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A Low-Profile Dipole Array Antenna with Monopole-Like Radiation for On-Body Communications

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Abstract

In this paper, a low-profile dipole array antenna with monopole-like radiation for on-body communications is proposed. The proposed antenna, operating in the industrial, scientific, and medical (ISM) band, is designed with consideration of the human body effect. By placing eight planar dipole antenna elements symmetrically around the z-axis, the proposed antenna achieves monopole-like radiation characteristics with a low profile. The antenna has overall dimensions of $0.44\ \lambda_0 \times 0.44\ \lambda_0 \times 0.013\ \lambda_0$ at 2.45 GHz in the ISM 2.45 GHz band (2.4–2.485 GHz) and a 10-dB return loss bandwidth of 4.9% ranging from 2.4 to 2.52 GHz.

Key Words: Low Profile, On-Body Antenna, Monopole-Like Radiation, Wireless Body Area Network (WBAN).

I. INTRODUCTION

Wireless body area network (WBAN) has recently received great attention due to its applicability in various services. Depending on the location of the transceiver on the human body, a WBAN system can be categorized as off-body, on-body, or in-body [1]. The radiation characteristics of an antenna for a WBAN system are particularly important in establishing a successful communications link between the transceivers. In order to establish a good on-body communication channel between two on-body devices, an antenna is required to have radiation characteristics similar to those of a vertical monopole antenna. However, a monopole antenna is not suitable for on-body communications, due to its large vertical size. Therefore, a low-profile antenna with monopole-like radiation characteristics is necessary for on-body communication. In order to obtain a low-profile antenna with a monopole-like radiation pattern, various types of antennas have been proposed [2−10]. Dielectric resonator antenna types for monopole-like radiation characteristics were published in [2, 3]; however, the vertical size of those antennas is too large for use in on-body devices. In [4], an Alford loop antenna for surface-wave generation was proposed, but the Alford loop antenna is not suitable for on-body communications because its performance is substantially affected by the human body environment.

In order to realize a low-profile antenna with a monopole-like radiation pattern, several types of patch antennas using various resonance modes have been proposed [5−10]. In [5], a microstrip monopolar patch antenna using TM_{01} and TM_{02} resonance modes for monopole-like radiation characteristics was suggested. A circular patch-ring antenna with TM_{02} mode was proposed in [6]. TM_{01} and TM_{02} mode antennas have greater gain than higher-order mode (TM_{21}, TM_{41}) antennas. However, the antennas should be large for on-body devices. Rectangular patch antennas using the TM_{21} mode were introduced in [7, 8]. Generally, the TM_{21} mode antenna is smaller than $TM_{01,\ 02,\ 41}$ antennas. However, $TM_{01,\ 02,\ 41}$ mode antennas generate a radiation pattern that is closer to omnidirectional compared to

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that of a TM_{21} mode antenna. TM_{41} mode antennas have a higher maximum radiation angle from the zenith than TM_{21} mode antennas [9, 10].

In this paper, a low-profile dipole array antenna with a monopole-like radiation pattern for on-body communications is proposed. The antenna operates in the 2.45 GHz industrial, scientific, and medical (ISM) band with omnidirectional radiation characteristics. The performance of the proposed antenna is verified both numerically and experimentally when it is attached to a two-thirds muscle-equivalent semi-solid phantom.

