Electrocardiograph: A Portable Bedside Monitor

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ABSTRACT : *Electrocardiograph is a biomedical device that measures electrical potential generated by electrical activity that occurs due to the heart's pumping action. The graphical presentation of the Electrocardiogram (ECG) can be interpreted so that normal and abnormal rhythms of the heart can be detected and diagnosed. Design, construction and manufacturing of this device in Africa would improve access to health care, create employment and improve the African economy. The major materials considered for the implementation include the instrumentation amplifier AD624, Low Noise JFET Operational Amplifier TL074, a clinical standard 12-lead ECG electrode, various electrical and electronic components such as resistors, capacitors and diodes for protection and an oscilloscope. The electrodes connected to the body convert the heart signal into electrical voltage. These voltages obtained from the body are too small for the oscilloscope to capture and so are amplified using AD624. Noise from the environment affects the ECG signal. To suppress the noise, the signal from the amplifier is filtered. According to the International Electrotechnical Commission (IEC) specification, the bandwidth required for an ECG filtering is between 0.5Hz – 150Hz. Band-pass filtering is used. The signal obtained from the band pass filter stage is then passed through a notch filter to further eliminate 50 Hz noise from the power line. The result is then displayed on an oscilloscope. The Electrocardiograph was tested on different subjects and the results compare favourably with results obtained with imported ECG monitor.*

KEYWORDS -*Electrocardiograph, Biomedical Device, Health Care, Noise, Filtering*

I. INTRODUCTION

Biomedical engineering is the application of engineering principles and design concepts to medicine and biology. This field seeks to close the gap between engineering and medicine: It combines the design and problem solving skills of engineering with medical and biological sciences to improve healthcare diagnosis, monitoring and therapy[1,2,3].

Patient monitoring is the process of continuously acquiring desired information from the body of a patient in order to determine the patient's health condition. How well it has improved or to what extent it has deteriorated. Over time, multitudes of portable, single parameter monitors or meters emerged for measuring such vital signs as blood pressure, glucose levels, pulse rate, temperature and various other biometric values. Today, patient monitors are portable, flexible devices capable of being adapted to a variety of clinical applications, supporting various wired and wireless interfaces [1].

Devices ranging from X-ray and Ultrasound machines to the uncommon MRI (Magnetic Resonance Imaging) and Bedside Monitors are important in hospitals. However, they are not all that common in African hospitals. This is basically because they are imported from developed nations at very high costs. Other problems associated with the use of these devices in African hospitals are the fact that by virtue of their design, sometimes they malfunction when used in an African setting [1,4].

The devices encounter problems arising from the fact that the ambient temperature and humidity are not compatible with manufacturer's specifications as they were designed for more temperate climates. These and many other problems such as irregular power supply and air pollution lead to frequent malfunctions, inaccurate operation and equipment failures[1,4].

To guarantee adequate access to health care, there is need to encourage local design and manufacturing of biomedical devices in Africa for Africa [1,5,6]. African Governments, African Non-Governmental Organisations (NGOs) and philanthropists need to encourage African Universities, Researchers and Manufacturers in these efforts. The work in this paper is one of such efforts which require funding and promotion.

Electrocardiography is a surface measurement of the electrical potential generated by electrical activity in cardiac tissue which is caused by current flow in the form of ions and contraction of cardiac muscle fibres leading to the heart's pumping action.An Electrocardiogram (ECG) is a graphical presentation of the heart activity over time. It is recorded by placing electrodes on the human body at certain points, and then measuring the potential difference between the electrodes caused by the depolarisations and repolarisations of the heart. The graphical presentation of the ECG can be interpreted, so that normal and abnormal rhythms of the heart can be detected and diagnosed [1,2,3,7,8].

In this work, a portable Electrocardiograph (ECG)bedside monitor is designed and constructed for use in hospitals with typical Nigeria environmental and power supply conditions. The Electrocardiograph has been designed to meet all of the requirements for any Cardiologist to run tests on a patient according to the stated international standard. It is compared with an imported ECG monitor.

