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A bandwidth adjustable integrated optical receiver with an on-chip silicon avalanche photodetector

Jin-Sung Youn[1], **Myung-Jae Lee**[1], **Kang-Yeob Park**[1], **Holger Rücker**[2], **and Woo-Young Choi**[1a)]

[1] *Department of Electrical and Electronic Engineering, Yonsei University*
134 Shinchon-dong, Seodaemoon-gu, Seoul, 120–749, Korea
[2] *IHP, Im Technologiepark 25, 15236 Frankfurt (Oder), Germany*
a) *wchoi@yonsei.ac.kr*

Abstract: A bandwidth adjustable integrated optical receiver having an on-chip silicon avalanche photodetector is realized with standard 0.25-μm silicon-germanium bipolar complementary metal-oxide-semiconductor technology for optical interconnect applications. With the controllable capacitive degeneration technique, the optical receiver bandwidth can be adjusted for the best bit error rate performance.

Keywords: high-speed optical receiver, silicon avalanche photodetector, silicon-germanium BiCMOS, transimpedance amplifier

Classification: Fiber optics, Microwave photonics, Optical interconnection, Photonic signal processing, Photonic integration and systems

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1 Introduction

As the required data rate is rapidly increasing in many interconnect applications, copper-based electrical interconnects face severe performance limitations due to large frequency-dependent losses, cross-talk noises, size, and power consumption. Fiber-optic techniques are gaining popularity as they can solve above problems. In addition, silicon-based optical interconnect techniques are emerging as a major driving force because they can provide low fabrication costs and powerful integration schemes. High-performance germanium photodetectors on silicon substrate have been demonstrated for 1.3-μm and 1.5-μm applications [1]. It is also possible to realize 850-nm silicon photodetectors without any process modification from the conventional silicon processing technology. We have previously reported various types of silicon-based avalanche photodetectors (Si APDs) which provide high responsivity and large bandwidth [2, 3]. In addition, we have demonstrated a monolithically integrated optical receiver having a Si APD fabricated with standard silicon-germanium (SiGe) bipolar complementary metal-oxide-semiconductor (BiCMOS) technology [4].

In this letter, we present an improved monolithic optical receiver with an on-chip Si APD based on standard 0.25-μm SiGe BiCMOS technology. Compared to the previous result [4], our receiver achieves better performance by employing an improved Si APD and such circuit techniques as DC compensation and capacitive degeneration. In particular, the new optical receiver includes the adjustable capacitive degeneration block so that receiver bandwidth can be optimized for the best bit error rate (BER) performance.

2 Bandwidth adjustable integrated optical receiver

Fig. 1 (a) shows the simplified block diagram of the fabricated optical receiver. The cross-section of the fabricated Si APD and BiCMOS transistors can be found in [4]. The optical receiver is composed of a Si APD, a DC compensation circuit, a single-ended transimpedance amplifier (TIA), a single-to-differential amplifier with a low-pass filter, and an output buffer. The core of the chip occupies the area of 480 μm × 150 μm, and consumes about 30 mW excluding the output buffer with the supply voltage of 2.5 V.

The Si APD is realized by a vertical P^+/N-well junction, and the output current is extracted from P^+ contact. Compared with the Si APD used in [4], the active area size is reduced to 10 μm × 10 μm so that larger photodetection bandwidth can be achieved. The measured 3-dB photodetection bandwidth of the Si APD is about 3.5 GHz with a 50-Ω load.

The TIA input node can suffer from undesired DC offset due to photodetector dark currents, amplifier offset, and/or DC component of the received signal [5]. This DC offset can affect the bias points for transistors and, consequently, the amplifier performance. This problem can be prevented by a DC compensation circuit, which is composed of an error amplifier and a transistor (M_1) acting as a variable current source. As shown in Fig. 1 (b), the voltage difference between node (A) and node (B), acting as a reference volt-

