A Novel Zigbee- based Low- cost, Low- Power Wireless EKG system

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***Abstract* — Electrocardiogram (EKG) monitoring is of prime importance in the medical world. Using the state of art technology to take it to a wireless platform can open up a broad spectrum of wireless medical devices which have a wide range of applications in medical services, military rescue missions, home cardiovascular monitoring, especially for senior people. This paper presents a platform for developing a Zigbee based low cost, low power Wireless EKG system using the unlicenced 2.4GHz ISM band. Zigbee is based on IEEE 802.15.4 standard for Wireless Personal Area Networks (WPANs), that is being used in many commercial and research applications today, where it has become an attractive solution for low power and low cost applications. Two system designs are proposed featuring excellent ranges and potential for "smart fabric" wearable implementations.**

***Index Terms* — Cardiovascular, commercial, medical services, electrocardiogram, wearable RF, wireless EKG, Zigbee.**

I. Introduction

Electrocardiography has been in clinical use for the diagnosis and monitoring of heart abnormalities for more than a century. It remains the best and least invasive method for the task it performs. EKG measurement systems have followed trends in technological advancement becoming more reliable, able to perform a wider range of functions and simpler to use as time has progressed [1]. The next step forward for the technological advancement of electrocardiography is a completely wireless system of measurement. Such a system would facilitate the tasks of doctors eliminating the usage of wires in operation theaters, as well as for senior people that need to wear monitoring devices for a continuous tracking of their heart condition. Another need for such a system would arise in war scenarios where the remote monitoring of the heart rate of every soldier would tremendously enhance rescue chances. An accurate indication of the frontal projection of the cardiac vector can be provided by three leads/electrodes, one connected at each of the three vertices of the Einthoven triangle [2]. The most prevalent and significant among them is Lead II for diagnosing rhythm problems. Fig. 1(a) shows EKG Lead II signal.

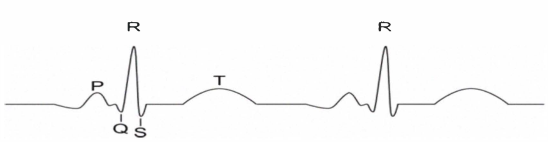

Fig. 1 (a).Lead II EKG signal

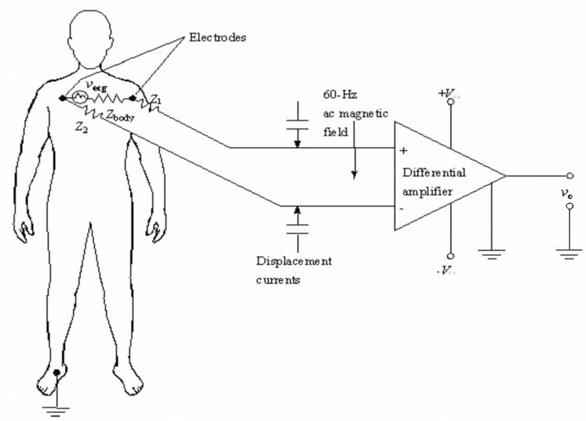

Fig. 1(b). EKG system design

Fig. 1 (b) shows the system design. The size of both designs proposed in this paper is 7cm x 7cm x 1cm. The advantage of the designs is the low form factor. Multi hopping is done to increase the range of transmission. However one disadvantage of design 1 proposed in this paper is the high current demand of Digi module which requires the usage of a high rated battery. Hence, while implementing multi hopping with this design power consumption is very high. This disadvantage is overcome by using CC2530 in design 2 proposed in this paper. The form factor of design 2 is almost same as design 1, but it gives an extra edge over design 1 by reducing power consumption of the device thereby effectively doubling the battery life. Section II describes the circuit for EKG acquisition and Section III explains the wireless modules. The electromagnetic effects and modeling of the proposed wearable EKG system are presented in Section IV, while benchmarking and measurement results are presented in Section V and Section VI.

