SURVEY ON DRY-CONTACT AND CONTACTLESS ELECTRODES FOR BIOPOTENTIAL SIGNALS

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Abstract: The need of medical assistance around the world never decreases but in-fact it rises substantially with the increase in number of diverse diseases and increase in population. Cardiac and neural signals are the most important electronic signals in the human body which need to be monitored as they are critical-health indicators. The conventional electrodes which are also known as wet electrodes makes use of adhesive Ag/AgCl gel in between the electrode and the skin for better conduction. Even though they are used universally in clinical applications to obtain the ECG and EEG of an individual, they are known to be uncomfortable for long duration monitoring applications and cumbersome for mobile use. The alternates to the wet electrodes so as to solve its disadvantages are the dry-contact electrodes where the need for an electrolyte is inessential or the contactless electrodes where there is no electrical contact between the electrode and the skin. These electrodes have been around for quite a while but still are yet to be accepted for clinical use. The process of obtaining or acquiring the biopotential signals such as the ECG or the EEG is the same and the device used for monitoring one can be used to monitor the other with minor modifications. In this paper, we will be providing an insight into the advancements in non-contact electrodes. This paper will also address the issues faced with dry and non-contact electrodes and the methods used to overcome these issues such as the noise level in the ECG or the EEG waveform. The advantages and the disadvantages of using the said methodologies will be explored. Upon studying the work done in this field to improve the efficiency of devices using dry electrodes and contactless electrodes, it has been concluded that it is not just probable but entirely possible that these may be used in future instead of the wet electrodes with same level of efficiency.

***Index Terms* - Bio-Potentials, Capacitive Electrodes, Contact Electrodes, Contactless Electrodes, Dry Electrodes, Electrocardiography, Electroencephalography.**

I. INTRODUCTION

Medical electronic devices are always required irrespective of the country or its quality of healthcare. Further, to ensure the quality of the said healthcare is up to the required standards and then some to ensure the citizens of a country remain healthy. Many devices of the medical sector need to be upgraded regularly and medical research is a never-ending race between the diseases and its cure. All the devices used in the medical field are of highly importance ranging from a simple thermometer to a highly complicated CAT scan machines. Two such machines used is the electrocardiogram to observe, record and display the heart beats of an individual and the electroencephalogram to observe, records and display the brain activity of the individual.

From the conception of the above said machine, the procedure to obtain the aforementioned bio-potential signals viz. the electrocardiography (ECG) and the electroencephalography (EEG) of an individual has been the same. These bio-potential signals are observed using electrodes known as the wet electrodes or Ag/AgCl Electrodes. The only possible way to obtain the bio-potential signals using these types of electrodes is to apply an electrolyte get on the human skin to decrease the resistance and improve the conductivity of the electrodes. But to obtain the EEG of the individual, the medical staff would need to shave the persons head to be in direct contact with the skin (scalp). This procedure has been known to be troublesome for the patients and said to be the major disadvantage. Further, since the electrolyte used is a gel-based electrolyte it is possible that the gel may vaporize from the skin increasing the resistance and decreasing the conductivity especially during long term monitoring of the individuals.

Few solutions present to overcome the mentioned issues with the wet electrodes is to make use of the dry electrodes or the contactless electrodes. The dry electrodes eliminate the use of the gel-based electrolyte on the skin or the scalp to acquire the ECG or EEG respectively. On the other hand, while making use of the contactless electrodes make it possible to be able to acquire the bio-potential signals without the application of the electrolyte and also be able to acquire them over the clothes of the individual or over the hair on the individual's head. In the present, the wet electrodes have not yet been replaced by the dry electrodes or the contactless electrodes but it may be done in the future once accuracy of the signals is same as that of the wet electrodes and the noise level in the signals becomes negligible.

