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Performance evaluation using BER/SNR of wearable fabric reconfigurable beam-steering antenna for On/Off-body communication systems

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On/Off-body 통신시스템을 위한 직물소재 웨어러블 재구성 빔 스티어링 안테나의 BER/SNR 성능 검증

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Abstract This paper presents a comparison of communication performance between the reconfigurable beam-steering antenna and the omni-directional (loop) antenna during standstill and walking motion. Both omni-directional and reconfigurable antennas were manufactured on the same fabric ($\varepsilon_r = 1.35$, $\tan\delta = 0.02$) substrate and operated around 5 GHz band. The reconfigurable antenna was designed to steer the beam directions. To implement the beam-steering capability, the antenna used two PIN diodes. The measured peak gains were 5.9 - 6.6 dBi and the overall half power beam width (HPBW) was 102°. In order to compare the communication efficiency, both the bit error rate (BER) and the signal-to-noise ratio (SNR) were measured using a GNU Radio Companion software tool and user software radio peripheral (USRP) devices. The measurement were performed when both antennas were standstill and walking motion in an antenna chamber as well as in a smart home environment. From these results, the performances of the reconfigurable beam steering antenna outperformed that of the loop antenna. In addition, in terms of communication efficiencies, in an antenna chamber was better than in a smart home environment. In terms of movement of antennas, standstill state has better results than walking motion state.

요 약 본 논문은 재구성 빔 스티어링 안테나와 전방향성(루프) 안테나 간 정지상태와 이동상태일 때 통신 성능 비교를 보여준다. 두 안테나는 동일한 직물($\varepsilon_r = 1.35$, $\tan\delta = 0.02$) 위에 제작되었으며 5 GHz 대역에서 동작한다. 재구성 안테나는 빔 방향을 조향할 수 있도록 설계되었다. 빔 스티어링 기능을 수행하기 위해 안테나는 두 개의 핀 다이오드를 사용한다. 측정된 최대 이득은 5.9-6.6 dBi 이고 반 전력 빔 폭(HPBW)는 102° 이다. 통신효율을 비교하기 위해 GNU Radio Companion 소프트웨어툴과 USRP(User Software Radio Peripheral) 장비를 이용하여 두 안테나의 BER(Bit Error Rate)과 SNR(Signal-to-Noise Ratio)를 측정하였다. 그리고 송, 수신 안테나 사이의 일정한 거리에서 수신 안테나가 고정된 상태와 이동중인 상태 두 가지 경우를 비교하였다. 본 측정은 이상적인 전파환경인 무손실 안테나 챔버와 전파간섭이 존재하는 실제적인 환경인 스마트홈에서 진행되었다. 본 측정의 결과로 빔 스티어링 안테나의 성능이 루프 안테나보다 우수함을 알 수 있다. 또한, 통신효율을 비교하면 측정환경 측면에서는 무손실 안테나 챔버가 스마트홈보다 우수하며, 안테나의 고정/이동 측면에서는 고정된 상태가 이동중인 상태보다 좋은 결과를 보임을 알 수 있다.

Keywords : Beam-steering antenna, BER, Loop antenna, SNR, Wearable fabric antenna, WLAN

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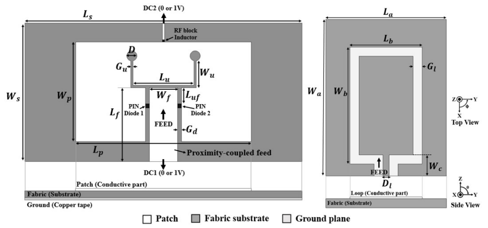
1. Introduction

Wearable antennas for wireless body-centric network to provide communication system have been studied widely [1]. To implement body-centric communications, fabric-based wearable antennas are necessary [2-3]. Wearable antennas need to have the characteristics of small size, simple design, and flexible substrate [4]. Since a wearable antenna in the presence of body suffers from time-varying wireless channels due to the motion of human, beam-steering capability is required to dynamically change the radiation pattern according to the human motion, as well as enhance the directivity along the desired directions [5]. Besides, in recent years high data rate techniques have gained considerable interests in communication systems. The most meaningful criterion for evaluation of performance of communication systems is the bit error rate (BER). A bit error rate is defined as the rate at which errors occur in a transmission system. This can be directly translated into the number of errors that occur in a string of a stated number of bits. Signal–to-noise ratio (SNR) is defined as the ratio of the desired signal power to noise power. SNR indicates the reliability of link between the transmitter and receiver.

