Multi-Functional Small Antennas for Health Monitoring Systems

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***Abstract*-Body-centric wireless communications (BCWCs) have become an active area of research due to their wide range of applications. Therefore, as an interface between the transceiver and the propagation environment, antennas in these systems need to be carefully designed. Moreover, in this paper, we proposed two multi-functional antennas for on-body (10 MHz) and off-body (2.45 GHz ISM band) communications in health monitoring system. In on-body communications, the received voltage and electric-field distribution are analyzed. In addition, in off-body communications, the reflection coefficients and radiation patterns are discussed.**

I. Introduction

Recently, body-centric wireless communications (BCWCs) have become a very active area of research because of numerous applications, such as personal healthcare, smart home, personal entertainment, and identification systems [1]. Especially, many researchers considered health monitoring systems as the biggest potential application with all kinds of wearable wireless devices.

In health monitoring systems, at least two important scenarios are required: on-body communications (collecting body signal data) and off-body communications (exchanging data with external equipment). For on-body communications, relatively low frequency bands (tens of MHz) are more suitable [2-3], while for the off-body communications, 2.45 GHz ISM band (2.40-2.48 GHz) is a good candidate [4]. Fig. 1 shows the proposed health monitoring system. The transmitters (sensors) and data collector (dual-mode antenna or switchable antenna) are mounted on the human body. The body signal information is transmitted to the data controller by the sensors at low frequency (10 MHz). The data controller also sends the information to an external device by ISM band at 2.45 GHz. In this way, the health monitoring system for home care or telemedicine system can be achieved. Thus, a multi-functional small antenna is the key component for health monitoring systems. In this paper, we propose two antennas named dual-mode antenna [5] and switchable antenna with on-body and off-body functions for different needs in medical applications. In dual-mode antenna, both on-body and off-body modes are operated simultaneously. In switchable antenna, a simple switching circuit is integrated in the antenna for on-body and off-body communications. Therefore, both on-body and off-body modes can be switched, it is suitable to be used in home care system.

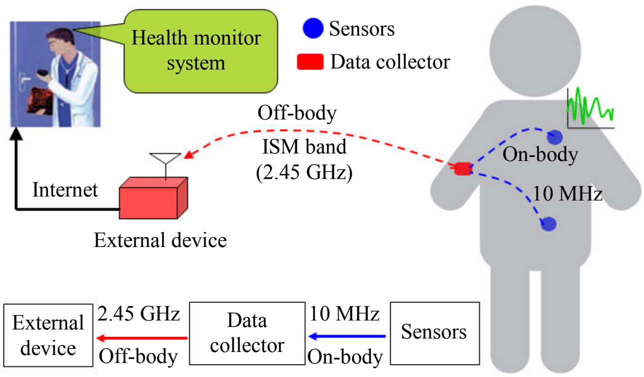


Figure 1. Proposed medical application.

II. Antenna Design and Phantoms

A. Dual-Mode Antenna Design

Fig. 2 presents the dual-mode antenna [5]. It consists of a feeding pin, a signal electrode and an L-shaped slit embedded in the ground plane. Therefore, the proposed antenna is similar to a pair of metallic electrodes. The area of the ground plane and the electrode are 30 × 36.5 and 30 × 10 mm^2, respectively. The height of the signal electrode is 4 mm and the feeding pin is located in the center of the signal electrode. An L-shaped slit with 2 mm in width is embedded in the ground plane for 2.45 GHz ISM band.

B. Switchable Antenna Design

Fig. 3 (a) presents the structure of the proposed switchable planar inverted-F antenna. This antenna includes a ground plane, a radiator, a feeding pin and a switching circuit board, which mainly includes a pin diode and replaces the conventional shorting plate. The radiator and ground plane have the same dimension of 30 × 12 mm^2. The height of the antenna is 8 mm. In the lower frequency band, the characteristic of the proposed antenna is equivalent to an electrode operating at 10 MHz while the pin diode located on the circuit board is in the off state. In the higher frequency band (2.45 GHz ISM band), the antenna operates as a planar inverted-F antenna, while the pin diode is in the on state. As shown in Fig. 3 (b), the area of the switching circuit board is 10 mm × 8 mm. In our design, the pin diode HVU131 from Renesas Tech. [6] was selected; thus, a resistor of 200 Ω is used to provide the bias for the diode. In addition, an inductor of 33 nH plays the RF choke and a capacitor of 100 pF is used to block the DC voltage.