II. EKG Acquisition Circuit

Electrodes are used for sensing bio-electric potentials as caused by muscle and nerve cells. EKG electrodes are of the direct-contact type. Silver chloride electrodes are used for this purpose because of the ease of availability, cost and its superior temperature range (32^o – 203^o F). Silver chloride electrodes undergo little change even after long usage. The potential of the electrode remains constant as chloride concentration remains constant. A differential input provides the best defense against ground and noise problems in a system implementation. The signal and its remote ground are both routed back to an instrumentation amplifier. Differential inputs provide immunity against noise. If twisted pair wiring is used, any noise which is induced should be induced equally into both wires. This is called common-mode noise. A differential input takes the difference between the two incoming signal wires. Any common-mode noise which is induced along the way will be subtracted out. Passive filters are used for the filter design because of the low power consumption [3]. A good filter design is important to obtain a reliable EKG signal. The standard limb lead configuration is tested in lab and circuit is shown in Fig. 2.

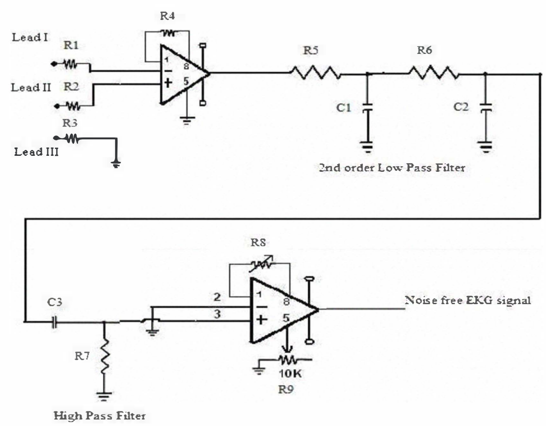

Fig. 2. EKG Acquisition Circuit

III. Wireless Modules

The proposed system involves one transmitter that is worn along with the electrodes, and one receiver at a distance apart the signal is continuously recorded on the computer to which the receiver is connected. The transmitter draws current from the battery while the receiver draws current from the power supply/computer. Hence, the careful design of the transmitter section is very important as it is to be integrated along with the electrodes and its power consumption directly impacts the battery life. Specifically, wireless EKG design calls for the usage of a short range and low power wireless protocol. Hence, Bluetooth and Zigbee wireless protocols are a good choice. Zigbee is chosen above Bluetooth because of its high range and low power characteristics. Few good candidates for the wireless modules are Xbee Pro (Digi), CC2530 (Texas Instruments), Pan4555 (Panasonic), MNZB-24-B0 (Meshnetics), ZB2430 (Laird Technologies), SPZB250 (STMicroelectronics). After exhaustive investigation, Xbee Pro and CC2530 were analyzed as they offer lower power consumption compared to the other modules. Fig. 3 shows flow chart of the system design [4]-[5].

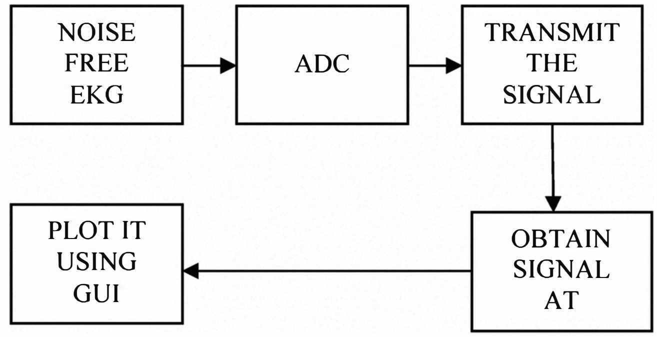

Fig. 3. Flow chart which models the device

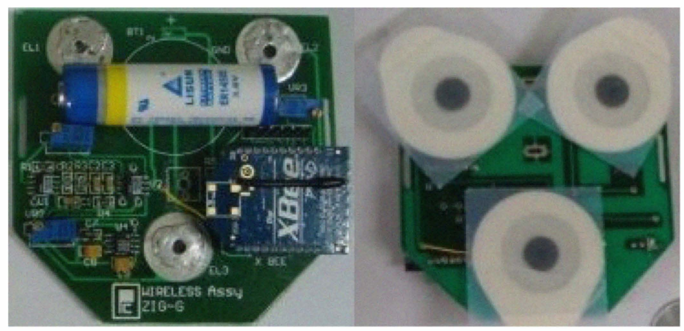

Fig. 4. Wireless EKG transmitter (Front and rear view)

A. Design 1

Atmega32 microcontroller is programmed for the ADC conversion and interfaced with the Xbee Pro Zigbee module for the wireless transmission. ADS 1178 can be used for simultaneous sampling that is critical for transmitting multiple leads information. The electrodes are connected to the PCB using twitch buttons. One prototype that has been realized on PCB has three twitch buttons to which the electrodes are locked as shown in Fig. 4. The receiver is USB based. Fig. 5 shows the transmitter and receiver pair-design 1.

