

Design of Dry and Long-Lasting Electrodes for ECG

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Abstract- Humans and animals both generate bioelectric signals through their tissues in static and active forms. These signals could be used to check the different physiological conditions of the body. Electrocardiogram (ECG) is one of the signals produced by the heart. ECG helps to monitor the health of the heart such as heart rate, contraction of heart muscles, and blood circulation. Abnormality in these parameters can cause serious cardiovascular diseases. Thus, monitoring of ECG helps to early diagnose cardiovascular diseases. To measure these signals electrodes or sensors are used. There are several types of electrodes are developed to measure heart bioelectric signals, but they are not very efficient, consume more power, and can harm the skin. The focus of this research was to design new and more efficient dry electrodes. For this purpose, ECG noise was simulated in MATLAB and the main schematic diagram was designed. Suitable components of the electrode were selected according to the desired output. The circuit was designed through Proteus software and printed on PCB sticker paper. The evaluation result revealed that our designed ECG dry electrodes were more efficient than traditional gel-based ECG electrodes. Newly designed electrodes displayed less noise impedance and did not harm the skin of the patients. These dry electrodes can be used in hospitals to monitor ECG.

Index Terms- Dry Electrodes, Electrocardiogram, LMP7708

I. INTRODUCTION

Cardiovascular disease is the process of building up the plaques that cause the blockage in the blood vessels such as heart arteries (coronary heart disease), legs (peripheral arterial disease), and brain (cerebrovascular disease). Cardiovascular diseases are notorious for causing heart attacks, death, strokes, etc. Chest pain, breathing difficulty are some common symptoms of cardiovascular problems. There are several assessment tools for identifying the disease or problems related to the heart. These tools can also help to account for the risk factors such as smoking, male sex, overweight, obesity, etc., to be the cause of heart disease [1]. Electrocardiogram (ECG) is an immediate investigation of the electrical activity of the heart. It is a non-invasive and cheap technique that can help provide important information about the heart rate and rhythm, and it also helps identify heart diseases[2].

A. Wet and Dry Electrodes

Ag/AgCl wet electrodes are the most popular noninvasive wet electrodes that are used with the conductive gels as they can provide reduced electrode-skin interface impedance and

that can give stable and accurate bioelectrical signals [3]. Wet electrodes are utilized for their excellent electrical properties to collect the bioelectrical signals, but there are some limitations to the use of the wet electrodes, specifically monitoring for the long term. The Ag/AgCl electrodes need skin preparation like dirt removing, hair-cutting, and gel coating by an electrolyte that is extremely time-consuming[4]. Additionally, the conductive gels might become dehydrated and coagulate after long-term usage and it may increase the detection noise and decreases the signal quality. Moreover, allergic reactions to the gel have also been observed in many patients [5].

Dry electrodes can be used to overcome the limitations that are mentioned above that are caused by wet electrodes as they are portable and are convenient to use[6]. The signals must be comfortable in long-term detection, and they should be of high quality for the analysis, which is the purpose of the recent works. The signals received by dry electrodes have lower amplitude, more randomness, noise, and higher impedance. There are more possibilities for utilizing the dry

electrodes because of the diverse materials and the integrated electronics [5, 7].

B. Working and Design of Dry Electrodes

The signals that are generated by the electrical activity of the heart are usually measured with the help of a voltage implied that has two basic requirements of input impedance and the current flowing between the body and the amplifiers[8]. The biopotential signals like ECG are very sensitive to the electromagnetic interference that is caused by coupling the body of the patient and the power lines that resulted in a common mode voltage or V_{cm} on the electrodes[9]. By improving the common mode rejection of the system, it is possible to get this phenomenon. To perform an ECG, the patient's body must be grounded with the ECG device. This grounding increases the V_{cm} because of the resistance. Thus, the impedance of the grounding electrode is reduced to compensate for the EMI generate current, which can be achieved by using the driven right leg electrode [10, 11]. Zompanti, et al. [12] conducted the study is based on the investigation of a suitable circuit topology that was given by [13] 14].

