

The ECG Monitor with Memory Card Data Storage

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Abstract - The paper presents a novel device that measures electrocardiogram (ECG) signals and heart rate. The ECG signals are acquired using electrodes placed on the patient's skin. The device has two operating modes. In the first operating mode, ECG signals are measured and stored temporarily in Flash memory card. After request (the taster button has been pressed), the signals are read from the card and sent to the personal computer (PC). In the second operating mode, the ECG signals are sent continuously to the computer via universal serial bus (USB) port.

I. ELECTROCARDIOGRAPHY

Electrocardiogram is a graphic representation of the voltage signals generated by heart during each heartbeat. It provides a very accurate assessment of heart functioning.

The heart produces tiny electrical impulse, which spreads through the heart muscle to make heart contract and relax in a timely order. The heart contraction and relaxation resulted from the depolarization and polarization of myocardial cells. [1]

The electrical conduction system of heart is shown in Fig. 1. The electrical sequence initiated by the sinoatrial node (SA), the main pacemaker of the heart. The pulses enter the ventricular through atrioventricular (AV), after that, the pulses reach to all parts of ventricular through His bundle and Purkinje fibers[2]. If the heart rate of SA is decreased or SA node is damaged the other parts of heart electrical system can take heart rate control. As a backup, the pulses can be generated within AV node or His bundle. The SA node has a faster rate of triggering than other specialized tissues, AV, His bundle and Purkinje fibers. [3]

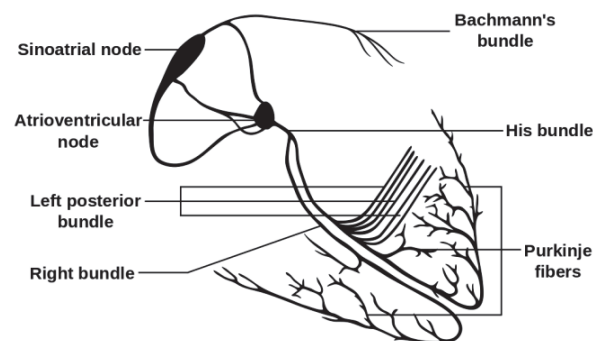


Fig. 1. The electrical conduction system of heart.

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The graphic representation of heart operation is ECG signal. This signal is composed of P wave, QRS complex and T wave. P wave is reflection of depolarization of atria. Abnormalities of atria reflected on the duration, amplitude and morphology of this wave. Atria polarization occurs during ventricular depolarization. QRS complex represent a depolarization of ventricular. Since myocardial mass and thickness are considerably greater on left than right most of the QRS complex represents left ventricular depolarization. Three part of the complex are Q, R and S wave. Q wave is the first negative deflection, R wave is positive deflection and S wave is the second negative deflection. The main causes of QRS abnormalities are myocardial infarction, ventricular hypertrophy and infra nodal conduction abnormalities. T wave reflection ventricular polarization. [4-6]

The proposed ECG device measures the potential difference between two measurement sites on the patient's skin. First electrode (electrode R) is attached to the right arm. The second is attached to the left arm (electrode L). The third electrode is attached to the right leg (electrode N) and used for 50Hz noise cancelation. The other ECG devices utilize also additional electrode F, which is attached to the left leg.



Fig. 2. An ECG waveform.

Graphical representation of voltage signal, measured between two measurement sites on patient's skin, is referred as an ECG lead. The most utilized leads are marked with Roman numerals, I, II and III. In 1901 Dutch physiologist Willem Einthoven defined the equations (1-3)[7]:

$$I = V_L - V_R \quad (1)$$

$$II = V_F - V_R \quad (2)$$

$$III = V_F - V_L \quad (3)$$

II. HARDWARE REALIZATION

where V_R , V_F and V_L are potentials measured at right arm, left leg and left arm respectively. The Fig. 3. presents the Einthoven's triangle and shows ECG leads I, II and III [8].

