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A NOVEL COMPACT UWB TEXTILE BUTTON ANTENNA

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Abstract—A novel compact textile antenna with the appearance of a button on clothing for body-centric wireless communications systems (BWCS) is presented. The antenna is placed on a textile substrate and fed by a coaxial line through the ground plane. The operating bandwidth of the antenna has met the requirement of the UWB communication system. The effects of the human body on S_{11} and S_{21} are presented and discussed in detail. The proposed antenna has good omni-directional radiation patterns and stable H-plane radiation patterns. The measured results show that the antenna is suitable for BWCS.

1. INTRODUCTION

Body-centric wireless communications systems (BWCS) have recently drawn great interest in the areas of electronics, biomedical engineering, and military applications. A wearable health sensor system has been demonstrated in [1]. Textile antenna is able to be integrated into clothing, which is usually unobtrusive and offers large area. A variety of textile antennas have been introduced in recent years [2–4]. In low/medium data-rate applications, the low-power operation and extremely low radiated power that can be offered by UWB [5–12] are very attractive for BWCS [13].

Most of wearable antennas designed in recent years are made of metal patches and flexible material, so that they can be conformed around any surface. However, the antenna using flexible metal patches will become unstable when it is stretched, bent or compressed from its original shape [14]. More recently a wearable antenna with the appearance of a button working at the 2.45 GHz and 5 GHz has been

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proposed in [15]. Some UWB metallic button antennas are introduced in [14, 16]. These button antennas can keep original shape for their rigid structure and be easily disguised by their button appearance.

This paper describes a novel compact textile button antenna that can be mounted on clothing as a button. The operating bandwidth of the antenna is from 3.1 GHz to 12.4 GHz. The parametric study of the antenna for design insight is given. Antenna II is defined for clarifying the effect of the cylinder structure. Furthermore, as the presence of the human body will have an effect on the performance of the antenna. The effects of the human body on S_{21} of the UWB button antenna are measured and discussed in this paper, which is rarely discussed. Good omni-directional patterns and stable H-plane radiation patterns are presented.

2. ANTENNA CONFIGURATION AND DESIGN

The structure of the antenna is shown in Fig. 1. It is made up of two main components: a cone and a cylinder, with dimensions of $(r_1, r_2) \times h_2$ and $r_2 \times h_3$, respectively. A $w \times w$ textile substrate with a relative dielectric constant approximate to 1.3 is used. The dielectric constant of the textile substrate is measured by the two-layer stripline method [17]. The $w \times w$ ground plane is made of thin copper plane, while the cone and cylinder are made of copper. The antenna is fed by a coaxial line through the centre of the ground plane. Critical parameters of the proposed antenna are tabulated in Table 1.

As the electrical length increases with the radius of the cone, it is expected that a wide bandwidth is realized. The cylinder helps to improve the total bandwidth of the antenna, especially the high frequency. Without the cylinder, bigger diameter is necessary to cover the same band, with the total height constant. It will be discussed

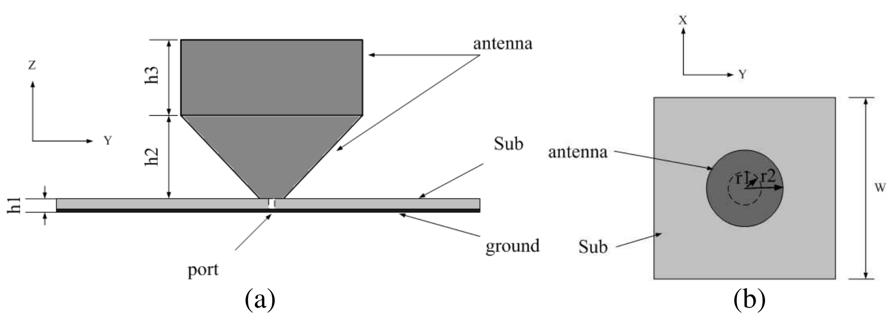


Figure 1. Geometry of the antenna. (a) Side view, (b) top view.

Table 1. Design parameters and values.

Parameter	Value (mm)	Parameter	Value (mm)
h_1	2	r_1	3
h_2	7.5	r_2	8
h_3	9	w	60

later.

To give preliminary dimensions of the overall design, the antenna is approximated to the cylinder. According to [18, 19]

$$L = 0.24\lambda \times F \tag{1}$$

$$F = \frac{L}{L + r + p} \tag{2}$$

$$f_i = \frac{7.2}{L + r + p} \text{ GHz} \tag{3}$$

$$L = h_2 + h_3 \tag{4}$$

$$r = r_2 \tag{5}$$

where L is the height of the cylinder, r the radius of the cylinder, p the length of the probe, and f_i the lower frequency. L, r, h_2, h_3, r_2, and p are in centimeters.