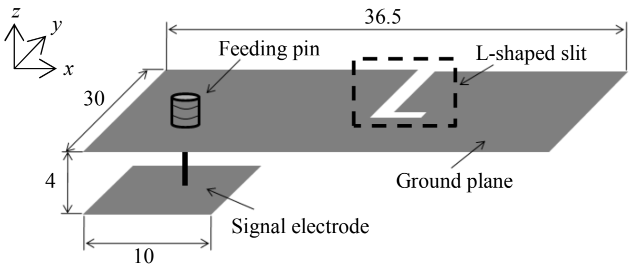
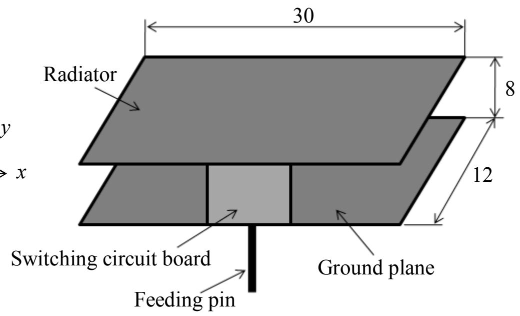


Figure 2. Structure of dual-mode antenna [5] (unit: mm).



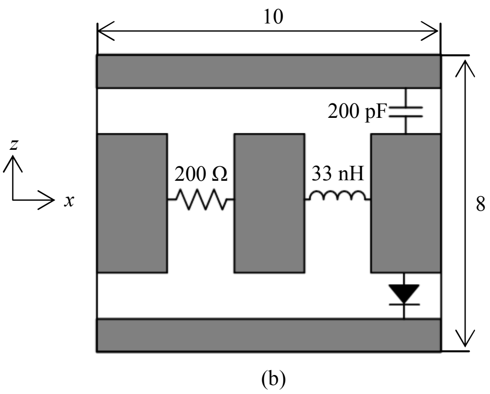


Figure 3. Structure of switchable planar inverted-F antenna: (a) 3D view and (b) switching circuit board (unit: mm).

C. *Phantoms*

Since the proposed antennas are applied in BCWCs, we discuss the results when the antenna is placed close to two kinds of two-thirds muscle equivalent arm phantoms: 10 MHz (ε_r = 106.73, σ = 0.42 S/m) and 2.45 GHz (ε_r = 35.2, σ = 1.16 S/m) for on-body and off-body communications. The ingredients of the two phantoms are shown in Table I.

TABLE I
COMPOSITION OF THE TWO PHANTOMS

	10 MHz	2.45 GHz
Material	Amount [g]	Amount [g]
Water	1291.2	3375
Agar	54	104.6
Sodium chloride	5.52	7
Polyethylene powder	0	1012.6
TX-151	0	30.1
Sodium salt	1.32	2

III. RESULTS

A. *Dual-Mode Antenna*

Fig. 4 presents the simulated and measured reflection coefficients in 2.45 GHz ISM band when the proposed dual-mode antenna is on the arm phantom (50 mm×50 mm ×500 mm). The measured bandwidth is 300 MHz (2.25-2.55 GHz) and the measured result is close to the simulated one. The simulated and measured radiation patterns at 2.45 GHz in *xz* and *yz* planes are shown in Fig. 5. From the results, the radiation patterns are relatively omni-directional and are of no deep nulls in the half-sphere above the arm phantom. Therefore, the proposed antenna is a good candidate for off-body communications.

