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INTERNAL SHORTED MONOPOLE ANTENNA FOR THE WATCH-TYPE WIRELESS COMMUNICATION DEVICE FOR BLUETOOTH OPERATION

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ABSTRACT: *An internal shorted monopole antenna suitable to be embedded within the watch-type wireless communication device is presented. The antenna generally has a planar configuration and is mounted conformal along the side surfaces of the wireless device to operate as an internal or concealed antenna. The antenna also shows a low profile of 4 mm only, yet providing a wide bandwidth for Bluetooth operation in the 2.4 GHz band (2400–2484 MHz). In addition, the antenna is designed to be short-circuited to an upper ground plane mounted above the main system ground plane of the wireless device. With the proposed arrangement, reduced coupling between the antenna and the nearby lossy medium can be achieved. Hence, when the wireless device with the proposed antenna is worn around the user's wrist or forearm, which functions as a lossy medium, the antenna's radiation efficiency can still reach about 50% over the operating band. Details of the proposed antenna and the promising watch-type wireless communication device are presented.* © 2007 Wiley Periodicals, Inc. Microwave Opt Technol Lett 49: 942–946, 2007; Published online in Wiley InterScience (www.interscience.wiley.com). DOI 10.1002/mop.22322

Key words: *mobile antennas; internal mobile antennas; bluetooth antennas; watch-type wireless communication device; user's effects*

1. INTRODUCTION

Wearable wireless communication devices have increasingly become popular for some emerging applications, such as locating the wireless user or automatically transmitting the user's health information to the medical center for real-time monitoring of the user's health. For this kind of applications, it is usually demanded that the employed small antennas for receiving/transmitting signals be embedded within the wireless communication device to function as an internal or concealed antenna. In this condition, the employed antennas are usually in close proximity to the human body. However, since the human body is a lossy medium, there are usually large effects of the human body on the radiation efficiency of the employed antennas [1, 2]. To achieve acceptable radiation efficiency (usually at least about 50%) over the operating band, the employed small antenna for each specific application should be carefully designed.

In this article, we present an internal shorted monopole antenna suitable for application in the watch-type wireless communication device for Bluetooth operation in the 2.4 GHz band (2400–2484 MHz). The studied watch-type wireless communication device is to be worn around the user's wrist or forearm and can be used to detect the user's health information and transmit the data to the medical center through the user's cellular mobile phone. For the proposed antenna in this specific application, a shorted T-shaped monopole antenna [3–5] with a low-profile of 4 mm only is used. The proposed antenna is easy to fabricate by printing on a dielectric substrate and is to be mounted conformal along the side surfaces of the wireless device to operate as an internal antenna. In this case, the proposed antenna generally does not occupy the valuable board space of the wireless device. In addition, to achieve acceptable radiation efficiency, the proposed antenna is short-circuited to an upper ground plane mounted above the main system ground plane or circuit board of the wireless device. With the proposed antenna geometry, the radiation power absorption by the user's hand [6] can be reduced, and good isolation between the antenna and the possible associated electronic components placed in between the upper ground plane and the main system ground plane of the wireless device can be achieved [7, 8]. Details of the proposed antenna and the watch-type wireless communication device are described in this study. Experimental and simulation results are also presented and discussed.

2. CONFIGURATION OF THE PROPOSED ANTENNA AND THE WATCH-TYPE WIRELESS COMMUNICATION DEVICE

Figure 1(a) shows the configuration and simulation model of the watch-type wireless communication device with the proposed antenna for Bluetooth operation. The wireless device is with a plastic wristband of width 20 mm and is worn around the user's forearm with a distance of d to the user's wrist (also see the experimental photo shown in Fig. 6). The simulation hand model, including the forearm is provided by SPEAG simulation software SEMCAD (Simulation platform for EMC, Antenna design, and Dosimetry) [9]. For the study over the 2.4 GHz band, the user's hand model comprises skin with relative permittivity $\varepsilon_r = 38$, conductivity $\sigma = 1.46$ S/m, muscle with $\varepsilon_r = 52.7$, $\sigma = 1.73$ S/m, and bones with $\varepsilon_r = 18.6$, $\sigma = 0.8$ S/m. The impedance and radiation characteristics of the proposed antenna as a function of the distance d will be analyzed with the aid of Figures 6–8 in Section 3.