The conical antenna with wide-angle configurations is frequently used as broadband antennas. According to [19]

$$30^\circ < \frac{\alpha}{2} < 60^\circ \tag{6}$$

where $\frac{\alpha}{2}$ is the half-cone angle of the conical antenna.

The original dimensions are obtained by (3) and (6). Then, the dimensions are modified by simulation and optimization. Finally, the antenna has a total height of 16.5 mm, which is far less than $1/4\lambda_{\max}$.

3. MEASURED RESULTS AND DISCUSSION

3.1. Antenna Discussion

The UWB button antenna is analyzed with HFSS based on the FEM. Fig. 2 shows that the measured and simulated S_{11} are in good agreement. The antenna has a shift about 0.2 GHz compared to the design frequency when it is below 6.5 GHz, owing to the fabrication imperfections.

To clarify the effect of the cylinder structure, antenna II is defined to be compared with the designed one, which is without the cylinder

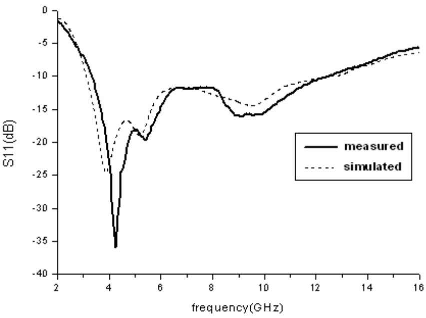


Figure 2. Simulated and measured S_{11} comparison.

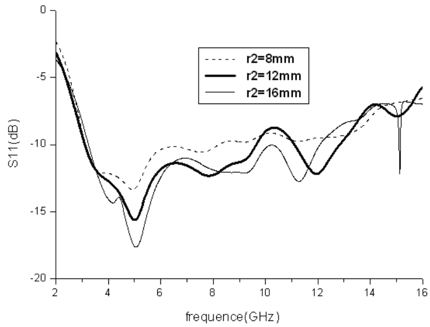


Figure 3. Simulated S_{11} for different r_2 (Antenna II).

structure and has the same height of the proposed UWB button antenna. The simulated S_{11} curve of antenna II is investigated in Fig. 3. As r_2 increases from 8 to 16 mm, more resonances are generated. Meanwhile the enhancement of the bandwidth and improvement of the matching are completely noticeable. Fig. 3 indicates that the diameter of antenna II is necessary to be bigger than the UWB button antenna to cover the same band. It was perceived that the cylinder structure is helpful to reduce the diameter of the antenna significantly.

Then, the effects of h_2, h_3 and r_1 are investigated in detail here. All the corresponding dimensions are the same.

It can be seen from Fig. 4 that as h_3 varies from 9 mm to 15 mm, the resonant frequency shifts to lower frequency and the peak value of S_{11} fluctuates severely in the low frequency. Meanwhile, h_3 affects the high frequency very slightly. So, h_3 mainly affects the performance of the antenna in the low frequency significantly. The simulated S_{11} curves with different h_2 are shown in Fig. 5. It is observed that increasing h_2 causes a shift at the high frequency significantly and affects the low frequency slightly. As seen in Fig. 6, r_1 affects the S-parameter evidently in the whole band. Therefore, r_1 should be chosen carefully, as it plays a significant role on the performance of the antenna.

Furthermore, the effect of the size of the ground plane is investigated in Fig. 7. From Fig. 7, it can be seen that the ground plane is strongly resonant in the low frequency. The downward shift of the lower frequency is caused by increasing w. Both increasing the height of the monopole and enlarging the area of the ground plane can be applied to improve the low frequency performance. In order to make the antenna more compact, the low frequency performance is improved by

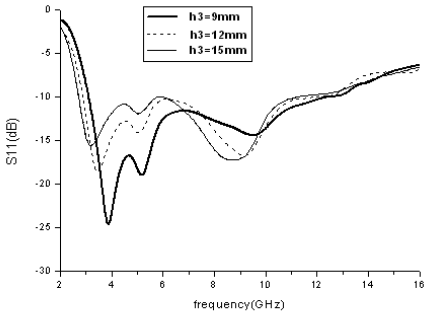


Figure 4. Simulated S_{11} for different h_3.

