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Design of a flexible diversity zeroth-order resonance antenna for WBAN applications

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Abstract: A flexible diversity antenna using zeroth-order resonance (ZOR) for WBAN applications is proposed to improve performance and overcome multipath fading. The dimension of the proposed diversity antenna, including the system ground, two antenna elements, and the decoupling network is 44 mm × 35 mm × 0.127 mm. When the antenna is located on a semi-solid flat phantom with equivalent electrical properties of a human body, the S_{11} and S_{22} values of the proposed antenna at 2.45 GHz are −22.8 dB and −25.4 dB, respectively. The measured specific absorption ratio (SAR) values of the antenna elements #1 and #2 are 0.54 W/kg and 0.75 W/kg (1 g tissue) and mean powers delivered from the two ports are almost identical since the proposed antenna has a measured ECC of 0.021 MEG ratio of 0.33 dB at 2.45 GHz.

Keywords: WBAN, on-body antenna, diversity, flexibility, ZOR

Classification: Microwave and millimeter wave devices, circuits, and systems

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1 Introduction

The applications of a Wireless Body Area Network (WBAN) have been expanding in medical services, police and military agencies, sports training, entertainment, wearable computing, and so on. In WBAN applications, antennas are required to have a compact size, flexibility, low human body effect and a low specific absorption ratio (SAR) [1]. The human body has a high dielectric constant with a high loss tangent and low conductivity at the microwave frequency band. Therefore, the gain and radiation efficiency of an antenna can be deteriorated when an antenna is operated on or in the human body.

Much research for a body channel at the ISM bands has been investigated [2, 3, 4]. In the WBAN system, multipath fading can occur due to the large relative movement of body parts, shadowing, polarization mismatch, and scattering by the body and the surrounding environment [3]. To improve the performance and overcome multipath fading, the antenna diversity technique can be adopted. The main idea of the diversity principle is that more than one independent, and hence uncorrelated received signals, can be utilized due to their independent fading characteristics. Antenna diversity involves the use of multiple antennas, different radiation patterns, and/or polarizations [5]. When two antennas are placed close to each other, isolation performance between the antennas must be low enough to prevent one antenna from affecting. The diversity technique can improve the signal strength, signal to noise ratio (SNR), or bit error rate (BER) over a single antenna with no diversity, at a certain level of outage probability [6, 7]. Another main issue in designing antennas for WBAN is flexibility because an

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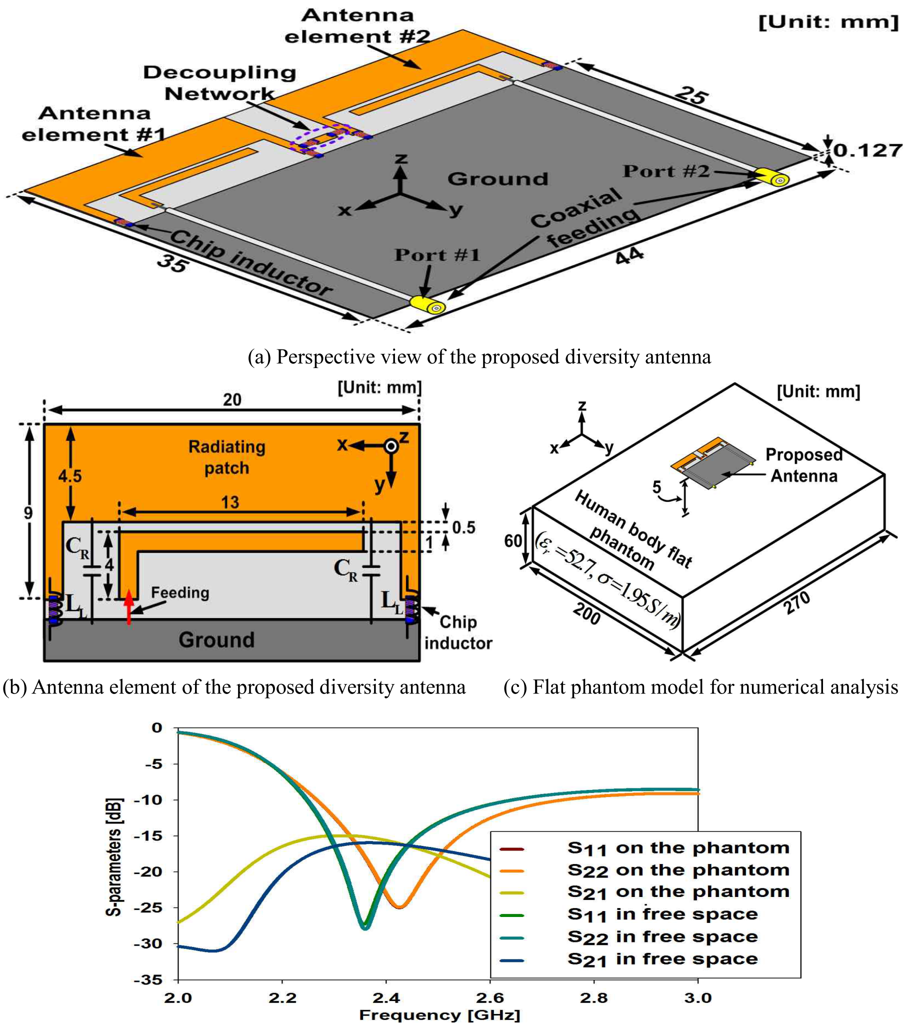
antenna might be placed on the human body with different surface shapes.

