Compact Antenna Designs for Wearable and Portable Medical System

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Abstract- A button wearable antenna and an L-shape planar inverted F antenna (PIFA) antenna were designed for medical eHealth system. A spiral top button wearable antenna was implemented into the antenna structure to obtain additional inductance. Both simulated and measured reflection coefficients show it can cover both the 2.4-2.5GHz and 5.15- 5.825 GHz ISM bands. Good omnidirectionality was achieved at x-y plane for all three bands. A compact L-shape PIFA antenna was designed and fabricated for laptop wireless local area network (WLAN) application to communicate with wearable antenna. The antenna was formed to L-shape to minimize the ground plane size, so that it can be fitted into the top corners of a laptop display. The effect of the presence of display panel was discussed.

I. Introduction

New microwave technologies have an ever-growing impact on our lives, and the personalized healthcare sector is no exception. For more than ten years, the European Commission has been trying to extend healthcare beyond hospitals to people's homes through an eHealth system. The system could optimize the communication between patients and doctors and allow early diagnosis and more cost-effective patient monitoring and consulting beyond the ordinary hospital environment [1]. The eHealth system could be in the form of wearable, or portable systems, as well as in-vitro point-of-care diagnostic devices for home use [2]. Wearable systems are able to monitor patients' health-related parameters such as heart rate, temperature, blood oxygen, etc. continuously and process and feed the information to the doctors. The portable system can be in the form of small wireless devices, such as a handset or laptop, which can operate at any location. They can be used to communicate with an implantable or wearable system or temporarily attached to the human body to have the similar function as a wearable system. The antenna is an essential part of wearable, or portable eHealth systems. The design complexity depends on the radio transceiver requirements as well as the propagation characteristics of the surrounding environment.

Wearable antennas have the advantages of low profile, small size and a relatively high gain. The existing wearable antenna designs include the microstrip patch antennas attached to clothing fabric substrate, and the so-called "textile type" wearable antenna. A rectangular patch with probe feed and linear polarization or with microstrip feed and circular polarization were studied in [3-4]. However, the fabric type of substrate has poor electrical properties as well as poor ability for moisture-proofing. To overcome these problems, small size button antennas were introduced [5-7]. Such button-shaped cylindrical structures with a metal disk on top connected to a ground plane were designed from the actual jeans button structure.

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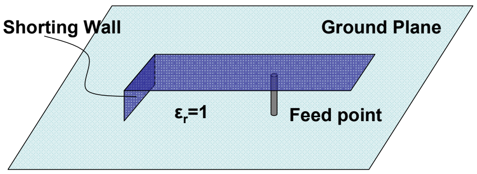
They can be considered as top loaded monopoles mounted on a fabric substrate. Due to its small ground plane, fabric substrate has much less effect on the performance of the "button type" wearable antenna as compared with "textile type" ones. Plus, a small ground plane also guarantees the flexibility of the antenna. The proposed wearable antenna is inspired by a conventional denim jeans button and can be used as a standard button for various garments. As shown at Fig.1, different from previous button antenna designs, a spiral top is implemented into the antenna structure as an additional inductor element. The button antenna is residing on a fabric substrate with ground plane at the bottom. A 50 Ohm coaxial probe is used underneath the ground plane to excite the antenna.

Fig. 1. WIPL-D [8] model of the multi-band spiral top button antenna.

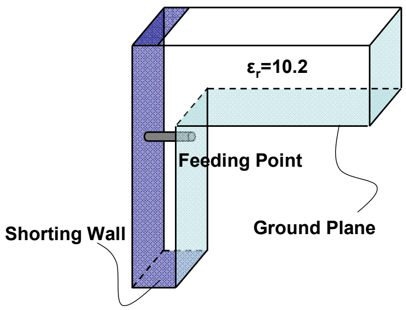
Nowadays, laptop usually acts as the portable system which is used to communicate with the wearable system. With the fast development of wireless local area networks (WLAN), more and more laptop computer manufacturers desire to integrate WLAN devices into their laptops. An integrated antenna for laptop computers is one of the most important parts in the design of laptop WLAN communication systems (e.g. Bluetooth, Wi-Fi, Wi-Max). In [9], an inverted-F antenna was designed on a PC card and was integrated into laptop computers by inserting the PC card into a laptop PC slot. To avoid the physical breakage and damage associated with external plug-in antennas, however, more and more laptop manufacturers prefer the complete integration of communication systems into laptops [10]. To avoid the shadowing effect from the laptop system and external environmental influence such as metal desks and user's hands or laps, as mentioned in [11], antennas are suggested to be mounted around the top or close to the top of the laptop display to achieve best coverage. To provide polarization diversity, usually more than one antenna is needed.

