A STUDY ON THE FREQUENCY CHARACTERISTIC OF A TRANSMISSION CHANNEL USING HUMAN BODY FOR THE WEARABLE DEVICES

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1. Introduction

As cellular phones, personal digital assistants (PDAs), digital video cameras, pocket video games, and other information and communication devices become smaller and more widespread, we have begun to adorn our bodies with these appliances and the opportunities to use these small computers have been increased in our everyday lives. We can say with fair certainty that miniaturization of these devices will evolve, and we will meet the ubiquitous computing society. However, currently there is no method for these personal devices to exchange data directly. If these devices are wire-connected, it is clearly impractical because they easily become tangled, so some sort of short-range wireless technology is required. The concept for networking these personal devices has been proposed as Personal Area Networks (PANs) which uses the human body as a transmission channel [1]. Although many studies have been made on the development of wearable devices using the human body as a transmission channel, little is known about the transmission mechanism of such devices in the physical layer.

Figure 1 shows an example of communication system of the PANs. When a user wearing the transmitter touches the electrode of the receiver, a transmission channel is formed via the human body. The merit of this system is that the data is exchanged through daily natural actions, such as simply touching the receiver. This communication system uses the near field region of the electromagnetic wave generated by the device which is eventually coupled to the human body by electrodes. Hence, the structure of electrodes is one of the key issues for the transmission using human body.

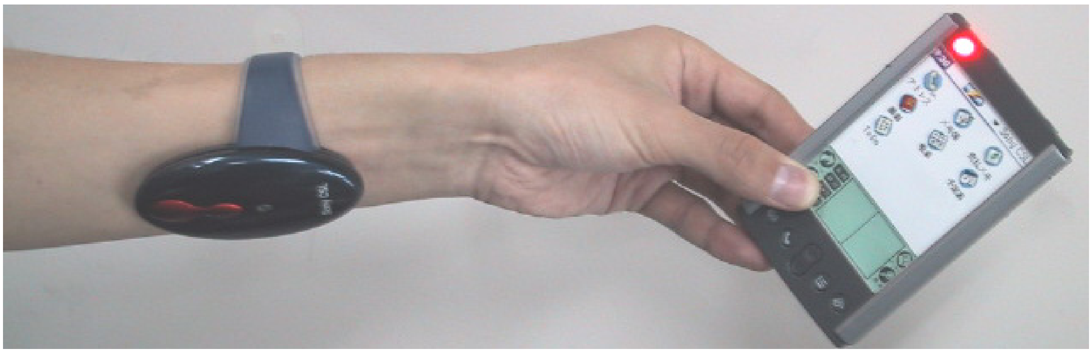

Fig. 1 Transmission system using the human body as a transmission channel [2].

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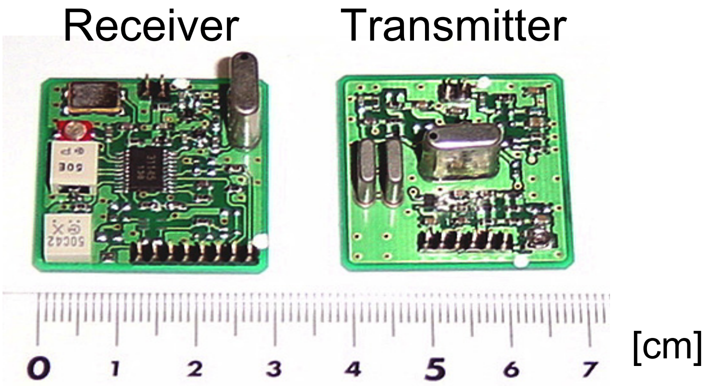


Fig. 2 Assembled wearable transmitter and receiver [3].

As for another example, small, lightweight, energy-saving, wearable intra-body FM transmitters and receivers were assembled (Fig. 2). A carrier frequency of 10.7 MHz was selected because 10.7 MHz is in the middle of the frequencies used in FM radios, and thus 10.7 MHz ICs are readily available. Moreover, because 10.7 MHz is seldom used for transmission, there is little noise associated with this frequency. The selection was also influenced by the gain characteristics of the human body. Both the transmitter and receiver measured 30 mm by 30 mm. With no batteries, the transmitter weighed 4.3 g and the receiver 5.4 g, with energy supplied by 3 V dry cells.