In this paper, performances of the reconfigurable beam-steering antenna and the loop antenna were compared and evaluated in the wireless LAN network compatible with IEEE 802.15.4. In this comparison, measurements were conducted using a universal software radio peripheral (USRP) device [6] in both an antenna chamber and a smart home environment. Since the radio propagation of wearable antennas depends on the posture of a human body in addition to the surrounding environment, the human body was in standstill and in a walking motion throughout the measurements. The results of performances are summarized in section 3.

2. Configurations and Properties

The configuration of reconfigurable beam-steering antenna is shown in fig. 1 (a). This antenna was fabricated on a fabric substrate with a thickness of 1.5 mm, relative permittivity of 1.35, and loss tangent of 0.02. A patch and a ground were positioned on the front and back of the substrate. The ground was manufactured with copper and consisted of the bottom plane to avoid affecting electromagnetic waves in the human body. The overall dimensions of the proposed antenna and the loop antenna are given in Table 1. The configuration of the loop antenna, which was fabricated on the same fabric substrate, is shown in fig. 1 (b). The loop was also manufactured with silver paste. The antenna patch and the proximity-coupled feed were designed to be connected using the two PIN diodes. These PIN diodes, which were configured with just a line connection, were located between the feeding line and the antenna patch to control the current distributions, and could be controlled by two DC bias inputs (DC1 and DC2). A U-slot structure was employed to miniaturize the system and to obtain a wide-band frequency range. There were three states (state 0, 1, and 2) created by using two PIN diodes, as shown in Table 2. The measured reflection coefficients of the proposed antenna (states 0, 1, and 2) and the loop antenna on the human body phantom are shown in fig. 2. All the reflection coefficients were under -6 dB (VSWR < 3) at an operation frequency band. The operation bandwidth of states 0, 1, and 2 are 5.69–5.96 GHz, 5.51–6.05 GHz, 5.43–6.03 GHz, respectively, while that of the loop is 5.27–6.22 GHz. Fig. 3 shows the simulated three-dimensional radiation patterns (YZ-plane) of the proposed antenna and the loop antenna at 5.9 GHz, demonstrating that the maximum beam directions of radiation patterns were clearly changed by the state (states 0, 1, and 2). In addition, fig. 4 shows the measured two-dimensional radiation patterns on the human body phantom in the YZ-plane (θ) at 5.9 GHz. The measured maximum beam direction, peak gain, and half power beam width (HPBW) of the proposed antenna's three states and the loop antenna are summarized in Table 3. These results indicate that the reconfigurable beam steering antenna is able to steer the beam direction and has high gain in comparison with the loop antenna. Fig. 5 shows photographs of two fabricated antennas on the human body chest. The value of the SAR is an essential factor in evaluating the antenna's effect in the vicinity of the human body for on-body applications. The simulation was therefore carried out in the condition of the antenna contacting a human chest at 5.9 GHz. The human model we employ has the relative permittivity (ε_r) of 35.36 and the loss tangent (tan δ) of 0.32. The IEEE standard requires below 1.6 W/kg over a volume of 1g of tissue, while the International Commission on Non-Ionizing Radiation Protection standard requires 2 W/kg over a volume of 10g of tissue. The peak SAR values of the proposed antenna were 0.68-0.98 W/kg (1g tissue) and 0.09-0.16 W/kg (10g tissue). In contrast, the peak SAR values of the loop antenna were 4.22 W/kg (1g tissue) and 0.74 W/kg (10g tissue). We thus confirmed that the reconfigurable beam-steering antenna satisfies the IEEE standard SAR values, while the loop antenna fails to do so.



(a) (b)

Fig. 1. Configurations of two antennas:
(a) Reconfigurable beam-steering antenna,
(b) Loop antenna.

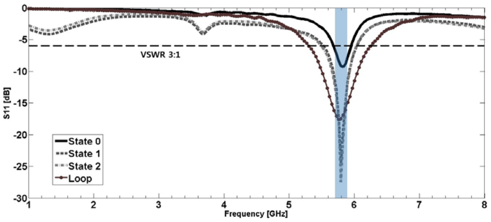


Fig. 2. Measured reflection coefficients (S11) of the reconfigurable beam-steering antenna and the loop antenna.

Table 1. Dimensions of the reconfigurable beam-steering antenna and the loop antenna.

Para.	L_s	W_s	L_p	W_p	L_f	W_f	
mm	60	30	38	21.6	16	6.04	
Para.	L_u	W_u	L_{uf}	G_u	G_d	D	
mm	13.2	6.1	3.5	0.5	0.9	2.2	
Para.	L_a	W_a	L_b	W_b	W_c	D_l	G_l
mm	20	26	12	19.4	3.5	1	1.5

Table 2. State configurations by PIN diodes and DC biasing.