Here, a low profile L-shape PIFA antenna is designed and fabricated for laptop WLAN application. The total antenna size including ground plane is small enough to fit in either the left or the right corner of a laptop display, as shown at Fig. 2. The new antenna is an extension of the original PIFA antenna concept by bending its substrate and ground plane to an L-shape, as shown at Fig. 3. Since usually laptop manufactures use extensive conducting shields inside the covers of the laptops to minimize radiation from high-speed processors, one of the major design challenges associated with wireless integration into laptops is to design an antenna which can radiate efficiently under such environment. Since the laptop keyboard base is electrically far from the proposed antenna locations, the lossy conducting LCD is the major factor to affect antenna performance. Therefore, to study the effect of the laptop on the antenna performance, a parasitic lossy PCB panel is used to mimic the laptop LCD panel. Both the cases of antenna alone and with display panel are simulated and measured. A full coverage of 2.4-2.5GHz ISM band is achieved. The effect of the presence of display panel is discussed.

Fig. 2. Proposed antenna locations inside of a laptop computer.



(a)



(b)

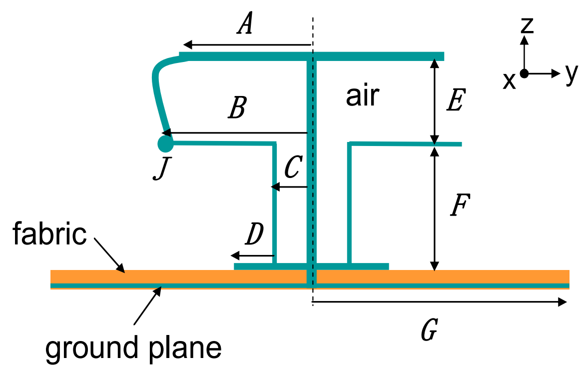
Fig. 3. (a) Original PIFA; (b) Proposed L-shape PIFA.

II. MULTI-BAND BUTTON WEARABLE ANTENNA

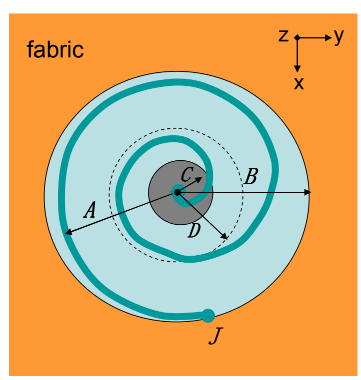
In this section, a multi-band spiral top button antenna was designed, fabricated and tested as a wearable electronic device for wireless local area network (WLAN) application. Compared with "textile type" wearable antenna, it has the advantages of compact size, small ground plane, less dependence on the fabric substrate. A spiral top was implemented into the antenna structure to obtain additional inductance. Both simulated and measured reflection coefficients are presented. Three resonance bands are achieved which cover both the 2.4-2.5GHz and 5.15-5.825 GHz industrial, scientific and medical (ISM) bands. Simulated far-field total gain patterns are also illustrated. Good omni-directionality is achieved at the x-y plane for all three bands.

2.1 Antenna design and geometry

Figure 4 shows both side and top views for the proposed multi-band spiral top button antenna mounted on a grounded fabric substrate. The whole antenna can be considered as a piece of air-filled coaxial line with inner conductor bent into a spiral shape and outer conductor folded into a circular disk as the cap of the button. The tail of the spiral is connected to the edge of the disk at point (J). The inner conductor also connects to another small base circular disk. The fabric substrate is modeled with dielectric constant of (ε_r) 1.3. The radius of the spiral top (A) is 8.5 mm and the number of turns is 3. The total length of meandered wire is around 54 mm. The radii of the inner and the outer conductors are 0.5 mm and 2.25 mm, respectively. The lower disk has a radius B of 8.5 mm. The radius of the base disk D is as small as 4 mm, which guarantees the flexibility of the antenna. The gap between spiral upper and lower disk is 4.5 mm while the distance between the lower disk and base disk is 7 mm. A 50 Ω coaxial probe is used to excite the button antenna. The antenna is designed with the help of WIPL-D.