B. Design 2

CC2530 (Texas Instruments) is programmed for ADC conversion and wireless transmission. The advantage of this design is that CC2530 has an integrated microcontroller with an RF transmitter which minimizes the transmitter circuitry. Multi hopping [6] can be implemented using this design which helps in increasing the range of transmission. It is expected to implement at least 6 hops. Each hop is expected to be 60m in open space. However further experimentation should be done in order to analyze the limit of multi hopping. Both designs operate at a bit rate of 9600 bits/sec for transmission of a single lead II signal. The sampling rate used is 500 samples/sec and resolution of ADC is 8 bit in design 1 and 9 bit in design 2. However for the transmission of multiple signals simultaneously a much higher bit rate is required. The maximum bit rate of the modules used is 250kB/s. The user can choose bit rate according to the application and set the baud rate of the computer connected to the receiver accordingly. Fig. 6 shows the transmitter and receiver pair-design 2. The receiver is mounted on a SmartRF05EB board which is connected to the computer through the USB port. The information is transmitted to the computer by the SmartRF05EB board.

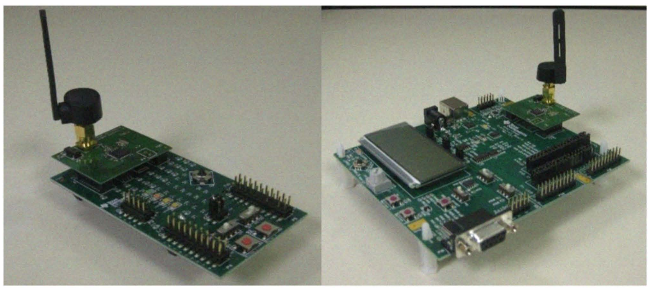

Fig. 6. Transmitter receiver pair – Design 2

IV. Antenna And Substrate Issues

Considering the low form factor and the frequency of operation (2.4GHz) a dipole antenna offers good prospects while implementing a wearable EKG system. Nevertheless, it is well known that the degraded performance of the most commonly used metal antennas close to the human body is one of the limiting factors of the power efficiency and range of bio-sensors and wireless body area networks (WBAN). Due to the high dielectric and conductivity contrast with respect to most parts of the human body the range of most of the wireless sensors operating in RF and microwave frequencies is very limited, when attached to the body. In the final paper, we will present the dramatically improved results replacing the metal dipole with liquid dipoles. It was recently published [7] that this approach allows for the improvement of the range by a factor of 5-10 in a very easy-to-realize way, just modifying the salinity of the aqueous solution of the antenna. The liquid antennas will be initially used for the Receiver module and then, they will be mounted on each electrode for "RFID-like" signal transmission to the wireless transmitter module without the need of electrode mounting.

An alternative wearable "smart textile" configuration is currently tested for the substrate of the wearable EKG system [8] including conducting nylon, phosphor bronze mesh, conducting paint, conducting ribbon and insulating wire. Care should be taken to maintain a balance feed in order to get good transmission characteristics. The characteristics of the materials can be obtained from IFAC website [9]. The calculated dielectric constant of the body while modeling the antenna should be lower than the average dielectric constant of the body muscle in the entire area. The reason being body consists of fatty tissue, which dielectric constant has much lower real and imaginary dielectric constants than the average muscle value.

V. Testing And Validation

The received signal is validated using a logged EKG signal with Biopack [10] as reference. Frequency analysis is done and the received signal frequency plot is compared to the reference signal. Fig. 7 shows the logged EKG data for 3 minutes. Frequency analysis is shown in Fig. 8. The frequency of each peak is about 0.8Hz.