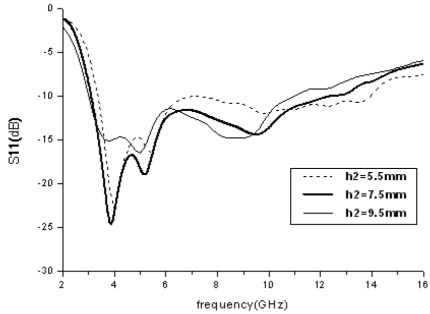


Figure 5. Simulated $S_{11}$for different h_2.

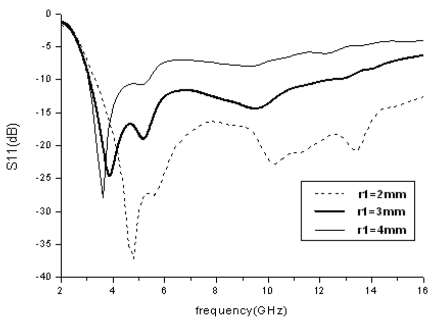


Figure 6. Simulated S_{11} for different r_1.

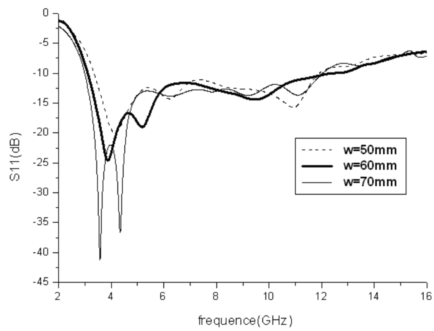


Figure 7. Simulated S_{11} for different w.

enlarging the area of the ground plane instead of increasing the height of the monopole. However, the antenna is assumed to be mounted on the shoulder where the area of the ground plane is limited, so the area of the ground plane is chosen as 60×60 mm by simulation and optimization.

3.2. The Effect of the Human Body

Button antenna is usually near the human body in practice. The effects of the human body on the antenna are investigated. Firstly, the on-body S_{11} measurement is done with the ground plane parallel to and about 8 mm from the chest. The antenna can be sewn into clothing. The distance between the measured antenna and human chest is as long as the distance from SMA connector to co-axial. Fig. 8 gives the measured S_{11} of the antenna when it is placed in the air and on

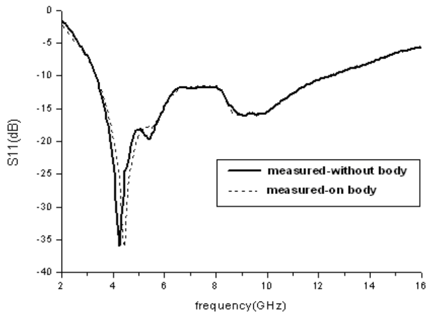


Figure 8. Measured S_{11} on and off body.

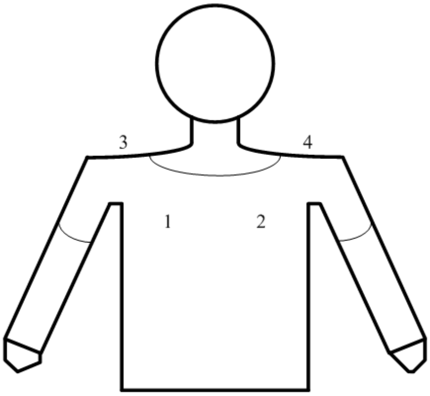


Figure 9. The locations for the button antenna.

the chest. The presence of the chest has not altered the S-parameter significantly. It is because that the ground plane serves as a shield against the power radiated by the antenna [2].

Secondly, as multi-button antennas may be mounted on the clothing surface, the effects of the body on S_{21} between two identical button antennas should also be studied. So, the measured S_{21} of two UWB textile button antennas with different position and distance are presented. The locations of the button antenna are shown in Fig. 9.

Figure 10 shows the measured S_{21} between two antennas in the air, while the distance of two antennas varies from 5 cm to 30 cm. It can be seen that the S_{21} decreases while the distance and the frequency increase.

Then, two antennas are placed as chest pocket buttons about 15 cm away from each other (Position 1 and 2, shown in Fig. 9). Fig. 11 shows the comparison of the measured S_{21} in the air and on the chest, and S_{21} changes little. So the effect of the body can be ignored when they are placed on the chest. It is because the chest is flat and nothing can obstruct the transmission between antennas.

After that, two antennas are placed on shoulders about 30 cm away from each other. Fig. 12 gives the measured S_{21} of the antennas placed in the air and on shoulders (Position 3 and 4), and S_{21} decreases about 10 dB when the antennas are on shoulders. It is due to the fact that the head insulates the two antennas. It could be used in the off-body communication for its independence with each other.