The International Electrotechnical Commission (IEC) 60601-2-25 is mainly safety standards for ECG. It provides the guidelines or regulation which is adhered to in the design and construction of the electrocardiogram. The International Electrotechnical Commission is a non-profit, non-governmental international standards organization that prepares and publishes International Standards for all electrical, electronic and related technologies – collectively known as "electrotechnology" [9].

II. DESIGN

Fig. 1 shows the block diagram of the proposed ECG bedside monitor. The function of ECG monitor is to amplify, measure, and record/display the natural electrical potential created by the heart. If two leads are connected between two points on the body, voltage can be observed between them. Note that cardiac electrical signals are different from heart sounds which are listened to with a stethoscope. The electrical signals which command cardiac musculature can be detected on the surface of the skin but the fluctuations are rapid and by the time these signals reach the skin they are extremely weak (a few millionths of a volt) and difficult to detect with simple devices. Therefore, amplification is needed.

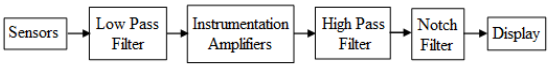


Fig. 1.Block Diagram of ECG Bedside Monitor.

2.1 SENSORS: ELECTRODES AND ELECTRODE PLACEMENT

Electrodes are used for sensing bio-electric potentials as caused by muscle and nerve cells. ECG electrodes are generally of the direct-contact type. They work as transducers converting ionic flow from the body through an electrolyte into electron current and consequentially an electric potential capable of being measured by the front end of the ECG system. These transducers, known as bare-metal or recessed electrodes, generally consist of a metal such as silver and a salt of the metal (usually silver chloride) with a jelly electrolyte that contains chloride and other ions.

The result is a voltage drop which is in the range of 1 mV - 5 mV across the electrode electrolyte interface. This varies depending on the electrical activity on the skin. The voltage between two electrodes is then the difference in the two half-cellpotentials [10].

As a general principle, the closer the electrodes are to the heart, the stronger the signal that will be obtained. The electrodes are placed on strategic positions of the body in order to properly capture the electric potentials as shown in Fig. 2 [11].

Standard ECGs make use of 12-leads. The most common 12-lead ECGs require 10 electrodes. **Nine** of the electrodes pick up electrical signals and the tenth electrode, on the right leg (RL), isa reference electrode or ground. There are actually nine measurements [2,3,7,8,11].

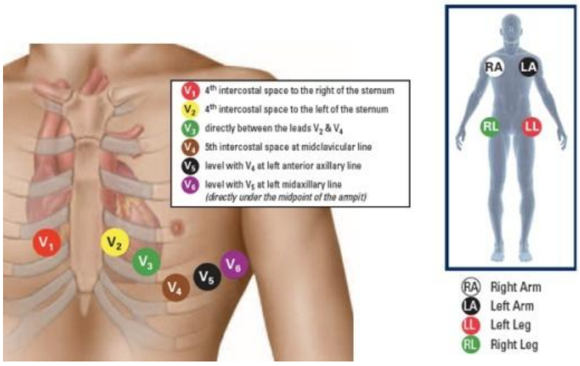


Fig. 2. Electrode Placement [11].

For the limb electrodes, the four electrodes are placed on the four limbs according to specifications which are written on the leads; RA, LA, LL and RL. There are six chest electrodes; V1, V2, V3, V4, V5 and V6. V1 is placed on the 4th intercostal space to the right of the sternum while V2 is placed on the 4th intercostal space to the left of the sternum. V3 is placed halfway between V2 and V4. V4 is placed on the 5th intercostal space at mid clavicular line while V5 is placed on the left 5th intercostal space at left anterior axillary line. V6 is placed at the same level with V5 at left mid axillary line directly under the midpoint of the armpit [11].

The nine measurements are arranged into twelve leads or views. Each lead or view of the heart, is the differential voltage between one electrode and another electrode or group of electrodes. When electrodes are grouped, their voltage is averaged. RA, LA, and LL are averaged for six of the leads (views) and become one side of the differential pair, while V1 to V6 are individually used for the other side of the differential pair. The six leads based on RA, LA, and LL contains duplicate information, but are displayed in different ways [2,3,7,8,11].

