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A Handbag Zipper Antenna for the Applications of Body-Centric Wireless Communications and Internet of Things

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Abstract—The idea of making use of the metal zipper on the handbag to serve as an off-body antenna is proposed and the simulations together with measurements have been carried out. The feeding point can be located at the bottom of the zipper, and to be more specific, around one of the teeth. The excitation at certain tooth of the zipper would bring variations in the reflection coefficients as well as the radiation patterns. No matter the zipper is totally closed, quarterly opened, half opened or is even totally opened, the antenna can operate with acceptable performance, though the common status of the handbag zipper is closed. Thus, it is to some extent reconfigurable, especially for radiation patterns. A fractional bandwidth of 4.92% at 2.44 GHz of the ISM (Industrial, Scientific, and Medical) band with a gain of about 5.0 dBi has been achieved. The impact of the human body has been evaluated. It is noticeable but affordable. The measured results indicate reasonable agreements to that of the simulations in both the matching performance and the radiation feature for the zipper antenna, which seems to be a promising candidate for body-centric wireless communications and the Internet of Things.

Index Terms—Body-centric communication, Internet of Things, off-body antenna, wearable antenna, zipper antenna.

I. INTRODUCTION

SMART interconnections and “To connect everything” are attracting more and more attention nowadays. The Internet of Things (IoT) is considered to be both a technical and a management development tendency that is worth investigating, which is not only important for the industry and economics, but also valuable for our everyday life [1]. Recently, a lot of

academic progress together with some interesting products are presented [2-3].

In another relevant area of wireless energy harvesting and power transferring, there is also much emerging progress. The design of the integration of FSS (Frequency Selective Surface) and rectenna for wireless power harvesting were proposed [4]. Dipole-coil-based power transfer systems [5] and a wireless alarm microsystem self-powered by vibration-threshold triggered energy harvester were developed [6]. Supportive techniques including selective wireless power transfer for smart power distribution in multiple-receiver systems [7-8], and a multiport RFID-tag antenna for enhanced energy harvesting of self-powered wireless sensors [9] etc., have been reported within the past 12 months.

At the same time, wearable antennas and systems together with techniques of antenna miniaturization have been paid much attention. To make the human body as an antenna for wireless implant communications has been studied [10]. Various antennas have been proposed for wearable applications, including a high-sensitivity ground radiation antenna system using a slot for Bluetooth headsets [11], a wearable shell antenna for 2.4 GHz hearing instruments [12], a printable planar dielectric antenna [13], a transparent and flexible antenna for wearable glasses applications [14], a small-size dual-antenna implantable system for biotelemetry devices [15], a dual-band on-body repeater antenna for body sensor network [16], etc. Investigations of the capacity of broadband body-to-body channels between firefighters wearing textile antennas [17], a configurable energy-efficient compressed sensing architecture with its application on body sensor networks [18], and the robustness of wearable PIFAs to human body proximity [19] have been carried out. A dual-band reconfigurable Terahertz patch antenna with graphene-stack-based backing cavity [20] and a graphene-based antenna for the design of modulated scattering technique wireless sensors [21] have also been presented [22]. A brief introduction of a novel textile zip monopole antenna on a jacket was presented in 2011, and a prototype of it was fabricated and evaluated based on the return loss and the radiation pattern with elementary analysis [23], which was the only antenna based on a zipper till now. Under the real application scenario, the zipper on a jacket would be dragged up and down, which will bring the performance variation of the

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antenna. In fact, to be totally opened is a common state for a zipper on a jacket, which is a key problem that the zip antenna has to deal with. Based on the metal zipper of a handbag, we will propose a new antenna with different material and present detailed analysis, including the current distribution, the impact of the dimensions and the feeding locations, and the influence of the human body, etc.

Referring to off-body networks and body-centric networks, there are also many achievements. An off-body channel model for body area networks [24] in indoor environments have been established. A planar reconfigurable mono-pulse antenna for indoor smart wireless access points application [25], Koch fractal circularly polarized antenna for handheld RFID reader applications [26], and a wideband implantable antenna for body-area impulse radio communication [27] have been developed recently. A watch strap antenna [28] and a shoelace antenna [29] have just been reported. Some of the investigations referred to the impact of the human body on the antenna performance [30], including the model of an arm and the influence of it for the transmission [31].

To make everything and everybody informatics and smart is on the way of realization, which refers to a large market in the near future. The above mentioned and many other wearable or body-centric antennas have achieved fairly good performance, especially for specific applications. However, most of them need to fabricate additional facilities on the body or onto the equipment to make an antenna, and the performance improvements for various applications are still needed. Thus, the investigations on novel styles of antennas have realistic values.

It is a good idea to make use of the metal zipper on the handbag to serve as an antenna, which has already existed there. The second part of this paper will introduce the configuration and structure of the handbag zipper antenna. After that, the third section will present simulations and parameter studies of the antenna performance. Finally, the fourth paragraph will provide the measurement results of the antenna.

II. CONFIGURATION AND STRUCTURE

A metal zipper on a handbag is shown in Fig. 1. The whole length of the zipper on a bag is usually about 20-50 cm with approximately 50-150 teeth on each side.



