Noise Characterization Framework for cECG Systems Using Isoelectric Baseline Analysis

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***Abstract*—This paper presents a TP-segment-based methodology for objective characterization of the system-level output noise of non-contact capacitive electrocardiography (cECG) systems directly from recorded signals. The proposed approach estimates output voltage noise characteristics from the isoelectric TP segments of the ECG and enables quantitative noise evaluation without requiring additional measurement instrumentation. The methodology was applied to compare two operational amplifiers, AD8642 and OPA2145, implemented in the same active capacitive electrode design. Experimental results demonstrate lower system-level output noise for the OPA2145 under both capacitive and galvanic coupling conditions, demonstrating the applicability of the proposed methodology to the objective evaluation and optimization of cECG measurement systems.**

Keywords—non-contact electrocardiography, active capacitive electrodes, noise characterization, isoelectric baseline, TP segment analysis

I. Introduction

Electrocardiography (ECG) is one of the most widely used techniques for the non-invasive assessment of cardiac activity. Recent advances in wearable healthcare technologies have increased interest in non-contact capacitive ECG (cECG) systems, which enable unobtrusive cardiac monitoring without direct galvanic contact between the electrodes and the skin. A typical cECG system consists of two main components: active capacitive electrodes and a signal processing unit (SPU). Among these, the active electrode plays a key role in determining the overall signal quality, as it directly affects the acquisition of weak bioelectric signals and the system's susceptibility to noise. Active capacitive electrodes employing a bias resistor are among the most widely adopted configurations for biopotential acquisition and have been reported in numerous studies [1], [2], [3], [4]. The bias resistor, connected between the operational amplifier (op-amp) input and ground, provides a grounding pathway for the input bias current. Without the bias resistor, electrical charge accumulates on the sensing electrode surface, leading to signal saturation [5]. Consequently, careful design of active capacitive electrodes with consideration of their noise characteristics is essential for reliable signal acquisition in cECG systems.

Compared with conventional contact ECG recordings, cECG signals are considerably more susceptible to noise and interference. The overall noise performance of a cECG system, and consequently the quality of the recorded signal, is largely determined by the active capacitive electrode, particularly by signal acquisition through the high-impedance capacitive interface. Additional factors affecting system-level noise include the operational amplifier (op-amp), front-end electronic noise, external electromagnetic interference, and motion artifacts. Consequently, objective evaluation of system-level noise and improvement of cECG signal quality remain key challenges in the design of cECG systems.

Previous studies have primarily assessed cECG signal quality using signal quality indices (SQIs) or machine learning approaches [6], [7]. Although these methods are effective for evaluating the overall quality of cECG recordings, they provide limited insight into the quantitative characteristics of system-level noise. Consequently, objective methods for the quantitative evaluation of system-level noise are needed to complement existing cECG signal quality assessment techniques while remaining fully compatible with conventional cECG quality evaluation frameworks.

Since the TP segment represents an isoelectric interval with minimal cardiac electrical activity, it provides a suitable region for estimating system-level noise without requiring additional measurement instrumentation. The proposed methodology was experimentally evaluated using two op-amps implemented in the same active capacitive electrode design: the AD8642 (Analog Devices, Inc., Wilmington, MA, USA), previously employed in cECG systems [8], [9], and the OPA2145 (Texas Instruments, Inc., Dallas, TX, USA).

In this paper, a methodology for evaluating the output voltage system-level noise characteristics of cECG measurement systems is proposed based on the analysis of TP segments extracted from recorded cECG signals. Two noise metrics are introduced to compare two op-amps implemented in the same active capacitive electrode design. The proposed methodology is experimentally validated under both capacitive and galvanic coupling conditions.

II. Materials and Methods

A. Active capacitive electrode with bias resistor

The active capacitive electrode with a bias resistor, shown in Fig. 1, consists of three layers: a top component layer, an intermediate guard layer, and a bottom sensing layer. The intermediate guard layer minimizes the effects of parasitic capacitances, thereby improving electrode performance. The operating principle of the guard layer and its role in reducing parasitic capacitances have been described in previous work [10].