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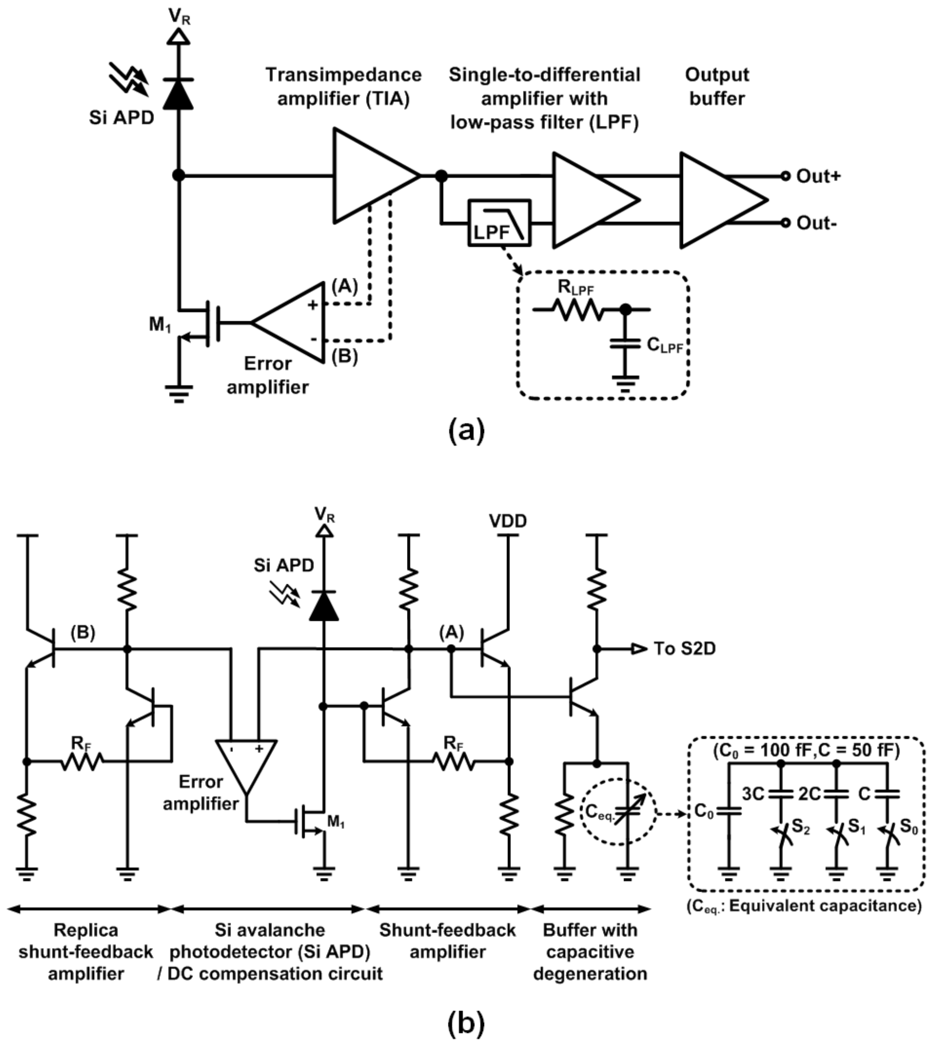

Fig. 1. (a) Simplified block diagram of the optical receiver. (b) Circuit diagrams of the TIA and DC compensation circuit.

age, is integrated by the error amplifier [6]. The output voltage of the error amplifier controls the amount of current flowing through M_1 and the voltage of node (A) tracks the reference voltage at node (B) to minimize the voltage difference. As a result, the DC offset can be compensated. With this, TIA bias points are kept stable, and output signal swing can be maximized.

The TIA is designed in the single-ended shunt-feedback configuration with feedback resistance (R_F) of $5\,k\Omega$. Although high feedback resistance increases TIA input impedance which can limit the receiver bandwidth due to a low-frequency pole, we choose the shunt-feedback configuration since this configuration with low input-referred noise provides us the best signal-to-noise ratio (SNR) for our receiver having Si APD, which has a substantial amount of noises due to avalanche gain.

As shown in Fig. 1 (b), the buffer contains the capacitive degeneration block that enhances the receiver bandwidth. Compared to the active inductor used in [4], capacitive degeneration requires less voltage headroom and, consequently, lower supply voltage. It generates a zero in the receiver fre-