II. DRY & CONTACTLESS ELECTRODES, AMPLIFIER FOR BIO-POTENTIAL SIGNAL DETECTION

Chi et al. [1] provides a in depth comparison analysis between standard Ag/AgCl or wet electrodes, dry electrodes and noncontact based biopotential electrodes is discussed in this paper. The drawbacks of the standard gel-based electrodes are discussed along with the extent of usability of dry and non-contact based electrodes. In the case of gel-based electrodes, the conducting metallic part is mixed with an electrolyte solution which helps in buffering the electrolytic composition through the layers of the skin. In the case of dry or noncontact based electrodes, reading the signal through the electrode-skin interface is much more complex given that the amplitude of ECG signal obtained is around 1mV and EEG signals are in the range of 10-100µV.

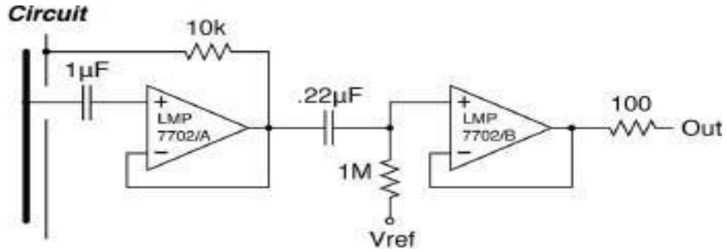

Fig. 1. Simplified Amplifier Design

In the paper [1], Chi et al. presents a design which has been able to sense the ECG from the electrode-skin interface by making use of dry and non-contact based electrodes. An amplifier design is presented, which is constructed to amplify the ECG signal sensed from the body by the electrodes and present the signal on a display by eliminating the noise factor. This design also accounts for any electrical coupling between the skin and amplifier circuit which is connected to the electrode for biopotential signal acquisition. This design is implemented by designing a PCB with a bottom sensing plate or the electrode and the amplifier circuit on the top. The inner layer acts as active shielding to prevent the coupling noise between the skin and the amplifier circuit.

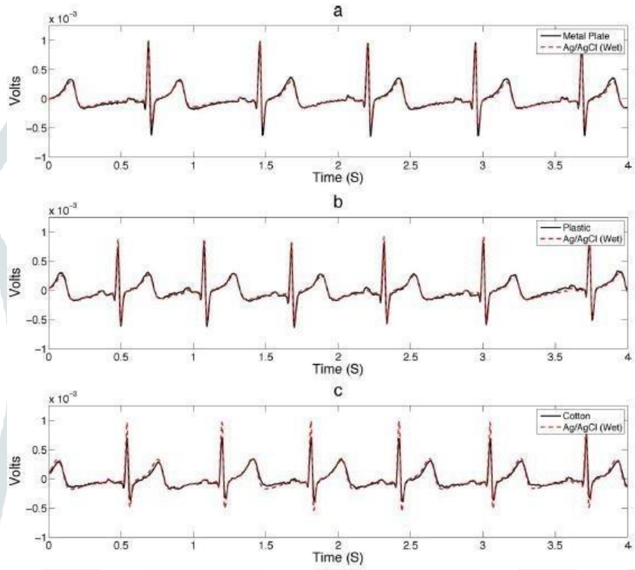

Fig. 2. ECG from various insulations against ECG from wet electrode

Harland et al. [2] is one of the first research to explore the field of dry electrodes and contactless electrodes. The block diagram provided is one of the simplest and basic solutions to the constructing a contactless or dry electrode. The probe connected to the body is guarded to ensure there is no external noise interference. This methodology is generally for off body detection of bio-potential signals where electrically there is no contact between the probe and the skin. The probe is usually in the size of a US coin with varying diameter and the signal obtained is sent to amplification. Before that the biasing is performed on the signal to ensure the noise doesn't get amplified. The feedback to the amplifier is to eliminate the problem of saturation at the output.

