Exploring Human Body Communications for IoT Enabled Ambulatory Health Monitoring Systems

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***Abstract*—Increasing market demand for high performance and portable computing devices requires energy efficient devices. When a network of devices is considered, as in the case of the Internet of Things, it is important to consider low power design at the sensor/actuator level as well as in the sensor network. Human body communication has proven to be an efficient mode of communication for near field body sensor network applications. In this paper we propose an architecture for an ambulatory health monitoring system using a body coupled communication channel. The proposed architecture can be used for smart health monitoring as part of the Internet of Things. The design was validated using Simulink®. A 31 % power reduction was observed in the proposed monitoring system when human body communication was used.**

Keywords*—Internet of Things (IoT), Smart Healthcare, Human body communication (HBC), Frequency selective baseband transmission (FSBT), Body coupled communication (BCC)

I. Introduction

With the increasing features added to a design, there is a continuous need for energy efficient systems [1]. Human body communication (HBC) has proven to be a low power wireless data communication technology [2]. The Internet of Things (IoT) is a way of connecting many sensors through a network which serves as backbone of smart cities [3]. It turns normal sensors and actuators into smart devices. With such enormous scope for smart networks and devices, the applications can range from a smart health care monitoring systems to efficient surveillance systems [4], [3]. Wearables designed using Human Body Communication (HBC) can help in energy efficient personal area networks. The medium of the network can be anything depending upon the application. In the health care domain, multiple sensors can be integrated to form a personal network and the data obtained can be processed based on the criticality. In order to connect sensors in the network, a wireless module such as Bluetooth or WiFi is required along with RF components. In terms of energy efficiency, these components consume a major portion of power. In this paper we propose a health monitoring system using HBC, which results in a low power implementation of the sensor network. The human body is used as a efficient communication channel between the sensors, whereas the wireless module such as Bluetooth or Zigbee is limited to one link server, which acts as the access point.

An illustration of the application of HBC for IoT is shown in Figure 1. The sensor is placed on the outer layer of the skin, i.e. the epidermis. HBC can be achieved by creating a potential difference between any two points in the body. The main advantage of human body communication is that the electrode does not have to be present exactly over the sensor in order to measure the output. Thus sensor implants that act as transmitters can be placed in the form of a band aid, chord, band etc., and the output can be measured from the receiver to obtain information from anywhere in the body or outside the body. Many such sensors can be connected together to form a body area network as shown in Figure 2.

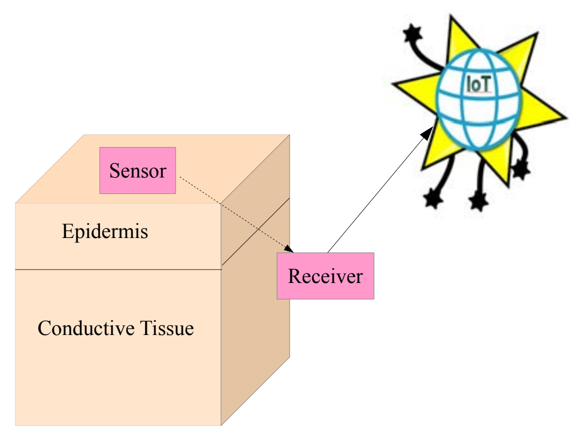

Fig. 1. IoT through Human Body Communication.

The rest of the paper is organized as follows: Novel contributions of this paper are discussed in Sec. II. An IoT perspective of Human body communication is discussed in Sec. III. Some of the already existing methods for HBC implementation are discussed in IV. Design of the HBC in Simulink® is discussed in Sec. V. The implementation and results are discussed in detail in Sec. VI. Conclusions and directions for future research are discussed in Sec. VII.

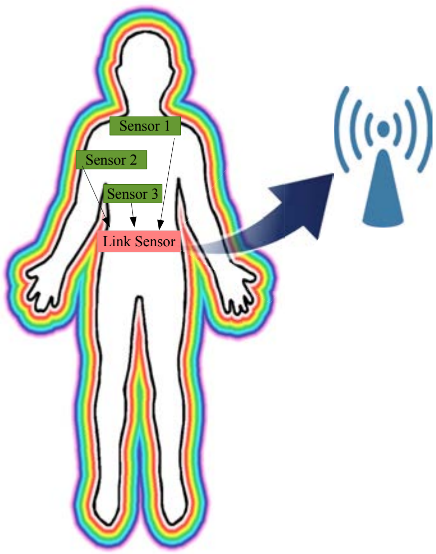

Fig. 2. Body Area Network.