The proposed antenna is a shorted T-shaped monopole antenna printed on a 0.4-mm thick FR4 substrate ($\varepsilon_r = 4.4$, $\sigma = 0.01$ S/m), and is bent to be conformal along the side surfaces of the wireless device [see the bending lines shown in Fig. 1(b)]. Note that the proposed antenna can also be printed on a flexible printed circuit board, which will make it more suitable for practical applications in the wireless device with curved corners in its side surfaces. Detailed dimensions of the proposed antenna are also shown in Figure 1(b).

The antenna has a uniform strip width of 1 mm, and is mainly with a T-shaped monopole formed by a horizontal strip of length 37 mm and a vertical or central strip of 3 mm, which is short-circuited to the upper ground plane mounted with a height of 5 mm (H) above the main system ground plane of the wireless device. The upper ground plane has a size of 25×35 mm^2 and is printed on the bottom surface of a 0.4-mm thick FR4 substrate, while the system ground plane has a size of 31×41 mm^2 in this study. The upper ground plane is centered above and also electrically connected to the system ground plane through two 1-mm wide metal strips of height 5 mm and one metal plate of size 5×25 mm^2 at the 2-side surfaces adjacent to the plastic wristband of the wireless device. In this case, the space between the upper ground plane and the system ground plane can be expected to provide a coupling-free region for accommodating the associated electronic components of the wireless device [7, 8]. As for the space on the upper

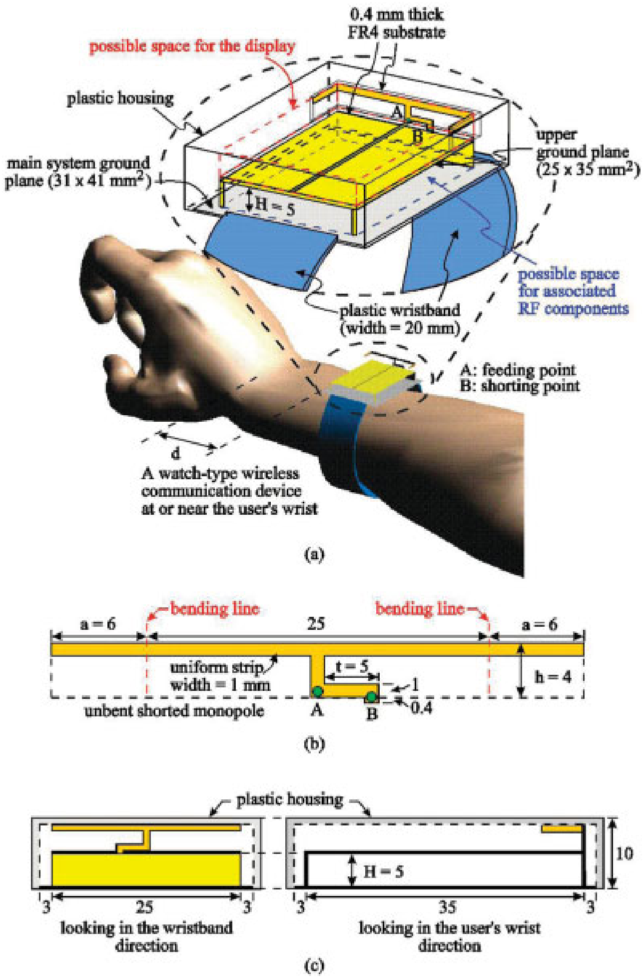

Figure 1 (a) Configuration and simulation model of the watch-type wireless communication device with the proposed internal shorted monopole antenna for Bluetooth operation. (b) Detailed dimensions of the proposed antenna. (c) Two side views of the studied watch-type wireless communication device. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com]

ground plane, it is promising to accommodate the display of the wireless device.

