A Cost-Effective 40-Gb/s ROSA Module Employing Compact TO-CAN Package

Sae-Kyoung Kang, Joon Ki Lee, Joon Young Huh, Jyung Chan Lee, Kwangjoon Kim, and Jonghyun Lee

In this paper, we present an implemented serial 40-Gb/s receiver optical subassembly (ROSA) module by employing a proposed TO-CAN package and flexible printed circuit board (FPCB). The TO-CAN package employs an L-shaped metal support to provide a straight line signal path between the TO-CAN package and the FPCB. In addition, the FPCB incorporates a signal line with an open stub to alleviate signal distortion owing to an impedance mismatch generated from the soldering pad attached to the main circuit board. The receiver sensitivity of the ROSA module measures below –9 dBm for 40 Gb/s at an extinction ratio of 7 dB and a bit error rate of 10^{-12}.

Keywords: ROSA, 40-Gb/s, optical receiver, TO-CAN package, optical transceiver, flexible PCB.

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I. Introduction

Currently, the explosive increase in the bandwidth of data centers owing to various social-networking services requires ultra high-speed and low-cost Ethernet network systems operating at a serial 40-Gb/s data rate. In March 2011 in IEEE 802.3ba, 40 GBASE-FR concerning a serial 40-Gb/s Ethernet was standardized [1]. It is necessary to reduce the size and cost of the optical transmitting and receiving modules to meet the demands from optical Ethernet transceiver markets. However, it is difficult to satisfy these needs with conventional serial 40-Gb/s optical transmitter and receiver modules, which have been implemented using a butterfly package employing expensive coaxial RF connectors for high-speed electrical signals [2]-[4].

As an attractive solution, a TO-CAN package has advantages of low manufacturing cost and compact size owing to a matured and simple fabrication process. The TO-CAN package has been popularly used for less than a 10-Gb/s optical module and interfaced with a flexible printed circuit board (FPCB) [5]. The FPCB has been adopted to electrically connect with the transceiver's main circuit board as it has the merit of providing several degrees of freedom in the system design, owing to a variability of shapes. With the TO-CAN package and FPCB technologies, several approaches have been reported to increase the operating frequency bandwidth over 10 Gb/s. Ban and others [6] reported a 25-Gb/s receiver optical subassembly (ROSA) module improving the signal transition path between the TO-CAN package and FPCB. It appears that their method is difficult in terms of assembling a very thin FPCB without an air gap between the TO package and signal pad on the FPCB. Uesugi and others [7] have studied the structure of the FPCB for an impedance match at the electrical connection between the FPCB and transceiver's main PCB. As another solution, Kyocera Corp. [8] is commercially providing a TO-CAN package integrated with a ceramic layer for a 25-Gbps module package. This seems to increase the optical module cost owing to an expensive package. We are interested in increasing the operating speed and lowering the module cost with a cost-effective TO-CAN package and a simple assembly. Practically speaking, a 40-Gb/s ROSA with a TO-CAN package can reduce the cost of a module by less than 40% compared to a commercial 40-Gb/s ROSA with a butterfly package [4].

This paper describes a low-cost and compact ROSA module operating at a data rate of up to 40 Gb/s for a serial 40 G Ethernet optical transceiver. The ROSA is implemented using a TO-CAN package with an FPCB.

II. Module Design

A TO-CAN package has been generally used in optical modules operating below a 10-Gb/s signal rate. It is necessary to improve the electrical connection structure of the TO package for its employment in a serial 40-Gb/s Ethernet application. Figure 1 shows the proposed structure of the 40-Gb/s ROSA module with the TO-CAN package and FPCB.

The proposed TO-CAN package is implemented using the fabrication process of a common TO-CAN package. The proposed TO-CAN package has the size of a TO-56 and employs an L-shaped metal support to offer a straight line path for high-speed signals. The L-shaped metal support provides an electrical grounding path and mechanically strong fixing. It is also capable of preventing an electrical disconnection between a lead pin and a signal pad on the FPCB, owing to the bending stress of the FPCB for attachment to the transceiver's main PCB.

