Surface-Mountable 10 Gbps Photoreceiver Module Using Inductive Compensation Method

Sung-IL Kim, Seon-Eui Hong, Jong-Won Lim, and Jong-Tae Moon

ABSTRACT—We propose an inductive compensation method for a surface-mountable 10 Gbps photoreceiver module. Since many typical 10 Gbps photoreceiver modules consist of a photodetector and low-noise pre-amplifier, the impedance mismatch between the photodetector and pre-amplifier, as well as package parasitics, may reduce the frequency bandwidth. In this paper, we inserted an inductive component between the photodetector and pre-amplifier in order to create frequency bandwidth expansion. From the measurement results, we have found that the proposed technique can increase the −3 dB bandwidth about 4.2 GHz wider compared with an uncompensated module. And, from a bit-error rate (BER) test, we observed −15.7 dB sensitivity at 10^{12} BER. This inductive compensation can be implemented easily and is compatible with common manufacturing processes of photoreceiver modules.

Keywords—Photoreceiver, module, inductive, compensation, wide bandwidth.

I. Introduction

With the drastic expansion of Internet usage, trends in optical transmission systems are aimed towards higher capacity, higher-speed, and lower cost. The demands of high-performance optoelectronics devices and packages have increased with these optical transmission system trends. High-speed optical and electrical device designs, as well as manufacturing technologies, have been key areas for high-performance optical transmission systems. High-performance package designs and assembly technologies, however, are also important.

These days, for high-speed optoelectronics applications, the butterfly type package is widely used. However, the butterfly type package requires a printed circuit board (PCB) with a mechanical hole which decreases the component mounting density compared with a PCB without a mechanical hole. Therefore, the optical package configuration has changed from the butterfly type package to a complete surface mountable style package due to easier PCB mounting and a higher component mounting density on the PCB [1].

In the case of an optical transmitter or receiver module with wideband characteristics, the inductive and capacitive parasitic components that are associated with a bond wire and transmission line, and the impedance mismatch between the optical and electrical devices, have limited the frequency response of the optoelectronics module [1]-[4]. Therefore, an effective compensation method on the package level is needed due to the frequency response degradation. In the on-wafer level, the inductive compensation method was introduced in [5] and [6]. But the inductive compensation method in the on-wafer level was not applicable in the package level because of a re-fabrication of the electrical device. This re-fabrication of the electrical device leads to an increase in development time and cost.

Consequently, we propose a high-performance complete surface-mountable package and demonstrate a 10 Gbps photoreceiver module using an inductive compensation method for the wideband characteristics.

In this paper, the surface-mountable package and photodiode (PD) sub-mount were designed by a 3-dimentional structure simulator which used the finite element method. From our measurements, we found that the package had an insertion loss of more than –1 dB and a return loss of less than –10 dB in the frequency range of 0 to 15 GHz. Also, we inserted the inductive component with a series of photodetectors and pre-amplifiers in order to expand frequency bandwidth. From further measurements, we have found that the proposed method can increase the –3 dB bandwidth about 4.2 GHz wider compared with an uncompensated module. The following section describes the technology, design, and results obtained for this 10 Gbps photoreceiver module.

II. Design, Measurement and Analysis

1. Surface-Mountable Package

The surface-mountable package for a 10 Gbps photoreceiver module consists of a substrate with a high-speed transmission line and a metal wall for mechanical protection. Since the microwave characteristics of the photoreceiver module are strongly dependent on the substrate, the substrate characteristics should be optimized because of package parasitic components [9]. And, using a surface-illuminated photodiode which vertically introduces an optical signal, a sub-mount block should be designed for the alignment between the optical-fiber and surface-illuminated PD. Therefore, we have simulated and designed a sub-mount block using a commercialized finite element method solver.

We have designed a surface-mountable package and PD sub-mount block with an Al_2O_3 substrate and conductor backed co-planar waveguide for high-speed data transmission [7].

For the surface-mountable package, the ground line in the co-planar waveguide (CPW) connected the package ground for the reduction of common ground inductance, while the CPW signal line opened the inside of the package due to a dc block capacitor. Next, the multiple dc bias lead-frame, which has a low parasitic inductance [5], was able to minimize the simultaneous switching noise.

The PD sub-mount block has an 'L' shape because our photodiode is of a surface illumination type. We have inserted a conductor plate in the sub-mount block and connected the CPW ground lines with filled via-holes to reduce any potential differences between the CPW ground lines.