The proposed design by the author can be used with the capacitive electrode that can be placed on the clothes of the patients[15]. According to the authors, it has been founded that this proposed method was more efficient than the wet electrodes. Moreover, the proposed topology of the circuit showed that the electronic interface was very low cost, and it does not use any expensive instrumentation amplifiers. The topology is modular, and it has shown the flexible electrode number. The electronic interfaces are based on the differential amplification, filtration and the DRL electrodes that are used to obtain a high signal to noise ratio[16, 17]. The beginner electronic interface uses the capacitive electrodes while the second one uses wet Ag/AgCl electrodes. The ECG recorded with the help of a contactless device showed the satisfying signal-to-noise ratio. The rib cage movement generated a sinusoidal pattern during the breathing. It was founded that the capacitive electrodes are sensitive to the nearby charge displacements[18]. During the tests, the body movements in the arms, head, and shoulders caused the signal artifacts of the output signal. ECG complexes that were extracted from the two devices showed comparable but not identical results and the intervals and segments had the same intervals, however, the R peak and T wave had different amplitudes [12].

II. EXPERIMENTAL DESIGN

A. Experimental Test Object & Materials

To check the functioning and efficiency of designed dry electrode a healthy man of 27-year age was selected from the laboratory. In order to perform the experiment, cotton swabs,

disinfectant, some disposable ECG electrodes, dry electrodes, several connection wires, power and data transfer lines, ECG acquisition module and cardiac monitor BSM-5000 were used.

B. Experimental Setup

ECG Noise Simulations using MATLAB:

We used the MATLAB tool for the simulations of the received ECG noise signals. MATLAB also helps in the denoising of the received ECG signals for their better interpretation [19-21].

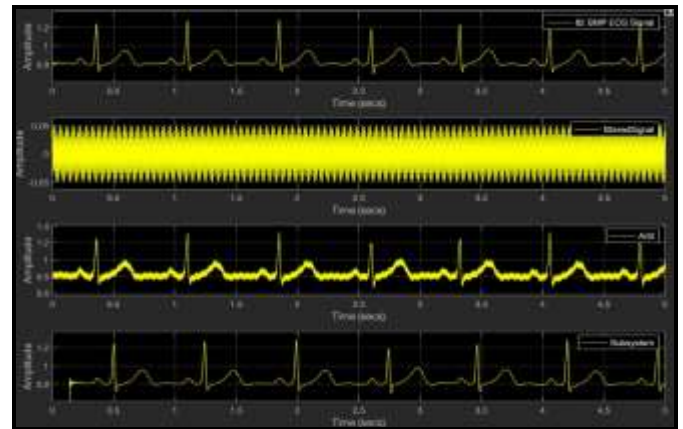


FIGURE 1. ECG Noise Simulation in MATLAB

Main Circuit Components:

Dry and long-lasting ECG electrodes were designed for this study. The main circuit comprised different component including input, output, electricity source, resistors, and capacitors.

- **Resistors:** Two resistors of 4.7k ohm (R1) and 10k ohm (R2) were used to control any electric surge from the signals coming from the source. Similarly, two more resistors of 1M ohm and 100 ohms were used to control the current going towards the output device.
- **Capacitor:** A capacitor of 0.22 μ f was included in the circuit as it saves the circuit from spurious electric signals and also prevents damage to the circuit
- **Battery:** A 3 Volt battery was also included in the circuit to run the whole operation.
- **LMP 7708:** A precision amplifier (LMP 7708) was also included with a purpose to enhance the signals coming from the source in case they are too weak.

The diagrammatic representation of the main circuit is shown in Fig. 2.