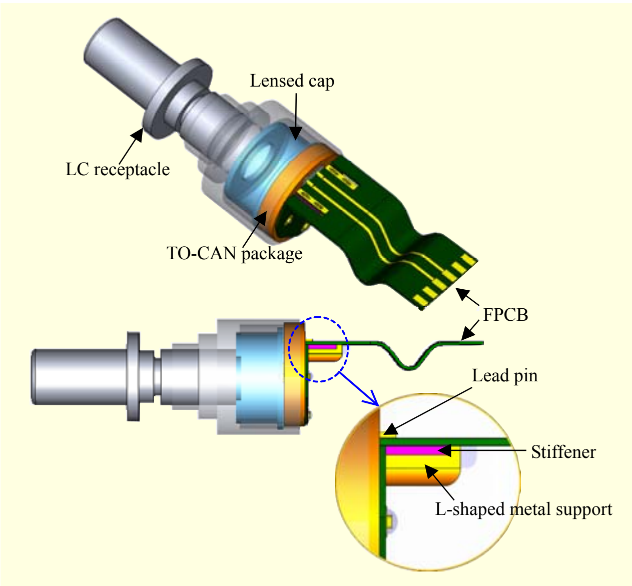

Fig. 1. Proposed concept of ROSA module.

As shown in the dotted circle in Fig. 1, the signal connection part using a polymer stiffener on the bottom side of the very thin FPCB (thickness of less than 100 μm) can be easily assembled into an L-shaped metal support on the TO-CAN package without wrinkles in the FPCB by high-temperature soldering. This section describes the electrical path design of critical paths consisting of a ROSA module.

1. Signal Path I: TO-CAN Package for FPCB

The conventional TO-CAN package for an optical module with less than a 10-Gb/s signal rate is orthogonally connected with an FPCB to an electrical interface with a transceiver PCB, as shown in Fig. 2(a) [5]. High-speed signals from the TO-CAN package suffer from an impedance discontinuity at the orthogonally soldered connection point at which the lead pins of the TO-CAN are put into the through-hole vias on the FPCB.

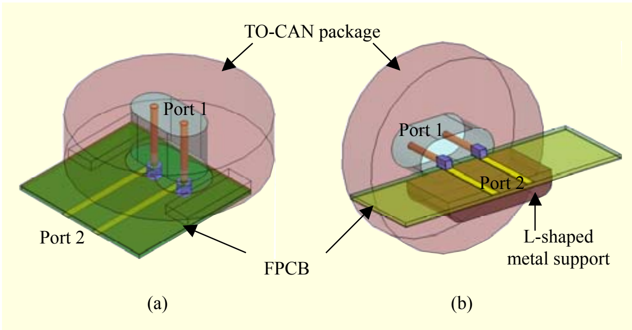

Fig. 2. 3-D modeling of package-to-FPCB transition path: (a) conventional and (b) proposed schemes.

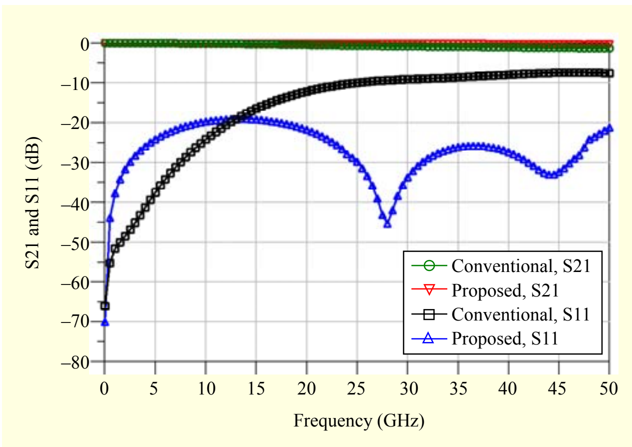

Fig. 3. Simulated insertion (S21) and return (S11) losses of conventional and proposed schemes at package-to-FPCB transition path.