As follow, we used the whole human models to discuss the received voltage at 10 MHz for on-body mode. As shown in Fig. 6, the calculation includes simple and high-resolution human models. We fixed the transmitter on the waist and located the two receivers on the right and left chest and two receivers on the right and left wrists. The height of the two human body models are 1750 mm and there is a 30 mm gap between the two feet and the earth ground. From the simulated results in Fig. 7, due to the shorter distance between the transmitter and the receiver, RX 3 obtained higher received voltage than the other receivers. In addition, the received voltage with the simple human phantom is higher than that with high-resolution human model. It is because the surface of the simple human phantom is flat and the signal electrode can attach to the surface of human model very well.

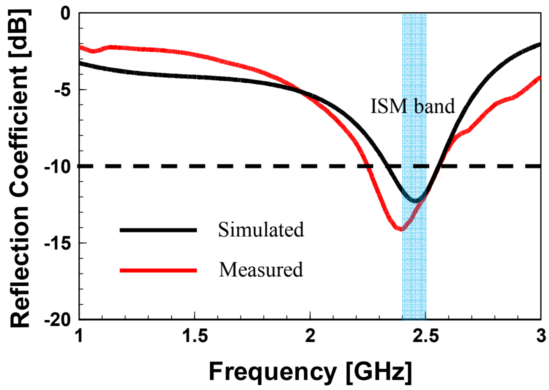


Figure 4. Simulated and measured reflection coefficients for dual-node antenna [5].

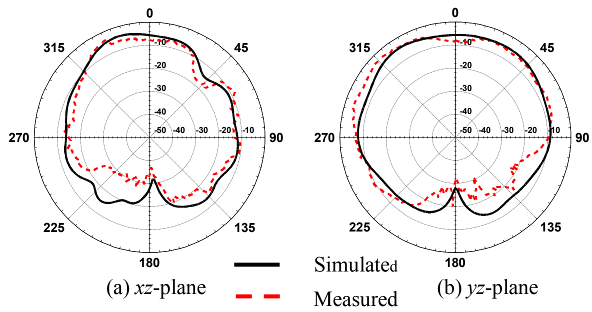


Figure 5. Simulated and measured radiation patterns for dual-mode antenna at 2.45 GHz [5] (unit: dBi).

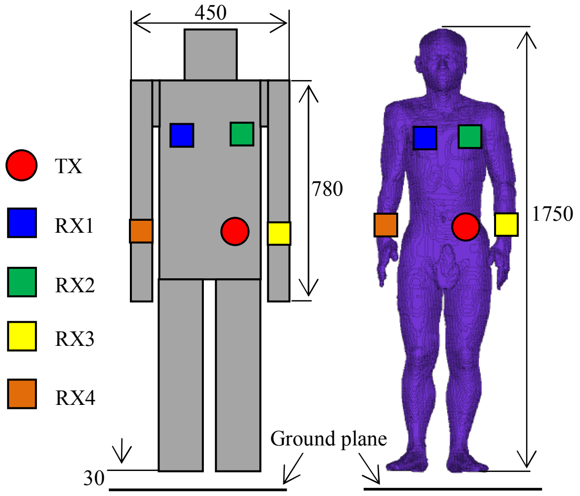


Figure 6. Simple and the high-resolution human models (unit: mm).

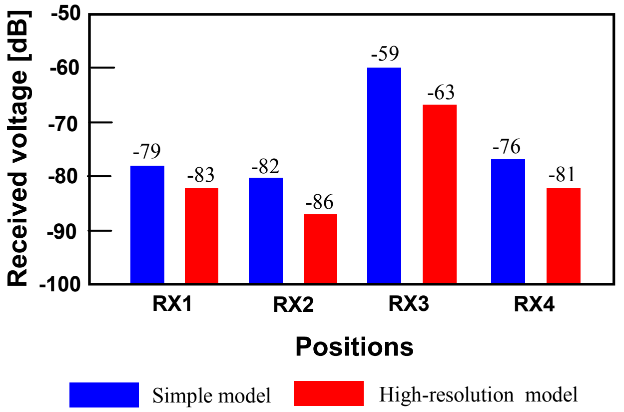


Figure 7. Received voltage for dual-mode antenna at 10 MHz on the human models. The received voltage is normalized by the input voltage of the transmitter.

