Microelectronics Journal xxx (xxxx) xxx–xxx

Contents lists available at ScienceDirect

Microelectronics Journal

journal homepage: www.elsevier.com/locate/mejo

An active dry electrode ecg interface circuit for wearable sensors

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ARTICLE INFO

Keywords:
Active dry electrode
ECG
Input impedance
CMRR

ABSTRACT

A high performance active dry electrode interface circuit for ECG signal monitoring in 0.18 μm CMOS process is presented in this paper. AC-coupled core amplifier, input impedance boost loop and CMFB (Common-mode Feedback) circuit are applied in this analog front-end circuit. The programmable gain of the core amplifier is set from 12 dB to 40 dB. With the input impedance boost loop, a constant 2.4 GΩ input impedance is achieved (0.1–150 Hz @ typical condition). CMFB circuit is utilized to reduce common-mode interference, and the CMRR reaches 85 dB with the configuration of ac gain 40 dB. In this design, amplifier-based active dry electrode is utilized, which achieves better noise performance than buffer-based active electrode.

1. Introduction

Recently, monitoring the physiological signals of patients has been integrated in modern wearable health care systems. More and more real-time ECG monitoring applications aim to detect electrical activities of heart. The electrodes used for signal acquisition directly affect the quality of the biomedical signal. Wet electrodes have traditionally been used to record bio-potential signals by using electric gels which improve the electric conductivity. They have good signal performance in short period of time and are most commonly used in hospital environment. However, short shelf life, skin irritation (i.e., itchiness, reddening, swelling even allergies), and discomfort for patients limit their usage for long-term monitoring. Furthermore, the conductivity of electrolytic gel decreases gradually as the material hardens, subsequently degrading the data acquisition quality [1].

For mobile applications, simplified sensors can be used. More and more gel-less ECG sensor systems are developed. The ECG sensors are made of two dry metal contact electrodes. Despite the ease of use, the high electrode contact impedance due to the passive circuit makes the received signal very sensitive [2].

In recent years a great deal of attention has been given to dry electrodes designs. In this work, the development of low cost mobile ECG monitoring device using two active dry electrodes is presented. The system is designed with maximum mobility and flexibility in ubiquitous healthcare. To improve the sensitivity of the dry electrodes, we proposed a "buffer" circuit as the "active dry electrode". The active dry electrode we proposed achieves high input impedance, low input referred noise and high CMRR, making it robust in sensing ECG signals.

2. Active dry electrode interface circuit

2.1. System architecture

The active dry electrode interface circuit we proposed is illustrated in Fig. 1, which consists of two AC-coupled core amplifiers, two input impedance boosting loops and a CMFB circuit. AC-coupled core amplifiers are utilized in this system. The AC coupling circuit makes sure that the measured small AC signal can be effectively coupled to the subsequent signal processing circuit. At the same time the electrode DC bias voltage will be shielded. It is very important to protect the small signal from the electrodes and prevent the amplifier into saturation state. Otherwise, it will result in error measurement, sometimes even lost function. The drawback of AC coupling is the reduction of the input impedance. For example, with the coupling capacitance 350 pF, the equivalent impedance is 10 MΩ at 50 Hz. As we know, the contact impedance between the patients and electrodes is just in MΩ magnitude [3,4]. The CMRR drops serious when the contact impedance and the input impedance are comparable, as well as bad performance in motion artifact. As shown in Fig. 1, impedance boosting loops are introduced to boost the input impedance. CMFB circuit senses the common mode voltage from the two core amplifiers and feeds it back to the inputs, thus improving the CMRR of the system.

2.2. Noise in active electrode

Dry electrodes cause high contact impedance between patients and readout circuits. So an impedance converter is introduced to make sure that enough signal flows into the readout circuit. In traditional design,

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http://dx.doi.org/10.1016/j.mejo.2017.05.008
Received 14 September 2016; Received in revised form 28 February 2017; Accepted 14 May 2017
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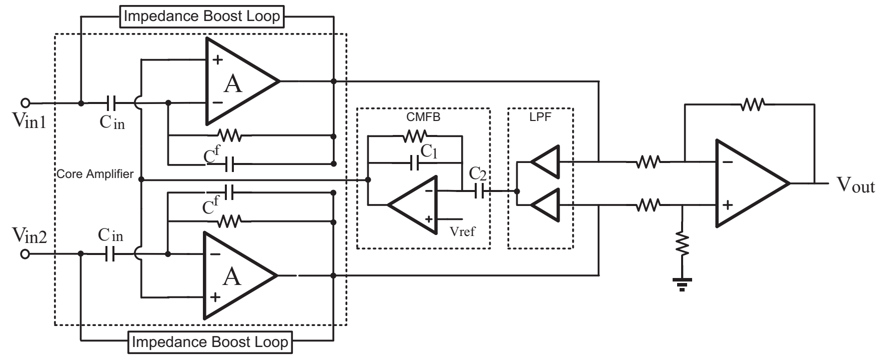

Fig. 1. Block diagram of active dry electrode interface circuit.

