Design, development and testing of an EKG emulator

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Abstract.*This article presents the design, development, and testing of a low-cost ECG simulator that can be used successfully in higher education institutions and other institutions dealing with medical equipment checking medical equipment. The practical realization of an EKG simulator combines both medical notions and notions of electronics, specific to the field of medical engineering. In this article, in the first part notions related to the anatomy of the cardiac system will be detailed, with the help of these notions you will better understand how an electrocardiograph (ECG) works, which reads the electrical impulses of the heart transformed into waveforms. The second part of the paper is the practical part of this project, the design of the electrical circuit, the simulation, and the practical realization (soldering the electronic components on a PCB and final assembly of all ECG components by integrating them into a specific housing). The last phase is dedicated to testing the device on a vital function monitor that belongs to a Cardiolife defibrillator. This simulator can perform 2 phases, a 60 bpm signal and a 120 bpm signal, having a button attached to the housing to change the signal, the difference of the signal is signaled by a green LED that is also on the surface plastic housing. The EKG simulator is mainly a signal generator, which mimics the signal generated by the human body.*

Keywords:ECG, simulator, signal, cardiac system.

Introduction

An electrocardiogram (ECG) describes the electrical activity of the heartrecorded by electrodes placed on the body surface. The voltage variationsmeasured by the electrodes are caused by the action potentials of the excitable cardiac cells as they make the cells contract. The resulting heartbeatin the ECG is manifested by a series of waves whose morphology and timingconvey information that is used for diagnosing

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diseases that are reflectedby disturbances of the heart's electrical activity. (Sornmo, L., et al., 2005) The time pattern thatcharacterizes the occurrence of successive heartbeats is also very important.The Dutch physiologist Willem Einthoven further developedthe recording device in the early 20th century by making use of a stringgalvanometer which was sensitive enough to record electrical potentials onthe body surface. He also defined sites for electrode placement on the armsand legs which remain in use today. The pioneering effort of Einthoven wasrewarded with the Nobel Prize in Medicine in 1924. Since then, the ECG hasundergone dramatic development and become an indispensable clinical toolin many different contexts. From having been a signal which was recordedat rest under favorable conditions, the ECG is today recorded in diverseclinical applications, often during strenuous or ambulatory conditions wheresignal processing algorithms are essential for extraction of reliable information. (Sornmo, L., et al., 2005)

The Electrocardiogram (ECG)

Generally speaking, the ECG provides a useful tool for monitoring a patient,basically when the purpose consists in detecting irregular heart rhythms or preventing myocardial infarctions.(AmineNa¨ıt-Ali, et al.,2009)A typical ECG beat mainly has 5 different waves (P, Q, R, S, and T), as shown in Figure no.1.Three characteristic features of the waveform are easily identified: the P wave, the QRS complex, and the T wave. The P wave is associated with the activation of the atria, the QRS complex with the activation of the ventricles, and the T wave with repolarization of the ventricles. The ST segment corresponds to the period time during which the ventricles remain in a depolarised state. The RR interval may be used as an indicator for some arrhythmias. The PQ and QT intervals are also used as essential indicators for diagnostic purposes. (AmineNa¨ıt-Ali, et al., 2009)

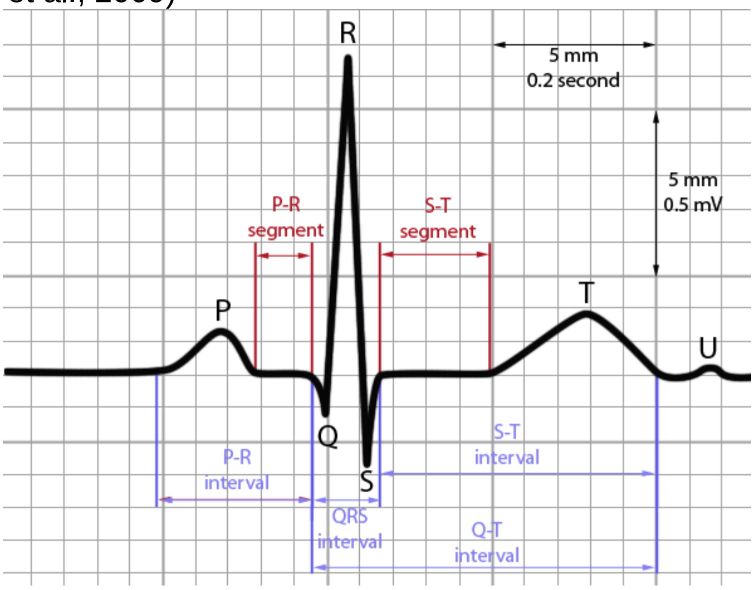

Figure no. 1. A typical Electrocardiogram Waveform
(source: The McGill Physiology Virtual Lab, Cardiovascular Laboratory, http://www.medicine.mcgill.ca/physio/vlab/cardio/introecg.htm)