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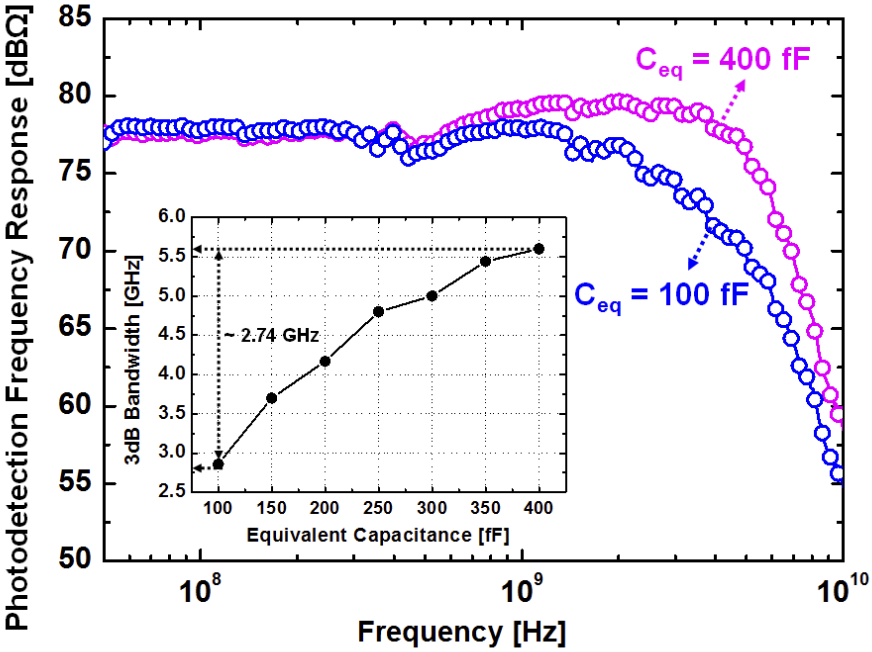

Fig. 2. Measured photodetection frequency responses of the fabricated optical receiver. Inset shows 3-dB bandwidth of the integrated optical receiver as a function of equivalent capacitance (C_{eq}).

quency response, whose location can be controlled by the impedance of the parallel resistor and capacitors. With a capacitor array digitally controlled by external switches, the equivalent capacitance (C_{eq}) can be controlled from 100 fF to 400 fF in steps of 50 fF. The adjustable receiver bandwidth is important because the optimum receiver bandwidth depends on the data rates as it is affected by both intersymbol interference (ISI) and noises [7]. The single-ended output of the buffer is converted into fully differential signal by single-to-differential amplifier with low-pass filter ($R_{LPF} = 20\,k\Omega$, $C_{LPF} = 7.5\,pF$).

Fig. 2 shows the measured photodetection frequency responses of the fabricated optical receiver. The optical receiver 3-dB bandwidth is about 2.86 GHz with C_{eq} of 100 fF, but it goes up to 5.6 GHz with maximum C_{eq} of 400 fF. The inset in Fig. 2 shows the measured optical receiver 3-dB bandwidth as a function of C_{eq}.

3 Optical data transmission results

In order to evaluate the fabricated optical receiver, optical data transmission experiments were performed. An 850-nm laser diode was used as an optical source and its output light was modulated by an external electro-optic modulator using a $2^{31} - 1$ pseudo random bit sequence. The modulated optical signals were transmitted through 4-m-long multimode fiber and injected into the integrated optical receiver using lensed fiber. The Si APD was biased with the reverse bias voltage of 12.3 V which was experimentally determined to maximize the SNR of the optical receiver. A commercially available 10-Gb/s