(a) Side view

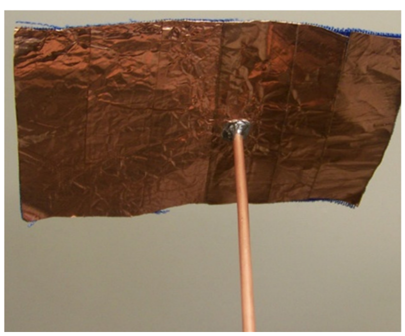


(b) Top view

Fig. 4. Geometry of spiral top button antenna.

In the experimental model, the button antenna is made of copper. A 50 Ohms coaxial cable with a SMA connector is used to excite the antenna. The spiral top is made by meandering the inner conductor of the coaxial cable. The fabric material is canvas which is commercially available, flexible and resistant to compression of its height. The bottom ground plane is made of adhesive copper tape which is also able to ensure the flexibility. Figure 5 shows photographs of the fabricated multi-band spiral top button antenna.

(a) Side view



(b) Bottom view

Fig. 5. Photo of fabricated spiral top button antenna.

2.2 Simulation and measurement results

Figure 6 shows both simulated and measured reflection coefficients curves of the proposed multi-band spiral top button antenna in free space. The dashed horizontal line marks the criterion for VSWR=2.5. The matching frequency band of the simulated results for this criterion is from 2.45 GHz to 2.6 GHz, 3.3 GHz to 3.4 GHz, and 4.1 GHz to 6.3 GHz. The frequency band of the measured result for this criterion is from 2.3 GHz to 2.7 GHz, 3.3 GHz to 3.4 GHz, and 3.9 GHz to 6.5 GHz. The calculated and measured values are in agreement. It can be noticed that the antenna bandwidth is wide enough to cover the 2.4-2.5GHz and 5.15-5.825 GHz ISM bands. It is assumed that a better impedance matching is attained in the measured results due to the loss copper material used and some fabrication tolerances, such as the bending of spiral wires, etc. The parametric studies for different lengths of the meandered wire, sizes of upper disk and lower disk, and different gaps and heights are also performed. But for the sake of the brevity, these results will not be presented here.

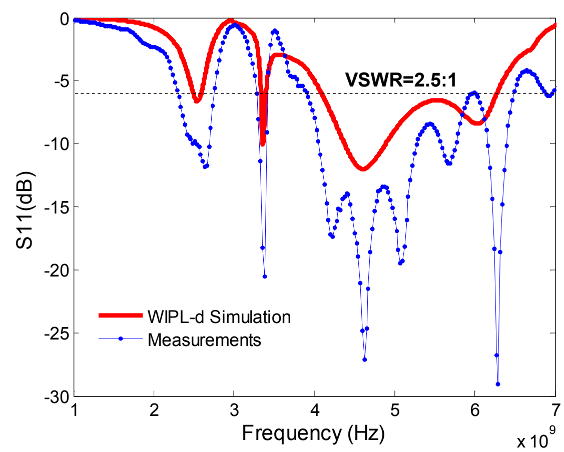


Fig. 6. Simulated and measured reflection coefficients of spiral top button antenna.

Figures 7 (a), (b), and (c) provide the simulated co-polarization and cross-polarization of the far-field gain patterns for the proposed multi-band spiral top button antenna at 2.5 GHz, 3.35 GHz and 5.2 GHz in the horizontal plane (x-y plane). It is shown that the total gain pattern has good omnidirectionality in the horizontal plane at both 2.5 GHz and 5.2 GHz. Since the z-axis is normal to wearer's body, as mentioned in [7], the shown far-field gain patterns indicate that some radiation is tangential to the body of wearer which may be beneficial for connecting to other wearable devices.