To test the antenna in the experiment, a 50-Ω microstrip feed line is printed on the opposite side of the upper ground plane. The microstrip feed line is connected to Point A (the feeding point) located at the open end of the antenna's central strip. Also, at Point A, a shorting strip with a horizontal length t short-circuits the antenna to the upper ground plane at Point B shown in the figure. By selecting a proper length t (preferred length 5 mm in this study), good impedance matching of the proposed antenna over the 2.4 GHz band can be easily achieved. More detailed effects of the length t on the impedance matching of the antenna will be discussed in Section 3 with the aid of Figure 4(a). It should also be noted that the achievable impedance bandwidth of the antenna is mainly controlled by the antenna height h (preferred length 4 mm in this study); a larger value of h generally can lead to a larger bandwidth. Effects of the length t on the obtained bandwidth of the antenna will be discussed with the aid of Figure 4(b).

As for adjusting the resonant frequency of the proposed antenna, it is most effective to fine-tune the length of the horizontal strip of the T-shaped monopole. That is, by fine-tune the length a (preferred length 6 mm in this study) at the two open ends of the horizontal strip, the desired resonant frequency (2442 MHz here) of the antenna can be obtained. Related effects of the length a on the antenna's resonant frequency will be discussed with the aid of Figure 6(c) in Section 3.

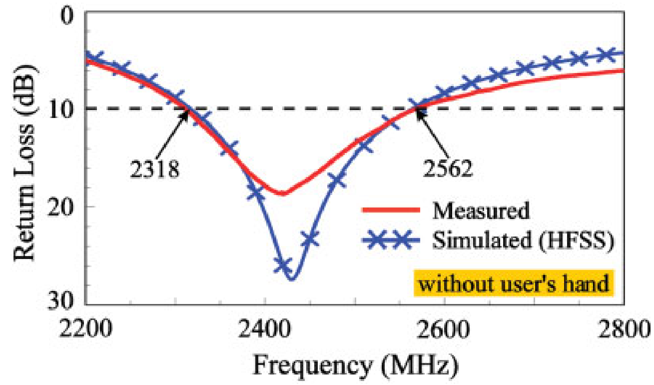

Figure 2 Measured and simulated (HFSS) return loss for the proposed antenna without the user's hand. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com]

Figure 1(c) shows 2-side views of the studied watch-type wireless communication device looking in the wristband and the user's wrist directions. Note that the wireless device is enclosed by a 1-mm thick plastic housing, which can avoid the direct contact of the system ground plane with the user's forearm in the experiment. With the plastic housing, the total dimensions of the wireless device are $10 \times 33 \times 43$ mm^3, which is a reasonable size to be worn around the user's wrist or forearm.

3. RESULTS AND DISCUSSION

The proposed antenna and the watch-type wireless communication device shown in Figure 1 with the preferred dimensions are fabricated and studied. The condition without the user's hand is first studied, and the results are shown in Figures 2–5. Figure 2 shows the measured and simulated return loss for the proposed antenna.