Fig. 1. Photographs of handbag zipper. (a) The zipper on the handbag, and (b) Close-up of the zipper.

Since there are a lot of small parts composing the zipper, the model of it need to be built with care, as shown in Fig. 2(a). The concrete structure of the handbag zipper may be divided into several groups. The first one is the switch handle, as shown in the left lower part of Fig. 2(b), which is fairly large in size compared to other parts. The second is the main body of the chain, consisting of two columns of teeth in parallel, as shown in the upper part of Fig. 2(b). And the third part is the two terminators of the zipper. To investigate the antenna thoroughly, the handbag itself is needed in the structure, as shown in Fig. 2(c). Not only the metal square rings on the handles of the bag, but also the half loops on both sides of the bag together with the rubber shell are generated in the model.

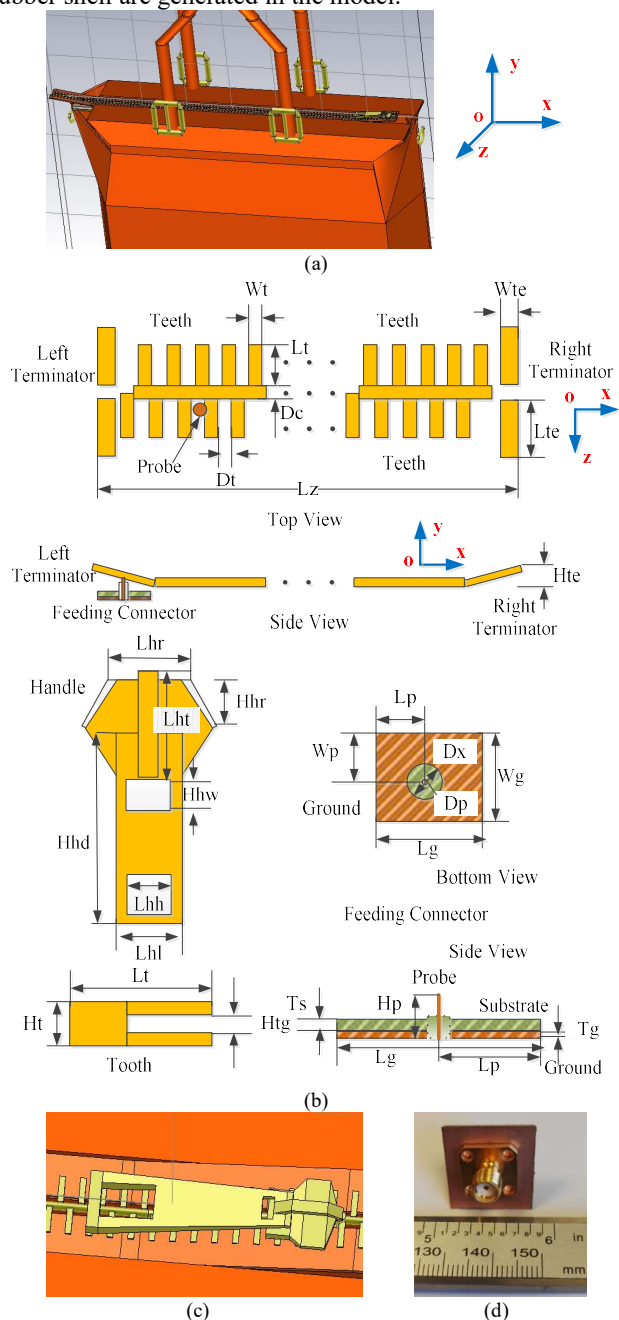


Fig. 2. The structure of the handbag zipper antenna. (a) Model of the handbag, (b) Geometry of the zipper antenna, (c) Model of the handle, and (d) Photograph of the feeding structure.

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The dimensions of the handbag zipper antenna are presented in TABLE I. A coaxial interconnector or simply a probe hidden in the bag can be used to excite the antenna from the bottom of the chain, by injecting signals into one of the teeth of the zipper. Fig. 2(d) is the photograph of a prototype of the feeding structure, whose geometry and dimensions are shown in the lower right part of Fig. 2(b) and TABLE I.

TABLE I
THE DIMENSIONS OF THE HANDBAG ZIPPER ANTENNA

Parameter	Dimension (mm)	Param.	Dim. (mm)	Param.	Dim. (mm)
Wt	1.0	Lt	4.5	Dc	1.0
Dt	2.5	Wte	2.0	Lte	6.0
Lz	385.0	Hte	20.0	Lhr	5.0
Lhl	4.0	Lhh	3.0	Lht	12.0
Hhr	5.0	Hhw	3.5	Hhd	33.5
Lp	10.0	Wp	10.0	Dx	2.0
Dp	1.2	Tg	0.035	Ts	3.0
Hp	5.835	Lg	20.0	Wg	20.0
Ht	4.0	Htg	1.5		

III. SIMULATIONS AND ANALYSIS

To study the performance of the handbag zipper antenna, simulations are carried out with the help of CST MWS. Relevant analysis on the impact of various parameters will be presented. In addition to the model in Fig. 2, the rubber and the cloth shell of the bag are calculated. Furthermore, a concrete (one-year-old) ground with a distance of 800 mm under the handbag and the dimensions of 400 mm×400 mm×3 mm are used to imitate the floor.