Due to the metal wall on the surface-mountable package and 'L' shaped sub-mount, we could not measure the full 2-port characterization. Therefore, we measured the return loss and estimated the transmission characteristics of the surface-mountable package and 'L' shaped sub-mount. For the
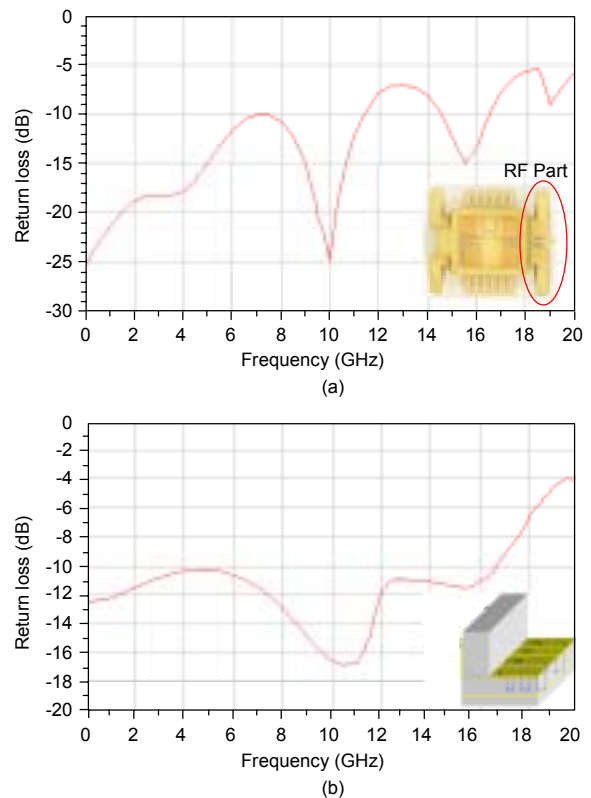

Fig. 1. (a) Surface-mountable package and (b) sub-mount for 10 Gbps photoreceiver module.

surface-mountable package measurement, we had to use the SMA connector because the lead-frame pitch between the ground and signal lines of the RF section of the package was wider than a conventional ground-signal-ground probe pitch. We terminated the CPW signal line with a 50 Ω termination resistor on the inside of the package and mounted the package with the SMA connector on the evaluation board. For the sub-mount measurement, we have attached the 50 Ω termination resistor to the PD attach pad on the sub-mount and used an 800 μm pitch ground-signal-ground probe.

The return-loss measurement results and photographs of the designed surface-mountable package and sub-mount for the 10 Gbps photoreceiver module are shown in Fig. 1(a) and (b).

In Fig. 1(a), in spite of the resonance due to the evaluation board, the return loss up to 11 GHz was less than 10 dB. And in Fig. 1(b), the return loss of the sub-mount showed less than –10 dB up to 16 GHz. Therefore, the surface-mountable package and sub-mount can utilize the 10 Gbps photoreceiver module.

2. Inductively-Compensated Photoreceiver Module

The inductive compensation method has been widely used for a wideband photoreceiver module or a preamplifier [5], [6]. But, the previous articles have focused on a monolithic

photoreceiver or a preamplifier in the semiconductor site. Therefore, in this paper, we have demonstrated the inductive peaking effects with a commercial chip inductor.

The equivalent circuit of the 10 Gbps photoreceiver module is shown in Fig. 2. The 10 Gbps photoreceiver module composed of the positive-intrinsic-negative (PIN) PD and transimpedance preamplifier converts light pulses into usable electrical signals. The equivalent circuit represents a PIN PD consisting of a capacitance C_{PD} and contact resistance R_{PD}, the compensation inductor L_{comp} with inductance L_O and parasitic capacitance C_{LP} (created by a commercial inductor data sheet), and the package parasitics composed of a bonding wire inductance L_{BW} and stray capacitance C_{pa} based on a 3D structure extracted value.
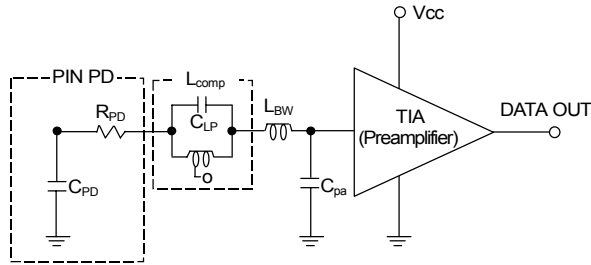
Table 1. Resonance frequency calculation result and extracted parasitic parameters.