In previous study, the authors proposed some calculation models of the transmitter and the receiver attached to the arm using the FDTD method to clarify the transmission mechanism [4]. From them, the authors estimated the difference in the received signal level due to the electrode structures of the transmitter under various conditions. Moreover, in order to verify the validity of these calculation models, the calculated received signal levels were compared to the measured ones by using a biological tissue-equivalent phantom. The result showed a good agreement between calculated and measured received signal levels. In addition, it was found that the GND electrode of the transmitter attached to the arm strengthens the generated electric field around the arm.

Then, the authors focused their attention on measuring the each component of the propagated signal using a shielded loop antenna. Moreover, in order to clarify the validity of the measurement, the authors compared the measured data to the calculated ones. Then the authors considered the current distribution inside the arm from each component of the distributed signal. From these results, the favorable direction of electrodes of the transmitter for using the human body as a transmission channel was proposed.

After the validity of this calculation model was demonstrated, the authors clarified the dominant signal transmission channel, because the question of whether the dominant signal channel was in or around the arm still remained unsettled. To clear this question, the authors proposed the calculation model of an arm wearing the transmitter and receiver placed into a hole of a conductor plate [5]. The electric field distribution and received signal voltage was investigated as a function of the gap between the hole of the conductor plate and the surface of the arm when signal passed through the hole made in the conductor plate. The results lead us to the conclusion that the dominant signal transmission channel of a wearable device using human body as a transmission channel is near the surface of the arm because the signal seems to be propagated as a surface wave.

However, these investigation was limited only 10MHz. The electrode structure to communicate between the wearable devices must be small and eligible to utilize higher bit rate for practical use. Therefore, the authors intend to employ Ultra Wide Band (UWB) system which has been authorized to use many GHz of band width from 3.1GHz to 10.6GHz for communication system using the human body as a transmission channel. This technology has the potential to provide unprecedented high-connectivity consumer products in ubiquitous computer society. Hence, in this paper, the carrier frequency of the wearable transmitter is shifted from 10MHz to 10GHz to establish the basis for transmission mechanism using the human body as a transmission channel.

2. Frequency characteristic of the wearable transmitter and receiver

In this part, the authors investigate the frequency characteristic of the wearable device by using the FDTD method. The calculation model of the arm wearing the transmitter and receiver is illustrated in figure 3. The transmitter has two electrodes. One is the signal electrode to feed an excitation signal (Sine wave of $3V_{p\text{-}p}$), and the other is GND electrode which is connected to the ground level of the electrical circuit. In the FDTD calculation, two electrodes and circuit board of the transmitter are modeled as perfect conductor sheets. The sizes of the electrodes are 2 cm × 3 cm and the size of the circuit board is 8 cm × 3 cm. The carrier frequency is shifted from 10MHz to 10GHz. In the case of the receiver, it has a receiving electrode. The receiving electrode and the circuit board are modeled as perfect conductor sheets. The numerical muscle-equivalent phantom used for the arm which is modeled by a rectangular parallelepiped (5 cm × 5 cm × 45 cm) has same relative permittivity ε_r and conductivity σ[S/m] in each frequency [6]. The distance between the transmitter and receiver is fixed to 17 cm because the transmitter is located at the center of the arm and the receiver is also located at the tip of the arm.

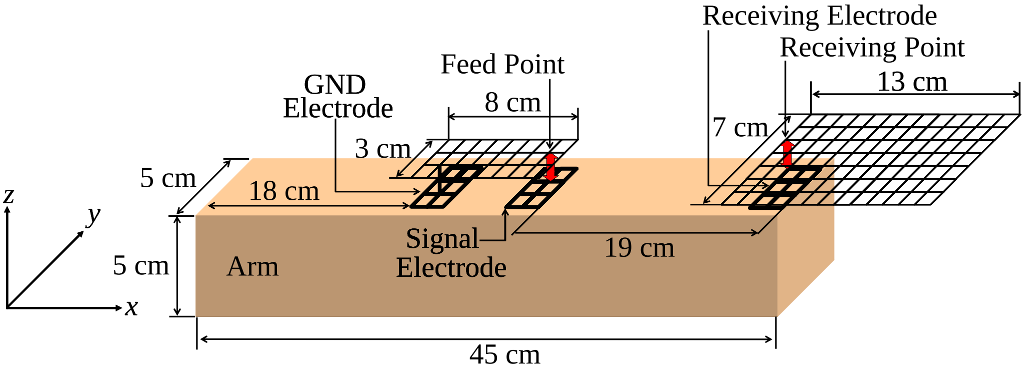


Fig. 3 FDTD calculation model of the arm wearing the transmitter and receiver [4].

