CMOS LOW NOISE ANALOG FRONT-END DESIGN FOR MULTI-LEAD NON-CONTACT ELECTROCARDIOGRAM

CHUNG WEI HONG

UNIVERSITI TEKNOLOGI MALAYSIA

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DEDICATION

This thesis is dedicated to my beloved parents

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ABSTRACT

Since the early 1980s, cardiovascular diseases (CVD) has been the leading cause of death and the use of a wearable device to monitor patients could greatly impact the disease outcomes on healthcare systems. However, Malaysians still lack awareness towards the cardiovascular diseases even although cardiovascular disease is the top killer in Malaysia. Cardiovascular disease (CVD) remains the main cause of morbidity and mortality in the world and hence early cardiovascular disease detection is very crucial so that appropriate treatments and counselling can be done in the early stage. Over the past decade, the detection and analysis of biological electrical signals from the surface of the skin using non-invasive electrode has shown to be a powerful device for the diagnosis of clinical conditions. The wet bioelectrode which is using the reticulated gel foam is a universal standard bioelectrode utilized in clinical settings. However, in a long-term application, dehydration of the gel can cause the bioelectrode to become unstable and troublesome, and hence it can result in severe signal attenuation and noise interference. As a result, detection of bioelectrical potentials using non-contact method is desired for the long-term recording of heart biopotential signals. This work is focusing on designing an integrated front-end CMOS analog circuitry that is capable to detect heart electrical signal while achieving low noise circuit performance. An electronic interface to be used with multiple contactless electrodes has been studied in order to develop a wearable health device that able to perform several lead measurements compared to conventional one-lead system. Furthermore, the ability of the proposed interface to amplify differential biopotentials and to reject common-mode signals produced by electromagnetic interference are investigated as well. This work is implemented using Silterra 0.13 µm CMOS technology using Cadence computer-aided design tool. From the simulation result, the CMOS operational amplifier design achieved the gain of 64.2286 dB and phase margin of 83.3°. It also obtained CMRR of 89.9357 dB, PSRR of 71.6896 dB and a lower power dissipation of 3.5 µW at the operating frequency range between 0.05 Hz to 250 Hz. In addition, the complete interface with driven right leg circuit in this project is able to achieve gain more than 50 dB at the same operating frequency as well. This amplifier output will be eventually connected to other peripherals that will make up a whole ECG monitoring wearable health device.