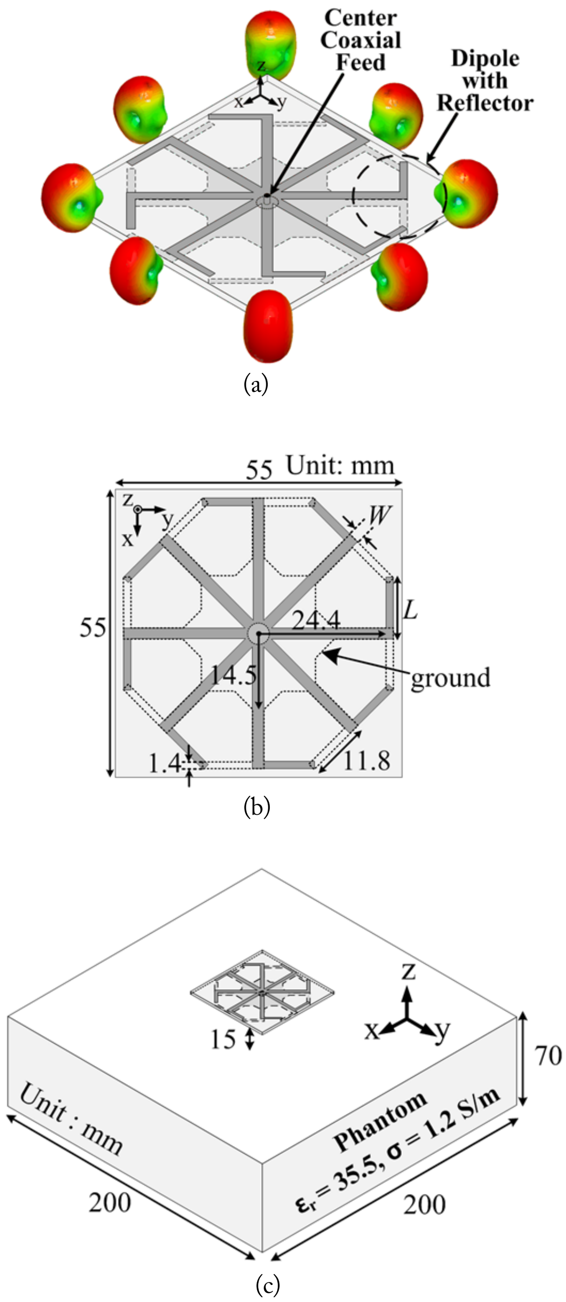


Fig. 1. Geometry of the proposed antenna. (a) Concept of the antenna. (b) Top view of the antenna. (c) Simulation setup for the antenna on the phantom.

II. ANTENNA DESIGN

Fig. 1(a) and (b) show the structure of the dipole array antenna. The proposed antenna, with dimensions of 55 mm × 55 mm × 1.6 mm (0.44 λ_0 × 0.44 λ_0 × 0.013 λ_0 at 2.45 GHz), is designed on a FR-4 ($\varepsilon_r = 4.4$, $\tan\delta = 0.0245$) substrate. Each dipole element with a ground, shown in Fig. 1(a), has a directional radiation pattern toward the horizontal direction, since the ground acts as a reflector. The proposed antenna consists of eight directional dipoles with a ground. As eight dipole elements are placed symmetrically around the *z*-axis, the proposed antenna generates a monopole-like radiation pattern with a low profile. The antenna is excited by a center coaxial feed. The width of the dipole element is 1.4 mm and the length of the dipole element is 11.8 mm. To reduce the human body effect, the ground is installed on the bottom plane. To analyze the performance of the antenna numerically, a two-thirds muscle-equivalent phantom ($\varepsilon_r = 35.5$, $\sigma = 1.2$ S/m) with dimensions of 200 mm × 200 mm × 70 mm was designed as depicted in Fig. 1(c) [11]. The proposed antenna was located 15 mm from the phantom surface, considering the height of a wearable device.

III. PARAMETRIC STUDY

Fig. 2 shows the comparison between the simulated return loss characteristics of the proposed antenna in free space and on the phantom. Due to the human body effect, the resonance frequency shifts slightly to the higher frequency side, and the bandwidth is decreased. The 10-dB return loss bandwidth was 4.1% (2.39–2.49 GHz) in the 2.45 GHz ISM band (2.4–2.485 GHz).

Fig. 3(a) and (b) show the simulated return loss characteristics for various design parameters. As the dipole length *L* or the feed line width *W* decreases, the resonant frequency shifts slightly to the high-frequency side and the impedance matching is improved, as shown in Fig. 3(a) and (b).

Fig. 4 shows the simulated electric field magnitude distribution of the antenna on the phantom in the xz-plane at 2.45