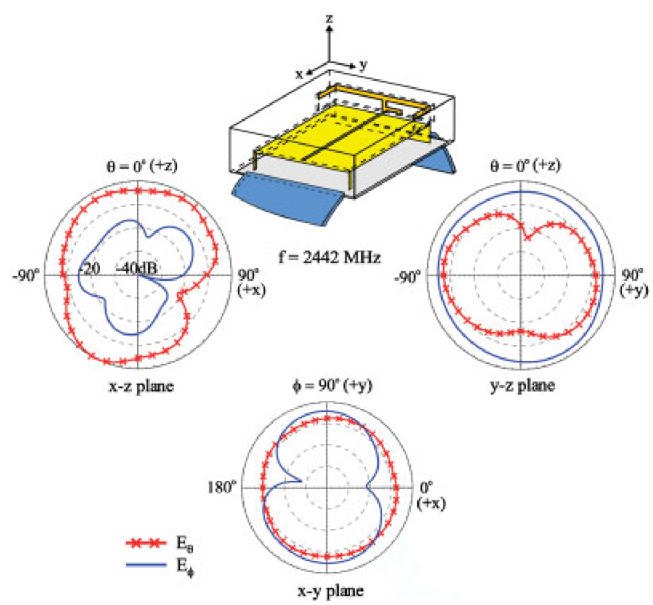

Figure 3 Measured radiation patterns for the proposed antenna without the user's hand at 2442 MHz. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com]

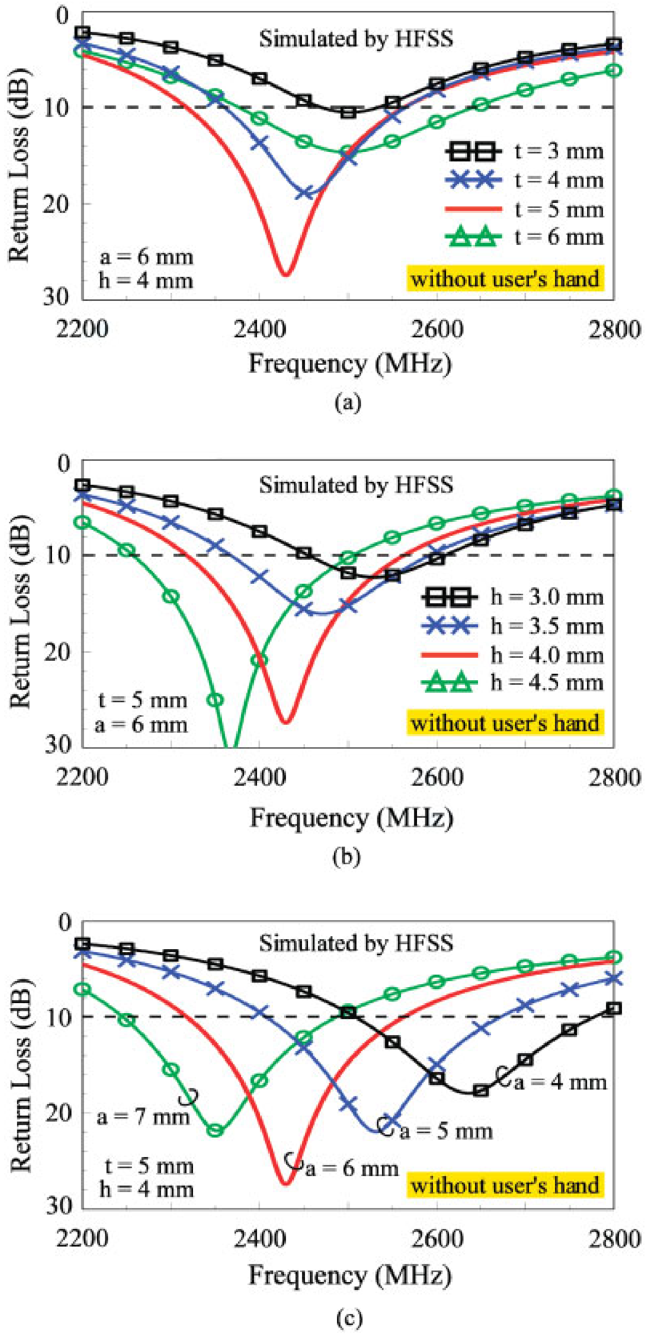

Figure 4 Simulated (HFSS) return loss for the proposed antenna without the user's hand. (a) As a function of the shorting-strip length t: $a = 6$ mm, $h = 4$ mm. (b) As a function of the antenna height h: $a = 6$ mm, $t = 5$ mm. (c) As a function of the bent-portion length a of the monopole: $h = 4$ mm, $t = 5$ mm. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com]

The simulated results are obtained using Ansoft simulation software HFSS (High Frequency Structure Simulator) [10]. Agree0ment between the measured data and simulated results is seen. From the measured data, the proposed antenna has a wide impedance bandwidth of 244 MHz (2318–2562 MHz, return loss better than 10 dB), allowing it to easily cover the bandwidth requirement for Bluetooth operation (84 MHz, 2400–2484 MHz). Figure 3 shows the measured radiation patterns for the condition without the user's hand at 2442 MHz. In general, symmetric radiation patterns in the three principal planes are seen, and the radiation patterns are also similar to those of the regular shorted monopole antenna.

