A wideband ZOR on-body antenna for WBAN applications

Jisoo Baek, Youngki Lee, and #Jaehoon Choi
Department of Electronics and Computer Engineering, Hanyang University
17 Haengdang-dong, Seongdong-gu, Seoul, 133-791, Korea
E-mail : hoijisoo@hanyang.ac.kr
#choijh@hanyang.ac.kr (corresponding author)

1. Introduction

Recently, there has been an increasing interest in WBAN systems for various applications such as biomedical, military and commercial services [1, 2, 3]. The WBAN systems should satisfy rigorous requirements for antennas such as small size, large bandwidth, low specific absorption rate (SAR), and stable performance when the antenna is applied to the various parts of human body [1]. To monitor a patient’s health status, the communication between biomedical device and human body needs to be done in real time. However, antenna performance is greatly affected by body tissues due to the electrical properties of human body. In order to overcome body effects and achieve small antenna size, the zeroth-order resonance (ZOR) antennas was proposed in [3].

In this paper, a wideband ZOR on-body antenna for Industrial, Scientific and Medical (ISM) band (2.4 GHz~2.4835GHz) is proposed. The wideband performance is achieved by utilizing the two slightly different ZOR frequencies. Moreover, the antenna performance is insensitivity to human body effect and the separation distance between the phantom and antenna.

2. Antenna Design

The configuration of proposed antenna is shown in Fig. 1. Taconic TLY(tm) with relative permittivity \(\varepsilon_r = 2.2\) and thickness of 3mm is used as a substrate. The proposed antenna is composed of two radiating elements divided by center-fed structure. Each element has two unit cells and the size of unit cell is \(9 \times 11\text{mm}\) (0.072 \(\times\) 0.088\(\lambda_0\)). To attain ZOR characteristics, shunt inductance (\(L_1\)) is materialized using a via-hole with spiral structure as shown in Fig. 1(b). The capacitance between top patch and bottom ground acts as shunt capacitance (\(C_R\)). From the above circuit description, the ZOR frequency can be found as

\[
\omega_0 = \frac{1}{\sqrt{C_R L_2}}
\]  

where \(\omega_0\) is the ZOR frequency [4].

The proposed antenna has two different resonance frequencies which can be controlled by \(C_R\). Because the length of U-slot regulates the coupling between the patch and bottom ground, the value of \(C_R\) changes depending on the slot length. Figure 2 shows the simulated return loss properties of the various U-slot (\(L_1\)) lengths. The smaller \(L_1\) results in a small value of \(C_R\) and a higher resonance frequency at fixed value of \(L_2\). By adjusting the length of \(L_1\), two resonance frequencies of ZOR structure are merged together, so that the proposed antenna can yield wideband characteristic.

For numerical simulation of the antenna, the human equivalent flat phantom that has a dimension of 200 \(\times\) 270 \(\times\) 130mm is modelled as illustrated in Fig. 1(c). In order to analyse the antenna performance on a human body, simulations were conducted using a human model that has equivalent electrical properties (\(\varepsilon_r = 52.7, \sigma = 1.95\text{ S/m}, \tan\delta = 0.27\)) with human body [5]. We assumed that the separation distance between the antenna and phantom is 5mm accounting for the thickness of clothes.
3. Results and Discussion

The simulation of the proposed antenna was carried out using the HFSS Ver.13 of ANSYS Inc. Figure 3 shows the simulated return loss characteristics of the proposed antenna. In free space, as shown in Fig. 3(a), two ZOR frequencies are 2.35 and 2.45GHz. When the proposed antenna is placed on the human equivalent flat phantom, it is observed that the resonant frequencies do not change significantly. When the antenna is placed 5mm away from the human phantom, the 10dB impedance bandwidth is 340MHz (14.3%) ranging from 2.2 to 2.54GHz which is wide enough to cover the ISM band (2.4~2.4835GHz). Figure 3(b) shows the return loss properties for various distances between the antenna and phantom. Even though the value of h changes, each ZOR mode occurs at frequencies very close to each other. Furthermore, wideband 10dB impedance bandwidth property is maintained.

Comparison of performances of the proposed antenna positioned in free space and on the phantom including various distance between the antenna and the phantom, as illustrated in Figure 3,
shows that there is slight change in ZOR frequencies. Because the size of the unit cell is very small (much less than 0.25λ₀), all elements can be considered as lumped components (or quasi-lumped components). Although input impedance seen from feeding structure is changed by the effect of the phantom, the values of C_R and L_L which determine the ZOR frequency have less of an effect on the electrical properties of surrounding structure. This feature is very advantageous to use the proposed antenna for WBAN systems.

Figure 4 shows simulated radiation patterns of the proposed antenna. It has near omni-directional patterns at the two ZOR frequencies (2.35GHz and 2.45GHz), since the E-field of the ZOR resonance generates an in-phase field distribution. However, the proposed antenna positioned on the human equivalent flat phantom has upward directional radiation pattern, as shown in Fig. 4 (c) and (d), because of dielectric loss of the phantom. The simulated peak gain is 1.50dBi at 2.45GHz in free space, and the proposed antenna placed on the human equivalent flat phantom has -0.29dBi peak gain at the same frequency.

![Simulated return loss characteristics of the proposed antenna.](image1)

(a) with or without phantom  (b) return loss for various separation distances (h)

Figure 3: Simulated return loss characteristics of the proposed antenna.

![Simulated radiation patterns of the proposed antenna.](image2)

(a) in free space at 2.35GHz  (b) in free space at 2.45GHz

(c) on phantom at 2.35GHz  (d) on phantom at 2.45GHz

Figure 4: Simulated radiation patterns of the proposed antenna.
4. Conclusion

We proposed a wideband ZOR antenna for WBAN systems. The bandwidth of the proposed antenna is wide enough to cover the ISM band. It can also be applied to Bluetooth services having the same frequency band as on-body area communication [1]. The size of the antenna is very small (0.072\(\lambda_0 \times 0.33\lambda_0\) by virtue of ZOR mode. It is observed that the resonance frequencies are not sensitive to the human body effect and the antenna has wide bandwidth. The wideband characteristic and insensitivity of resonance frequencies are major advantages that make the proposed antenna a good candidate for WBAN systems.

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References