The diverse connections between the probe and the zipper tooth would bring variations of the reflection coefficients, as shown in Fig. 3, where the contact is made from the side and the bottom of the tooth with tight or loose links, respectively. There are available operation frequency ranges that could be observed from the curves in the three scenarios. For instance, loose contact from the side obtains three operation bands around 1.20 GHz, 1.58 GHz and 2.15 GHz, respectively, with the S11 lower than -10 dB.

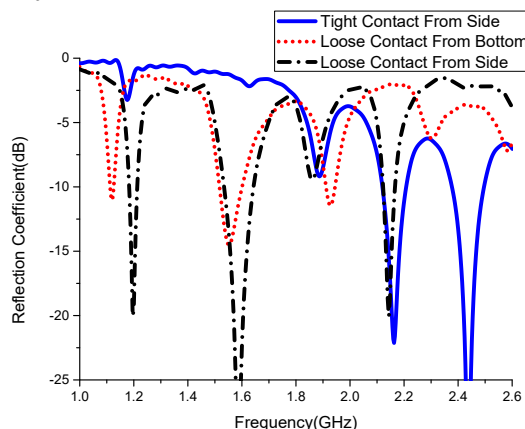


Fig. 3. Reflection coefficients corresponding to different feeding locations around the teeth.

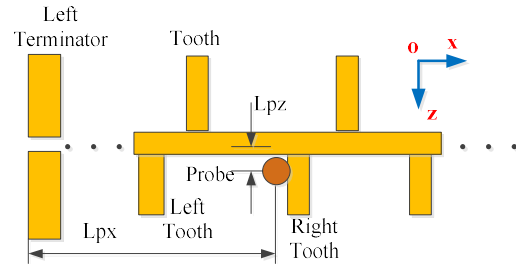


Fig. 4. The feeding location of the probe adjacent to the tooth.

Where, $L_{px}=34.5$ mm, and $L_{pz}=1.75$ mm.

In the above calculations, the feeding location is 1.75 mm in the z-direction and 34.5 mm in the x-direction beside the right tooth, as shown in Fig. 4, under the assumption that the original point of the coordinate system is set at the opposite side of the handle when the zipper is totally closed.

Actually, the specific coordinates of the probe would influence the return losses of the antenna, as shown in Fig. 5, where the reflection coefficients at feeding locations of 1.75 mm, 2.75 mm and 3.75 mm along the right of the feeding area beside the tooth and 1.75 mm on the left are computed. A poorer and poorer matching performance of the antenna could be observed when the probe moves from the center to the outer places. The antenna obtains the best S11 value at 2.44 GHz with a frequency range of 2.37 GHz-2.49 GHz, which belongs to the ISM (Industrial, Scientific, and Medical) public band. And the width is 120 MHz with a fractional bandwidth of 4.92%.

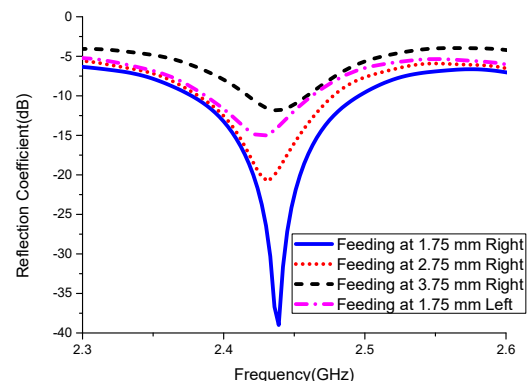


Fig. 5. Reflection coefficients corresponding to different feeding locations around the teeth (continued).

The radiation and the total efficiencies of the handbag zipper antenna are shown in Fig. 6, among which the lowest radiation efficiency is 97.0% at 2.90 GHz and the highest total radiation efficiency is 97.4% at 2.70 GHz. Where, the radiation efficiency is defined as the ratio of gain to directivity or equivalently the ratio between the radiated to the accepted (input) power of the antenna, while the total efficiency is defined as the ratio of radiated to stimulated power of the antenna.

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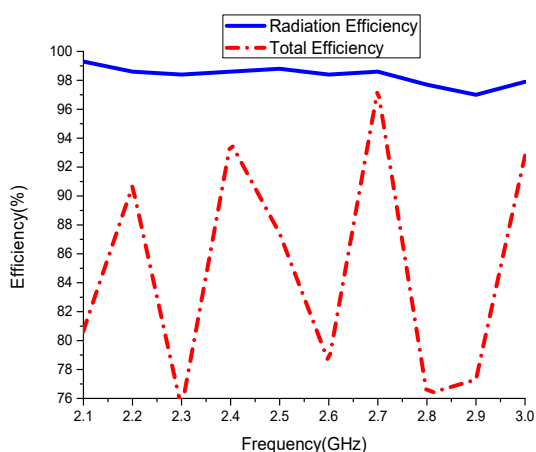


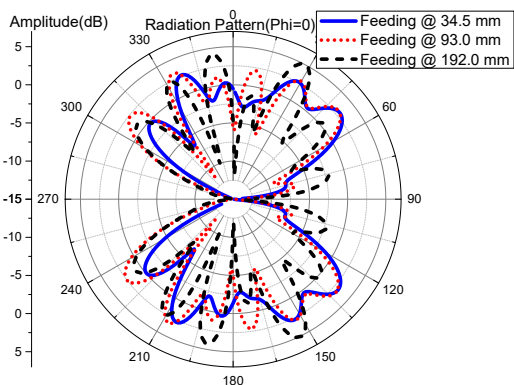
Fig. 6. The radiation efficiency and the total efficiency of the handbag zipper antenna.