Electrocardiographic Leads

During activation of the myocardium, electrical forces or action potentials are propagated in various directions. These electrical forces can be picked up from the surface of the body using electrodes and recorded in the form of an electrocardiogram. A pair of electrodes, that consists of a positive and a negative electrode constitutes an electrocardiographic lead. Each lead is oriented to record electrical forces as viewed from one aspect of the heart.The position of these electrodes can be changed so that different leads are obtained. The angle of electrical activity recorded changes with each lead. Several angles of recording provide a detailed perspective of the heart.Twelve conventional ECG lead placements constitute the routine 12-lead ECG..(AtulLuthra, 2012)The 12 ECG leads arelimb leads or extremity leads (six in number) and chest leads or precordial leads (six in number)- Figure no.2.The limb leads are derived from electrodes placed on the limbs. An electrode is placed on each of the three limbs namely the rightarm, left arm, and left leg. The right leg electrode acts as the grounding electrode (Figure no. 2).Standard limb leads and augmented limb leads are three in number.

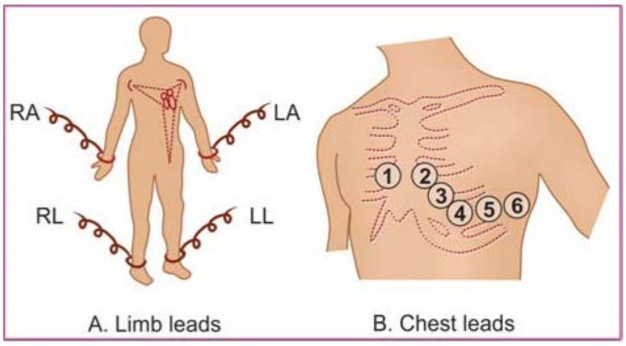

Figure no. 3. Electrode placement for ECG recording.(AtulLuthra, 2012)

The ECG simulator is one of the essential pieces of equipment for an ECGdevice. This device can simulate the vital signals of the heart andaccordingly, eliminates the possible defects of the ECG. By connectingthe simulator to the electrocardiogram, the typical ECG signal shouldbe displayed on the electrocardiographic device monitor. With thissimulator, the ECG can be inspected and repaired, as well as thefunctions; device alarm settings, and terminal connections. ECGSimulator can simulate the signals from the electrical activity of theheart and can examine more than 30 types of arrhythmias, waveformsof varying frequencies, and linearity according to standards, as well as the number of ECG modulator lids from 3 Up to 12 leads are variable.(Shirzadfar H, et al.,2018).