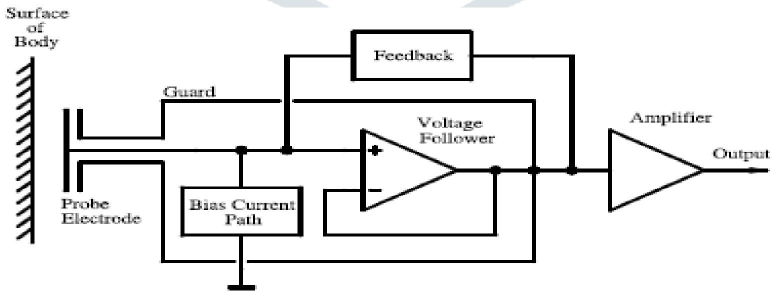

Fig. 3. Block Diagram of typical sensor for detecting Bio-Potential signals

Sullivan et al. [3] explains how the magnitude of electric fields that are coming from the brain are measured using the EEG sensors and similarly the magnitude of electric fields that are from our heart are measured using the ECG sensors. The results of these EEG sensors give the collective information about the activities taking place in a huge number of neurons. Basically, these are the electrical potentials that are measuring these electric field on the scalp recorded by the EEG sensors.

Let us discuss about the circuit designed shown in Fig. 5. for developing an EEG/ECG sensor for amplification purpose:

- This circuit is designed for sensing, amplifying and acquiring the signal. Here the signal coming from the skin capacitively couples to a metal plate at the bottom of the printed circuit board (PCB) that is included with electric insulation like a solder mask of the sensor.

- The circuit starts with first amplification of the incoming signal by using an instrumentation amplification that is 1NA116 which is configured at a gain of 50.
- The shield used is applied as an internal layer of steel on the PCB above the sensor metal layer. As it's far actively driven to make another copy of the incoming voltage, it avoids parasitic capacitance division of sign benefit.
- The extremely small input bias, when that is left unattended will pressure the high-impedance effective input node of the amplifier towards one of the supply rails. We fight this with a reset circuit which includes transistors and two resistors.

Richard et al. [4] has constructed a device using gel-less electrodes which is of low-power and used just to measure the ECG of an individual. The device constructed has no reference electrode but made use of biasing techniques. The device consists of an amplifier, made using instrumentation amplifier to achieve common mode rejection. The amplifier comprises of input conditioning stage followed by a differential amplifier. At the input conditioning stage, through DC isolation person safety is provided. Differential amplifier section consists of an IC circuit with high gain but a 3dB attenuator is present to avoid signal saturation. The data is digitally converted but prior to that bandwidth-limited amplification is performed. Bandpass amplification is between the frequencies of 0.5 and 160Hz which gives effective anti-aliasing especially when sampling rate is above 300SPS (samples per second). The overall gain of the constructed is said to be near 1000. Reference driver is mentioned as optional for evaluating if the body's common mode signal can be used to improve the ECG signal.