Note that good impedance matching over the operating band of the proposed antenna can be effectively adjusted by selecting proper lengths t and h, and the resonant frequency of the operating band can be easily controlled by the length a. Figure 4(a) first shows the simulated return loss as a function of the shorting-strip length t. Other parameters are the same as given in Figure 1. Simulated results for t varied from 3 to 6 mm are shown. The obtained results indicate that impedance matching over the operating band can be effectively improved by selecting a proper value of t, and the preferred value of t is 5 mm in this study. Effects of the antenna height h are studied in Figure 4(b). Again, improved impedance matching over the operating band is quickly obtained when a larger antenna height is selected. In this study, the antenna height h is selected to be 4 mm; in this case, the antenna can have a large bandwidth to cover the Bluetooth operation, yet with a low profile of 4 mm only. In Figure 4(c), simulated results for a varied from 4 to 7 mm are shown. Obtained results clearly show that the resonant frequency of the operating band can be effectively controlled by the length a. From the results, the preferred length a is selected to be 6 mm in this study. Figure 5 presents the measured antenna gain and simulated radiation efficiency of the proposed antenna. Without the user's hand, the radiation efficiency over the operating band is about or larger than 80%, and a stable antenna gain of about 1.5 dBi is obtained over the band.

The condition with the users hand is then studied in Figures 6–8, using SPEAG simulation software SEMCAD-X [9]. The experimental photo is shown in Figure 6, and results of the measured and simulated return loss as a function of d are presented in Figures 6(a) and 6(b), respectively. From the obtained results, the simulated data in general agree with the measured ones, which can ensure reliable simulated results shown in Figures 7 and 8. Also, from the obtained results, it indicates that the distance d has small effects on the return loss of the antenna, and there is small frequency detuning observed when the distance d is varied.

The simulated three-dimensional total-power radiation patterns for the antenna with and without the user's hand are presented in Figure 7. Figure 7(a) shows the pattern for the case without the user's hand (that is, in free space), while Figures 7(b) and 7(c) show the case with the user's hand for $d = 0$ and 70 mm. Large distortion in the radiation patterns in Figures 7(b) and 7(c) is seen, as compared with that in Figure 7(a). This behavior is mainly because the user's hand usually functions as a lossy medium, and large radiation power of the antenna will be absorbed by the user's

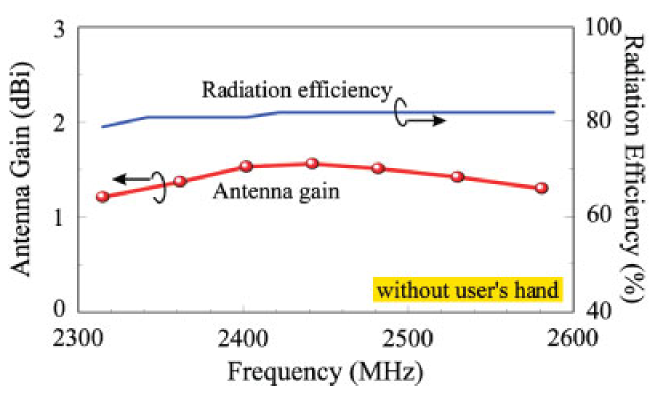

Figure 5 Measured antenna gain and simulated (HFSS) radiation efficiency for the proposed antenna without the user's hand. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com]