The detailed values of the efficiency between 2.00 GHz - 3.00 GHz can be found in TABLE II.

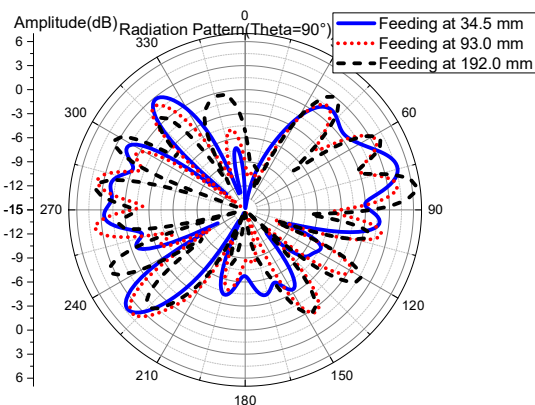
TABLE II
THE EFFICIENCY OF THE BAG ZIPPER ANTENNA

Frequency (GHz)	Radiation Efficiency (dB, %)	Total Efficiency (dB, %)
2.00	-0.02, 99.5	-2.41, 57.4
2.10	-0.03, 99.3	-0.93, 80.7
2.20	-0.06, 98.6	-0.42, 90.7
2.30	-0.07, 98.4	-1.23, 75.3
2.40	-0.06, 98.6	-0.28, 93.7
2.44	-0.04, 99.0	-0.06, 98.6
2.50	-0.05, 98.8	-0.58, 87.4
2.60	-0.07, 98.4	-1.05, 78.5
2.70	-0.06, 98.6	-0.11, 97.4
2.80	-0.10, 97.7	-1.17, 76.3
2.90	-0.13, 97.0	-1.12, 77.3
3.00	-0.09, 97.9	-0.32, 92.8

The radiation patterns would vary when we move the feeding location along the x-direction. Fig. 7 provides the 2-D radiation patterns of the handbag zipper antenna at 2.44 GHz at the position of $x=34.5$ mm, 93 mm and 192 mm, respectively. The curves indicate the magnitude of electric field of the antenna. Moreover, it is the same configuration for the latter radiation patterns.



(a)



(b)

Fig. 7. The 2-D radiation patterns of the bag zipper antenna @ 2.44 GHz. (a) View of Xoz plane, (b) View of YoX plane.

Fig. 7(a) is the cut plane of $\Phi=0^\circ$ and Θ varies from 0° to 360° (the Xoz plane, horizontal polarization), and Fig. 7(b) is that of $\Theta=90^\circ$ and Φ varies from 0° to 360° (the YoX plane, vertical polarization). It is symmetric in the Xoz plane according to the structure, while the view of the other plane reveals distinguished directivity.

Fig. 8 presents the 3-D radiation pattern of the first configuration in the above, where the main lobe could be seen in the upper front direction. Here, the zipper is along the x-direction and the concentration of the radiation is mainly caused by the reflection of the bag as well as the teeth of the zipper, combining the contribution of the floor.

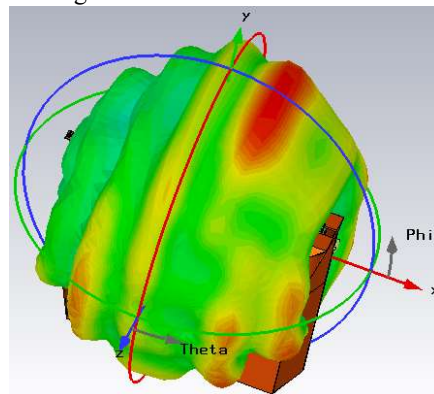


Fig. 8. The 3-D radiation pattern of the bag zipper antenna feeding at $x=34.5$ mm @ 2.44GHz.

The electric field distribution around the feeding port 1 is shown in Fig. 9, including the absolute values and the total electric field.

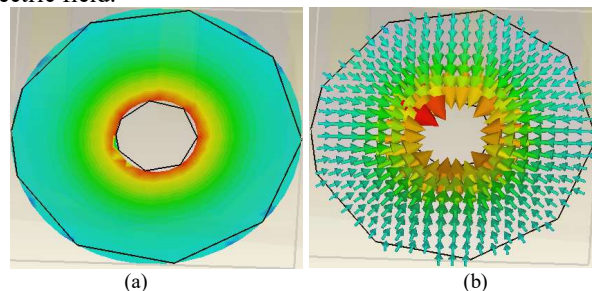


Fig. 9. The electric field distribution around the feeding port 1. (a) Magnitude of the field, (b) Vector field.