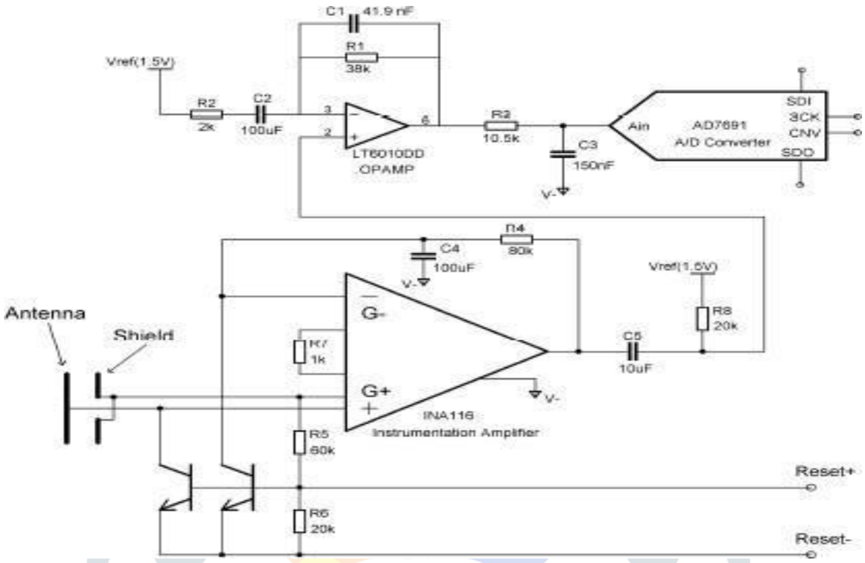

Fig. 4. Design of the amplifier

Gandhi et al. [5] focuses the discussion on the properties of the dry and contactless electrodes for wearable devices to obtain the bio-potential signals. As noticed in many other devices, the noise present in the signals is due to multiple various reasons such as the intrinsic thermal noise, noise due to chemical interactions at the skin, noise generated cause of the movement and biological noise. The total overall noise in the signal can be represented using the equation as shown below

$$v_n^2(\omega) = v_{na}^2 + \left(i_{na}^2 + \frac{4kT}{R_s}\right)\left(\frac{R_s^2}{1+\omega^2 R_s^2 C_s^2}\right) + v_{nb}^2 + v_{ni}^2 \quad (1)$$

where the vna is amplifiers voltage noise, ina is amplifiers current noise, vnb is biological noise, vni is the electrochemical noise and ine is thermal noise. Below is a table showing the impedances of electrodes for various insulations present between the skin and the electrode.

Wet Ag/AgCl	660kΩ || 36nF
HASL	6MΩ || 5.2nF
Latex	100MΩ || 280pF
Silver Cloth	40MΩ || 900pF
Soldermask	1.5GΩ || 400pF
Cotton	1GΩ || 40pF

Table 1. Electrode impedances for different insulation media

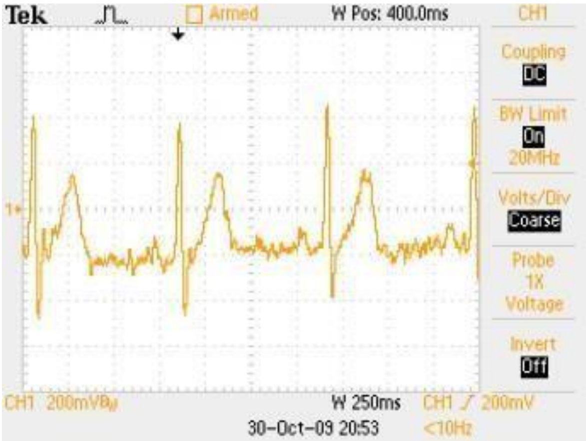

Fig. 5. Capture of ECG with bandpass amplification

Chi et al. [6] have developed a wireless biopotential instrumentation device for non-contact based ECG where the sensors can be placed on top of a relaxed individual. For the purposes of testing of the system insulation material used is fabric. The system designed here consists of an amplifier, filter, buffer which connects to a wireless base unit and is battery powered

Talking about the circuit design for the designed front end amplifier used:

- LMP7702 is being used in this system since it is highly suitable for ultra-high impedance sensors and it is also specified to work at a very low supply voltage.
- The first stage is configured as unity gain voltage buffer.
- The 10nF and 10kohms are connected to protect the input of the amplifier as well as to isolate the output of the amplifier from the active shield.
- The second stage op-amp is the amplifier which amplifiers the signal coming from the voltage buffer stage.
- The lack of bias network results in undefined DC operating point. So as to avoid the offset as well as low frequency noise a passive RC high pass filter with corner frequency of 0.7Hz is used to centre the amplified signal at Vref.
- The 100ohms resistor is used to isolate the cable capacitance from the amplifiers output.