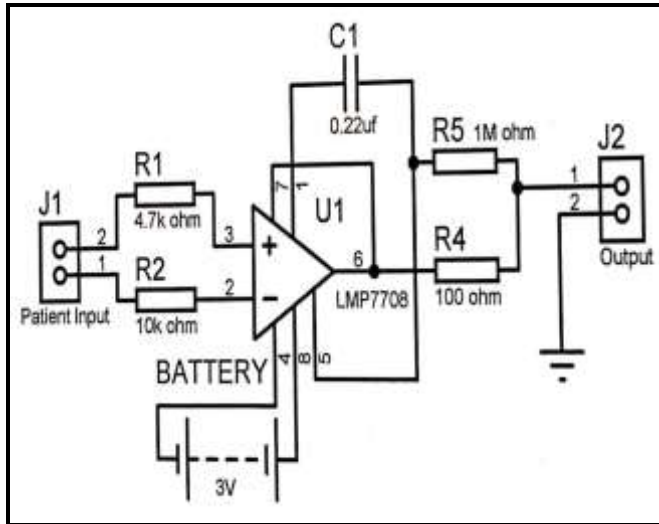


FIGURE 2. Design of Dry and Long-lasting Electrodes

LMP 7708

The main reason behind choosing LMP 7708 are its key properties which are illustrated below.

- One of its key features is its high impedance sensor interference. Which makes it quite suitable to work with small amount of current or power. Also, it has a very low input bias current of almost 200 fA.
- Similarly, it has high gain amplifier property which makes its power consumption efficient as well as increases its overall output.
- It can also endure a wide range of temperature from -40°C to 125°C , making it suitable for varying environmental conditions as well as over-heating of the circuit.
- Moreover, it has an important capability to reduce the CMRR glitch.
- Most importantly, LMP 7708 has a built-in electrostatic discharge (ESD) protection.

As LMP 7708 works with very small electric signals, therefore, it is quite useful in such studies where the purpose is to detect minute electric signals and their alterations in heart.

The block diagram of LMP 7708 is represented in Fig. 3. It indicates that LMP 7708 is a dual low offset voltage amplifier that can operate at an input ranging from 2.7 V to 12 V.

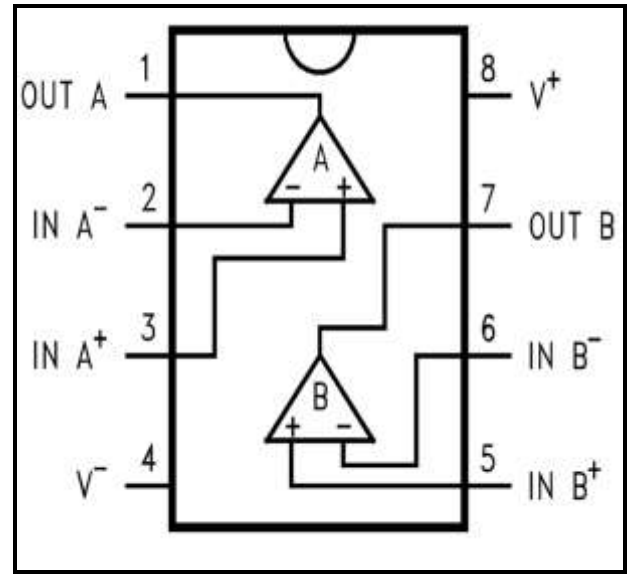


FIGURE 3. Block Diagram of LMP 7708

C. Proteus Design Suite for Drawing Circuit

After selecting all the suitable components required for the designing of the dry and long-lasting ECG electrodes, the circuit was first tested using the simulated circuit which was designed using the Proteus design suite[22]. Proteus design suite is a simulation tool used for drawing the circuits in the form of electronic prints which can be used for the actual printing of circuit boards. Before directly moving towards hardware implementation this online tool helps in the schematic simulation of the designed circuit. The simulated schematic circuit was designed on the Proteus design suite to compare its activity and performance with the actual hardboard printed circuit [23, 24]. The Proteus design of the ECG electrodes is shown in Fig 4.

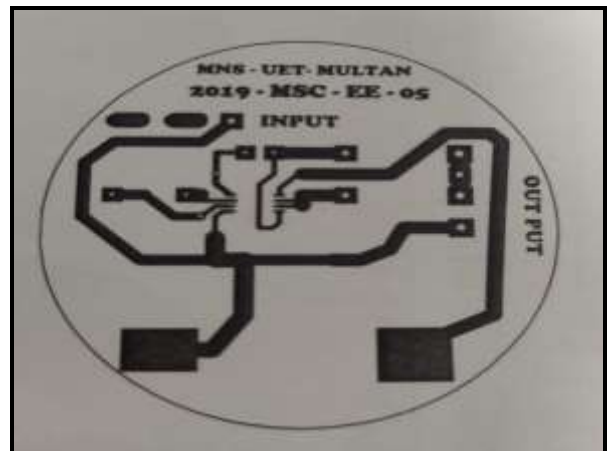


FIGURE 4. Schematic simulation of the designed circuit through Proteus.

