On-Chip Integrated Photoreceiver for Real-Time Brain Imaging

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Abstract—A new silicon avalanche photodiode is integrated with transimpedance amplifier and photon counting circuitry front-end in order to be applied in a miniaturized optical brain imaging system. This on-chip integrated system is fabricated using low-cost standard CMOS process and offers high sensitivity, high-speed, with low-power and low-noise characteristics.

I. INTRODUCTION

Functional near infrared spectroreflectometry (fNIRS) is a noninvasive, safe, minimally intrusive, and high-temporal resolution system for real-time and long-term brain imaging and brain-computer interface (BCI) applications. It is a potential neuroimaging technique that can non-invasively monitor the rapid changes in both fast neuronal and slow hemodynamic signals (regional cerebral blood volume and tissue oxygenation). Since cerebral blood volume and tissue oxygenation are indirect indicators of neuronal activity, such imaging information is of great value in the understanding, evaluation, and treatment of the common neurological problems such as stroke and epileptic seizures. Besides of the significant advantages of fNIRS system it still suffers from few drawbacks including low spatial resolution, high-level noise, inflexibility and high sensitivity to movement.

II. PROPOSED SYSTEM

In order to overcome the limitations of currently available non-portable fNIRS systems, we have proposed a new miniaturized, reconfigurable and low-noise fNIRS Photodetector front-end. It includes low voltage, high efficiency, and high-gain silicon avalanche photodiodes (SiAPDs) with maximum sensitivity and minimum noise, integrated with front-end circuitries for Linear and Geiger-modes of operation. This fully integrated system is implemented on-chip using submicron complementary metal-oxide-semiconductor (CMOS) technology to achieve a smart imaging sensor for several applications. Proposed SiAPDs are designed in p+/n-well structure with guard rings realized in different shapes [1]. They exhibit high-avalanche gain (>100), low-breakdown voltage (<12V) and high photon detection efficiency accompanying with low dark count rates. Proposed rectangular and octagonal SiAPDs have the avalanche gain of 100 and 45 with the breakdown voltage of 6V and 9V and the photon absorption efficiency of 45% and 25% at 800nm respectively. The linear-mode circuitry includes three new Transimpedance amplifier (TIA) front-ends with high gain-bandwidth product (GBW) and ultra-low noise to be applied for continuous-wave (CW) fNIRS. The TIA front-end has been designed using distributed-gain concept combined with resistive-feedback and common-gate topology to reach low-noise, low power-consumption, high GBW characteristics and is robust against power supply variation (1V-3V). Fabricated TIA front-end has high transimpedance gain (up to 250MV/A), tunable BW (1kHz-1GHz), extremely low input and output noise (100fA/√Hz, 1.8μV/√Hz), high stability (phase margin≥40°), robust against power supply variations and low power consumption (0.8mW), all the essential requirements for fNIRS photoreceiver front-end [2]. The proposed TIA front-end also shows efficient results in two different bias voltages. In order to operate the SiAPDs in Geiger-mode for photon-counting application, an ultra-fast Quench-Reset front-end is also implemented on-chip using standard CMOS technology. It introduces an integrated hold-off time control and on-chip counter in a small area with a significant low power consumption and low-noise characteristics.

The Geiger-mode photon counting front-end also exhibits a controllable hold-off and rest time with an ultra fast quench-reset time (few ns). The on-chip integrated APDs with the proposed front-end circuitries preserves the high-performance characteristics of both APDs and TIA/Quench while offering a more compact photodetector front-end with high fill factor to be used in arrays of detectors in different optical detectors and for low-intensity light detection applications. The work is in progress on integration of this Photoreceiver front-end with electroencephalography (EEG) and wireless integrated circuits, already developed in our lab using standard CMOS process. This will offer a wireless multimodal (fNIRS+EEG) imaging system for long-term, real-time and wireless brain monitoring application.

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