C_{PD} (pF)	L_O (nH)	C_{LP} (pF)	L_{BW} (nH)	C_{Pa} (pF)	f_{req} (GHz)
0.18	1.0	0.14	1.0	0.35	12.7
0.18	2.2	0.15	1.0	0.35	6.8
0.18	3.3	0.17	1.0	0.35	5.8

Fig. 2. Equivalent circuit composed of PIN PD, compensated inductor, and package parasitic.
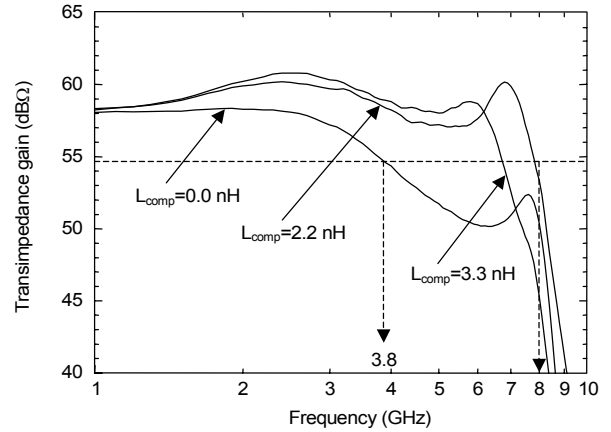
Fig. 3. Frequency response for the surface-mountable packaged 10 Gbps photoreceiver module.

In Fig. 1, since the capacitance and inductance act as a resonance circuit, we can estimate the resonance frequency(f_{req}) by (1), and the resonance characteristics can increase the frequency bandwidth of the 10 Gbps photoreceiver module.

$$f_{req} = \frac{1}{2\pi\sqrt{(L_o + L_{BW}) \cdot ((C_{PD}\|C_{LP}) + C_{Pa})}}. \quad (1)$$

The resonance frequency, using our typical parameters, calculated the results shown in Table 1. In Table 1, L_O and C_{LP} were referred by the data sheet of a commercial inductor, while C_{pa} and L_{BW} were extracted by a 3D structure simulator.

Based on Table 1, we have found that increasing the commercial chip inductor value decreases the resonance frequency, and an optimum inductor with a photoreceiver can be determined for frequency bandwidth expansion. In our case, the optimum inductor is either 2.2 nH or 3.3 nH.

The measured frequency response of the surface-mountable 10 Gbps photoreceiver module with the photodiode and pre-amplifier, which introduced the 5 V DC bias, is shown in Fig. 3. In Fig. 3, L_{comp} = 0.0 nH, L_{comp} = 2.2 nH, and L_{comp} = 3.3 nH, and each is the frequency response of the module which is not compensated, the frequency response in the case of a 2.2 nH inductor or 3.3 nH inductor. In this figure, the –3 dB bandwidth of L_{comp} = 0.0 nH is 3.8 GHz. The reason for this is the high return loss of the pre-amplifier. But, in the case of L_{comp} = 2.2 nH, the –3 dB bandwidth has increased about 4.2 GHz compared with L_{comp}=0.0 nH. This is due to the resonance effect between the photodiode and inductive compensation component.

The receiver sensitivity is measured with an externally modulated 1.55 μm 10 Gbps 2^{23}–1 pseudorandom non-return-to-zero signal. Figure 4 shows the bit-error rate (BER) test results. The receiver sensitivity can be observed as –15.7 dBm at 10^{-12} BER. According to the ITU-T standard, the 10 Gbps photoreceiver module sensitivity must be more than –14 dBm at 10^{-12} BER. Therefore, the module with L_{comp} = 2.2 nH is more capable for the 10 Gbps receiver system compared with the uncompensated module.