B. *Switchable Antenna*

Fig. 8 presents the simulated and measured reflection coefficients of the switchable antenna at 2.45 GHz with the same arm phantom while the diode was in the on state (3V is supplied by a battery box). The measured bandwidth was 350 MHz (2.30-2.65 GHz) and the measured result was close to the simulated one. Fig. 9 shows the simulated and measured radiation patterns at ISM band 2.45 GHz in the *xz* and *yz* planes. The results suggest that the radiation patterns for the ISM band are relatively omni-directional without deep nulls in the half-sphere above the arm phantom; the weaker radiation toward the phantom is due to absorption by the phantom. Therefore, the proposed antenna is shown to be a good candidate for off-body communications.

In this section, we will evaluate the performance of the proposed switchable antenna for on-body communications while the diode was in the off state at 10 MHz. Fig. 10 presents the simulation setup and received voltage results, the proposed antenna is installed at all the transmitter and receivers; all are attached to the chest phantom (525 mm × 370 mm × 70 mm). From the result, the received voltage between the transmitter and the receiver decreases with the increasing distance. It is because the mutual coupling decreased as the increase of the distance between the transmitter and the receiver. Fig. 11 illustrates the electric-field distribution at 10 MHz on the surface of the chest phantom. From the result, the intensity of the electric-field distribution decayed with the increasing distance between the transmitter and the receiver.

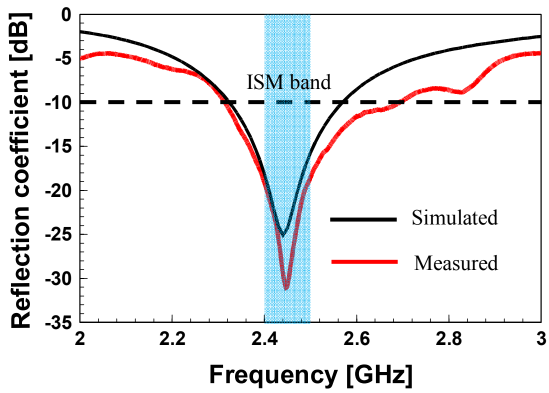


Figure 8. Simulated and measured reflection coefficients for switchable antenna.

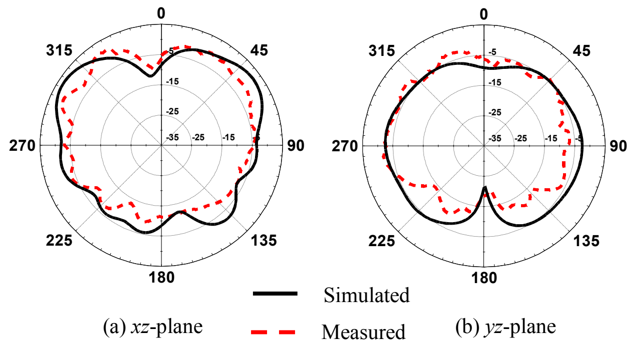


Figure 9. Simulated and measured radiation patterns for switchable antenna at 2.45 GHz (unit: dBi).

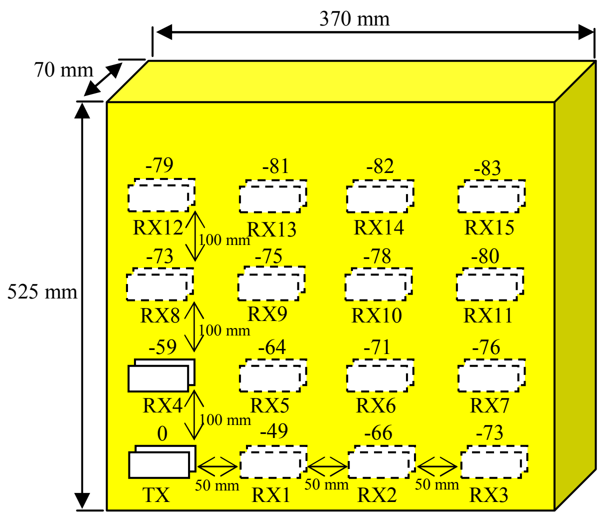


Figure 10. Normalized received voltage for switchable antenna at 10 MHz on the chest phantom (unit: dB).