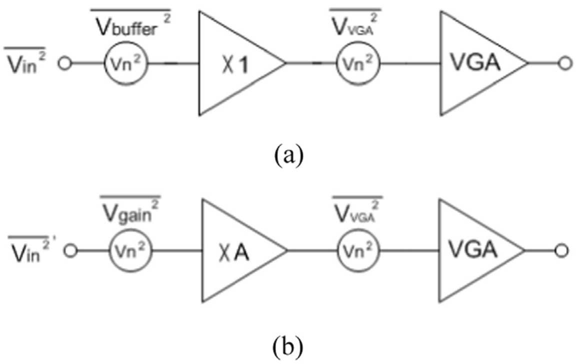

Fig. 2. Noise model of active electrode (a) with buffer (b) with gain.

active electrode is normally a dry electrode followed by a buffer. The buffer behaves as an impedance converter. The problem is that buffers provide no gain but consume power. Why not substitute the buffer with an amplifier? Amplifiers act as impedance converter just as buffers do and also provide additional gain, what's more, better noise performance than buffers. The noise model of the two circuits mentioned above are shown in Fig. 2, where $\overline{V_{in}}^2$ and $\overline{V_{in}'}^2$ are the input referred noise of buffer-based active electrode and amplifier-based active electrode, respectively. $\overline{V_{VGA}}^2$ represents the input referred noise of VGA. The input referred noise of the two circuits shown in Fig. 2 is calculated as follows,

$$\overline{V_{in}}^2 = \overline{V_{buffer}}^2 + \overline{V_{VGA}}^2$$
$$\overline{V_{in}'}^2 = \overline{V_{gain}}^2 + \frac{1}{A^2}\overline{V_{VGA}}^2 \tag{1}$$

The input referred noise of VGA in amplifier-based active electrode reduces by a factor of A^2 compared with the buffer-based one. The total input referred noise reduces when the buffer and the amplifier have the same amount of input referred noise.

2.3. Core amplifier

A folded-cascode amplifier is employed in this interface circuit, as shown in Fig. 3. This amplifier provides a good balance between output voltage swing and power consumption. The amplifier consists of two stages: a folded-cascode amplifier and a class-AB output stage. In order to reduce the noise and offset caused by the class-AB driver and guarantee a good performance of the amplifier, a compact class-AB output stage is utilized. The class-AB driver consists of two common-source transistors, M25 and M26. There are two translinear loops in this circuit, M20, M21, M22, M25 and M19, M23, M24, M26. In these two translinear loops, M19, M20 form the floating current controller and the stack diode-connected transistors M23-M24, M21-M22 provide bias voltages for the gates of M19 and M20 respectively. The two translinear loops keep the gate voltage of the output transistors constant and determine the quiescent current of the output transistors, making the quiescent current insensitive to the power supply.

2.4. Input impedance boost circuit

The input impedance in Fig. 4(a) is expressed as Eq. (2). It is clear that the input impedance is dominated by the AC couple capacitor C_{in}. The input impedance is approximate 10 MΩ@50 Hz according to Eq. (1) when C_{in} is set at 350 pF. As mentioned above, the skin-electrode contact impedance is also in MΩ magnitude. This will degrade the CMRR and increase the motion artifacts, which will severely degrade the performance of the interface circuit.

$$Z_{\text{in}} = \frac{1}{sC_{in}} \tag{2}$$

A positive feed back loop is implemented in this interface circuit to boost the input impedance of the front-end circuit [5]. As shown in Fig. 4(b), the input impedance boost loop consists of an AC-coupled amplifier A_{Boost} and two capacitors in parallel, C_{coarse} and C_{fine}. The output of the amplifier A will be amplified by the impedance boost loop amplifier A_{Boost} and then generate a feedback current I_f. In the ideal situation, the current generated by the input impedance boost loop

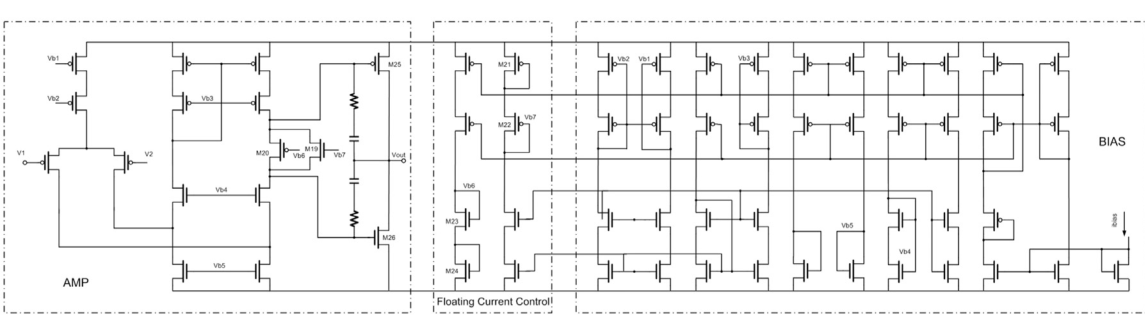

Fig. 3. Schematic of Amplifier.