II. Novel Contributions

In this paper we present an efficient design of a health monitoring system through HBC for IoT applications. An ambulatory monitoring system is proposed with an array of sensors as shown in Fig. 3. The proposed monitoring system is energy efficient since it employs a low power communication channel for inter and intra sensor communication, which decreases the power budget of indvidual sensors. A Simulink® prototype of frequency selective baseband transmission is implemented, which is a service based on touch and play and does not need additional RF components. Multiple Input and Multiple output system design was used for employing the monitoring system in IoT.

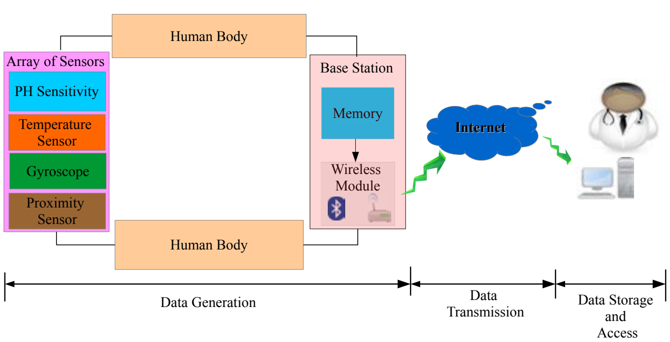

Fig. 3. Block level diagram indicating flow of data in ambulatory health monitoring through IoT.

III. Human Body Communication in IoT: A Broad Perspective

The human body has conductive tissue under the epidermis layer. At high frequencies, it has some electrical conductivity. Body coupling helps in transmitting electrical signals via the human body but it is dangerous for excessive currents. Limitations on the amount of current that can be passed through the body have been set by many countries. As the electrodes are placed near the skin, the signal frequency increases as the current limit is increased.

By providing an efficient communication channel between the sensors and the data acquisition module, power dissipation can be greatly reduced. Figure 3 shows the basic architecture for human body communication in IoT. Here the array of sensors used include pH sensitivity sensor for analyzing salt content in the sweat, temperature sensor for acquiring temperature values, gyroscope which can be used to analyze orientation of the body and proximity sensor which can be used to analyze if the sensor is attached to the human body or not. The human body acts as a communication channel from these sensors to the receiver which is a data acquisition module connected to the Internet.

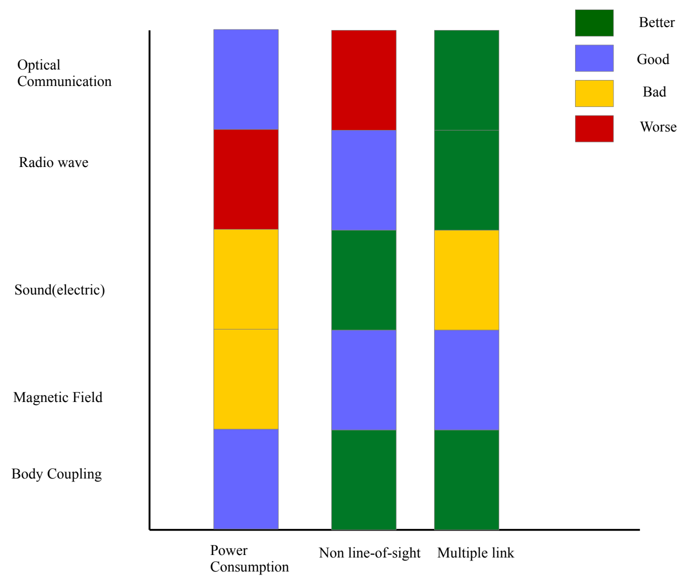

Fig. 4. Performance Comparison of different methods of wireless Communication [5].