An unwanted signal reflection owing to an impedance discontinuity degrades the signal quality. To overcome this problem, we propose an advanced TO-CAN package with a straight line path of high-speed signals at the transition from the TO-CAN package to the FPCB, as illustrated in Fig. 2(b). It incorporates an L-shaped metal support to offer the straight line path of the signals. The L-shaped metal support provides electrical grounding and a mechanically strong fixing of the FPCB. Using this concept, we are able to considerably improve the signal integrity of a high-speed electrical signal connection between the TO-CAN package and an FPCB.

Figure 3 plots the simulated insertion loss (S21) and return loss (S11) for differential mode signals of the conventional and proposed transition paths between the TO-CAN package and the FPCB. The excellent broadband RF performance of the proposed scheme for up to 50 GHz as compared to the conventional scheme is proven through a 3-D EM simulation. The insertion and return losses of the proposed scheme are calculated as below 0.4 dB and –20 dB at up to 50 GHz, respectively.

2. Signal Path II: FPCB to Main Circuit Board

The electrical interconnection between the TO-CAN package and main circuit board (transceiver PCB) employs an FPCB with a high-frequency performance and high flexibility. As shown in Fig. 4, the FPCB is connected to a PCB using through-hole vias formed in the soldering pad of the FPCB. The through-hole via can be modeled with parallel capacitances, serial inductance, and resistance components. In addition, the signal line near the soldering pad of the FPCB cannot have a return current path, that is, bottom-side ground plane, to prevent an electrical short between the ground plane and the signal soldering pad at the bottom side, as represented by the red lines in Fig. 4(a).

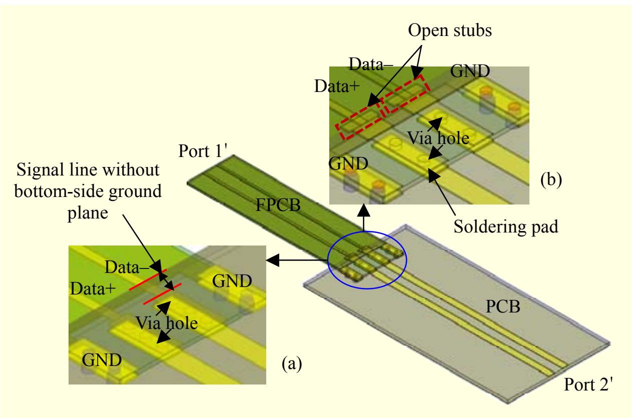

Fig. 4. FPCB-to-PCB transition path: (a) conventional signal pattern and (b) proposed signal pattern on FPCB.

The signal line corresponding to the discontinuous area of the return current path can be modeled using a parasitic inductance component. The signal distortion owing to parasitic capacitance corresponding to the through-hole vias is negligible. These unwanted parasitic inductance components result in an impedance mismatch on the signal path and thus deteriorate the signal waveform. To alleviate this problem, we propose a signal line pattern with open stubs on the FPCB. The parasitic inductances can be compensated by the capacitance components induced by the open stubs. Figure 5 plots the insertion and return losses of the conventional and proposed patterns at the transition point between the FPCB and the transceiver PCB. The figure clearly indicates that applications with a high bandwidth of up to 50 GHz can be supported using this proposed structure. The insertion and return losses of the proposed pattern are calculated as below 2.7 dB and –10 dB at