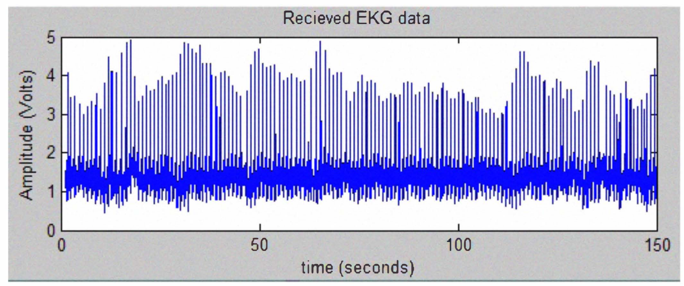

Fig. 7. Logged EKG data

FFT is performed to determine the Signal to Noise ratio (SNR). SNR is calculated by finding 20*log [(Amplitude of 0.8Hz component)/(Amplitude of other frequency components)] that is found to be equal to15.2dB.

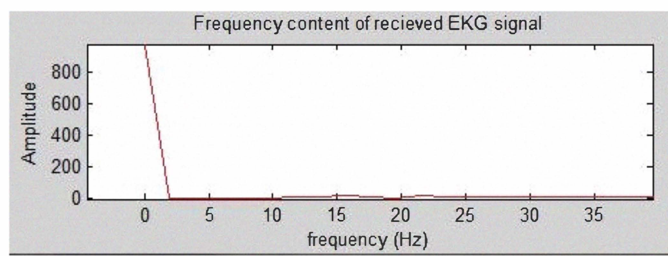

Fig. 8. Frequency analysis of received EKG signal

VI. Results

Analysis showed closer placement of electrodes to the heart resulted in a better quality of signal obtained. Initial placement of electrodes was 30cm apart; however a better signal is observed when the electrodes are placed 7cm apart. Both design 1 and design 2 are analyzed with electrodes placed close to the heart. Fig. 9 shows EKG data obtained from the tested circuit on the oscilloscope. The experimental set up is conducted by having a fixed receiver connected to the computer and moving source which bears the EKG device and moves away from receiver. It is observed that a good signal (SNR > 10dB) was obtained until the source was within a certain distance from the transmitter beyond which the signal was distorted. We fixed this point as the range of transmission. Power consumption is calculated by taking an average of worst case and best case power consumption. Best case is when the source is very close to the receiver. Worst case is when the source is at the maximum possible distance from the receiver.

Fig. 9. Lead II EKG signal obtained on oscilloscope

TABLE I
COMPARISON OF BOTH DESIGNS

Design	1) Digi	2) CC2530
Power (100% Duty cycle)	774 mW	87 mW
Battery supply	3.6V (1000mAh)	2x1.5V (500mAh)
Current drawn by transmitter	215mA	29mA
Range (in open	150m	432m
Battery Life (Range < 50m and 100% duty	6 hours	4 hours

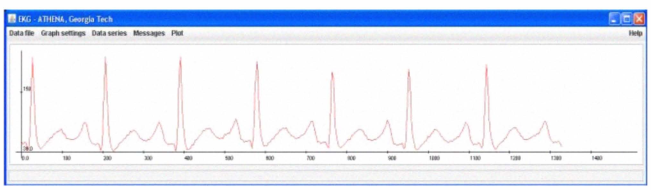

Fig. 10. Plot of the received EKG signal with GUI developed

TABLE II
COMPARISON OF OUR DESIGN WITH PREVIOUS RESEARCH

Design	Powe	Transmit Range
[11]	1m	10
[12]	60m	20-30m
Design 1	774mW	150
Design 2	87m	432

The higher power consumption in our designs can be attributed to the higher transmission range. Power consumption of design 2 is low because of the lesser transmitter current drawn.

VII. CONCLUSION

A novel Zigbee based low- power, low- cost Wireless EKG design has been proposed. The resulting device can be deployed for continuous monitoring of EKG signal of a patient. The transmission of three lead EKG data is tested in a wireless fashion around 2.4GHz for a range of 150m in open space and 50m in closed area using design 1. Design 2 is being tested for wireless transmission. CC2530's maximum transmission range is claimed to be 432m in open space [13], however a range of 300m is expected considering the interference from other sources. Work is currently ongoing for improving the range of transmission of the EKG signal using multi hopping and ionic liquid antennas. The proposed approach could set the foundation for a wearable "smart fabric" wireless platform that could also integrate EEG, and EMG signals.

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