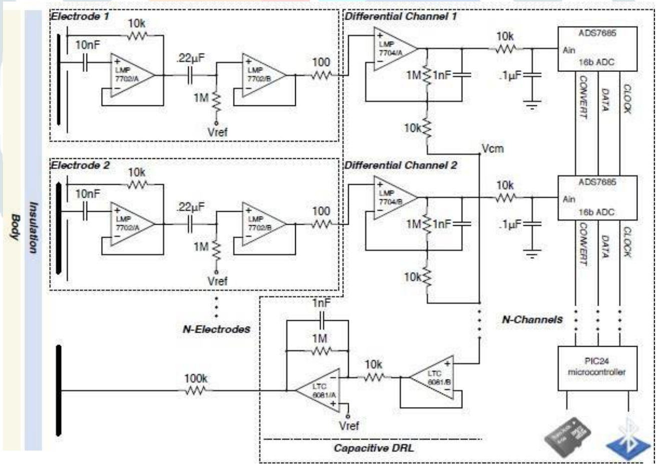

Fig. 6. Full Schematic of the wireless ECG/EEG System

Grounding is shown to be very important for obtaining high signal quality. A separate electrode is used as capacitive grounding to connect circuits ground to the body due to fact that the system is completely insulated. Active driven grounding has been adapted for the sensors to remove the common mode interference. Using the passive ground is causing a 60Hz noise pickup, hence avoided completely. Further same concepts have been used to develop an EEG headband to record the brain activity of the individual.

Chi et al. [7] emphasizes on the improvements in wireless era and electronics miniaturization mainly in the medical field, so as to the use EEG/ECG which has nonetheless been largely constrained by means of the inconvenience and discomfort due to the conventional wet contact electrodes. The design of the system is of sensors which can either be in physical contact to the skin or embedded within clothing. They have included a wireless base to power the entire setup and a transmitter to transmit the data to a nearby external device. Each electrode provides 46dB of gain over a .7-100Hz bandwidth with a noise degree of 3.8µV RMS for high quality of the brain and cardiac recordings.

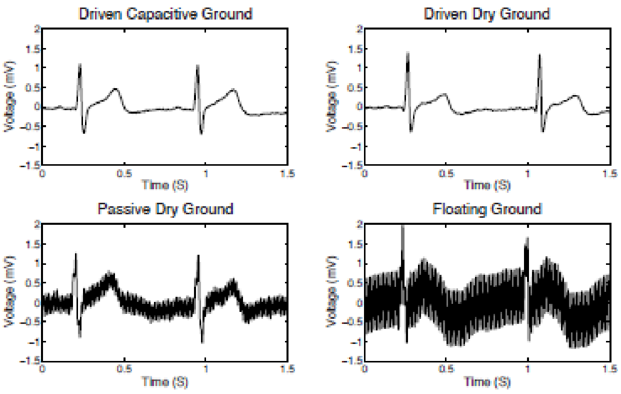

Fig. 7. Waveform for different grounding techniques

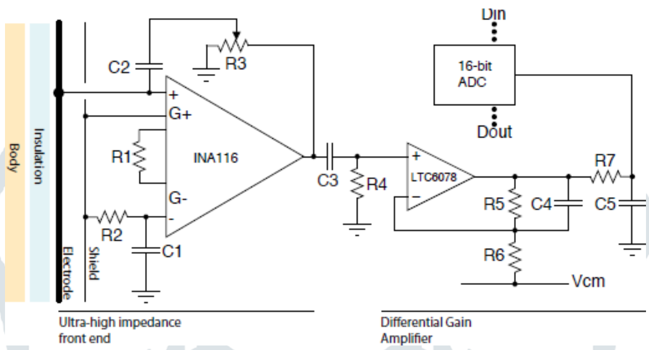

Fig. 8. Full schematic of the electrode.

For the electrode construction, two PCBs of the size of US quarter are constructed, where the upper PCB contains the low noise differential amplifier with a 16-bit Analog to digital converter (ADC) and the lower PCB consists of an ultra-high input impedance configured using 1NA116 IC. For this system, the insulation material used is solder mask and the bottom surface of the PCB is a copper fill. Here, an active shield is fashioned by the inner solid plane that protects the electrode from picking up external noise. But to limit the shield capacitance, an additional thick PCB is used for the electrode.