D. Proteus PCB Designing of The ECG Electrode's Circuit

After designing the circuit through the Proteus design suite, the circuit was printed on sticker paper. This sticker paper which is actually glossy paper was then placed on the copper board. Before placing sticker paper, the copper board was cut into the appropriate size. The sticker was placed in such a way that the print faced the copper layer. Alignment was ensured and print was placed accurately. To ensure rigid alignment, the copper board was heated for 10-15 minutes with heated by an iron heat source[25]. Fig. 5 shows the print of the circuit design on the copper board.

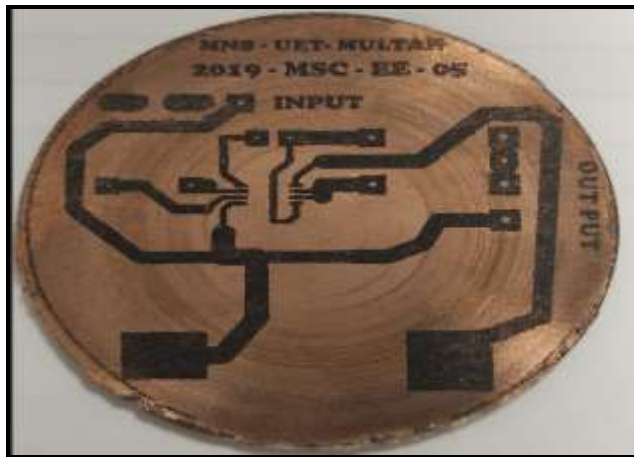


FIGURE 5. Copper board with printed circuit design

After firm attachment of printed circuit on copper board, it was placed into light warm water to remove the extra sticker paper. Then this copper board having circuit design on it was dipped into the solution of ferric chloride as shown in Fig. 6[26].



FIGURE 6. Preparation of circuit on copper board

Placing the copper board into ferric chloride solution prompted the disintegration of any excess copper. As a result, only our design stayed on the board.



FIGURE 7. Proteus Design of the ECG Electrodes

Board was rinsed properly, and print was removed via thinner or nail polish remover. Necessary holes were drilled through a PCB drill. Components were soldered on the board and extra pins were cut down.

Proteus PCB design was used for the Printed Circuit Board (PCB) of the designed and simulated ECG circuit[27]. The sticker paper was used for the printing of the circuit using the Proteus PCB design. The PCB design enables the circuit components to connect electrically upon an already manufactured circuit board [25]. The final designed dry and long-lasting ECG electrodes are shown in Fig. 8.

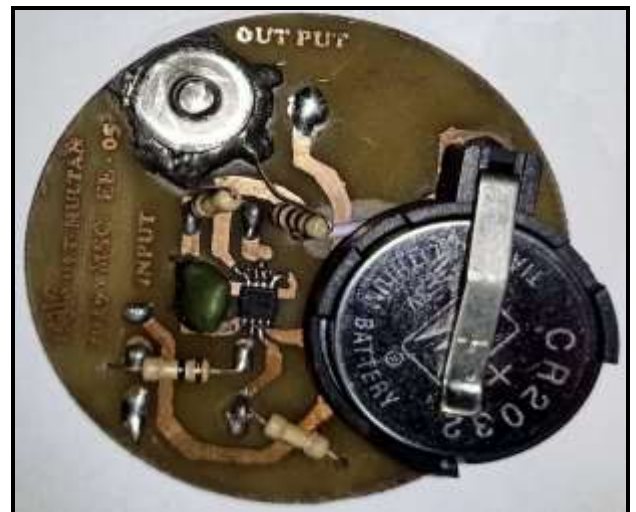


FIGURE 8. Final Designed Dry and Long-Lasting ECG Electrodes

III. RESULTS

A. Output Of Newly Designed ECG Electrode

Figure 9 shows the result of our designed dry ECG electrode on cardiac monitor BSM-5000.