Figure 4 shows a performance comparison of different wireless communication methods as discussed in [5]. In Figure 5, a transceiver model for human body communication is presented. It can be observed that the human body can be modeled as capacitors in series with spreading resistance, leading to high pass filters.

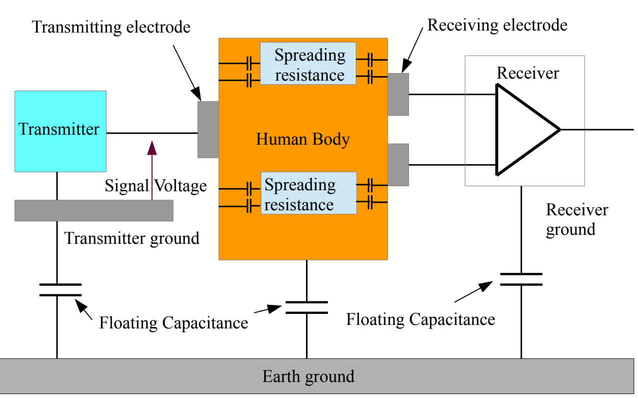

Fig. 5. Transceiver model for Human Body Communication.

IV. Related Prior Research

An early personal area network is discussed in [6]. HBC can be achieved by using Galvanic coupling, electric coupling, capacitive coupling, body coupled communication, etc. Galvanic coupling is achieved by applying signals differentially in the transmitter and receiving signals differentially in the receiver. It was investigated and analyzed by Oberle in [7] and Hachisuka *et al.* in [8]. Body coupled communication is achieved by creating a potential difference in one area of the body and analyzing the resulting potential difference from other areas of the body [9]. The variations in the dedicated tissue layers and geometrical body variations are analyzed in [10]. The electrical coupling method is discussed in [11]. Wider range of applications is obtained by using electro-optic sensors in HBC [12].

V. Proposed Ambulatory Health Monitoring System

Figure 6 depicts the proposed health monitoring system. When the vital signs are to be monitored, the body area network is initiated with a 'Start' signal thereby activating the sensor nodes. The array of sensors starts sensing and their values are transmitted to the base station through body coupled communication (BCC) or through frequency selective baseband transmission (FSBT). The input resistance helps in setting a corner frequency of one high-pass filter and passband level. As the input resistance increases, the level of passband increases and the corner frequency decreases which helps in improving the gain of the BCC channel. Here a MIMO system is considered in the base station as it has become an integral element of wireless communication standards. The Modulator modulates the input signal and gives output as a column vector. This output is fed into the Encoder block which encodes the input message using an orthogonal space-time block code at varying rates depending upon the number of transmission antennas used. The encoded output is transmitted through the MIMO channel. The 6 fading channel is implemented using either Rayleigh or Rician fading channel.

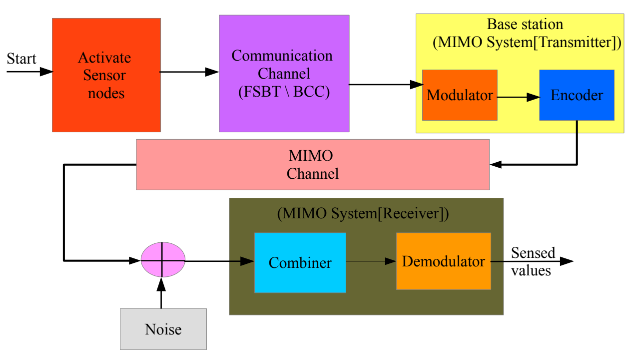

Fig. 6. Datapath across the health monitoring system.

A. Array of Sensors

A Body Area Network (BAN) can be implemented by integrating an array of sensors. Depending upon the application more sensors can be integrated. For example in a BAN for elderly, the sensors will need to acquire the vital signs such as temperature, blood pressure, iris movement and also fall detection. But when a BAN is designed for an athlete, the sensors will range from accelerometer, gyroscope, heart rate monitoring, pH sensitivity sensor, tracking number of steps taken, etc. In this research, we have considered an ambulatory health monitoring system for which a temperature sensor is used, a proximity sensor helps in identifying if the sensor is placed close to the body, a gyroscope helps in understanding the orientation of the user and a pH sensitivity sensor helps in making the sweat analysis.