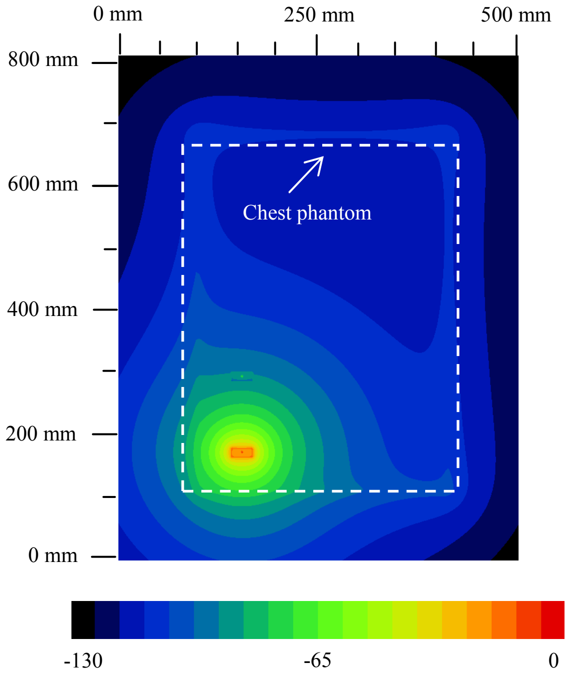


Figure 11. Electric-field distribution at 10 MHz (unit: dB).

IV. Conclusion

In this paper, we discussed a dual-mode antenna and proposed a switchable antenna for health monitoring systems in medical applications. The dual-mode antenna can operate on-body mode (10 MHz) and off-body mode (2.45 GHz) simultaneously. Therefore, it is suitable to be used in some emergencies. However, in order to save the power of the wearable device and prevent the interference between the on-body mode and off-body mode, for example, when the two modes work at the same time, the interference may be caused by the leakage from the off-body mode. Besides, the antenna gain in dual-mode antenna is lower since the radiation is due to the slit structure in the ground plane. In order to improve the above issues, we proposed a planar inverted-F antenna with switching function. Therefore, both the on-body mode and the off-body mode can be switched and the gain is higher since it is equivalent to a PIFA antenna at 2.45 GHz compared with the L-shaped slit structure in dual-mode antenna. Since the on body mode and the off-body mode can be switched, the switchable antenna is suitable to be used in home care system. For example, the body signals can be detected and recorded in on-body mode for one or two hours and transmitted to external equipment in off-body mode.

The comparison between dual-mode antenna and switchable antenna is presented in Table II. From this table, (a) both the two antennas can work for the on-body mode and the off-body mode, (b) the performance such as the bandwidth and the gain of the switchable antenna is better than the dual-mode antenna. It is because the switchable antenna is designed by the PIFA structure.

In this study, all the characteristics of the two antennas are discussed by the human phantoms. In the future, the characteristics of the switchable antenna on the whole human body model and more practical antennas in medical applications will be discussed and proposed.

TABLE II
COMPARISON BETWEEN DUAL-MODE ANTENNA [5] AND SWITCHABLE ANTENNA

Parameter	Dual-mode [5]	Switchable
Frequency	10 MHz / 2.45 GHz	10 MHz / 2.45 GHz
Bandwidth [MHz]	320	400
Average gain [dBi]	-8	-5
Size [mm^3]	30×36.5×4	30×12×8
Feature	On and off-body mode operate at the same time	On and off-body mode can be switched

Acknowledgment

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