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Fig. 10 displays the current distribution of the handbag zipper antenna, with a close-up of the left part. It could be seen that the excitation is effective and the current runs along the zipper from the left to the right since the feeding probe is mounted near the left terminator of the zipper.

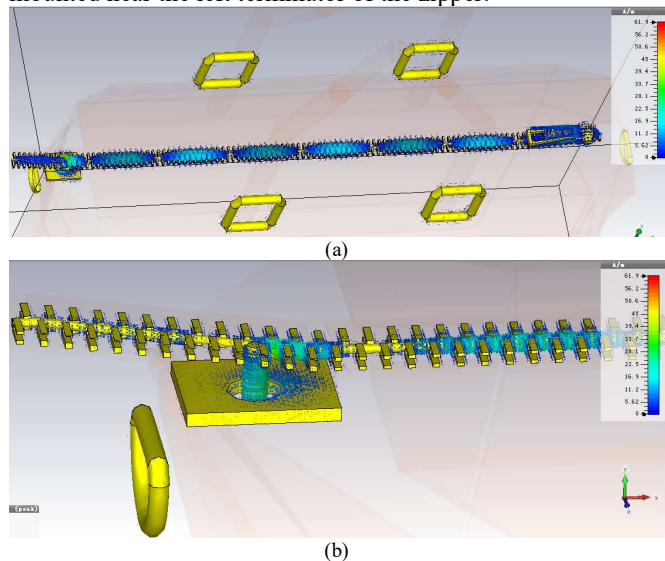


Fig. 10. The current distribution of the handbag zipper antenna. (a) The whole scene, (b) Close-up of the left part.

In the real applications, the zipper may be opened to some extent. Fig. 11 presents some typical radiation patterns.

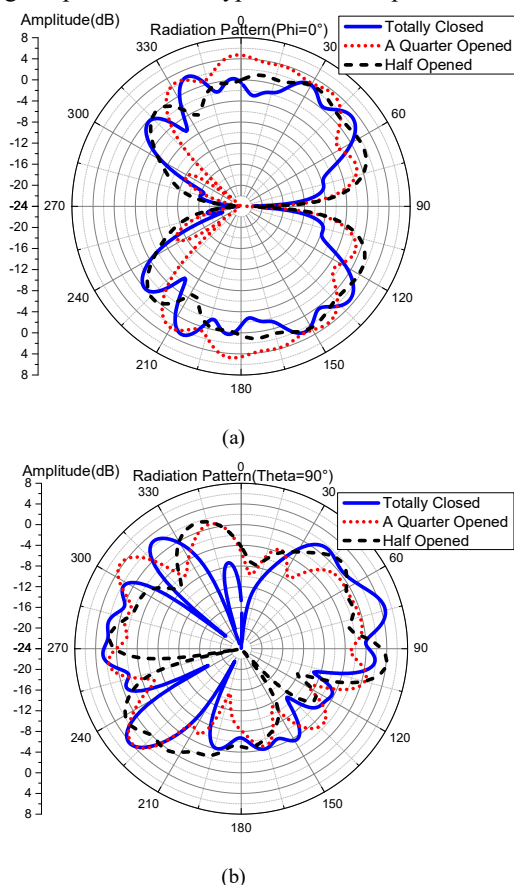


Fig. 11. Radiation patterns of the handbag zipper antenna at different open statements including totally closed (@ 2.41GHz), a quarter opened (@ 2.35GHz) and half of the zipper opened (@ 2.48GHz). (a) View of XoZ plane, (b) View of YoX plane.

The radiation patterns presented in Fig. 11 include curves under the situations where the zipper is closed, quarterly opened or half opened, the central frequency of which is 2.41 GHz, 2.35 GHz and 2.48 GHz, respectively. There are not many changes in the XoZ plane, while the main radiation direction in the YoX plane would vary due to the structure variations when the zipper is opened, as it could be seen from the curves. Actually, the teeth that have been opened would still act like directors for the closed part of the zipper antenna.

In consideration of the impact of the parameters, we studied the length of the zipper teeth. Fig. 12 offers the radiation patterns corresponding to the teeth length of 3.0 mm, 4.5 mm and 6.0 mm, whose frequency is 2.29 GHz, 2.44 GHz and 2.53 GHz, respectively. The gain of the antenna increases slightly with the teeth length due to the growing of the electric size, as shown in the figure. For instance, a relative amplitude of 4.72 dB, 4.74 dB and 5.79 dB corresponding to the three lengths at 82° , 74° and 70° could be seen in Fig. 12(b).