Three of the leads measure RA, LA, and LL against the average of the other two electrodes. The remaining three leads come from RA, LA, and LL measured as individual pairs in accordance withEinthoven triangle of Fig. 3 [7,8,11]. The Einthoven triangle is an equilateral triangle with the heart at the centre.

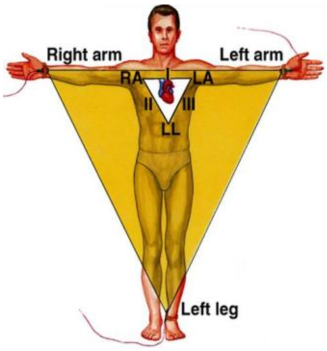


Fig. 3. Einthoven triangle [11].

Therefore, the twelve outputs or leads or views are **Lead I** [LA-RA], **Lead II**: [LL-RA], **Lead III**: [LL, LA], **aVL** [LA-Average of (LL&RA)], **aVF**[LL-Average of (LA&RA)], **aVR** [RA-Average of (LA&LL)], **C1**[V1-Average of (LA,LL&RA)], **C2**[V2-Average of (LA,LL&RA)],**C3**[V3-Average of (LA,LL&RA)], **C4** [V4-Average of (LA,LL&RA)], **C5**[V5-Average of (LA,LL&RA)], **C6**[V6-Average of (LA,LL&RA)].

2.2 AMPLIFICATION, FILTERING AND DISPLAY

The electrode, being the first stage, is connected to the body will convert the heart signal into electrical voltage in the range of 1 mV – 5mV.

For the second stage, the electrical voltages from the electrodes are too small for the oscilloscope to capture. In order to make the electrical signal stronger an amplifier is needed. The amplifier has to be able to amplify the signal in range 1 V - 5 V so that it can be viewed by an oscilloscope. The amplification needed is 1 V / 1 mV = 1000. The amplifier has to give very high signal to noise ratio for the amplified electrical signal to be useful. Instrumentation amplifier AD624 is suitable for this purpose [12].

For the third stage, to reduce the noise, the electrical signal from the amplifier needs to be free of unwanted frequency components. According to the International Electrotechnical Commission (IEC) specification, the bandwidth of the ECG is from 0.5Hz to 150Hz. After an amplification, the signal is filtered with band-pass filter. A second order band pass filter is used here in order to obtain optimum result [9].

For the fourth stage, the signal is passed through a notch filter to eliminate 50 Hz noise from the power line. A second order notch filter is also used for optimum result [10]. Finally, an oscilloscope displays the electric signal for view and diagnosis. Fig. 4 shows the circuit diagram of ECG circuit for each of the 12 leads. Terminals IN1 and IN2 of Fig. 4 are the two inputs for the lead or view. For example, V5 is connected to IN1 and average of LA, LL and RA is connected to IN2 for lead C5.Fig. 5 and Fig. 6 shows the ECG circuit on Vero board and the bunch of ten electrodes respectively.

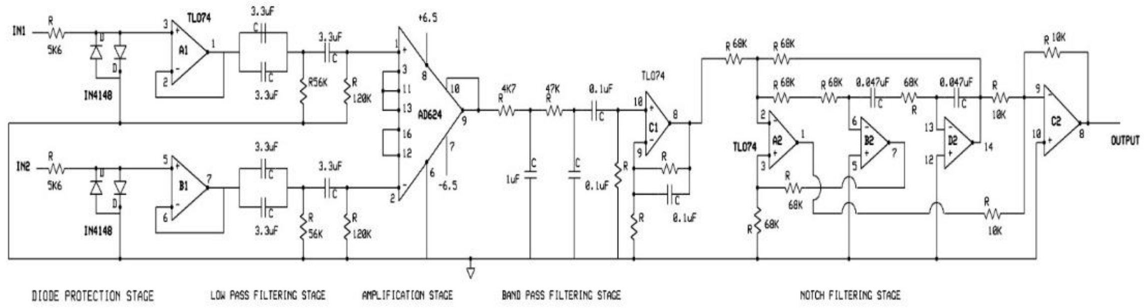


Fig. 4. Circuit diagram of ECG monitor for each of the twelve leads.