1) Temperature Sensor: A temperature sensor can be designed with the help of ring oscillators [1]. A basic ring oscillator architecture consists of an odd number of inverters. In order to achieve oscillation the ring should provide a 2π phase shift and have unity voltage gain at the oscillating frequency. The oscillation frequency is given by the following:

$$f_{\text{osc}} = \frac{1}{N_{\text{stage}}(T_{\text{pd,LH}} + T_{\text{pd,HL}})}, \tag{1}$$

where $\mathrm{N_{stage}}$ is the number of stages in the ring oscillator and $\mathrm{T_{pd,\ LH}}$ and $\mathrm{T_{pd,\ HL}}$ are the Low-to-High and High-Low propagation delays. These depend on the threshold voltage $\mathrm{V_{Th}}$ which is very sensitive to temperature fluctuations. Thus as temperature increases the oscillating frequency decreases. This is used to analyze the variation of temperature based on the oscillating frequency.

2) Proximity Sensor: The proximity sensor can also be called a simple distance sensor as it helps in tracking the distance between the object and the sensor. The proximity sensor helps in sensing the distance which is normal to the sensor surface. In the given sensing distance, the sensor detects an object for a given radial offset R.

3) Gyroscope: A gyroscope sensor helps in analyzing the orientation of an object. It can be used in a BAN to analyze the orientation of the patient or the sensor itself. A gyro consists of a small vibrating mass. When the gyro is rotated, the mass experiences a small force which displaces the original mass from its path. The gyroscope uses capacitance to sense this displacement and output a proportional number of counts. A block level diagram of the gyroscope sensor is shown in Fig. 9. The vibrating mass is modeled under MEMS Gyro dynamics. The sensors are subject to static bias and outward noise. Thus these values are added along with the output of the dynamics block. The scale factor helps in converting the output to proportional number of counts.

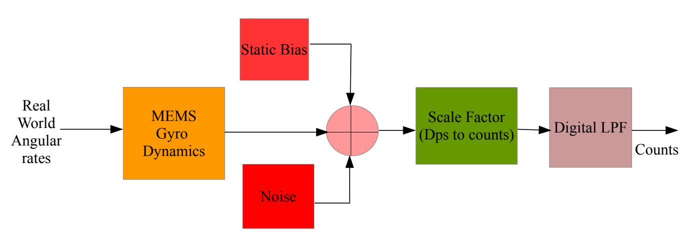

Fig. 7. Block Diagram of a simple MEMS based Gyroscope

4) pH Sensitivity Sensor: Sweat analysis is gaining more importance recently as it helps in monitoring vital signs such as glucose, sodium, vitamin deficiencies, etc. in a person. The measurement of the acidity or alkalinity in sweat is done with the help of pH sensitive sensors. In laboratories pH sensitivity is monitored using the potential difference between the reference electrode and the test electrode. The sensor can be designed based on an operational amplifier, i.e. the difference in the values between the inverting and non-inverting end can be used as pH variation values.

B. Communication Channel

In the initial days of HBC, it was mainly considered as a way of transferring data through human body. Thus continuous modulation schemes were used but these modulations do not aid in the touch and play mechanism. BANs can be implemented using low power radios [13], eTextiles where the textiles are embedded with sensors and wires [14] and body coupled communication (BCC) [15]. Though eTextiles do not need additional amplifying circuitry, they have some drawbacks such as causing inconvenience for the user with all the wires and sensors. Low power radios and BCC have almost the same efficiency and give more flexibility for the user. In a BAN the data rate varies from 10 Kbps to 10 Mbps.

1) Frequency Selective Baseband Transmission: The requirements of BAN can be met only when no RF/IF components are used in the specified frequency band. Walsh code helps in implementing Frequency Selective Baseband transmission (FSBT). A Walsh (Hadamard) code consists of an M_n matrix where n is an even integer. It has all 1s and 0s such that all rows differ from each other by exactly $1/2n$ positions. In Figure 8 the transmitter and receiver of FSBT is demonstrated. The 64 Walsh code matrix is divided into 4 subgroups by using the corresponding index. In the transmitter, the input is given to the serial to parallel block which divides the input into 4 subgroups. These 4 signals are given as input for the FSBT Modulator, where the input is spread using a 64 Walsh code in the frequency spreader. Since the human body has high attenuation, the input to the receiver is considered with additive noise and intrinsic channel with attenuated symbol. The demodulation is done by adopting the maximum likelihood detection method.