Materials and Methods

The ECG simulator electrical circuit

Figure no.4 shows a schematic diagram of the ECG Simulator kit. The circuit has a digital block, formed bytwo frequency dividers (integrated circuits IC1 and IC2) and the analog output network, which shapes theheart electrical signal. The switch S2 selects the cardiac rate, which can be either 1 Hz or 2 Hz (60 bpm/120 bpm).Using a quartz crystal, an ECG signal can be simulated and constructed to maximize and minimize heart rate. (Shirzadfar H, et al., 2018;Engineering World Health: https://ewh.org/images/docs/Kits/ECG_Simulator-Laboratory_Activities-Student_Handbook.pdf, 2021)The first digital block in Figure no.4 corresponds to an oscillator and a 24 bits counter (IC1 - MC14521B).The HEF4521B is a type of CMOS (Complementary Metal–Oxide– Semiconductor) series for dividing the frequency from 2 to 18 or 2 to 24. The CMOS series ICs are simple and inexpensive, and their current consumption is still close to zero. These types of ICs have high input impedance and work with a wide range of power supplies. This IC is a type of oscillator that has a pulse production capability, also has 24 flip-flop chains, with asynchronous reset input and an input circuit with three operating modes.(Shirzadfar H, et al., 2018).It has the frequency setting in the counter is X1-crystal at a frequency of 4,194,304 Hz. The IC1 will divide frequency out of 16 Hz; its output is a square wave to output Q18 (pin 10). And, S2 is selector switch to choose the output frequency of IC 1 is a low frequency of 1Hz or 2 Hz. Then, the 16 Hz output frequency is a clock signal; it gets into IC2, HCF4017B (a Decimal Counter circuit). The HCF4017B is a counter, in fact, a divisor of 10, which is active by the count of the number counted every clock. By applying the pulse to the IC clock input, the outputs from 0 to 9 go from logical zero to logical mode, and after this cycle, again, this repeats.(Shirzadfar H, et al., 2018) The 1N4148 diode performs rectifier operation at high switching rates up to a maximum of 4 nanoseconds. After that, the second signal will be filtered with R11 and C6. They are a waveform in spikes into pin 15 of IC2. Then, D4-diode will block a negative voltage not flow into pin 15. And, IC2 will count to 9 and on hold this state. And, pin 11 connects with pin enable input (pin 13) to reset working, which is the wave conditions in the U form. By the first wave is a pulse that has been transformed into a P waveform, by the filter in integrator form. For T waveform, we get it from the integrator of R7 and C5.

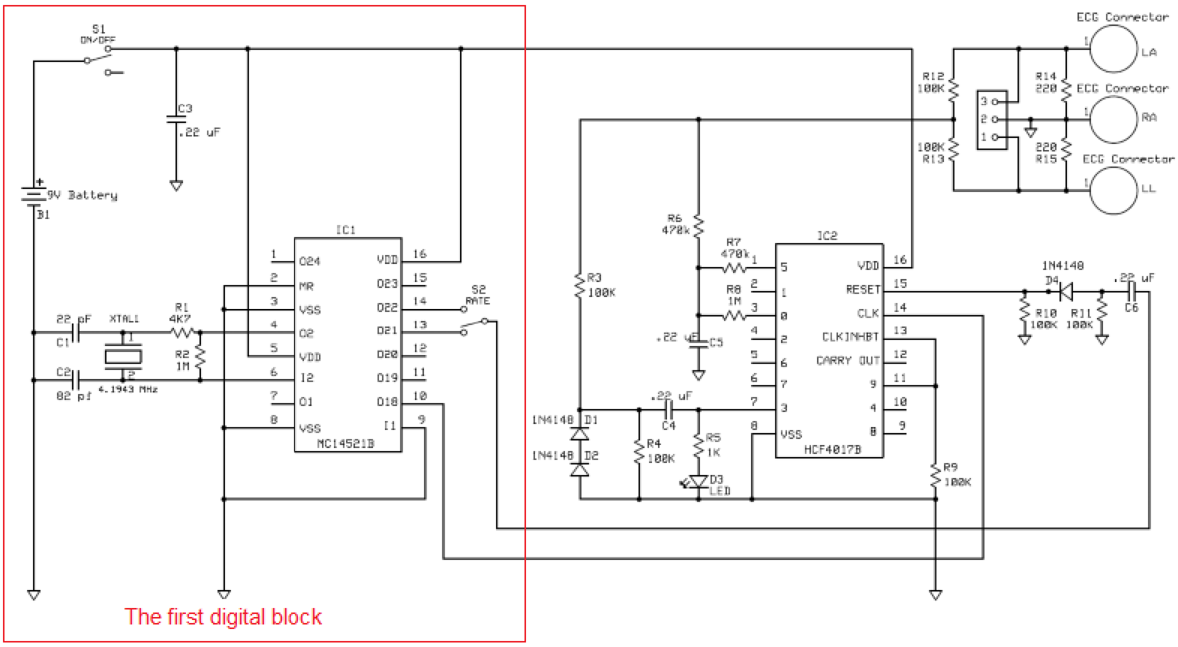

Figure no. 4. The ECG simulator circuit

(Engineering World Health: https://ewh.org/images/docs/Kits/ECG_Simulator-Laboratory_Activities-Student_Handbook.pdf, 2021)

The R7 is the resistance of less than half of the R6. And the pulse waveform of Q6 will charge more up; C5 is 2 times of the P waveform. And, LED blinks while the R-wave forms. Then, the spike waveform passed R12, R13, R14 and R15 will convert the output voltage is 1V and 1mV as we need. This circuit uses a 9-volt battery and the rate of consumption of the circuit about 2.5mA

Practical realization of the device

After testing the electrical circuit of the ECG simulator, using the EAGLE 9.6.2 software, the PCB layout was developed. The next step was to solder the electrical components to the PCB, according to the wiring diagram (Figure no. 5).

