A Self-Equalizing Photo Detector

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***Abstract*— A self-equalizing photo-detector (SEPD) that mitigates the bandwidth limitations of electro-optical components of optical communication systems is demonstrated, enabling higher rate of data transmission, using slower components. Unlike other all-optical equalization schemes, SEPD is optically wide band, thus does not require wavelength tuning.**

Keywords—feed-forward equalizer; equalization; silicon photonics; active optical cable; photo detector

I. INTRODUCTION

The implementation cost of optical communication channels has been an impediment to broad deployment of high speed optical systems for short range front-end of communication networks. The advances in silicon photonics enabling co-integration of electronics and photonics on the same substrate combined with the availability of low-cost laser light sources have enabled low-cost high-speed optical connectivity solutions [1].

Active optical cables have become the de-facto standard connectivity solutions in data centers and high performance computing clusters. The main bottleneck limiting the data rate in these cables is the bandwidth of the electro-optical components, such as the optical modulator and the photo-diodes. Equalization techniques that have been widely used in copper based communication channels [2] can also be used for optical communication channels [3]. The work presented in this paper demonstrates a novel hybrid electro-optical equalization approach on an integrated silicon photonic chip, hence not constrained by the bandwidth and speed limitations of the following electronic circuitry and lowering the overall power consumption of the system. Also, unlike other optical equalizers that utilize a narrowband optical filter to shape the spectrum of modulated data (e.g., [4]), the proposed scheme does not have a strong wavelength dependency; therefore it can be used without the need of accurate optical wavelength tuning.

II. DESIGN AND FABRICATION

An Equalizer usually acts as a high-pass filter that cancels out channel attenuation at higher frequencies. The high-pass filter can be placed anywhere in the link, e.g. in the transmitter or receiver, or can be implemented through digital signal processing, as long as the link is substantially linear. In optical links, this high pass filter can be simply implemented as an electro-optical hybrid using the components available in a typical silicon photonics process. Such electro-optical equalizer can take advantage of the high optical bandwidth and hence provide better equalization than what can be achieved with a purely electronic solution. At the same, the electronic eliminates the strong wavelength dependence of the narrowband grating-based optical equalization solutions (e.g., [4]).

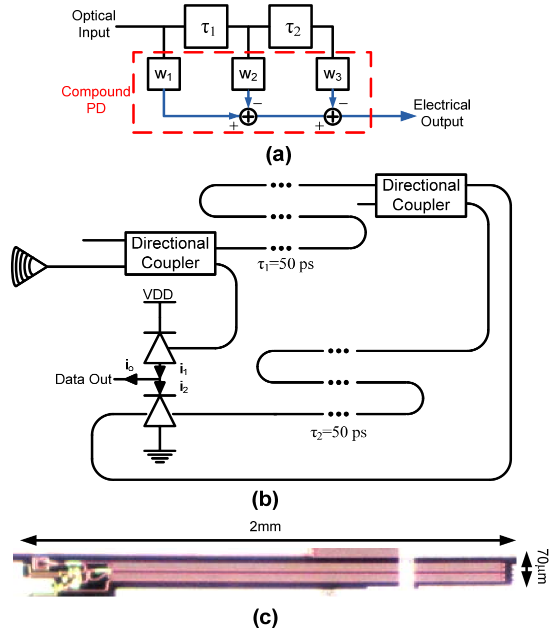

Figure 1. Proposed self-equalizing photo detector. (a) Conceptual block diagram, (b) detailed implemented block diagram, and (c) the die photo of fabricated detector

Figure 1 shows the block diagram and the die photo of the designed self-equalizing photo detector (SEPD). A laser source emitting in 1550nm is coupled into the silicon photonic chip through a lensed grating coupler. An imbalanced evanescent mode coupler split the light into two branches guiding most of the input light to a SiGe photodiode, PD_1. The remainder of the input light is guided to the second imbalanced coupler through a 50ps delay line.. A fraction of the delayed optical signal is incident on the second photo detector PD_2 without any extra delay while the remainder of the optical signal is passed through a second 50ps delay line before being fed to PD_2. The electrical connection between PD_1 and PD_2 is such that the photocurrent of PD_2 is subtracted from the photocurrent of PD_1, producing opposite polarities for w_1 with respect to w_2 and w_3. This architecture effectively forms a high pass filter that equalizes and detects the optical signal. Assuming optical delays of τ_1 and τ_2 and directional couplers with coupling ratios of α_1 and α_2, the frequency response of the detector can be calculated as

$$(1)\quad i_o = \frac{RP}{1-\alpha_1}[1 - w_1 e^{-2i\pi f \tau_1} - w_2 e^{-2i\pi f(\tau_1+\tau_2)}]$$

where R is the responsivity of the photo detectors, P is the optical power coupled into the chip, $w_1 = (1-\alpha_2)\alpha_1 / 1-\alpha_1$, and $w_2 = \alpha_1\alpha_2 / 1-\alpha_1$. As the equation suggests, the equalizer represents the frequency response of a finite impulse response (FIR) filter.