ABSTRAK

Sejak awal 1980-an, penyakit kardiovaskular (CVD) telah menjadi punca utama kematian dan penggunaan peranti sedia pakai untuk memantau pesakit boleh memberi kesan besar kepada sistem penjagaan kesihatan. Namun, rakyat Malaysia masih kurang sedar terhadap penyakit kardiovaskular walaupun jantung berhenti seketika secara tiba-tiba merupakan sebab utama kematian di Malaysia. Penyakit kardiovaskular (CVD) kekal sebagai punca utama morbiditi dan kematian di dunia dan justeru pengesanan awal penyakit kardiovaskular adalah sangat penting supaya rawatan dan kaunseling yang sesuai dapat dilakukan pada peringkat awal. Sepanjang dekad yang lalu, pengesanan dan analisis isyarat elektrik biologi dari permukaan kulit menggunakan elektrod bukan invasif telah terbukti sebagai peranti yang berkuasa untuk diagnosis keadaan klinikal. Bioelektrod basah yang menggunakan buih gel retikulasi ialah bioelektrod standard universal yang digunakan dalam tetapan klinikal. Walau bagaimanapun, dehidrasi gel dalam penggunaan jangka panjang boleh menyebabkan bioelektrod tidak stabil dan menyusahkan kerana hal ini boleh mengakibatkan pengecilan isyarat biopotensi jantung yang teruk dan gangguan bunyi. Akibatnya, pengesanan potensi bioelektrik dengan menggunakan kaedah bukan sentuhan mampu untuk rakaman isyarat biopotensi jantung dalam jangka masa yang panjang. Dalam projek ini, kerja ini akan memberi tumpuan dalam mereka bentuk litar analog CMOS bahagian hadapan bersepadu yang mampu mengesan isyarat elektrik jantung sambil mencapai prestasi litar hingar rendah. Antara muka elektronik yang akan digunakan dengan berbilang elektrod tanpa sentuh akan dikaji untuk membangunkan peranti kesihatan boleh pakai yang mampu melakukan beberapa pengukuran plumbum berbanding sistem satu plumbum konvensional. Tambahan pula, keupayaan antara muka yang dicadangkan untuk menguatkan biopotensi pembezaan dan menolak isyarat mod biasa yang dihasilkan oleh gangguan elektromagnet akan disiasat juga. Kerja ini akan dilaksanakan menggunakan teknologi Silterra 0.13 µm CMOS dalam rangka kerja reka bentuk bantuan komputer Cadence. Pengeluaran yang dijangkakan bagi projek ini ialah penguat isyarat ECG yang direka boleh dikuasakan oleh bekalan kuasa kurang daripada 1.2 V, nisbah penolakan mod biasa yang tinggi (> 60 dB) dan voltan hingar yang dirujuk input rendah. Daripada hasil simulasi, reka bentuk penguat operasi mampu mengarkibkan keuntungan sebanyak 64.2286 dB dan margin fasa 83.3°. Ia juga menyediakan CMRR sebanyak 89.9357 dB, PSRR sebanyak 71.6896 dB dan pelesapan kuasa yang lebih rendah sebanyak 3.5 µW pada frekuensi operasi 0.05 Hz hingga 250 Hz pada tahap skematik. Selain itu, reka bentuk lengkap dengan reka bentuk litar kaki kanan terdorong dalam projek ini mampu mengarkibkan keuntungan lebih daripada 50 dB pada frekuensi operasi 0.05 Hz hingga 250 Hz pada tahap skema juga. Pengeluaran penguat ini akhirnya akan disambungkan ke peranti lain untuk membentuk keseluruhan peranti kesihatan boleh pakai pemantauan ECG.

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LIST OF ABBREVIATIONS

CVD	-	Cardiovascular Diseases
ECG	-	Electrocardiogram
CMOS	-	Complementary Metal Oxide Semiconductor
DC	-	Direct Current
EDA	-	Electronic Design Automation
PMOS	-	P-type Metal-Oxide-Semiconductor Transistor
NMOS	-	N-type Metal-Oxide-Semiconductor Transistor
SoC	-	System on Chip
PSRR	-	Power Supply Rejection Ratio
CMRR	-	Common Mode Rejection Ratio

CHAPTER 1

INTRODUCTION

1.1 Research Background

Since the early 1980s, cardiovascular diseases (CVD) has been the world's top cause of death. According to the research, around 17.9 million deaths worldwide in 2019 were attributable to CVDs or 32% of all fatalities in the world. Among these 32% of deaths, 85% were caused by heart attack and stroke. The majority of CVD deaths occur in low and middle-income nations [11]. Ischaemic heart disorders continued to be the leading causes of mortality in Malaysia, 17% of the 109,155 medically certified deaths in 2020 [12]. However, Malaysians still lack awareness towards the cardiovascular diseases even although cardiovascular disease is the top killer in Malaysia. In the world now, cardiovascular disease (CVD) continues to be the leading cause of morbidity and mortality and hence cardiovascular disease detection in an early stage is very crucial so that appropriate treatments and counselling can be done in the early stage.

In the last ten years, the researchers were interested in wearable device technology since this technology could help the CVD patients that need long-term heart condition monitoring and thus they do not necessarily have to stay in the hospital. In addition, wearable devices have also gained attention and interest from the leading industries around the world [9]. At the moment, most of the wearable devices in the market are mainly only capable to track and monitor activity parameters such as heart rate, distance count, step count and so on. Meanwhile, the latest sensors used in some wearable devices are also able to track and monitor physiological parameters relevant to CVD, such as blood pressure and oxygen saturation (SpO2).