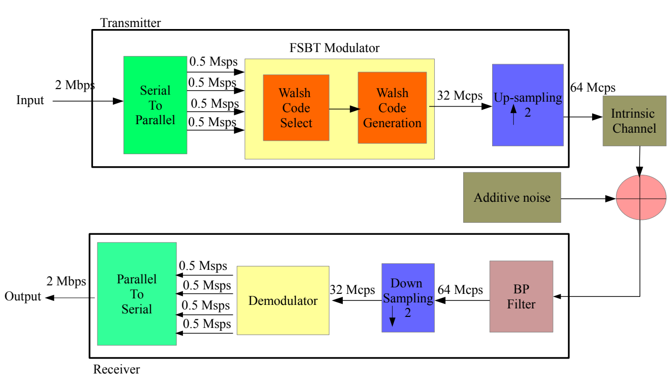

Fig. 8. HBC Block Diagram with FSBT Modulator

2) Body Coupled Communication: Body Coupled communication can be done by either capacitive coupling or galvanic coupling [16]. In the galvanic coupling technique, the transmitter sends a signal through the human body and irrespective of the environment, the receiver receives it [17]. Both transmitter and receiver electrodes are directly placed in contact with the skin. Due to its robustness, it is ideal for wearables and implantable devices. But it has a drawback of working efficient only in smaller distances and limits the transmission rate as it is directly in contact with skin and passing high signals at the transmission end can be harmful for the user. In capacitive coupling, though the transmitter electrode is placed on the human skin, the other electrode is left floating in such a way that the floating electrodes are coupled to ground through the air and create as return path whereas the attached electrode creates a forward path [18]. Ideally, the simplified BCC model can be implemented as a pair of High pass filters in case of capacitive coupling and in galvanic coupling method as a channel which would only exhibit one high pass filter.

VI. Implementation and Validation of Ambulatory Health Monitoring System

This section presents the implementation of the proposed system using Simulink®. Simulink® was used as design validation platform due to its available primitives and libraries [1]. Fig. 9 shows the implementation of the gyroscope in Simulink®. Fig. 10 shows the capacitive coupling in a human body which is modeled as spreading resistance. The input resistance helps in setting a corner frequency of one high-pass filter and passband level. As the input resistance increases, the level of passband increases and the corner frequency decreases which helps in improving the gain of the BCC channel.

A Rayleigh distribution is used for non-line of sight path and a Rician distribution is used for line-of-sight path. The encoded signal is given as input to the combiner along with white noise. The output of the combiner is again fed into the demodulator which demodulates the signal at the output. When FSBT is being used for communication channel, only the transmitter is used for transmitting the input and at the receiver end, the demodulation for FSBT is performed.

When sensor values are transmitted along the sensor network, white noise is added to it as it becomes easier to transmit instead of discrete values. Fig. 9 shows the output of gyroscope at '0' instance, i.e. when the sensor is aligned properly. The output of the bandpass filter used at the receiver module to remove the noise components and to pass the main energy of the signal can be seen in Fig. 12. A 64 Walsh code is shown in Fig. 13 which can be used for human body communication.

The frequency spectrum was analyzed with the help of the spectrum analyzer block in Simulink®. The performance of HBC in FSBT implementation is evaluated based on Average Signal to Noise Ratio and Bit error rate. A surface plot of the performance analysis is shown in Fig. 14.

When body coupled communication was implemented using resistance and capacitance, the channel gain was estimated based on the transmitter frequency. Fig. 15 shows the BCC channel gain for capacitively coupled human arm model for input resistance 50 Ohms and 250 Ohms. The frequency was varied from 10 MHz to 100 MHz. It can be observed that as the input resistance was increased, the gain increased but the slope gradually decreased, thus indicating variation in corner frequency. Table I lists the methods used in implementing the body area network. It can be observed that power consumption was 3.14 mW which implies a 31 % power reduction compared to the related research work in [19].

