time segments. The graph is known as an eye pattern. The results show four separate voltage levels and clear eye openings. The SI analysis results reveal very favorable characteristics, with losses, vias, and lands minimally affecting the transmission characteristics.

4. Conclusion

In the propagation of high-speed signals, the effects of PI and EMI/EMS need to be considered in addition to discontinuities in the general characteristic impedance. A PI- or SI-based approach can be used to examine EMI/EMS. This paper demonstrated that electromagnetic field analysis (including some circuit analyses) is a highly effective means of doing this. The transmission rate of optical transceivers is expected to improve further. The solution described in this paper is independent of the transmission rate. Development of next-generation optical transceivers is underway using design techniques incorporating the electromagnetic field analysis approach reported in this paper.

Technical Terms

*1 Via: A vertical wiring element used to connect layers of a multilayer PCB. Vias are created by a small-diameter drill or laser.

*2 Land: Creating vias is subject to manufacturing variations. A land is provided to accommodate this variation. Lands are also intended to ensure stronger connections when providing consecutive vias through multiple layers.

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