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A monolithic based NIRS front-end wireless sensor

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Abstract

This paper concerns a novel analog front-end of a wireless brain oxymeter smart sensoring instrument based on near-infrared spectroreflectometry (NIRS). The NIRS sensor makes use of dynamic threshold transistors (DTMOS) for low voltage (1 V), low power and low noise enhancement. The design is composed of a transimpedance amplifier (TIA) and an operational transconductance amplifier (OTA). The OTA differential input pairs use DTMOS devices for input common mode range enhancement. The OTA was fabricated in a standard 0.18 μm CMOS process technology. Measurements under a 5 pF capacitive load for the OTA gave a DC open loop gain of 67 dB, unity frequency gain bandwidth of 400 kHz, input and output swings of 0.58 and 0.7 V, a power consumption of 18 μW, and an input referred noise of 134 $nV/\sqrt{Hz}$ at 1 kHz without any extra noise reduction techniques. The achieved features of the proposed oxymeter front-end will allow ultra low-light level measurements, high resolution and good temperature stability.
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Keywords: Near-infrared spectroreflectometry (NIRS); Low noise; Low power; CMOS; Dynamic threshold MOSFET (DTMOS); Operational amplifier; Transimpedance

1. Introduction

Near-infrared spectroreflectometry (NIRS) requires light in the near-infrared (NIR) range to determine cerebral oxygenation, blood flow, and metabolic status of the brain [1]. It provides a non-invasive, monitoring and portable means to image brain function and biological tissues because of the relatively low absorption of water and high absorption of oxy- and deoxyhemoglobin in the NIR range of 600–950 nm. Due to these properties, NIR light can penetrate biological tissues in the range of 0.5–3 cm, offering the possibility of investigating deep tissues, and the ability to differentiate between healthy and diseased tissues. Among existing imaging systems, NIR light offers the advantage of having much lower absorption than visible light. This explains why the application of optical techniques in biology and medicine is gaining importance, providing researchers with means of using NIR light as a probe for tissue examination and inspection. NIRS has been commonly used in combination with other biomedical imaging techniques such as electroencephalogram (EEG) or functional magnetic resonance imaging (fMRI) to help identify epileptic foci on patient suffering from epilepsy [2–4]. Not only are video recordings of EEG still needed, but they are only suitable for the most known form of the epilepsy disease, temporal lobe epilepsy, and the patient is not free to move during these analyses. Nevertheless, the NIRS technique may contribute to important progress in epileptic seizure precursor signature detection. It has been reported that these signals begin several hours in advance of the clinical onset of a seizure [5]. An overview of the techniques used in optical tomography outline that optical measurements are achieved by means of three fundamentally different approaches based on time domain, frequency domain or continuous wave techniques [6]. The proposed NIRS device uses the continuous wave approach, since the emitters provide light signal with constant amplitude, and is composed of two parts: the emitter and the smart sensors. Changes in the reflected light amplitude are used to calculate changes in concentrations of blood oxygen. Additionally, a continuous wave based system offers the

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advantage of building very light and simple monitoring devices. The drawback of such a system as presented by Bozkurt et al. [7], is that it is not a standalone cerebral hemodynamic monitoring device, and the patient cannot move while measurements are being taken, the patient has to be laid down.

In this paper, a new analog front-end of a smart sensor for the NIRS wireless oxymeter instrument is proposed, which includes transimpedance amplifier (TIA) and operational transconductance amplifier (OTA) building blocks based on DTMOS transistors for low voltage (1 V), low noise and low power operation. Section 2 focuses on the model design and extracted requirements needed for analog signal processing blocks. Section 3 depicts the TIA and OTA, and in Section 4 we report the obtained post-layout simulation results for the TIA, and the experimental results for the OTA.

2. Description and modeling of the NIRS front-end receiver

The emitter of the wireless oxymeter apparatus smart sensor consists of three discrete light emitting diodes, corresponding to the three selected wavelengths, and a set of identical detector modules as depicted in Fig. 1(a). NIR light sources emit photons that propagate through the cortical tissues, and some of the injected photons are reflected to the surface of the sensors' photodiodes. When these photons travel through cortical tissues, the light transmission is dependent on the reflectance, scattering, and absorption that occur in each particular tissue. A fraction of the injected photons survive to return and exit the skin surface after being strongly scattered inside the scalp, skull and brain, following the banana shaped path illustrated in Fig. 1(b). The amount of reflected photons depends on the power of the light sources and the source-to-receiver distance. The level of attenuation with a source-to-receiver distance of 4 cm, for a five-layer head model (scalp, skull, cerebrospinal fluid (CSF) layer, and gray and white matters), can be approximated by Eq. (1) as reported by Okada et al. [8],