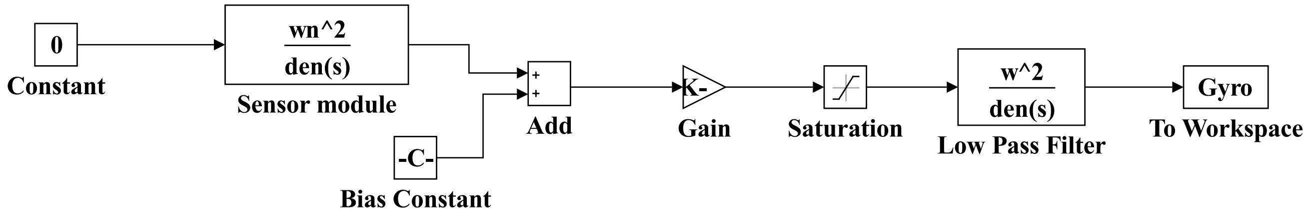

Fig. 9. Gyroscope Block Diagram in Simulink®.

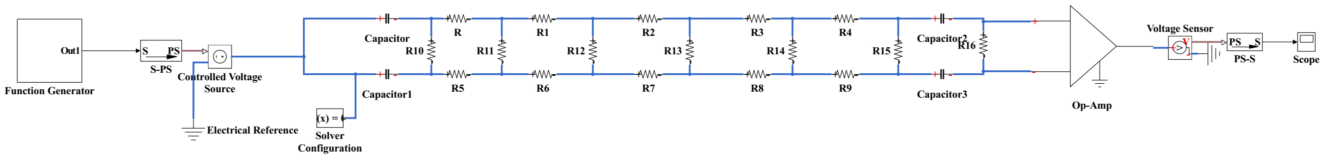

Fig. 10. Body modeled as a spreading resistance. The transmitter and receiver are capacitively coupled to the body.

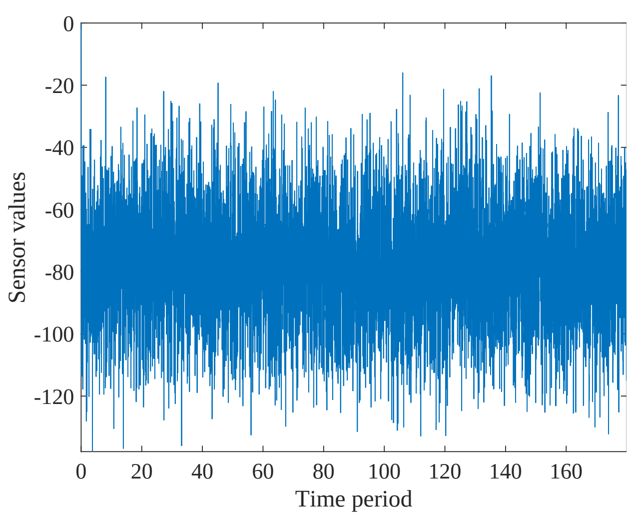

Fig. 11. Output of Gyroscope sensor module with white noise.

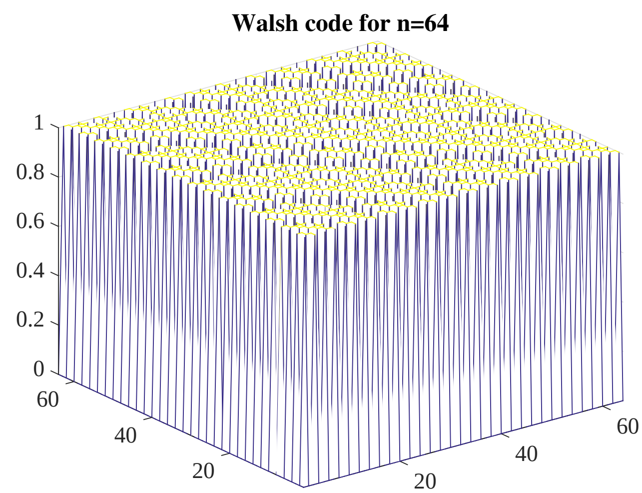

Fig. 13. A mesh of Walsh code for n=64, i.e. $M_{64\times64}$ of all 1s and 0s.