Figure 4 shows the transmission efficiency T [dB] as a function of the carrier frequency of the wearable transmitter. The transmission efficiency T [dB] is defined as follows,

$$T = 20\log_{10}\left(\frac{V_{Rx}}{V_{Tx}}\right) \text{ [dB]} \qquad (1)$$

where V_{Tx} [V] means voltage of the feeding point of the transmitter; accordingly $3V_{p\text{-}p}$, and V_{Rx} [V] means received signal voltage of the receiver. The received signal voltage is calculated from the electric field at the receiving point. In figure 4, the result shows that the received signal voltage decrease rapidly from 10MHz to 1GHz. More than 1GHz, the received signal voltage is almost flat. To understand this mechanism, the electric field distribution should be investigated.

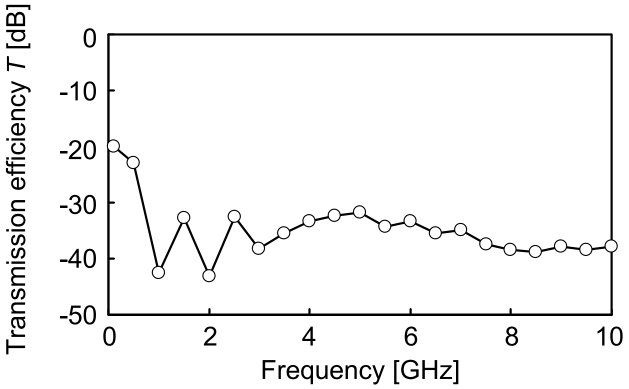
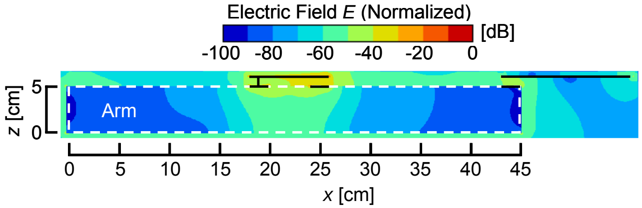
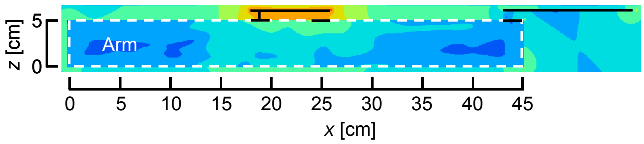


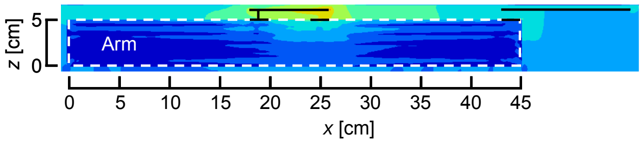
Fig. 4 Transmission efficiency T vs. frequency.



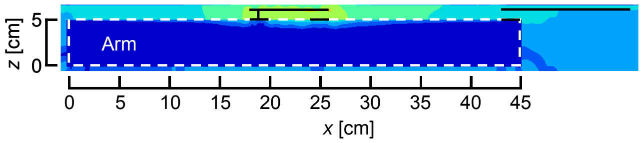
(a) 10MHz



(b) 1GHz



(c) 5GHz



(d) 10GHz

Fig. 5 Electric field distributions in and around the arm.

Figure 5 illustrates the electric field distributions (root-sum-square) in and around the arm. The reason of discussing the electric field distribution is that the received signal voltage of the receiver is calculated from the electric field. Thus, the argument from the view point of the electric field is essential. The observation plane is the *x*-*z* plane including the receiving point of the receiver. The electric field is normalized to the value at the feeding gap. As the frequency shifted higher, surface wave component is reduced. Electric field is not propagated toward the receiver but radiated upper side of the arm. Therefore, we can use the human body as a transmission channel effectively below the 1GHz.

3. Conclusion

In this paper, the authors intend to employ Ultra Wide Band (UWB) system which has been authorized to use many GHz of band width from 3.1GHz to 10.6GHz for communication system using the human body as a transmission channel. The transmission property from 10MHz to 10GHz was investigated. The result shows that as the frequency shifted higher, surface wave component is reduced and the electric field is not propagated toward the receiver but radiated upper side of the arm. Therefore, we can use the human body as a transmission channel effectively below the 1GHz in the structure of our transmitter.

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