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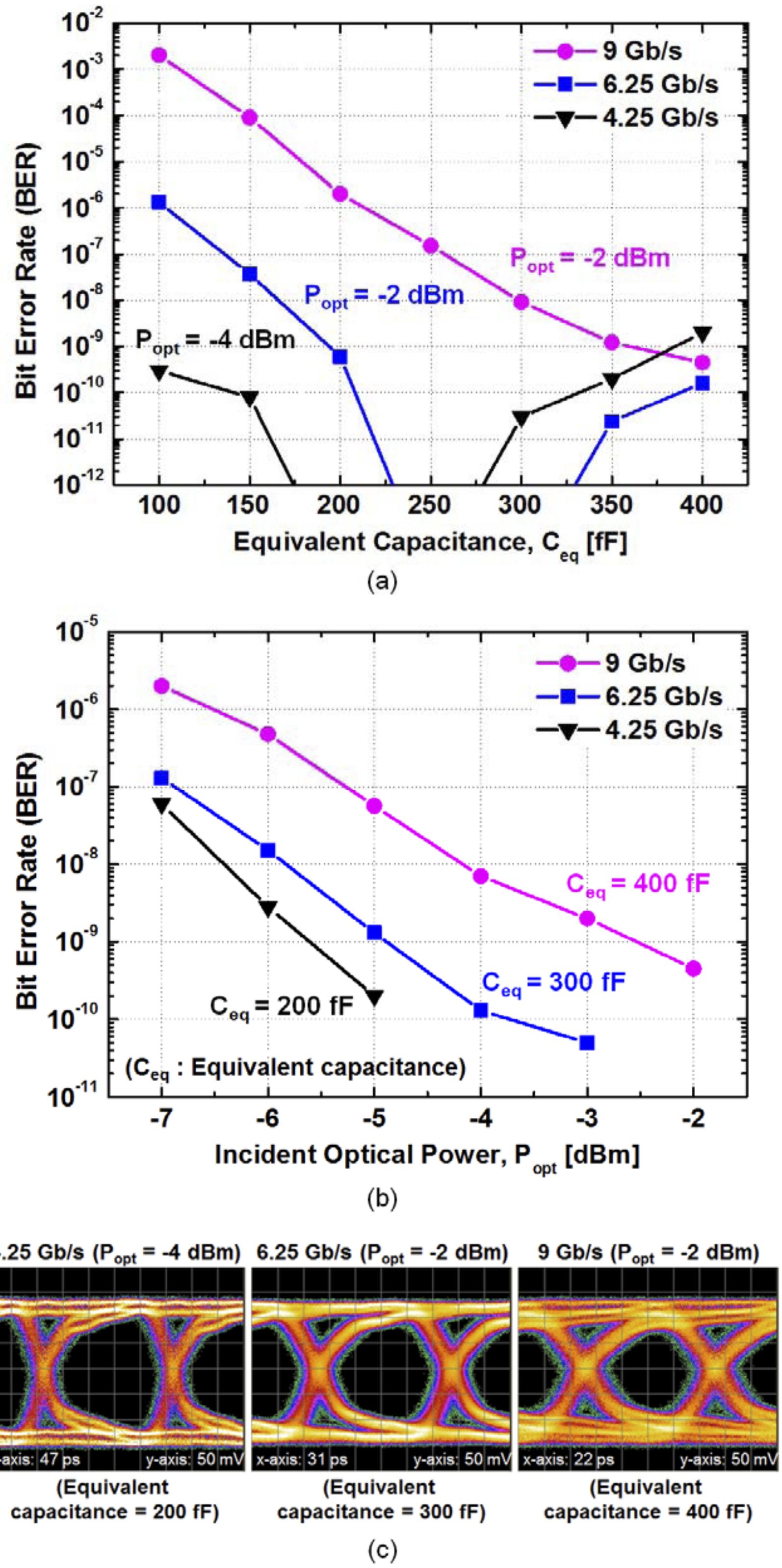

Fig. 3. (a) BER performances as a function of equivalent capacitance (C_{eq}) (b) BER performances as a function of incident optical power (P_{opt}) (c) Eye diagrams of 4.25-, 6.25-, and 9-Gb/s data at output of the limiting amplifier. The P_{opt} is -4, -2, and -2 dBm, respectively.

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limiting amplifier was used to satisfy the input sensitivity requirement for a BER tester.

Fig. 3 (a) shows measured BER performances as a function of C_{eq} when three different 4.25-, 6.25-, and 9-Gb/s optical data were transmitted. The incident optical power was −4 dBm for 4.25 Gb/s and −2 dBm for both 6.25 and 9 Gb/s. The measurement results show the trade-off between ISI and noise. With 6.25 Gb/s, for example, the receiver bandwidth is insufficient for C_{eq} below 250 fF, resulting in more ISI and worse BER with smaller C_{eq}. When C_{eq} is above 350 fF, the BER gets worse with larger C_{eq} because the receiver bandwidth is too large allowing excessive noises. For 9 Gb/s, the BER performance is limited by the receiver bandwidth. This clearly demonstrates that the optimum receiver bandwidth depends on the data rate, and our optical receiver with the capability for adjustable bandwidth can be useful for optimizing the receiver performance for various data rates.

Fig. 3 (b) shows measured BER performances as a function of incident optical power with three different data rates, 4.25, 6.25, and 9 Gb/s. The value of C_{eq} is 200 fF, 300 fF and 400 fF for 4.25, 6.25, and 9 Gb/s, respectively. Fig. 3 (c) shows the eye diagrams for the best BER for each data rate.

4 Conclusion

A bandwidth adjustable integrated optical receiver with an on-chip Si APD is implemented with standard 0.25-μm SiGe BiCMOS technology without any process and layer modification. Using the high-performance Si APD and the adjustable capacitive degeneration block, the optical receiver bandwidth can be optimized to achieve the best BER performances for each data rate.

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