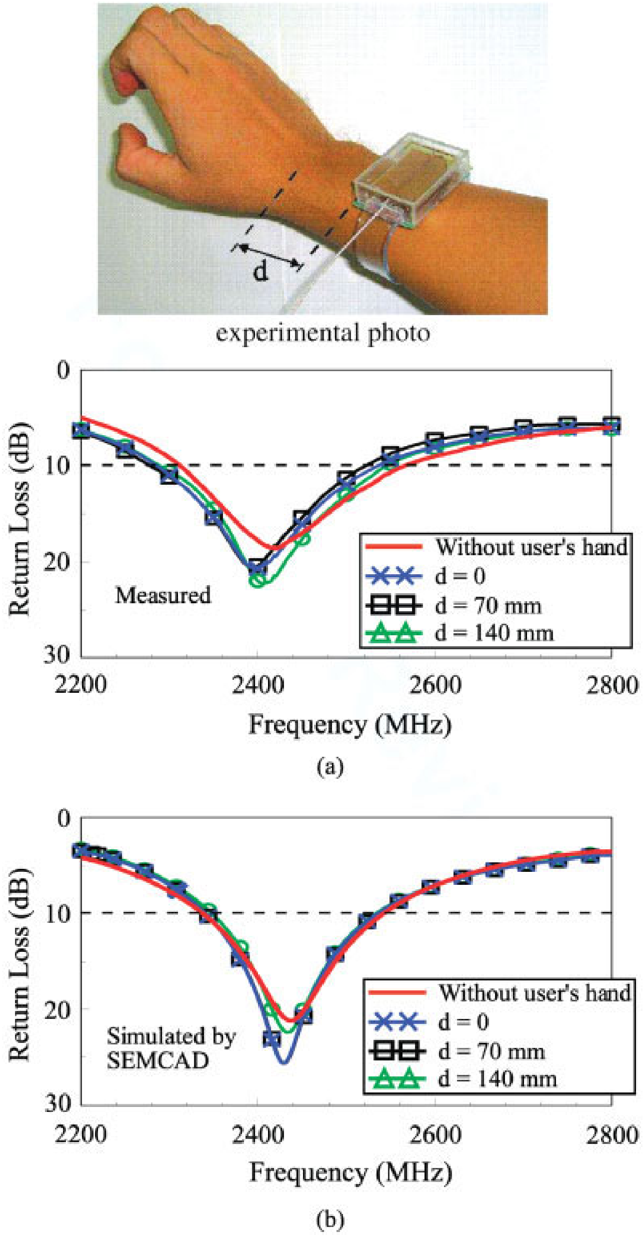

Figure 6 (a) Measured and (b) simulated (SEMCAD) return loss for the proposed antenna with the user's hand as a function of *d*. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com]

hand. The pattern distortion will also become more significant when the distance d is smaller (that is, the wireless device is much closer to the user's wrist or the palm portion of the user's hand).

igure 8 demonstrates the simulated radiation efficiency versus d at 2442 MHz. The free-space (no user's hand) radiation efficiency at 2442 MHz is about 82% and is shown by the dashed line in the figure. With the presence of the user's hand, results for the two cases of H = 5 mm and 0 are shown. Note that the case of $H = 0$ indicates that there is no upper ground plane, and the antenna is directly short-circuited to the system ground plane. In this case, it is seen that the radiation efficiency is quickly decreased to be lower than 30%. However, for the proposed arrangement with $H = 5$ mm, smaller radiation power absorption by the user's hand is expected, and the obtained radiation efficiency can reach about 50% over the operating band. It is also noted that, for d varied from 0 to 140 mm shown in the figure, the obtained radiation efficiency remains about the same; that is, the antenna shows stable radiation efficiency when the wireless device is worn around the user's wrist at various possible locations. When a much larger H ($H > 5$ mm) is selected in the proposed design, a larger radiation efficiency than that obtained here can be expected. However, a much larger H will also lead to an increased height or thickness of the studied wireless device, which may not be attractive for practical applications.