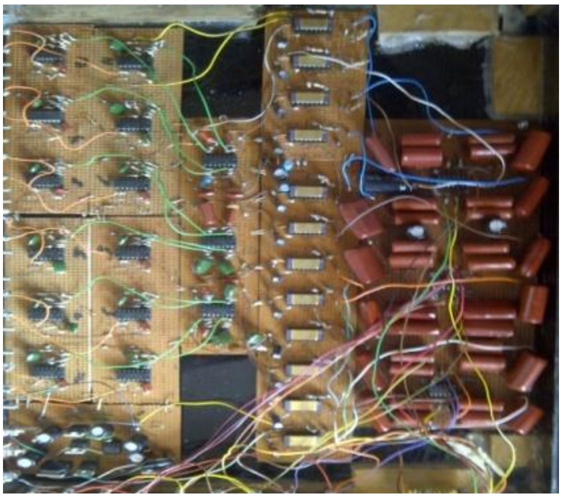
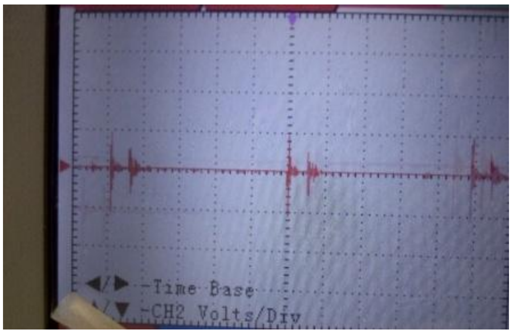


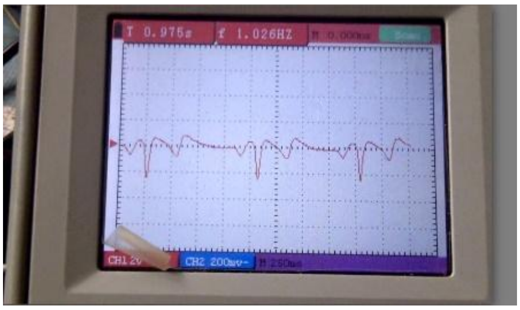
Fig. 5. ECG Circuit on Veroboard.

Fig. 6. Ten ECG Electrodes.

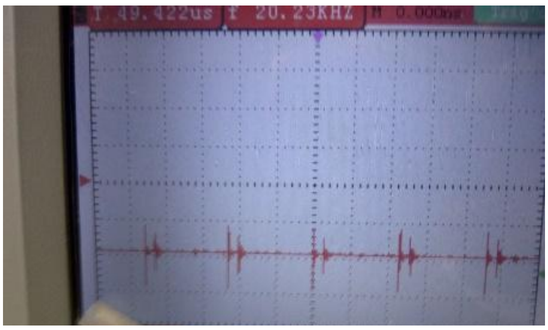
III. TESTS AND RESULTS

The ECG device is tested. Fig. 7 shows some the ECG plots obtained on the oscilloscope.The ECG device correctly recognizedthe beginning, peak and end points of each wave such as P, QRS and T wave. The plots compares favourablywith similar plots obtained with an existing J-Rapha Clinic's ECG device.