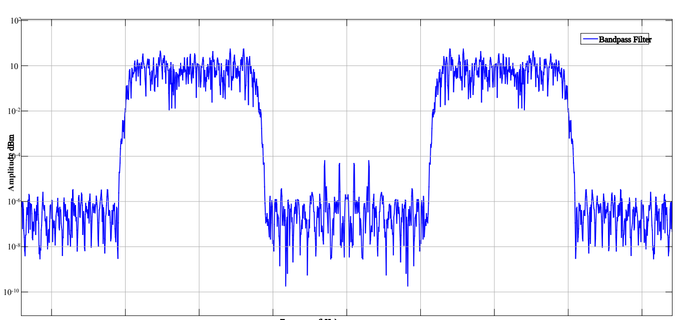

Fig. 12. Frequency spectrum after BPF in HBC implementation.

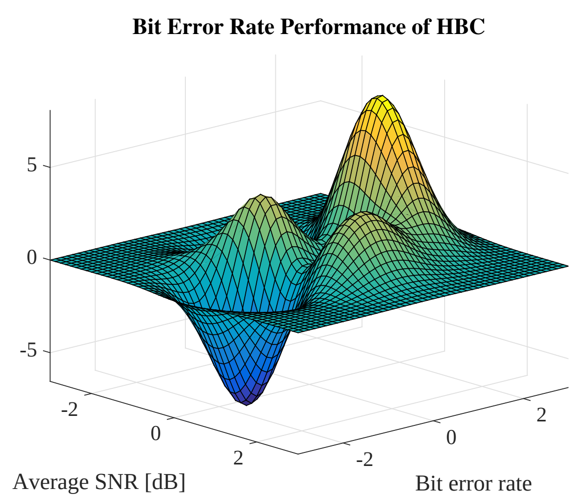

Fig. 14. Performance of HBC with FSBT.

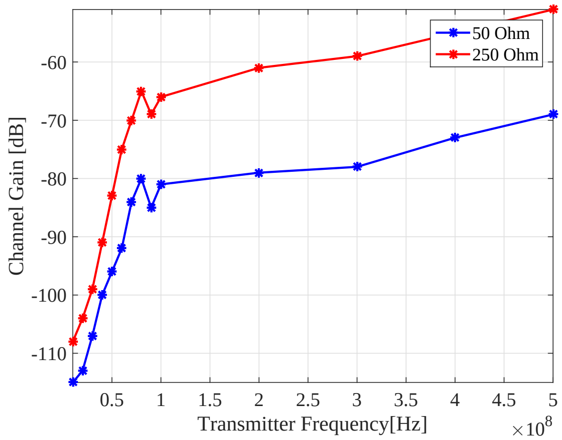

Fig. 15. Frequency response for BCC Channel.

TABLE I. CHARACTERIZATION TABLE.

Frequency Band	Frequency Selective Baseband
Spreading	Frequency Selective Walsh Modulation
Communication Environment	Intra Body Communication
MIMO Encoder	Orthogonal Space Time Block Code
MIMO Channel	Rayleigh distribution
MIMO Combiner	Orthogonal Space Time Block Code
Walsh Code Size	64
BCC coupling method	Capacitively coupled
Frequency range of Operation	1- 100 MHz
Power Consumption	3.14 mW

VII. CONCLUSIONS AND FUTURE RESEARCH

In this paper, we propose an ambulatory health monitoring system using FSBT and BCC in Simulink® for IoT applications. Human body communication helps in reducing the system complexity and power consumption as additional RF components are not being used. A Multiple Input Multiple Output System was used in this design in order to use the system for IoT applications as MIMO has become essential in wireless communication. It was observed that in independent applications such as touch-based intuitive service, FSBT plays an important role in HBC and for inter-sensor communication, BCC is very important as it reduces the power budget of the sensors at a price of higher attenuation. Future research involves developing smaller prototypes of the human body communication channel such that it can be used for integrating real-time sensors to Simulink® and also exploring more communication methods to reduce power consumption in body area networks.

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