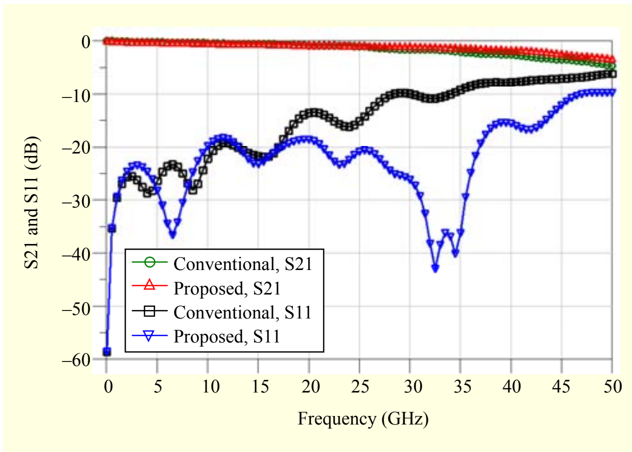

Fig. 5. Simulated insertion (S21) and return (S11) losses of conventional and proposed patterns at FPCB-to-PCB transition path.

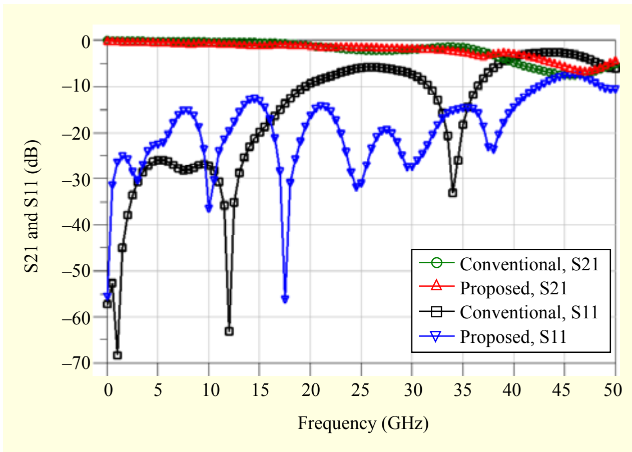

Fig. 6. Simulated insertion (S21) and return (S11) losses of conventional and proposed patterns at TO package-to-PCB transition path.

up to 50 GHz, respectively.

3. Overall Signal Path: TO-CAN Package to Main Circuit Board

Figure 6 plots the simulated results of the combined signal path of two signal paths from the TO-CAN package to the main circuit board. The reflection, S11, of the proposed structure is calculated as below –10 dB at up to 40 GHz. From the simulated results, the proposed scheme is capable of supporting up to a 40-Gb/s data rate.

III. Module Performance

We fabricate a 40-Gb/s ROSA module with an FPCB, as shown in Fig. 7(a). Figure 7(b) shows the ROSA module attached to an evaluation board.

We use a photodiode with a responsivity of about 0.5 A/W and a 3-dB optical-to-electrical (O/E) bandwidth of about 35 GHz, as well as a transimpedance amplifier that has a differential transimpedance of 520 Ω and a 3-dB bandwidth of 40 GHz. The RF connectors of the evaluation board are employed by a HUBER+SUHNER coaxial PCB connector

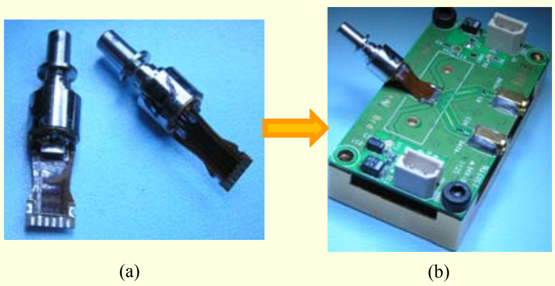

Fig. 7. (a) Photographs of 40-Gb/s ROSA module and (b) ROSA module attached to evaluation board.