State	PIN didoe 1	PIN didoe 2	DC 1 (V)	DC 2 (V)
State 0	Off	Off	0	0
State 1	On	Off	1	0
State 2	Off	On	0	1

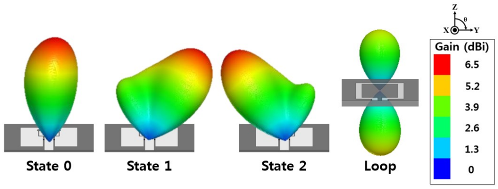


Fig. 3. Simulated three-dimensional radiation patterns of the reconfigurable beam-steering antenna at 5.9 GHz.

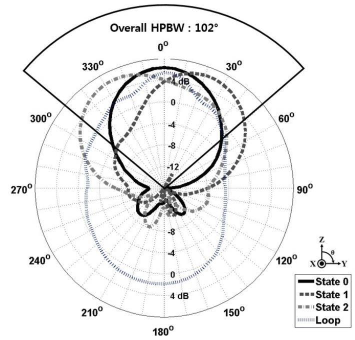


Fig. 4. Measured radiation patterns of the proposed antenna's three states (state 0, 1, and 2) and the loop antenna at 5.9 GHz.

(a) (b)

Fig. 5. Photographs of two fabricated antennas on the human body chest: (a) Reconfigurable beam-steering antenna, (b) Loop antenna.

3. BER/SNR Performance Comparison

3.1 Measurement Setup

The measurement was performed using a GNU Radio Companion software tool running on a USRP (Ettus Research N210) device equipped with XCVR2450 daughter boards as radio frontend [6]. The transmitted signal waveform was generated via O-QPSK (Offset Quadrature Phase-shift keying) modulation. To measure both BER and SNR, we use GNUradio IEEE 802.15.4 implemented by Bastian Bloessl [7], but we extract only a PHY layer in order to simplify the system while transmitting and receiving data normally. Although IEEE 802.15.4 do not support 5.9GHz, we set the frequency band of the RF signal for this measurement to 5.9GHz for our antenna characteristics. We used USRP that was connected to a host computer through a high-speed link. The host computer uses the host-based software to control the USRP hardware and transmit/receive data. It is noted that some USRP models also integrate the general functionality of a host computer with an embedded processor, which allows the USRP device to operate in a stand-alone fashion. The method of measuring SNR is different from that of BER measurement because it is impossible to measure the signal and noise separately. The values of SNR are actually estimated (rather than measured) [8]. A block diagram for BER/SNR measurement is illustrated in fig. 6. The USRP 1 connected by an RF cable to the standard antenna (Tx) generates the signal waveform, while the proposed antenna (Rx) connected to the USRP 2 receives the transmitted signal. All measurements were taken at a nominal Tx-Rx separation of 3 m, and all body-centric received powers were normalized with respect to measurement of an isolated antenna where the position of the antennas on the participant's body were at the same height and separation. Specifically, the position of the antenna was on the human chest. The received signal is then analyzed through the software tool. Figs. 7 and 8 present the two environments, a chamber and a smart home, respectively, in which the measurement of BER/SNR performance was conducted. When the standard antenna (connected to USRP 1 – Tx) had transmitted data to the proposed antenna (connected to USRP 2 – Rx), we measured BER, SNR values according to Tx power. There are several cases:

1. Measurement of each antenna attached on the chest when human is staying (standstill).
2. Measurement of each antenna attached on the chest when human is walking (walking motion).

This measurement is conducted in both the chamber and the smart home. The measurements were carried out with the help of a participant. During the measurement 2, the participant was affected by shadowing or other effects caused by a body motion. On the receiver side, we used a frequency discriminator belonging to a category of non-coherent detector, which effectively reduces its power consumption. It is noted that no error correction code is applied [9].

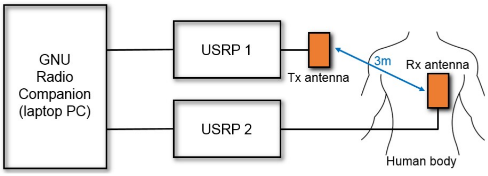


Fig. 6. The block diagram of measuring BER/SNR performances.