Recently, electrocardiogram (ECG) monitoring is setting up to be one of the most powerful health-related functions of the advanced wearable devices. The global healthcare systems might be significantly impacted by the usage of a wearable device to monitor patients. On the other hand, the wearable devices in the market now can only record single-lead ECGs using several dry contact electrodes [9]. This type of measurement can be used only for the diagnosis of arrhythmia. Numerous ECG leads are needed to diagnose other cardiac disorders. To a certain extent, the accuracy of the representation of the heart's electrical activity will be increased when more points are recorded through multiple ECG leads [13].

Traditional 12-lead ECG can detect and capture cardiac voltages on the skin, with amplitudes of small voltages and frequencies between 0.01 Hz to 150 Hz. To use the traditional 12-lead ECG, the patient is needed to lay on an examination bed for a limited time so that the ECG measurement can be performed. The wet bioelectrode which is using the reticulated gel foam is a universal standard bioelectrode in traditional 12-lead ECG measurement [9]. However, the reticulated gel foam will get dehydrated after some time and it can cause the bioelectrode to become unstable and troublesome and hence it can cause serious signal attenuation and noise interference. Over the last few years, non-contact electrodes have been implemented in several research [14]. Investigation of the patient’s body using capacitive electrodes have been done as well [15–18]. By implementing the electrodes into portable gadgets etc., it may be possible to employ more ECG leads, but marginally compromising patient comfort. The best electrodes to be implemented in the portable device are the dry capacitive electrodes. As a result, advanced electronic interfaces need be created to meet the application requirements in order to employ the capacitive electrodes. High impedance on the electronic interface and EMI rejection are the two key criteria of the new electronic interfaces. Compared to the previous years, it is undeniably that there is a growing trend and demand for more portable medical equipment. It is more obvious in the recent time when excitement of the arrival of the internet of things (IoT) in the coming future. As a result, it is crucial to design the electronic interface system that is capable to detect heart electrical signal using non-contact method through dry capacitive electrodes and also fit to be used with the wearable devices.

1.2 Problem Statement

Over the past decade, using non-invasive electrodes in performing the detection and analysis of biological electrical signals from the skin surface has proved to be a very effective tool for the diagnosis of clinical disorders. However, the reticulated gel foam will get dehydrated after some time and it can cause the bioelectrode to become unstable and troublesome, and hence it can cause serious signal attenuation and noise interference. Dry capacitive electrodes can detect ECG signals without using the conductive reticulated gel. Dry electrodes can overcome the disadvantages of wet electrodes and provide a stable detection and analysis of cardiac signals especially for a long-term application.

In recent years, health monitoring in advanced wearable device is rapidly increasing. However, health monitoring wearable device that is using sensor will have a bigger size and less flexibility to implement more customizations. As a result, a low noise and high-performance system design are playing an essential role to accomplish a single-chip portable ECG monitoring system in a wearable device.

1.3 Research Objectives

The research objectives of the project are:

a) To design a low noise and high performance CMOS amplifier that is capable to detect capacitive heart electrical signal.

b) To develop a fully integrated CMOS front-end interface for multi-lead capacitive ECG.

1.4 Scope of Research

In this work, Cadence Virtuoso tool is used to design and simulate the operational amplifier based on the design specification of the project. The process technology node used for this project is 0.13 μm CMOS standard from Silterra.

1.5 Thesis Outline

There are five chapters of contents in this thesis, including introduction, literature review, project methodology, result and discussion, and finally a conclusion. The first chapter presents the research background, the problem statement, project objectives and the scope of the project.

Chapter 2 covers the non-contact ECG and the ECG amplifier in monitoring cardiovascular health. This chapter also discusses the theoretical background of the operational amplifiers. In addition, a summary of reviewed research papers by other researchers are presented as well.

Chapter 3 presents the project methodology and the scheduling of the design in project flowchart. Additionally, the reference design topology and the performance specifications of the design are shown in this chapter.

Chapter 4 discusses about the simulation results obtained after the completion of the workflow of the research. Schematic diagram of the circuit design and simulated output waveform are presented in this chapter to discuss about the simulation results after the simulation is done.

The last chapter summaries the overall research. Suggestions for further works and improvements in the future are discussed in Chapter 5 too.

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