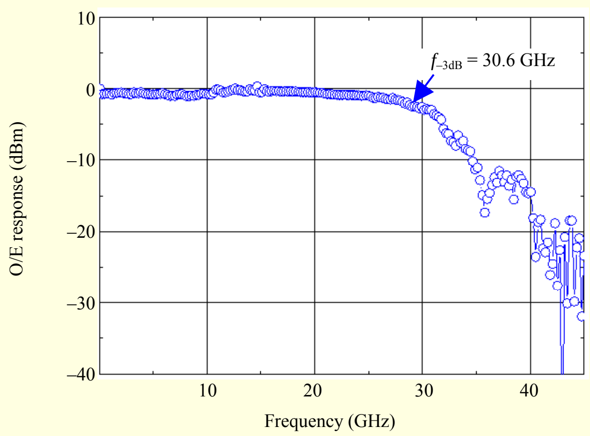

Fig. 8. Measured O/E frequency response.

operating at up to 67 GHz. Figure 8 shows the O/E frequency response, and the 3-dB bandwidth measures about 30.6 GHz.

Figures 9(a) and 9(b) show the measured electrical output waveforms of the ROSA module for back-to-back transmissions at 40-GB/s and 43-Gb/s data rates. The inputted optical signal is generated by modulating a continuous light beam through a lithium niobate modulator according to the delivered electrical data. The extinction ratio is about 7 dB. The output electrical eye diagrams of the ROSA module are measured in 40-Gb/s and 43-Gb/s NRZ pseudorandom binary sequence signals with pattern lengths of 2^{31}–1 at 25ºC. Eye diagrams from both data rates are clearly opened at various optical power levels.

Figure 10 plots the measured bit error rate (BER) performance of the ROSA module for back-to-back transmissions at 25ºC.

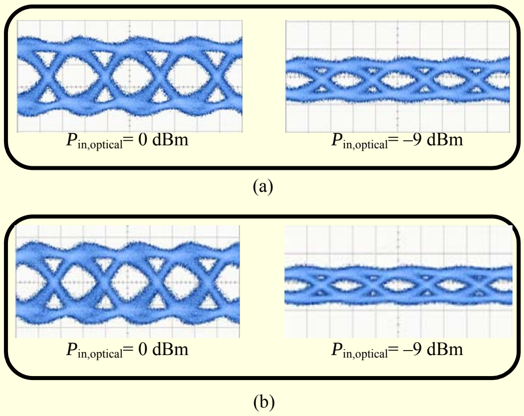

Fig. 9. Eye diagrams at (a) 40 Gb/s and (b) 43 Gb/s.

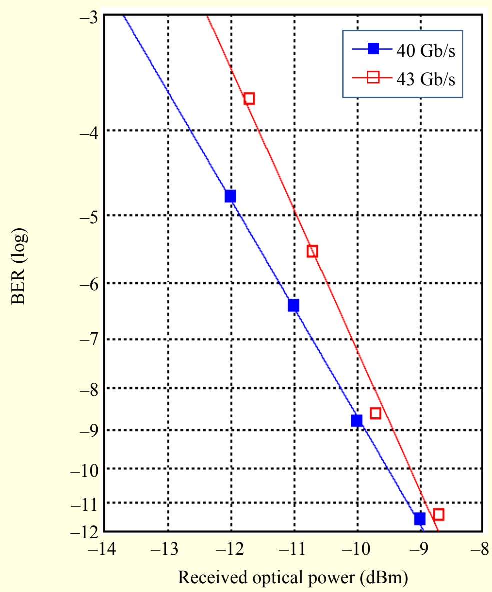

Fig. 10. Measured BER performance.

The receiver sensitivities of the ROSA are –9 dBm for 40 Gb/s and –8.7 dBm for 43 Gb/s at an extinction ratio of 7 dB and BER of 10^{-12}. The observed difference in the slopes of the BER for both data rates results from the use of a clock and data recovery block optimized to 40 Gb/s for this experimental setup.

IV. Conclusion

In this paper, we developed and successfully demonstrated a 40-Gb/s ROSA module by employing a cost-effective TO-CAN package with a straight line signal path and flexible PCB with an open stub structure. The receiver sensitivity of the ROSA module measured below –9 dBm for 40 Gb/s and –8.7 dBm for 43 Gb/s at an extinction ratio of 7 dB and a BER of 10^{-12}.

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