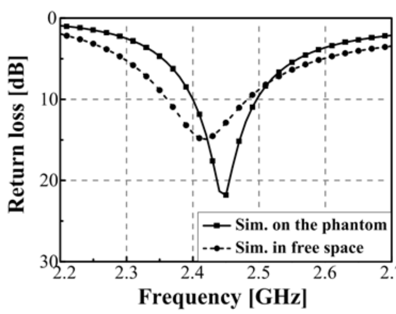
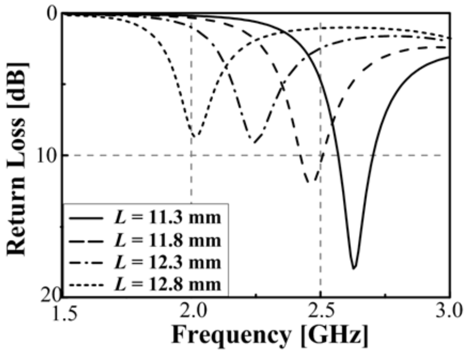
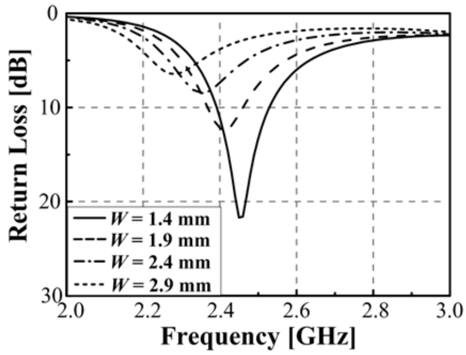


Fig. 2. Comparison between the simulated return loss characteristics of the proposed antenna in free space and on the phantom.



(a)



(b)

Fig. 3. Comparison between the simulated return loss characteristics for various design parameters. (a) Variations in length *L*. (b) Variations in width *W*.

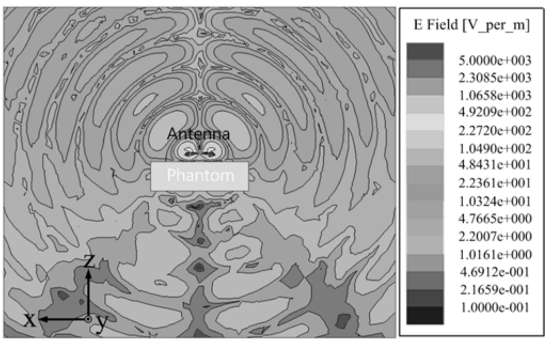
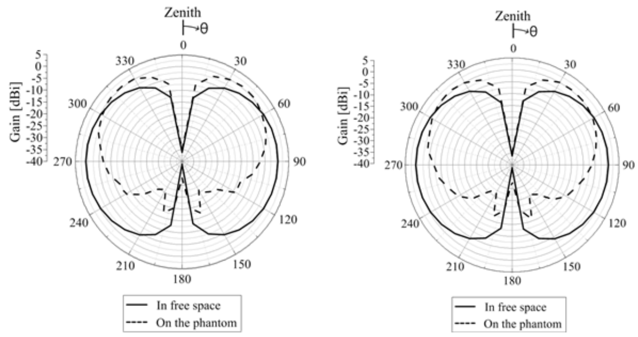


Fig. 4. Simulated electric field magnitude distribution at 2.45 GHz.

GHz. The proposed antenna is suitable for on-body communications due to the similarity of its radiation pattern to that of a vertical monopole antenna.

Fig. 5(a) and (b) show the simulated far-field radiation patterns of the proposed antenna in free space and those of the phantom at 2.45 GHz in the xz-plane and in the yz-plane, respectively. The minimum radiation of the proposed antenna is at θ = 0° and the maximum radiation is at θ = 50°. The simulated realized peak gains of the proposed antenna in free space and on the phantom are 0.5 dBi and 0.8 dBi, respectively. Due to the reflection from the phantom, the peak gain of the proposed antenna on the phantom is higher than the peak gain



(a) (b)

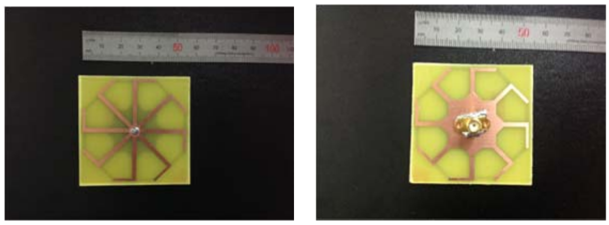
Fig. 5. Comparison between the simulated far-field radiation patterns of the proposed antenna in free space and on the phantom at 2.45 GHz. (a) xz-plane. (b) yz-plane.

in free space. The total radiation efficiencies of the proposed antenna without and with the phantom are 84.3% and 34.06%, respectively. The simulation results of this work were obtained by High Frequency Structure Simulator (HFSS) v.14.0.0 (ANSYS Inc., Canonsburg, PA, USA).