4. CONCLUSION

A promising internal antenna for Bluetooth operation in the watch-type wireless communication device has been proposed. The stud-

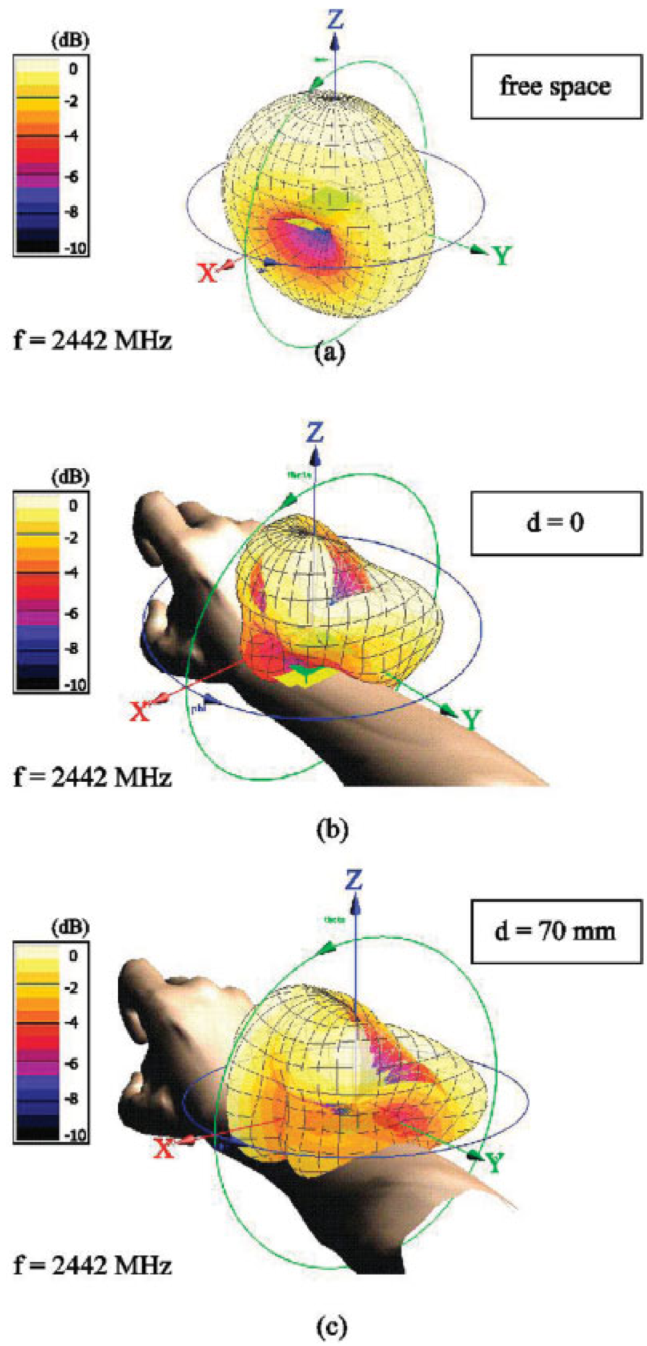

Figure 7 Simulated (SEMCAD) three-dimensional total-power radiation patterns for the proposed antenna. (a) In free space (without the user's hand). (b) With the user's hand, d = 0. (c) With the user's hand, d = 70 mm. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com]

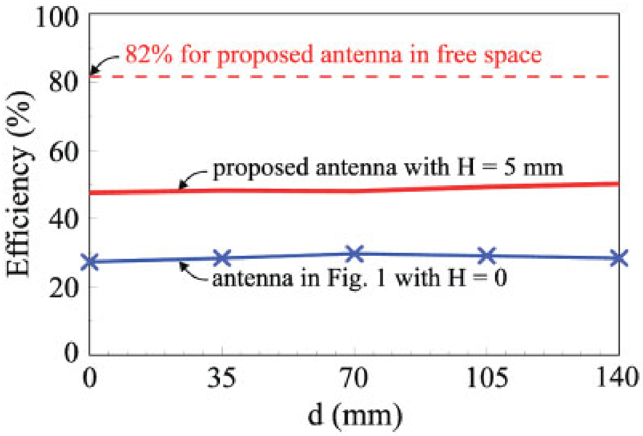

Figure 8 Simulated (SEMCAD) radiation efficiency at 2442 MHz versus d for the proposed antenna with $H = 5$ mm and 0. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com]