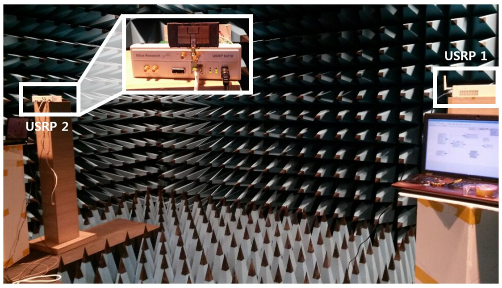


Fig. 7. Measurement of BER/SNR performances in an antenna chamber.

Fig. 8. Measurement of BER/SNR performances in a smart home.

3.2 BER/SNR Measurement Results

In this sub section, we compare the communication efficiency of the omni-directional and beam-steering antennas in terms of both BER and SNR. From the measurements of the received power, it was found that received power levels for the proposed antenna was higher than that of the loop antenna in both of the two environments. The results of four cases are shown in figs. 9 - 12. The values of BER/SNR increased and decreased proportionately in the standstill situation, as shown in figs. 9 and 11. By contrast, the values of BER/SNR increased and decreased irregularly in the moving situation, as shown in figs. 10 and 12. The BER values of the loop antenna were about 39.4 % higher than those of the proposed antenna in all cases. The higher the value of BER, the bigger the number of bit errors divided by the total number of transferred bits during a specific time interval. While, the SNR values of the proposed antenna were about 22.24 % higher than those of the loop antenna, as shown in figs. 10 and 12. The higher the value of SNR, the lower the noise effect. In other words, the communication efficiency of the proposed antenna is better than that of the loop antenna.

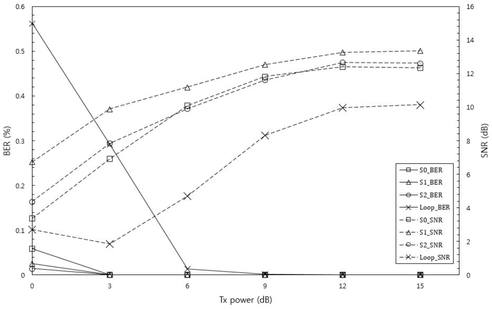


Fig. 9. Measured BER/SNR performances in an antenna chamber (standstill).

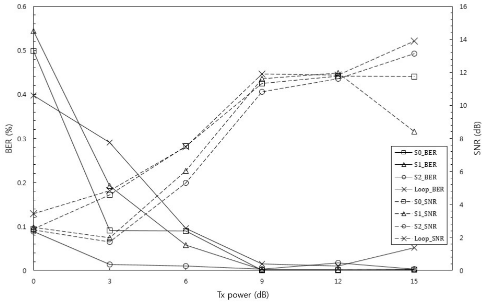


Fig. 10. Measured BER/SNR performances in an antenna chamber (walking motion).

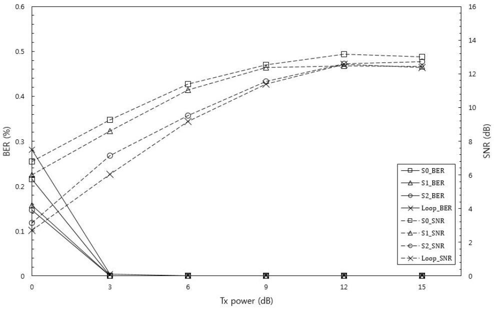


Fig. 11. Measured BER/SNR performance in a smart home (standstill).

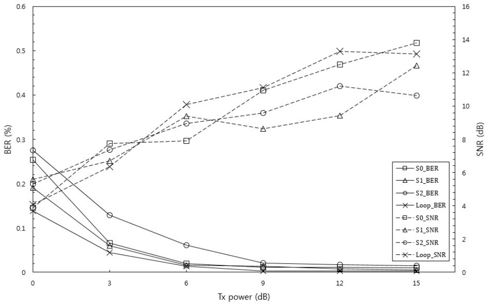


Fig. 12. Measured BER/SNR performance in a smart home (walking motion).

4. Conclusions

In this paper, the performance of the reconfigurable beam-steering antenna on a wearable fabric substrate was compared with that of the loop antenna. The operation frequency band of the two antennas was the IEEE 802.15.4 with 5.9 GHz. The measured results clearly indicated that the proposed antenna had higher gain and lower SAR than the loop antenna. In addition, the communication efficiency of the proposed antenna was better than that of the loop antenna as demonstrated by the measurement of BER/SNR performances. Therefore, the reconfigurable beam-steering antenna using a single antenna element has a variety of benefits in on/off-body communication systems.

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