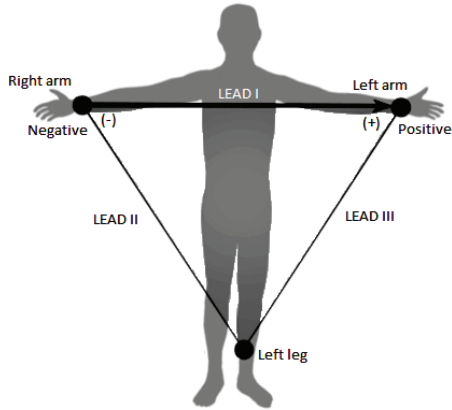


Fig. 3. Einthoven's triangle.

In addition to leads I-III, the cardiologists frequently use Goldberger's ECG leads, which are given by equations (4-6):[9]

$$aVl = V_L - \frac{1}{2}(V_R + V_F) \quad (4)$$

$$aVr = V_R - \frac{1}{2}(V_L + V_F) \quad (5)$$

$$aVf = V_F - \frac{1}{2}(V_L + V_R) \quad (6)$$

The realized ECG monitoring system is composed of four main units::

- an analog part which consists of analog filter and amplifier,
- the microcontroller part,
- the communication controller, which uses RS 232 and USB protocols and
- Micro Secure Digital (SD) memory card.



Fig. 4. Block diagram of hardware realization.

A. Analog block

The analog block consists of the amplifier and band stop filter. It performs analog signal processing that is required prior to analog to digital (AD) conversion. The structure of ECG signal amplifier is given in Fig. 5. The biopotential amplifier consists of five operational amplifiers and has embedded high pass filter for direct current (DC) component discrimination. Furthermore, the biopotential amplifier boosts input signals having small amplitude levels.

The two upper panels of Fig. 5 present the results of circuit simulation in time domain. The top panel gives input signal, which is applied between the inputs Lead_L and Lead_R inputs. The middle panel shows the amplifier output signal. It can be seen that signal morphology has not distorted and that the amplifier gain is equal to 470. The bottom panel of Fig. 6 gives the amplifier's frequency response.

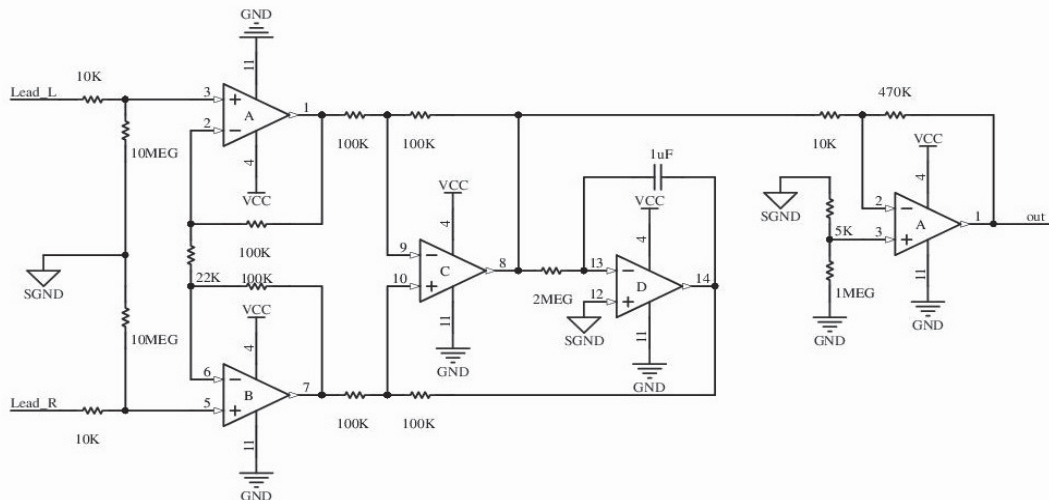


Fig. 5. The Amplifier circuit which is used in device.

The simulation of amplifier is done using Altium Designer. The circuit implements the pass-band filter with low cut-off frequency is equal to 100 mHz. The upper cut-off frequency is equal to 4kHz. Lower cut-off frequency can be changed by changing resistor and capacitor values of High Pass filter. The high cut-off frequency is determined by Gain-Bandwidth characteristic of utilized operation amplifiers.