Finally, as the antenna is supposed to be placed on the chest or shoulders, the position of arms will affect the antenna when the

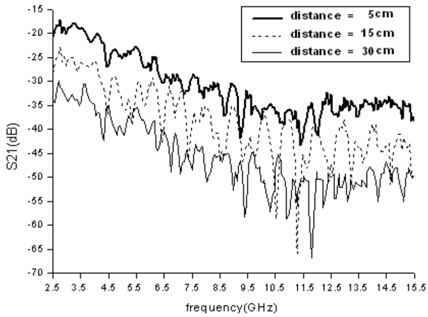


Figure 10. Measured S_{21} for different distance in the air.

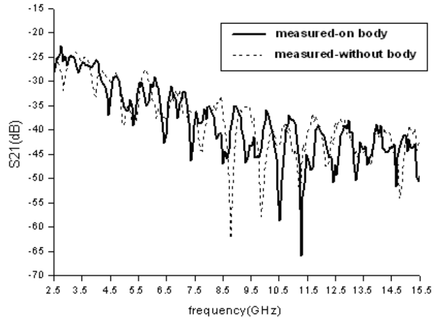


Figure 11. Measured S_{21} on and off chest.

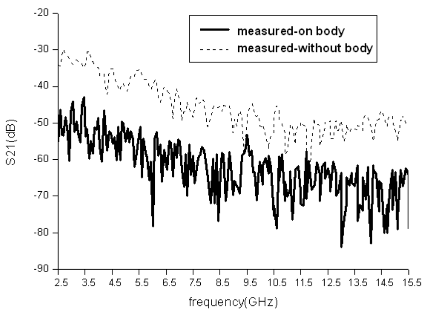


Figure 12. Measured S_{21} on and off shoulder.

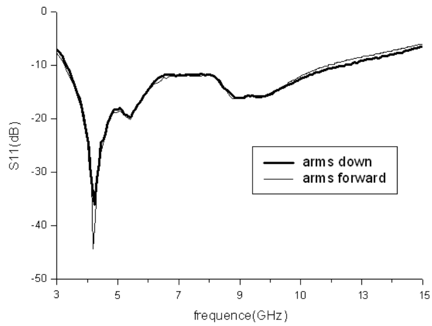
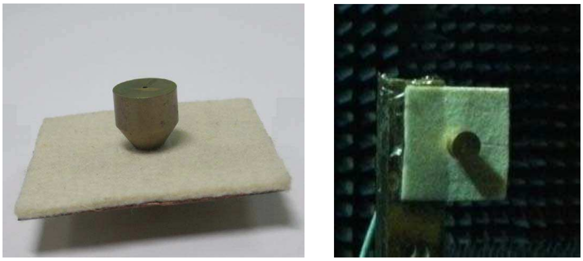


Figure 13. Measured S_{11} with arms forward and down.



(a) (b)

Figure 14. (a) The photograph of UWB button antenna. (b) Photograph of measuring pattern of UWB button antenna in anechoic chamber.

human body moves. The measured results are given with arms moved. Fig. 13 shows that the movements of arms change the S_{11} little. Further research will be done in the future.

3.3. Radiation Patterns

The photographs of the realized compact UWB button antenna are shown in Fig. 14. The radiation patterns of the UWB button antenna are measured in anechoic chamber. The simulated and measured radiation patterns at 6 GHz, 8 GHz and 10 GHz are shown in Figs. 15 and 16, respectively. It can be seen that the radiation patterns are omni-directional in H-planes. H-planes are stable in the whole band. E-planes examined at the same frequencies are symmetrical around the z-axis. It shows that the radiation patterns are similar to that of a typical monopole antenna.