The silicon photonic chip was implemented in OpSIS/IME SOI process with silicon thickness of 220nm on a 2µm buried oxide layer [1]. The light was coupled into the chip via a grating coupler and single mode on chip waveguides with group index of 4.2 were used as delay lines. The process also incorporates a Ge epitaxial layer that is used to create the photo-detectors.

III. Measurement Results

The effectiveness of the self-equalizing photo-detector (SEPD) is demonstrated in a 12.5Gbps data link and the performance of the proposed detector was compared to a standalone 35GHz photo diode. The frequency response of the electro-optical test channel is shown in Figure 2. This response includes the bandwidth limitation of the optical modulator, its driver, and the electrical cables that connect the pattern generator to the modulator and the photo-detector to the oscilloscope. The channel has around 12.5dB of attenuation at the Nyquist frequency resulting in a closed eye diagram when measured with the 35GHz photo-detector (Figure 3(a)).

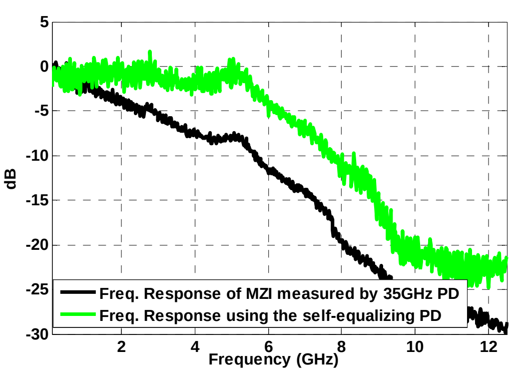

Figure 2. Electro-optical frequency response of the channel with a 35GHz PD and with proposed self-equalizing PD. The self-equalizing PD provides up to 7dB of equalization.

Figure 3(b) shows that resulting eye diagram of using the proposed self-equalizing photo-detector in place of the 35GHz PD. The open eye diagram shows that the proposed detector is able to equalize the optical signal successfully.

IV. Conclusion

A self-equalizing photo-detector (SEPD) capable of equalizing an electro-optical channel with 12.5dB of attenuation is presented. The proposed detector uses low loss optical waveguides to achieve true time delay that is required for creating a wavelength independent feed-forward equalizer. The proposed photo-detector hence enables higher rate of data transfer in bandwidth limited optical communication systems.

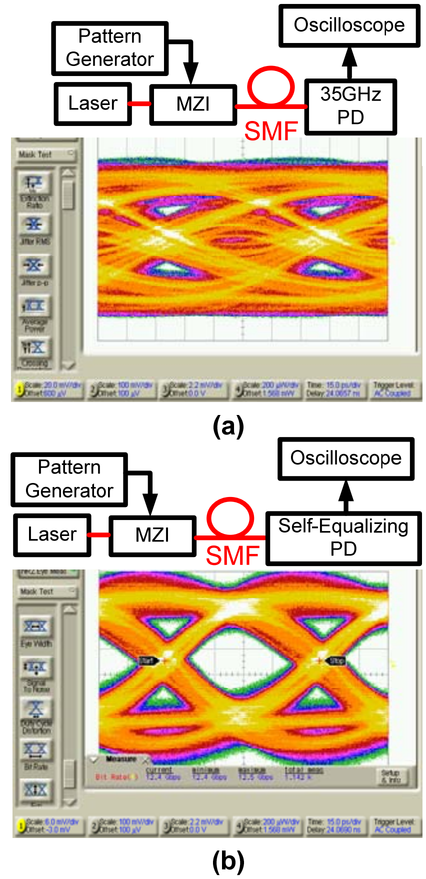

Figure 3. (a) Eye diagram of the electro-optical channel measured using a 35GHz photo diode. (b) The eye diagram obtained using the proposed self-equalizing photo-detector

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