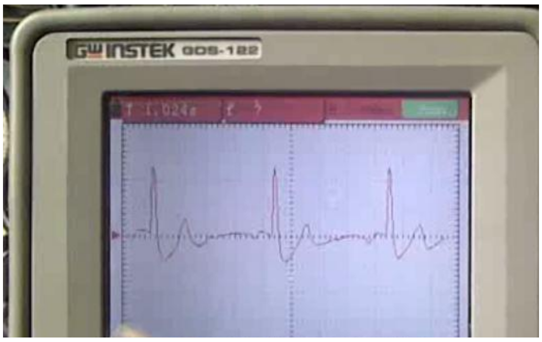


(b) aVR

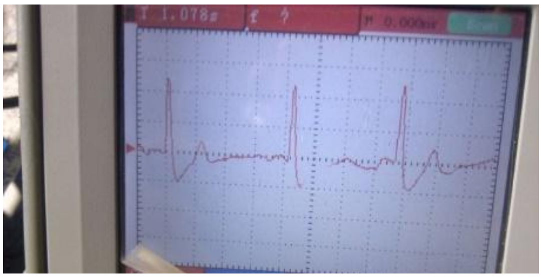


(c) aVL

Fig. 7. Displayed ECG Waveforms.



(d) V1



(e) V4

Fig. 7 (Continued). Displayed ECG Waveforms.

In calculating the heartbeat of the patient, using the result obtained from V4, the peak to peak time is T= 1.078s. This is the time it takes for one heartbeat. The number of heartbeat per minute is (1.078 x 60) which is equal to 64.7 bpm. The value obtained for the same subject using the existing J-Rapha Clinic's ECG device is 66 bpm. Therefore, the performance of the designed ECG device is within the 2% tolerance compared with imported device.

IV. CONCLUSION

An Electrocardiograph (ECG) bedside monitorhas been designed for use in hospitals with typical Nigeria environmental and power supply conditions. The performance of the ECG bedside monitor is found to be comparable with existing imported similar devices. The local design can be improved to clinical stage and wholesale manufacturing with the help of research and development fund. Local design and manufacturing of biomedical devices in Africa would increase access to health care, create employment in and improve the economy of African countries.

REFERENCES

[1] A.R. Zubair, Biomedical Instruments: safety, quality control, maintenance, prospects & benefits of African Technology. *African Journal of Medicine and Medical Sciences,39(Suppl.)*, 2010, 35-40.

[2] J.M. Brown and J.O. Carr, *Introduction to Biomedical Equipment Technology* (New York: John Wiley & Sons, 1981).

[3] R.S. Khandpur, *Handbook of Biomedical Instrumentation*(New Delhi:McGraw-Hill, 1987).

[4] IAEA, *Handbook on Care, Handling and Protection of Nuclear Medicine Instruments*(Vienna: The International Atomic Energy Agency (IAEA), 2000).

[5] A.R. Zubair, C.O. Adebayo, E.U. Ebere-Dinnie and A.O. Coker, Development of Biomedical Devices in Africa for Africa: A Blood Glucose Meter,*International Journal of Electrical and Electronic Science, 2(4)*: 2015, 102-108.

[6] A.R. Zubair, O. J. Odelanu, O.M. Ibe and A.O. Coker,Safety and Preventive Maintenance of Biomedical Devices in Nigerian Hospitals: A Portable Low Cost Electrical Safety Analyzer,*Academic and Applied Studies, 6(2)*, 2016, 1-19.

[7] P.H. King, *EKG analysis techniques, Design of Biomedical Devices and Systems, first edition*, (New York: Marcel Dekker Publication, 2003).

[8] A. Khorovets, What is An Electrocardiogram?,*The Internet Journal of Health, 1(2)*, 2000.

[9] International Electrotechnical Commission IEC, International Standards for Medical Electrical Equipment and Systems,*Available at:* *http://www.iec.ch/about/electromedical.pdf*(Accessed February 13, 2014).

[10] K.Lacanette, 1991. *A Basic Introduction to Filters - Active, Passive and Switched-Capacitor*(Santa Clara: National Semiconductor Corporation, 1991).

[11] 12-Lead-ECG, Available at https://bloggingforyournoggin.wordpress.com/2016/04/20/demystifying-the-12-lead-ecg/ (Accessed February 13, 2014).

[12] Analogue Devices Inc,*Precision Instrumentation Amplifier AD624*, (Norwood: Analogue Devices Inc, 1999).