In this paper, a flexible diversity zeroth-order resonance (ZOR) antenna for WBAN applications at the ISM band (2.4 GHz ∼ 2.485 GHz) is proposed. To achieve flexibility and a compact size of an antenna for on-body communications, a flexible substrate with a thickness of 0.127 mm and the ZOR technique are used. Also, two antenna elements are placed on one substrate with a small ground to improve the performance and overcome multipath fading. The performance of the antenna on the human body tissue, including S-parameter characteristics, radiation patterns of each antenna element, envelope correlation coefficient (ECC), mean effective gain (MEG), MEG ratio, and specific absorption ratio (SAR), is analyzed through simulation and measurements utilizing a semi-solid flat phantom with equivalent electrical properties of a whole human body at the ISM band.

2 Antenna design

Fig. 1 (a) and (b) show the configuration of the proposed diversity antenna



(a) Perspective view of the proposed diversity antenna

(b) Antenna element of the proposed diversity antenna

(c) Flat phantom model for numerical analysis

(d) Simulated S-parameter characteristics of the proposed diversity antenna

Fig. 1. Configuration and simulated S-parameter characteristics of the proposed diversity antenna

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for on-body WBAN applications. The elements of the proposed diversity antenna are designed by utilizing ZOR characteristics to achieve a compact size.

The antenna is composed of two antenna elements fed by a coaxial connector and a decoupling network to improve the isolation between the two ports. In Fig. 1 (a) and (b), the antenna element which has a size of 20 mm × 9 mm is located on the top side of a flexible substrate with $\varepsilon_r = 2.2$ and a thickness of 0.127 mm. To attain epsilon negative ZOR, shunt inductance (L_L) was realized by using two Murata's LQW18A_00 series chip inductors with a value of 6.8 nH, which are mounted between the patch and the ground plane. The parasitic components can be modeled as shunt capacitance (C_R), as shown in Fig. 1 (b). From the above circuit description, the ZOR frequency can be found as Eq. (1)

$$\omega_0 = \frac{1}{2\pi\sqrt{2C_R \times L_L/2}} = \frac{1}{2\pi\sqrt{C_R \times L_L}} \tag{1}$$

where ω_0 is the ZOR frequency [8]. Owing to the inductance of the chip component, the proposed diversity antenna can be realized in a compact size. To improve the isolation between the two ports, a decoupling network composed of two Murata's LQW18A_00 series chip inductors with a value of 33 nH and a strip line between the two chips is used. The overall dimension of the proposed diversity antenna, including the system ground, is 44 mm × 35 mm × 0.127 mm.

In order to analyze the antenna performance on a human body, simulations were carried out after placing the proposed diversity antenna on a human body model which has equivalent electrical properties ($\varepsilon_r = 52.7$, $\sigma = 1.95$ S/m) of a whole human body and the dimension of 200 mm × 270 mm × 60 mm, as shown in Fig. 1 (c) [9]. Fig. 1 (d) shows the S-parameter performance of the proposed diversity antenna in free space and on the human body model. Even though the resonant frequencies of the proposed antenna in free space and on the human body model are different by about 65 MHz, the −10 dB impedance bandwidth at the ISM band is satisfied due to the wide band characteristics of the proposed antenna.