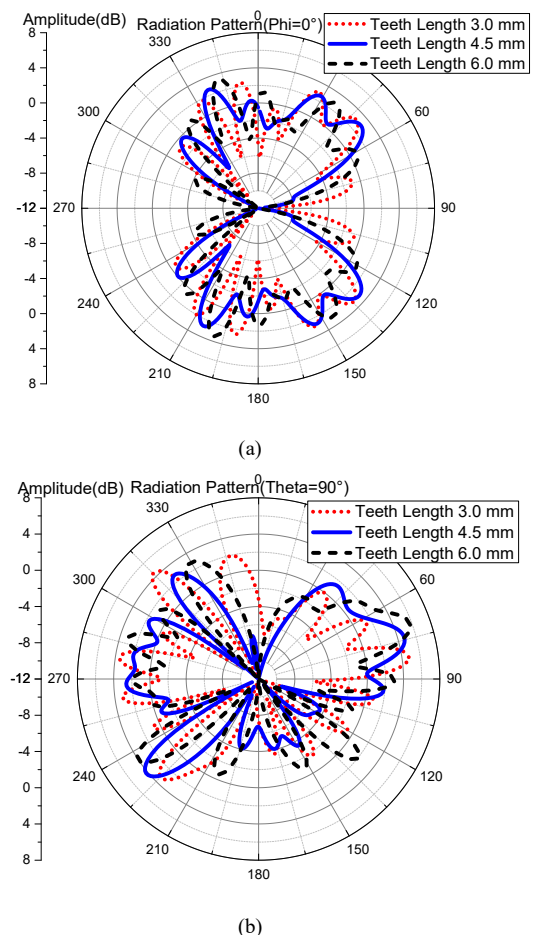


Fig. 12. Radiation patterns of the handbag zipper antenna corresponding to different zipper teeth lengths (the frequency of 2.29 GHz, 2.44 GHz and 2.53 GHz, corresponding to the teeth length of 3.0 mm, 4.5 mm and 6.0 mm, respectively). (a) View of XoZ plane, (b) View of YoX plane.

At the same time, the reflection coefficients vary with the teeth length due to the changes of the structure dimensions. Fig. 13 shows the calculated results. It can be seen that the resonance frequency shifts to higher points regardless of the teeth length varying from 4.5 mm to 3.0 mm or 6.0 mm.

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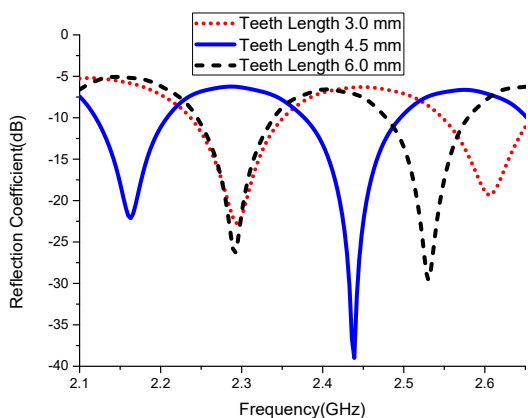


Fig. 13. Reflection coefficients of the handbag zipper antennas with different teeth lengths.

On the other hand, the width of the zipper teeth will influence the voltage stand wave ratio too, as shown in Fig. 14. All the three configurations achieve two resonance points in the range of 2.0 GHz -2.6 GHz. The resonance frequency changes from 2.16 GHz and 2.44 GHz to 2.19 GHz and 2.47 GHz when the width varies from 1.0 mm to 1.5 mm. And the frequency decrease to 2.15 GHz and 2.42 GHz when the teeth width decreases to 0.5 mm.

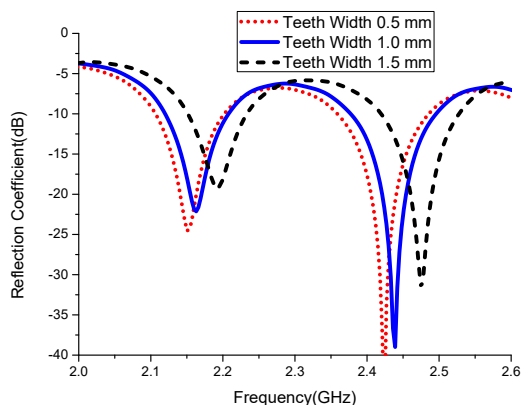


Fig. 14. Reflection coefficients of the antennas with different teeth widths.

The gain values of the handbag zipper antenna with different feeding locations are shown in Fig. 15, including results of the probe near the left terminator, on the left quarter and on the center of the zipper.

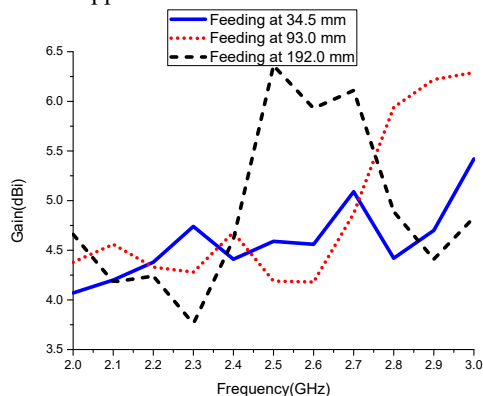


Fig. 15. The gains of the bag zipper antenna at different feeding locations.

The following consideration is the influence of the zipper teeth length on the gain of the antenna, as shown in Fig. 16. The gain does not vary monotonically with the size of the teeth, as a result of the relative comparison between the wavelength and the size of the teeth.