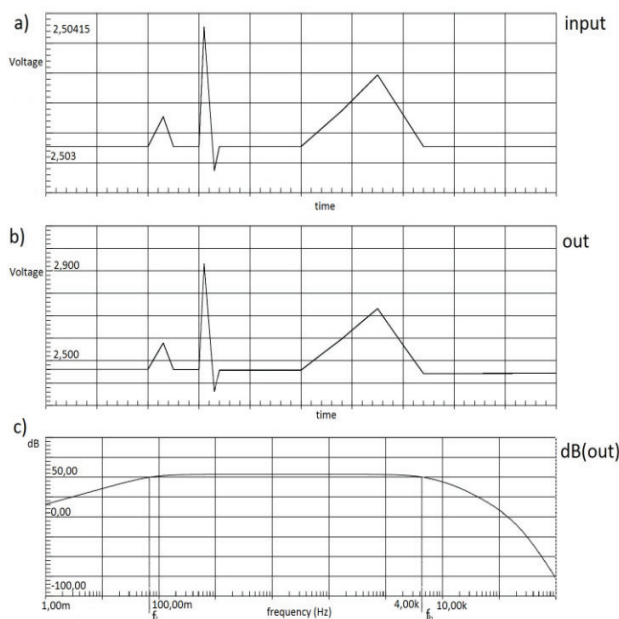


Fig. 6. The simulation of bipotential amplifier: top and middle panel present the simulation results in time domain, while bottom panel gives the circuit's frequency response.

After signal amplification the signal has been filtered. The notch filter removes 50 Hz noise. The notch filter frequency response is given in Fig. 7. The output of analog filter is fed to AD controller embedded in the microcontroller.

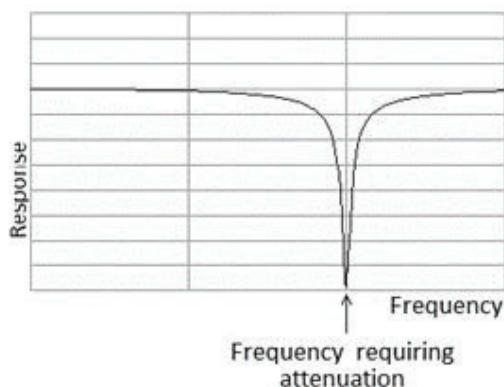


Fig. 7. Notch filter frequency response.

B. Digital signal processing

In the design we utilized the Microchip's PIC18F2520. The microcontroller has a 10-bit A/D converter, USART module, timers/counters and other useful peripheral units [10]. The ECG signals are sampled at data rate of 250 samples per second. The resolution of converted samples is 10 bits. After AD conversion, the ECG data is processed digitally. Several digital filters are implemented within the microprocessor's software. Also, the software executes the operations dedicated to heart beat detection, which are described in [11].

The ECG data is sent continuously to the personal computer (PC) through USART to USB communication controller [12]. The block diagram of UART to USB realization is given in the Fig. 8.

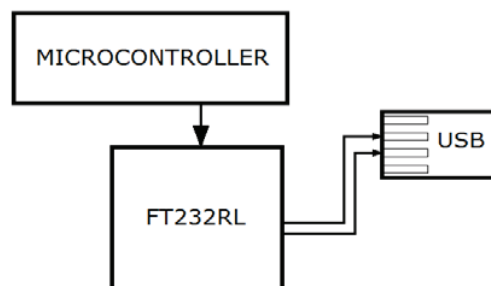


Fig. 8. Block diagram of USB communication.

The ECG data is temporarily stored into on-board Flash memory device. For this purpose, we utilized the Micro SD card. The data format which is used for data transmission will be explained in the next section.

III. SOFTWARE REALIZATION

The device has two operating modes. In the first operating mode, ECG signals are acquired and stored temporarily in Micro SD memory card.