Ⅳ. MEASURED RESULTS

Fig. 6 shows the top and bottom view of the manufactured antenna. The antenna was fabricated on a FR-4 (ε_r = 4.4, tanδ = 0.0245) substrate 1.6 mm in thickness.

Fig. 7 shows the simulated and measured return loss cha-



(a) (b)

Fig. 6. Photographs of the manufactured antenna. (a) Top view. (b) Bottom view.

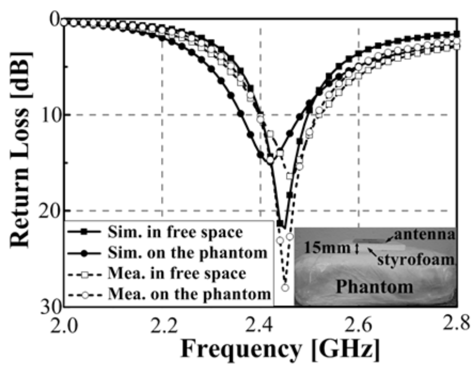


Fig. 7. Simulated and measured return loss characteristics of the proposed antenna.

racteristics of the proposed antenna. To analyze the antenna performance experimentally, a two-thirds muscle-equivalent semi-solid phantom ($\varepsilon_r = 35.5$, $\sigma = 1.2$ S/m) with dimensions of 200 mm × 200 mm × 70 mm was used. The measured result agrees well with the simulation. From the measurement, the 10-dB return loss bandwidth is 120 MHz (4.9%), ranging from 2.4 to 2.52 GHz, which is wide enough to cover the entire 2.45 GHz ISM band (2.4–2.485 GHz).

Fig. 8 shows the simulated and measured far-field radiation patterns of the proposed antenna on the phantom at 2.45 GHz in the E-plane and the H-plane. The measurement results agree reasonably well with the simulation. The minimum radiation of the fabricated antenna is in the direction normal to the phantom surface (zenith direction), and the maximum radiation is at $\theta = 50°$. The measured peak gain of the proposed antenna on the phantom in the E- and H-planes is 0.4 dBi.

Table 1 shows the comparison of the size of the proposed antenna and those of the reference antennas with monopole-like radiation. It is observed that the proposed antenna is well designed for its compact size.

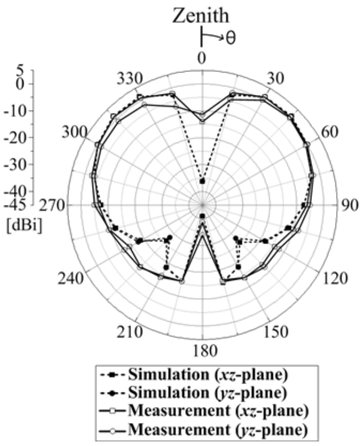


Fig. 8. Simulated and measured far-field radiation patterns of the proposed antenna on the phantom at 2.45 GHz.

Table 1. Comparison between the size of the proposed antenna and those of the reference antennas with monopole-like radiation

Ref.	Size
Proposed	$0.44\ \lambda_0 \times 0.44\ \lambda_0 \times 0.013\ \lambda_0$
[2]	Thickness: $0.23\ \lambda_0$
[3]	Thickness: $0.23\ \lambda_0$
[5]	Diameter: $1.356\ \lambda_0$; Thickness: $0.024\ \lambda_0$
[6]	Diameter: $2.9\ \lambda_0$; Thickness: $0.03\ \lambda_0$
[7]	Thickness: $0.059\ \lambda_0$
[8]	$0.3\ \lambda_0 \times 0.24\ \lambda_0 \times 0.05\ \lambda_0$
[9]	$0.49\ \lambda_0 \times 0.49\ \lambda_0 \times 0.026\ \lambda_0$

V. CONCLUSION

In this paper, a low-profile dipole array antenna with a monopole-like radiation pattern for WBAN on-body communications applications is proposed. The bandwidth of the proposed antenna can cover the 2.45 GHz ISM band (2.4–2.485 GHz) fully while maintaining a low-profile configuration with a height of only 0.013 λ_0 at 2.45 GHz. To obtain a monopole-like radiation pattern with a low profile, eight dipole elements were placed symmetrically around the z-axis. Moreover, the measured results show that the proposed antenna generates monopole-like radiation characteristics with a compact size. The proposed antenna has a maximum radiation angle (measured from the zenith) greater than those reported in [6, 7]. Therefore, the proposed antenna is a promising candidate for on-body communications devices.

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