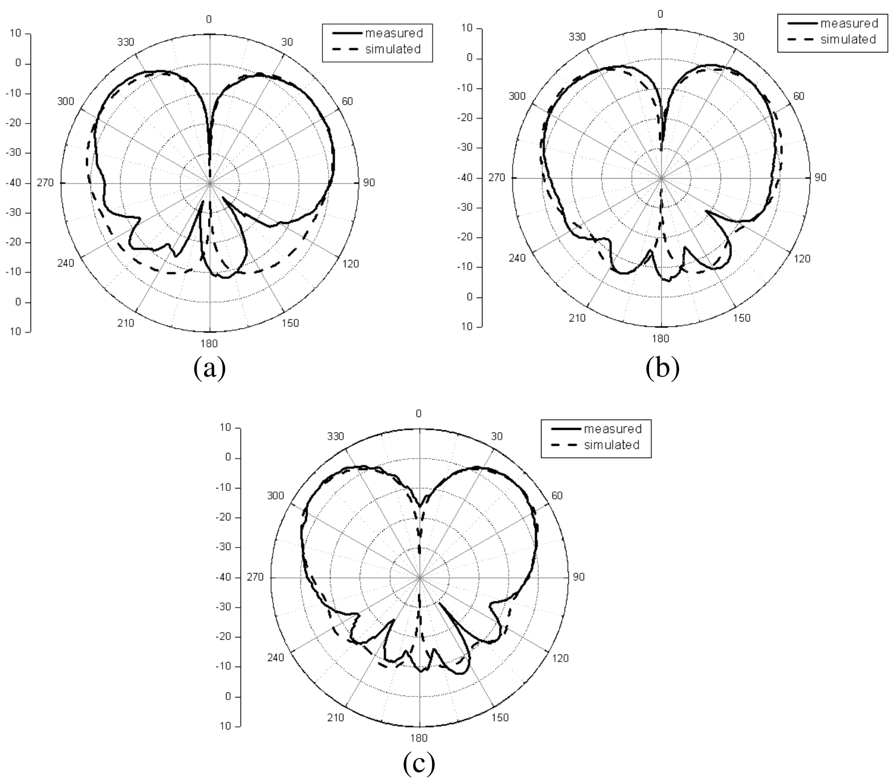


Figure 15. The simulated and measured E-plane patterns of the antenna. (a) $f = 6$ GHz, (b) $f = 8$ GHz, (c) $f = 10$ GHz.

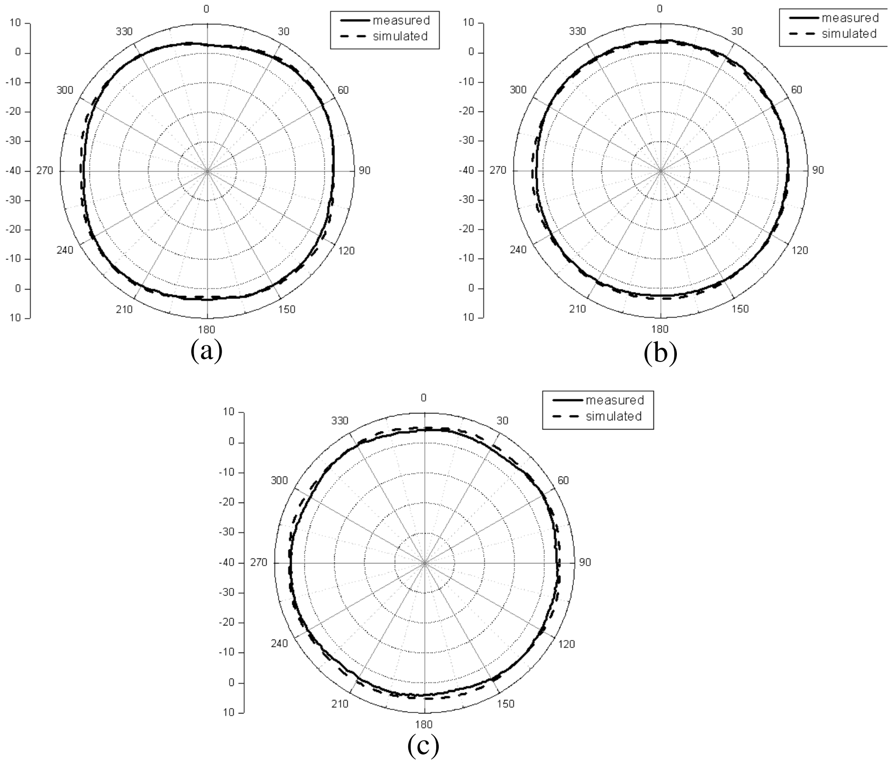


Figure 16. The simulated and measured H-plane patterns of the antenna. (a) $f = 6\,\text{GHz}$, (b) $f = 8\,\text{GHz}$, (c) $f = 10\,\text{GHz}$.

4. CONCLUSION

A novel compact UWB textile button antenna is presented and investigated. The total height of the antenna is far less than $1/4\lambda_{\max}$. The measured and simulated results of the antenna show an excellent agreement. The effects of the human body on S_{11} and S_{21} are discussed. The measured S_{11} result shows that the antenna performs well in the proximity of the human body. S_{21} of the antennas changes little when the two antennas are placed on the chest. Meanwhile S_{21} of the antennas decreases about 10 dB, when the antennas are placed on shoulders. The measured results show that S_{11} changes little with the movement of arms. The antenna has good omni-directional performance radiation patterns and stable H-plane radiation patterns. The measurement indicates that the proposed antenna can be used in BWCS.

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