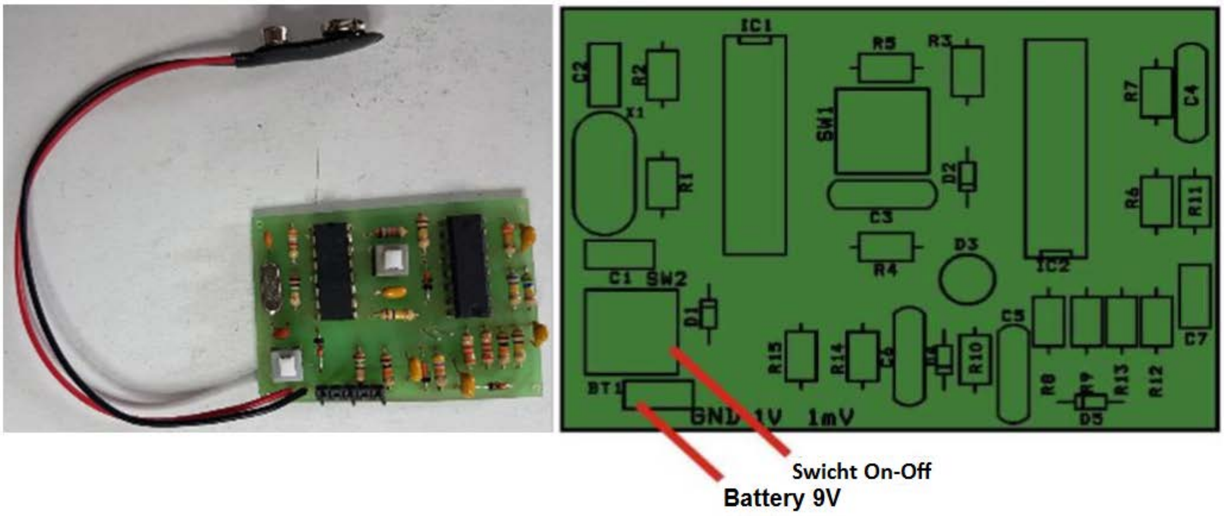

Figure no. 5. PCB layout with soldered components

The PCB, once completed, was placed in a sealed plastic housing with a transparent cover,which allows the visualization of the components and wiring used (Figure no. 6).

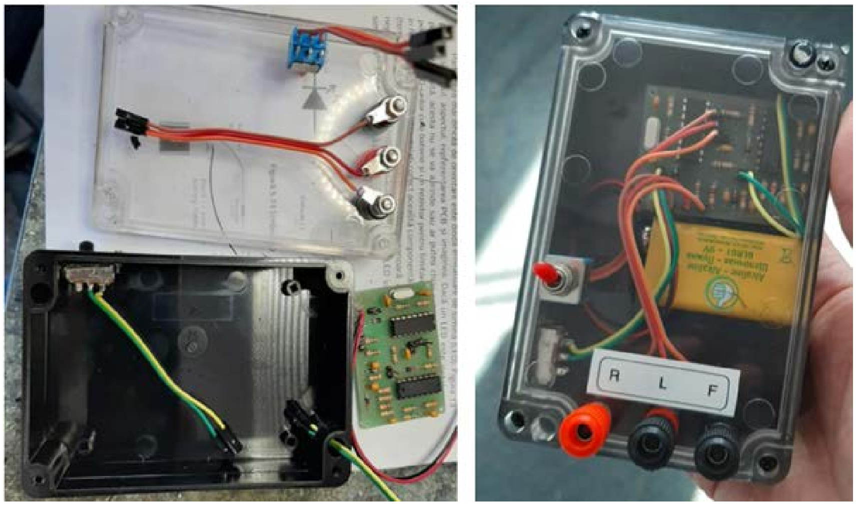

Figure no. 6. Placement of the PCB in the plastic housing (final version of the device)

On the upper surface of here are two buttons on the case, one that controls the power supply and has a label ON/OFF, the second one that allows changing the signal generated by the device from 60bpm to 120 bpm. A green LED is also positioned as an indicator of signal change. At the bottom are positioned three terminals with the label R (right upper limb) F (left lower limb / neutral point) L (upper limb left), which allow connection to an ECG device. The 9V battery was glued and fixedinside the case (Figure no. 6).