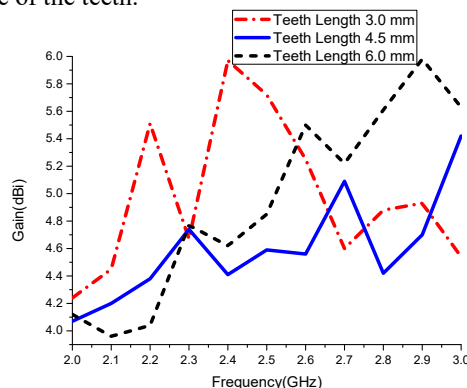


Fig. 16. The gains of the bag zipper antenna with different teeth lengths.

Furthermore, the impact of the zipper teeth width on the radiation pattern is studied, as shown in TABLE III. There are not many differences occurred according to the variation of the teeth width from 0.5 mm to 1.0 mm and 1.5 mm (corresponding to 2.33 GHz, 2.28 GHz and 2.46 GHz), which means this parameter weighs little in the performance consideration of the antenna.

TABLE III
THE GAIN OF THE HANDBAG ZIPPER ANTENNA WITH DIFFERENT TEETH WIDTH

Teeth width (mm)	Gain of horizontal polarization (dBi)	Gain of vertical polarization (dBi)
0.5	2.44	5.12
1.0	3.25	4.75
1.5	3.92	4.46

Fig. 17(a) shows an application scenario of the handbag zipper antenna. The bag is put near the hand of a man, whose height is 175 cm with a medium body. Fig. 17(b) is the close-up view of the handbag zipper antenna near the model.

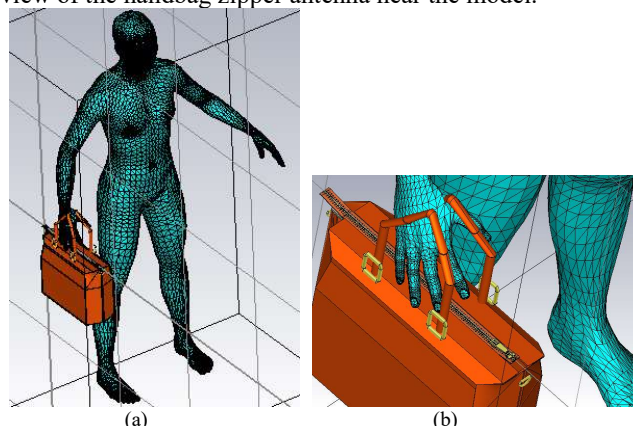


Fig. 17. The application scenario of the handbag zipper antenna. (a) The bag in a hand. (b) The close-up of the model of the handbag zipper antenna.

Fig. 18 presents the comparison of the radiation patterns considering the influence of the human body for the handbag zipper antenna. The simulation results at 2.40 GHz indicate that the difference is noticeable but not very large. A gap of not more than 1.0 dB could be observed in the main lobe. Similar

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behavior occurs at other azimuths. Furthermore, the main radiation azimuth and the zero points remain the same positions with some ups and downs in the amplitudes. As for the return loss, there are more slightly changes when with or without the model of human body, due to the contactless characteristic of the antenna. On the other hand, the distance between the bag and the person also benefit the performance.

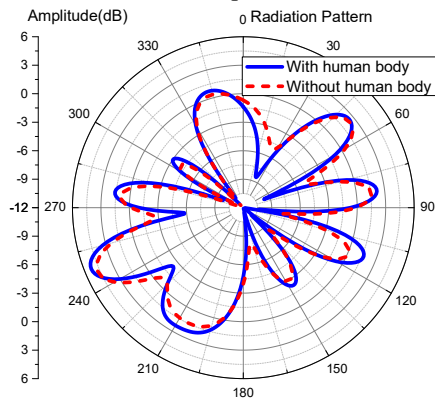


Fig. 18. Comparison of the radiation patterns @ 2.40 GHz considering the influence of the human body for the handbag zipper antenna.

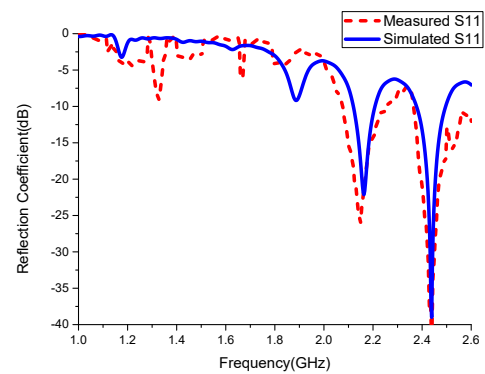
The movement of the person will bring the variation of the altitude and the elevation of the handbag. As it is an antenna with wide radiation angles, the performance reduction of the communication or the interconnection would be affordable.