The Micro SD card is connected to MCU over Serial Protocol Interface (SPI). After request (the on board taster button has been pressed), the signals are read from the Micro SD card and sent to the PC.

In the second operating mode, the ECG signals are sent continuously to the computer via USB port.

The MCU's program code is explained as follows.

The MCU utilizes the on-board oscillator of 25 MHz. At the beginning of the MCU's program code, the basic operating parameters are set. Among these parameters, the UART is set to the baud rate of 38400.

During initialization, the MCU's Timer 1 is set to convert ECG samples after every period equal to 4 ms. Actually, the Timer 1 generates interrupts after every 100 μ s. Additional counter is used to produce the sampling interval of 4ms. The sampling interval of 4ms corresponds to the sample rate of 250 samples per second. In the

interrupt routine, the program code performs AD conversion and some additional ECG signal processing.

The microcontroller has a 10-bit A/D converter. Because AD converter stores 10-bit result into two 8-bit special function registers, the 10-bit samples are packed into appropriate data formats for USB transmission, as well as for storing into Micro SD card.

The conversion of three 10-bit ECG samples Sample0, Sample 1 and Sample 2 into four data bytes Byte0, Byte1, Byte2 and Byte3 is illustrated in the Fig. 10. These four bytes are as a part of 512 byte package stored further into SD memory card.

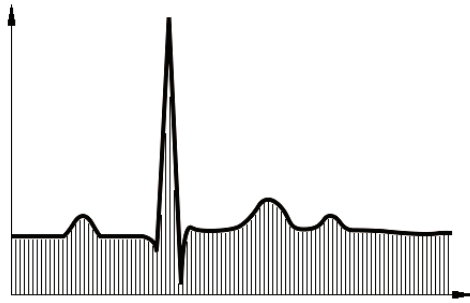


Fig. 9. A/D converter sampling of an ECG signal.

The byte arrays consisting of 512 bytes are stored in SD memory card. The process of SPI data transmission requires some amount of microcontroller's time. Since the MCU has to process ECG signals without any interruption, we had to use two arrays of 512 bytes. While one array was filled with ECG samples (produced by AD converter), the other was sent to Micro SD card.

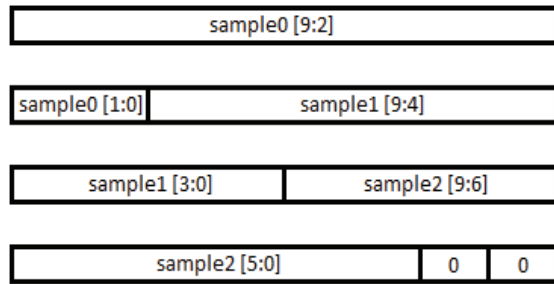


Fig. 10. The way of packing data for memory card

Data is read from Micro SD card using the same data format as for data storing. After every 512 bytes are read, 10-bit ECG signals are extracted, and then, the signals are sent to the PC.

The data format of USB data transmission consists of nine bytes. The data format is shown in Fig. 10. The 10-bit ECG signal sample is embedded into third and fifth byte of data package. The first byte indicates the transmission start

and is equal to hexadecimal value of 0xAA. The other bytes of packet are not used and they are set to 0x00.

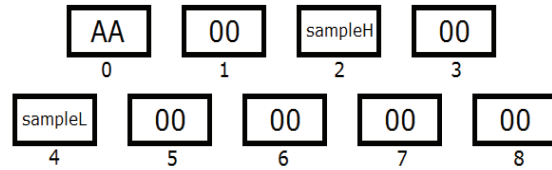


Fig. 10. The data package used for transmission.

IV. CONCLUSION

This paper describes the realization of a simple electrocardiograph device. The proposed device receives analog ECG signals from electrodes through conductive electrodes and cables, and transmits ECG data to personal computer. The connection to computer is achieved through USB port. The device is reliable and easy for use. It needs only three electrodes for a patient connection. Moreover, small size reduces the obtrusiveness of the recording process. The device has simple structure and it is very efficient in identifying cardiac disorders.

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