ied wireless device is to be worn around the user's wrist or forearm for practical applications. Instead of mounting the antenna to the main system ground plane of the wireless device, the proposed antenna is short-circuited to an upper ground plane mounted above the system ground plane. Results have indicated that, with the proposed arrangement, the obtained radiation efficiency can reach about 50% over the operating band for the proposed antenna with the presence of the user's hand. In addition, the proposed antenna shows a low profile of 4 mm only, and the total height or thickness of the studied wireless device can be about 10 mm only, which makes it very promising and attractive to be worn around the user's wrist or forearm for practical applications.

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SURFACE-WAVE BANDGAP OF POLARIZATION DEPENDENT ELECTROMAGNETIC BANDGAP STRUCTURES

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ABSTRACT: *Polarization-dependent reflection-phase feature could be realized by using a rectangular patch in mushroom-like electromagnetic bandgap (EBG) structures. The surface-wave bandgap of this polarization-dependent EBG structure have been investigated in this article. It has been shown that the surface-wave bandgap along two periodic directions almost overlaps and compactness in one direction could be achieved by increase the length of the other. One compact EBG microstrip line has been presented.* © 2007 Wiley Periodicals, Inc. Microwave Opt Technol Lett 49: 946–949, 2007; Published online in Wiley InterScience (www.interscience.wiley.com). DOI 10.1002/mop.22321

Key words: *electromagnetic bandgap (EBG); surface-wave; microstrip line*

1. INTRODUCTION

Electromagnetic bandgap (EBG) structures have been extensively explored in the recent years. Many kinds of EBG structures have been presented and applied to microwave circuits and antennas [1–6]. The hot field focuses on a mushroom-like EBG surface [7, 8], which is composed of metal islands and vertical connections to the ground plane embedded in the microstrip substrate. The structure is prominent for its unique characteristics: in-phase reflection and surface-wave bandgap and they exist in almost the same frequency range. It has been widely applied to the design of low profile high efficiency wire antennas and microstrip antennas with improved performances [9–12].

Among the mushroom-like EBG structures, most of them adopt square unit cells, where the dimension along the two periodic directions is same and the metal patch is square. Recently, rectangular shape EBG structures have been proposed [13], in which

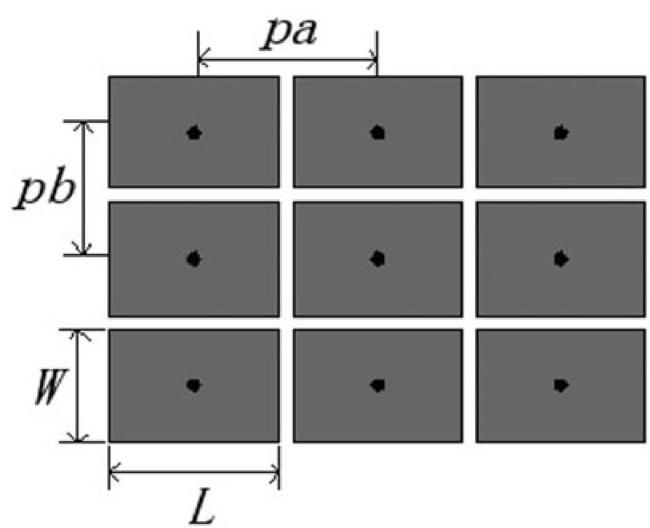

Figure 1 Geometry plot of PDEBG structure. The periodic spacing and the patch are both rectangular