IV. MEASUREMENT AND RESULTS

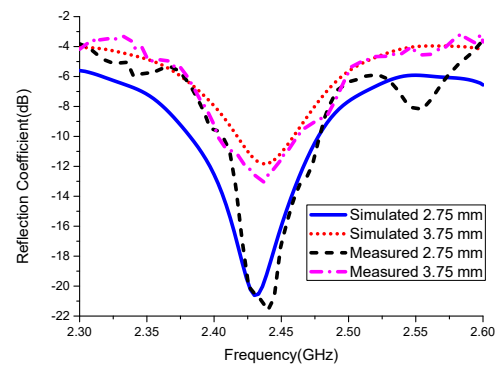
A handbag zipper antenna is fabricated and measured for verification. The substrate is FR-4 (a dielectric permittivity of 4.3) with the dimensions of 20 mm×20 mm, which is very small in size and only a bit bigger than the connector to benefit the portable applications. An SMA connector is used to feed signals. For the measurement of reflection coefficients, a vector network analyzer, Anritsu 37369A, is used to obtain the S11 curves in the anechoic chamber, as shown in Fig. 19(a). Fig. 19(b) presents the close-up of the feeding structure of the antenna. It is showed out of the handbag for a clear view while we would prefer to put it inside of the bag when carrying it here and there.



Fig. 19. Measurement of the reflection coefficients of the handbag zipper antenna with a vector network analyzer. (a) The scenario of the measurement. (b) The close-up of the feeding structure.



(a)



(b)

Fig. 20. Comparison of the simulated and measured results of the S11. (a) Feeding at $x=34.5$ mm and $z=1.75$ mm, and (b) Exciting around the tooth at $z=2.75$ mm and $z=3.75$ mm.

Fig. 20(a) presents the comparison of the simulated and the measured S11 curves from 1.0 GHz to 2.6 GHz, when the feeding point locates at the coordinate of $x=34.5$ mm and $z=1.75$ mm. And Fig. 20(b) is that for the feeding point mounted around the tooth with $z=2.75$ mm and 3.75 mm. The curves agree fairly well, especially at the central frequency of 2.44 GHz.

The radiation patterns of the magnitude of the electric field have been measured in the anechoic chamber with the help of a non-metal turntable, as shown in Fig. 21.



Fig. 21. Measurement of the radiation patterns of the bag zipper antenna in the anechoic chamber.

Fig. 22 presents the comparison of the simulated and the measured radiation patterns at 2.44 GHz, when the zipper

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totally closed. The pointing direction of the main lobe in the radiation pattern of vertical plane (the view of YoX plane) for the measurement result is similar to that of the simulated, while the former has fewer side lobes and a smaller back lobe. The main radiation angle is about 20° above the ground, due to the impact of the lower part of the handbag.

As for the horizontal plane (the view of XoZ plane) in Fig. 22(b), the shapes of the radiation patterns are similar and there are not much difference in values among most of the directions, only to note that the beam of the measured result is sharper than that simulated.

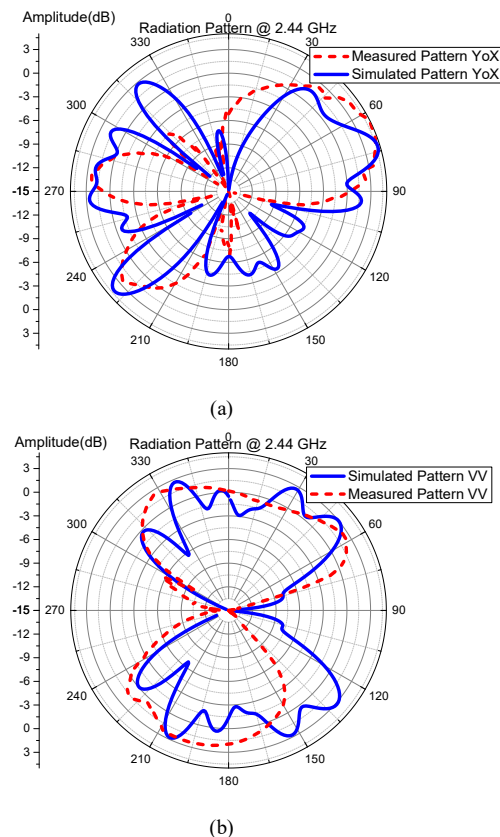


Fig. 22. Comparison of the simulated and measured radiation patterns of the handbag zipper antenna @ 2.44 GHz. (a) View of YoX plane, and (b) View of XoZ plane.

V. CONCLUSION

The simulation and measurement results demonstrated the validation of the handbag metal zipper antenna. A gain of about 5 dBi could be obtained at 2.44 GHz. To make use of the zipper in the handbag is a good idea to benefit the off-body systems. There is no need to change the conventional zipper or to destroy it. Special impedance transforming structure could be designed if certain frequency bands or points are demanded. It is larger in size than the common types of wearable and body-centric network antennas, which will benefit the radiation patterns as well as the gains. The price of the antenna is nearly zero. It has no need for extra space to mount onto or near the body and it is firmly fixed in the handbag, without the worry of dropping off. The handbag zipper antenna can operate in multiple frequency bands by changing the feeding location and can obtain different radiation directivities by dragging the handle of the zipper open or closing it.

Promising application areas refer to the body-centric networks, the Internet of Things, the smart household electrical appliances, smart factories and smart cities, the monitoring for the environment, the wireless communications and the power transferring, and the navigation together with the positioning, etc.

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