3 Experimental results

The fabricated antenna and a semi-solid flat phantom are shown in Fig. 2 (a) and (b), respectively. Also, the measured relative dielectric constant and conductivity of the phantom using an Agilent 85070E dielectric probe kit and an 8719ES network analyzer are shown in Fig. 2 (c). The semi-solid flat phantom with the dimension of 200 mm × 270 mm × 60 mm is used to measure the S-parameter characteristics and 3D radiation patterns, as shown in Fig. 2 (d), (e), and (f). Fig. 2 (d) shows the measured S-parameter characteristics of the proposed diversity antenna. When the antenna is located 5 mm above the semi-solid phantom surface, the S_{11} and S_{22} values of the proposed antenna are −22.8 dB and −25.4 dB at 2.45 GHz, respectively. The −10 dB impedance bandwidth of the antenna elements #1 and #2 are over 68 MHz

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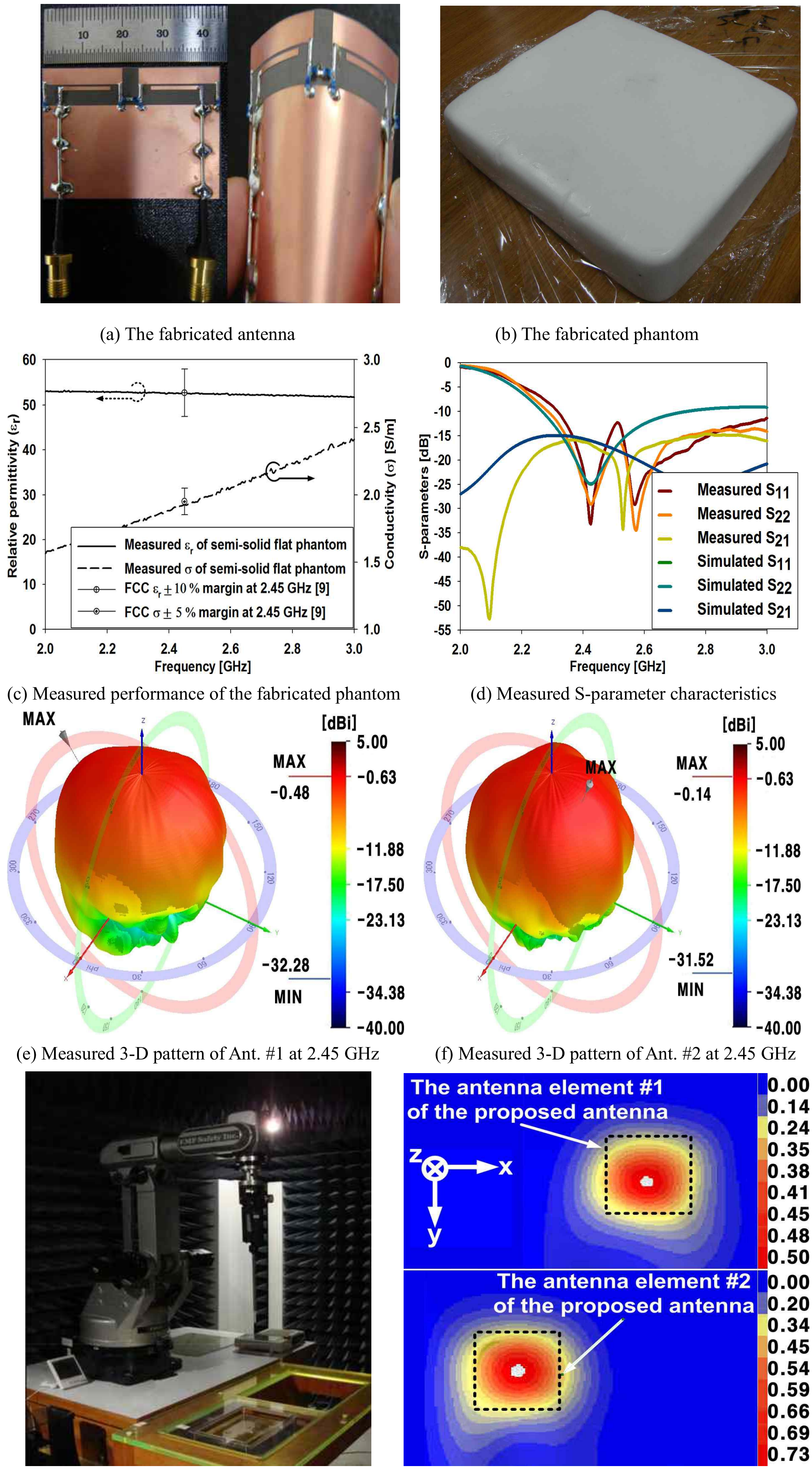