FIGURE 9. Output of Newly Designed ECG Electrode

B. Output With Disposable Wet Electrodes

Results showed that ECG signal response obtained when the subject was in resting state via the wet disposable electrode, it was detected that there were many differences found in amplitudes of ECG signals. Moreover, noise interference was also detected greatly. Fig. 10 shows the ECG signal record of disposable wet electrode. It was difficult to observe and differentiate between the main components of the ECG signal: the QRS complex wave, P-wave and T-wave[28]. Moreover, the R-peak demonstrated amplitude variations that will influence the detection of the R-R Interval (RRI) length which is used to calculate the interval between neighboring QRS complexes and can affect the estimation of the heart rate[29].



FIGURE 10. ECG signal response of wet disposable electrode

C. Output With Dry ECG Electrodes

Results have shown that the ECG signal obtained by applying the dry ECG electrode displayed little or no difference in amplitudes. It also exhibited very less noise impedance. Fig. 11 shows the ECG signal response of our designed dry electrode. From this signal, it was possible to clearly observe and identify the typical ECG components; QRS-complex, P-wave and T-wave. The better ECG signal obtained from the dry ECG electrode can be attributed to the fact that this printed electrode has an improved mechanical contact with the skin due to its flexible and conformal physical form factor[30]. These results demonstrate that the response of the dry ECG electrode had a better performance, in terms of identifying a typical ECG signal while the subject is in rest.

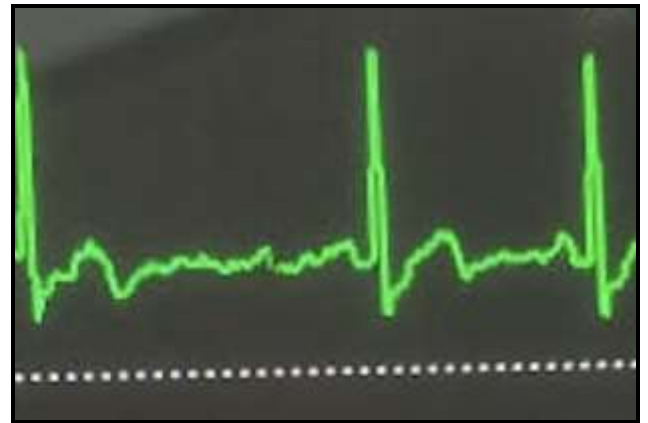


FIGURE 11. ECG signal response of dry reusable electrode

The output obtained from newly designed gel free dry ECG electrode in a cardiac hospital where a patient was laying on the bed by direct contact of electrode with patient skin. The output was analyzed on cardiac monitor BSM-5000. Results revealed the better performance of our designed dry electrode as compared to gel based wet disposable electrodes. Designed electrodes also consume less power and can be reuse. Also, these electrodes did not harm the skin of subject.

IV. CONCLUSION

Currently, major focus of medical science is to synthesize electrodes, which can be easily manufactured. Traditional electrodes are not considered efficient because of excessive power consumption, greater background noise, short shelf life and allergic reactions on skin caused by conductive gel. To overcome these issues many researchers and scientists are exploring dry electrodes for the advancement in ECG signal monitoring. The focus of our research study was to design

dry electrodes for efficient ECG signal monitoring. Results revealed that ECG signal noise was successfully simulated by MATLAB. Moreover, the circuit of electrode designed through the Proteus design suite was accurately printed on PCB, and components were precisely soldered. Finals Results of ECG data taken from a healthy young male patient revealed that ECG response signals obtained from dry electrodes were more accurate and exhibit less signal-to-noise ratio when compared with wet gel electrode ECG signal response. The variations in amplitudes of ECG signal from dry electrode were less than that of wet gel electrode. Dry electrodes efficiently measured ECG signals for a long time without damaging the skin surface of the patient and reused. Thus, our designed dry ECG electrodes could be used at a wider level to monitor cardiovascular diseases more efficiently and accurately.

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