Results and discussions

Since the simulator has three terminals (R, L, F) for verification, it is necessarythe use of a device that reads three leads. Figure no. 7was used for verificationof a Cardiolife defibrillator that also has the function of vital function monitor.Designed to improve the quality of resuscitation, Cardiolife is a professional biphasic defibrillator. It comes with the help of life support equipment, from hospitals and clinics, with intuitive, fast, easy to transport, and efficient operation – from early detection, resuscitation, post-cardiac management. Cardiolife supports efficient management after cardiac arrest by capture and analyzingvital sign parameters. The innovative capONE sensor (ETCO2) and BluPRO (SpO2) technology help monitor key vital signals of patients accurately.The results of the ECG simulator verification at 60 and 120 bpm are presented in Figure no. 8.

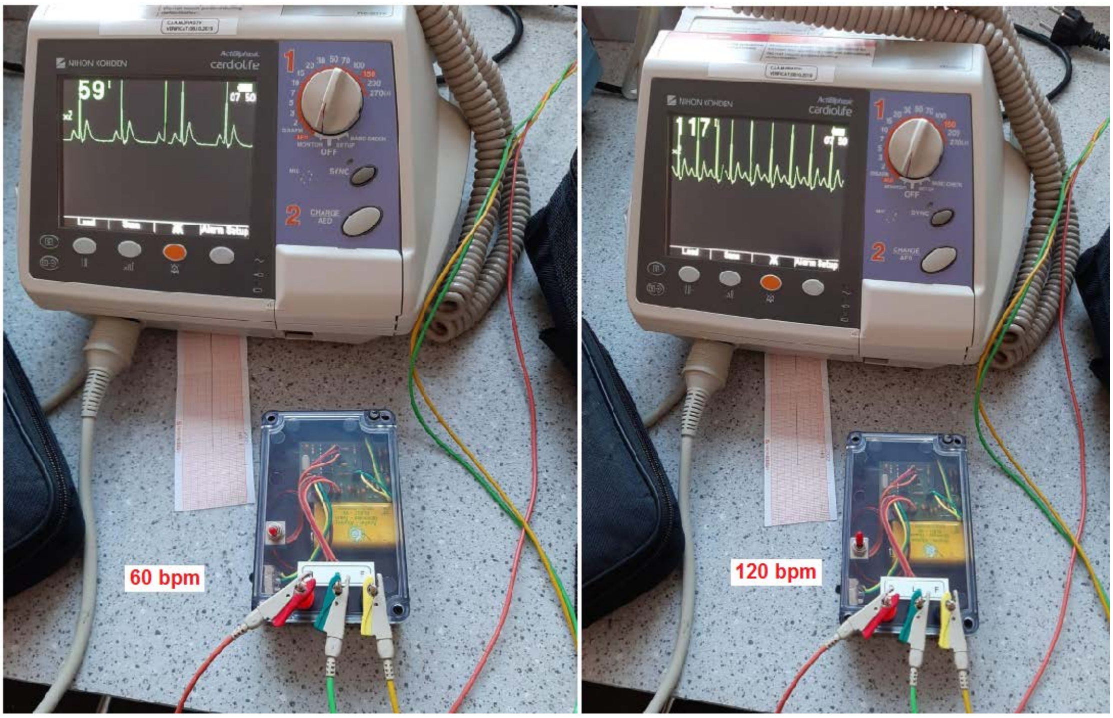

Figure no.7. Checking the device in 60 bpm and 120 bpm modes

Figure no.8. The result of verification (electrocardiograms at 60 and 120 bpm)

Conclusion

According to existing laws, all medical devices that are in direct communication with humans should be properly tested and safety tested. All measurement parameters must also be properly tested by the device to obtain the correct results when using the device. Therefore, the vast majority of medical devices should have a simulator to check their performance.An ECG device is one of the most important and vitalmedical devices for the diagnosis of cardiovascular diseases. Therefore, theaccuracy function of this device is very important. A simulator is usedto check the performance of this device, by which it can simulate heartsignals and evaluate the accuracy of the ECG device. In this paper, thesimulator was designed and built-in small size and low cost, which makesit easy to use and use this device.

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