(a) The fabricated antenna (b) The fabricated phantom

(c) Measured performance of the fabricated phantom (d) Measured S-parameter characteristics

(e) Measured 3-D pattern of Ant. #1 at 2.45 GHz (f) Measured 3-D pattern of Ant. #2 at 2.45 GHz

(g) The SAR Measurement by ESSAY system [11] (h) Measured SAR distributions by element #1 and #2

Fig. 2. The fabricated antenna and measured performance

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(from 2.32 GHz) and over 700 MHz (from 2.3 GHz), respectively. Also, the −15 dB isolation bandwidth is 440 MHz (from 2.3 GHz to 2.74 GHz). The simulated and measured resonant frequencies show very good agreement in Fig. 2 (d). However, the measured S-parameters (S_{11} and S_{22}) have two resonances unlike the simulation. We believe that this discrepancy is due to the fixed impedance value of the chip inductors used in the simulation.

Fig. 2 (e) and (f) show the measured 3D radiation patterns of the proposed antenna elements #1 and #2 located on the semi-solid flat phantom. The antenna elements #1 and #2 on the phantom have a peak gain of −0.48 dBi and −0.14 dBi at 2.45 GHz, respectively.

Table I. ECC, MEG, and MEG ratio of the proposed diversity antenna

Freq. [GHz]	ECC	Ant. #1 MEG [dBi]	Ant. #2 MEG [dBi]	MEG ratio [dB]
2.45	0.021	-10.645	-10.313	0.33

The performance of the proposed diversity antenna including ECC, MEG, and MEG ratio are summarized in Table I. From Table I, it was determined that the proposed diversity antenna satisfies the criteria given in [10] such that:

$$ECC < 0.5 \text{ and } 10\log|MEG_1/MEG_2| < 3\,dB \tag{2}$$

When a uniform propagation environment is assumed, the MEG ratio approaches unity. Therefore, the proposed diversity antenna indicates that the mean powers delivered from the two antenna ports are almost identical.

The SAR is an essential factor to consider when the antenna is operated on or inside the human body. The SAR was measured at the Radio Research Agency of Korea using the ESSAY system [11]. The proposed antenna is excited by a signal generator. Fig. 2 (h) shows the measured SAR distributions of the proposed diversity antenna located 5 mm away from outside of the bottom of the liquid flat phantom, which has a dimension of 300 mm × 200 mm × 200 mm. It is filled with a liquid electrically equivalent to body tissue ($\varepsilon_r = 52.7$, $\sigma = 1.95$ S/m) at 2.45 GHz. The input power of 250 mW which is usually used for SAR measurements of mobile application devices is used to measure SAR at 2.45 GHz. The FCC of the United States requires that the SAR value should be below 1.6 watts per kilogram (W/kg) over a volume of 1 gram of tissue to evaluate SAR [9]. When the proposed diversity antenna is placed on outside of the liquid flat phantom, the SAR value of the antenna elements #1 and #2 are 0.54 W/kg and 0.75 W/kg (1 g tissue), respectively.

4 Conclusion

In this paper, a flexible diversity antenna using zeroth-order resonance (ZOR) for WBAN applications is proposed to improve performance and overcome

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multipath fading caused by large relative movements of body parts. The whole dimension of the proposed diversity antenna including the system ground is 44 mm × 35 mm × 0.127 mm. The antenna performance including bandwidth, MEG ratio, ECC, etc. is good enough to be used for WBAN applications. Also, the antenna is well suited for on-body applications due to its compact size and flexibility.

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