From [7], we obtain the equation for input referred noise as

$$v_n^2 = v_{na}^2 \left(1 + \frac{C_{in} + C_n}{C_s}\right)^2 + \frac{i_{na}^2 + i_{nb}^2}{\omega^2 C_s^2} \qquad (2)$$

where, the Vna refer to amplifier noise, ina refer to input current noise and the inb refer to the additional current noise. This equation shows the effects of the parasitic input capacitance and leakage currents on the noise performance of the amplifier and the difficulty in designing a noncontact electrode. The reason for using the INA116 for the front-end amplifier is because of its exceptionally low current noise ($0.1 fA/\sqrt{Hz}$). From the system designed, the output obtained is seen to be of very low noise but lacking some of the required characteristics of the waveform as shown here.

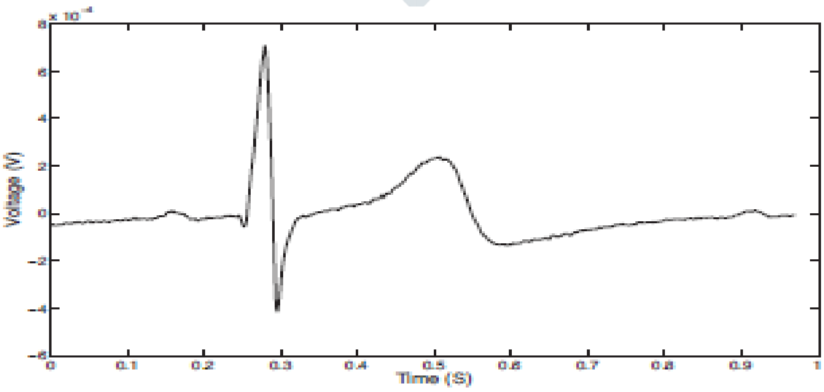

Fig. 9. High resolution ECG waveform.

Peng et al. [8] describes about a cardiac pre-amplifier circuit design based on JFET, as they are highly efficient for low noise applications when the source impedance of the signal is high. But the problem with using JFET for operational amplifier designs is that it may cause a voltage offset problem. The techniques to reduce this offset voltage are discussed here. The fluctuations of the input leakage current of the JFET cause a large noise interference for high impedance signal sources. The proposed amplifier design is of a charge amplifier with double feedback and this amplifier is used as buffer amplifier for biopotential signals. This amplifier design simultaneously achieves good low frequency response, high gain and leakage current compensation without any need for high value resistors or high input impedance needed by other preamplifier designs. They have also designed a prototype sensor for noise measurement.

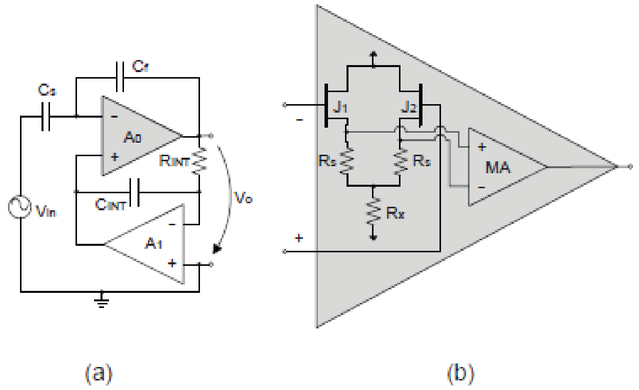

Fig. 10. (a) Input leakage current compensated amplifier with double feedback loop (b) Amplifier composed of differential JFET pair in common drain configuration.

The complete equivalent noise added to the signal source terminal is 0.76 µVrms integrated over a frequency bandwidth from 0.05 to 100 Hz for a measured source capacitance of 21pF.

III. Conclusion

In conclusion, the disadvantages of using the wet electrodes can be overcome by making use of different type of electrodes viz. dry and contactless electrodes. The outputs obtained for both the bio-potential signals are comparable to those obtained using the conventional wet electrodes. Lot of researches and devices are constructed to show the demonstration of the possibility of these electrodes replacing the conventional wet electrodes in the future. Efforts directed towards reducing the noise level in the waveform to a smaller level and making the devices eliminate the inherent sensitivity to the motion artefacts would help in bringing the future earlier.

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