3. Implementation of the Inductive Compensation

Figure 5 shows a photograph of the 18 × 16 mm² size surface-mountable 10 Gbps photoreceiver module with the inductive compensation. In Fig. 5, the sub-mount, L_{comp}, and transimpedance amplifier are shown on the sub-mount with the
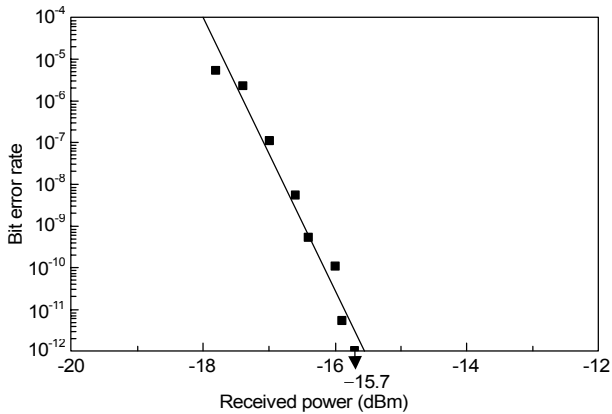
Fig. 4. Bit-error rate for the surface-mountable packaged 10 Gbps photoreceiver module.
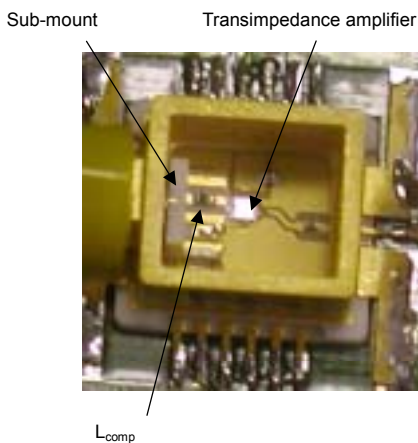

Fig. 5. Surface-mountable packaged 10 Gbps photoreceiver module with the inductive compensation method.

PIN PD, the inductive compensation component, and the transimpedance amplifier used as the pre-amplifier. We can easily implement the inductive compensation method as the series insertion between the PIN PD and the transimpedance amplifier. Therefore, this inductive compensation method can be implemented easily and is compatible with common manufacturing processes of the photoreceiver module.

III. Conclusion

The surface-mountable package and PD sub-mount have been designed by a 3-dimentional structure simulator using the Finite Element Method. From the simulation and measurement results, we found that the package characteristics had an insertion loss of over −1 dB and a return loss of under −10 dB within the frequency range of 0 to 15 GHz. Therefore, the designed surface-mountable package and PD sub-mount can be used for a 10 Gbps photoreceiver module.

We inserted the inductive component as part of a series with the photodetector and preamplifier in order to increase frequency bandwidth expansion. From the measurement results, we have found that the proposed method can increase the −3 dB bandwidth about 4.2 GHz wider compared with a module that is uncompensated. From a bit-error rate test, we observed a −15.7 dBm receiver sensitivity. According to the ITU-T standard [8], the −15.7 dBm receiver sensitivity is compatible with a 10 Gbps receiver system. This inductive compensation method and surface-mountable package can be implemented easily and is compatible with the common manufacturing process of the photoreceiver module.

References

[1] S. Morioka and M. Yanagisawa, "High Speed Mini-DIL Package Technology," *Lasers and Electro-Optics Society 1999 12th Annual Meeting, LEOS'99 IEEE*, vol. 2, 1999, pp. 429-430.

[2] H. Tjassens and J.T.M. Kluitmans, "A Laser Module for 4-Gbps Optical Communications," *Philips Tech. Rev.*, 44, No. 5, Nov. 1988, pp. 162-164.

[3] S.-Y. Yun and H.-Y. Lee, "Parasitic Impedance Analysis of Double Bonding Wires for High Frequency Integrated Circuit Packaging," *IEEE Microwave Guided Wave Lett.*, vol. 5, no. 9, Sept. 1995, pp. 296-298.

[4] Y. Oikawa et al., "Packaging Technology for a 10-Gb/s Photoreceiver Module," *J. Lightwave Technol.*, vol. 12, no. 2, Feb. 1994, pp. 343-352.

[5] R.K. Montgomery et al., "A 28 GHz Transimpedance Preamplifier with Inductive Bandwidth Enhancement," *IEDM*, 1992, pp. 423-426.

[6] Kyounghoon Yang et al., "Design, Modeling, and Characterization of Monolithically Integrated InP-Based (1.55 μm) High-Speed (24Gb/s) p-i-n/HBT Front-End Photoreceivers," *J. Lightwave Technol.*, vol. 14, no. 8, Aug. 1996, pp. 1831-1839.

[7] K.C. Gupta et al., *Microstrip Lines and Slotlines*, Artech House, 1996.

[8] ITU-T G. 691, *Series G: Transmission Systems and Media, Digital Systems and Networks*, Oct. 2000.