$$\frac{I_{\text{out}}}{I_{\text{in}}} \in [5, 12] \times 10^{-8}, \tag{1}$$

where I_{in} is the incident light intensity and I_{out} is the intensity of the detected light. Eq. (1) outlines the need for a receiver which is capable of processing ultra low-amplitude light signals. Moreover, for noise immunity enhancement of the overall system, we proposed an activation sequence as depicted in Fig. 1(c), in which emitters, E_1, E_2, and E_3 are activated simultaneously during a period of time "T". Then, for the same amount of time, all emitters are turned OFF, and the collected noise data are used to adjust the previously collected data, as part of the offset correction and compensation procedure.

The light sources are three NIR laser diodes emitting light at discrete wavelengths of 735, 840, and 940 nm. The NIR lights are modulated by a stabilized sinusoidal current at a frequency varying between 10 and 50 kHz. The sources are placed on the scalp of the subject, and are activated one at a time as described in Fig. 1(c). The light from each

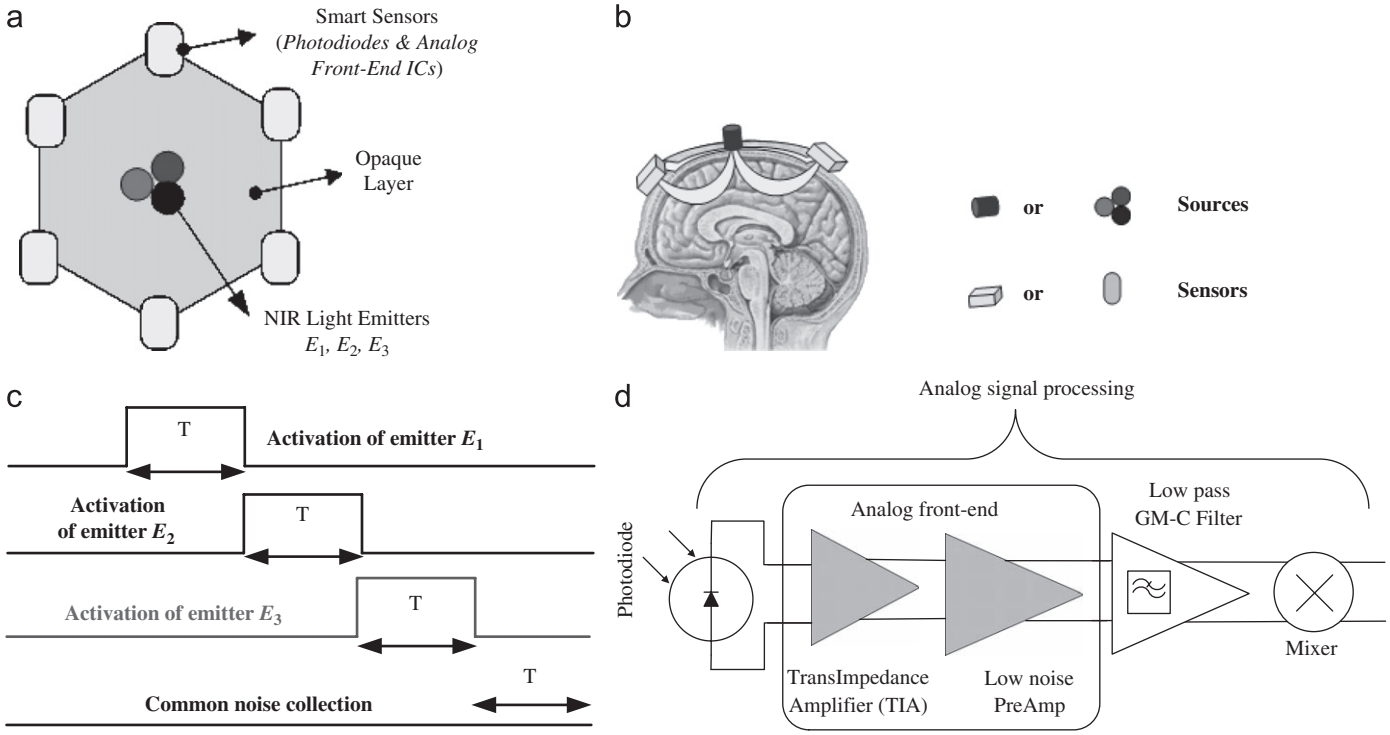

Fig. 1. NIRS emitter–receiver system: (a) NIRS basic module, (b) light propagation path, (c) emitter activation sequence, and (d) block diagram of one channel of the NIRS front-end receiver.

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