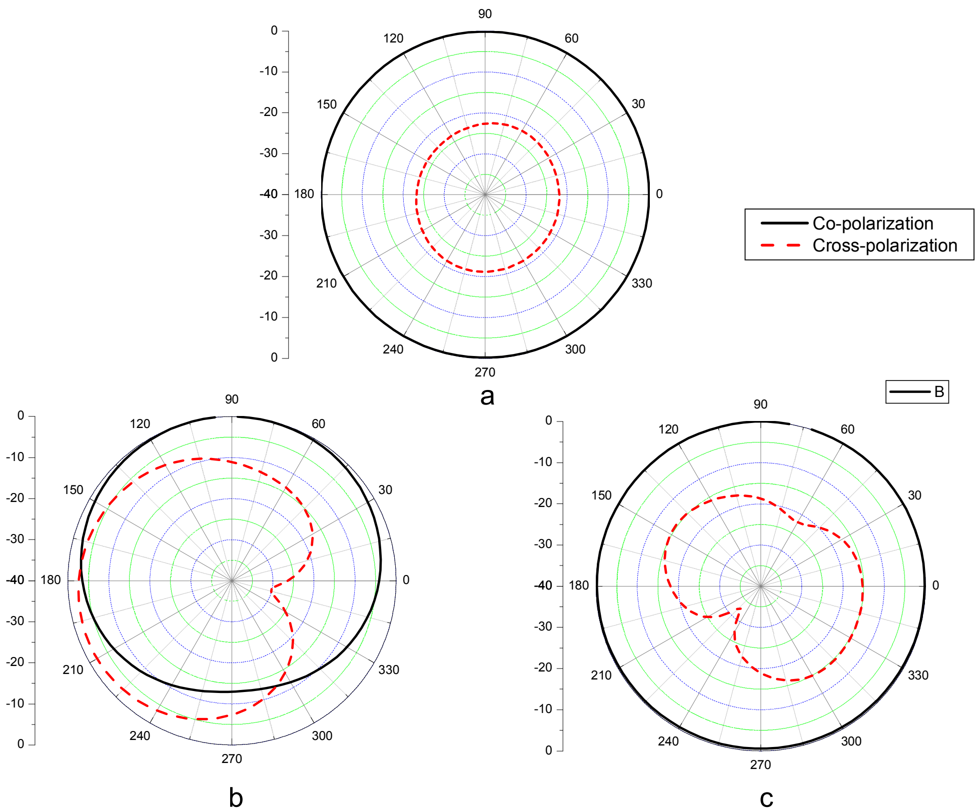


Fig. 7. Simulated x-y plane radiation patterns of spiral top button antenna: (a) 2.5 GHz; (b) 3.35 GHz; (c) 5.2 GHz.

III. L-SHAPE PIFA DESIGN FOR LAPTOP WIRELESS COMMUNICATION

3.1 Antenna design and geometry

Figure 8 shows the geometry of the proposed L-shape PIFA. The new PIFA can be regarded as the original PIFA bent into a L-shape. The ground plane has the same width (W=5 mm) as the antenna top surface. Instead of free space, the dielectric material Rogers RT/Duroid 6010 with dielectric constant (ε_r) of 10.2 is used as the substrate. The heights of the L-shape PIFA in x-dimension and z-dimension are A (24.5 mm) and B (23 mm), respectively. The distance between the antenna top surface and ground plane or the shorting wall height C is 3.85mm. The height D is 13.9 mm and the width E is 22.65 mm. A 50 Ω coaxial probe excites the antenna. The height of the probe inside of the antenna is the same as C and the probe location G is 12.73 mm high at the center of W. The top horizontal part of the L-shape antenna has the height F of 9.1 mm. The antenna is designed using the frequency domain commercial software, WIPL-D. WIPL-D is based on the surface integral equations and method of moments. It should be mentioned that in the fabrication model the electric conducting tape is used to model both the antenna top surface and ground plane. Fig. 5.9 (a) shows the photograph of a fabricated L-shape PIFA. A lossy PCB panel with size of 30 mm x 25 mm is used to mimic the lossy conducting laptop LCD, as shown at Fig. 5.9 (b).

3.2 Simulation and measurement results

Figure 10 (a) shows simulated and measured reflection coefficients curves of the L-shape PIFA alone in free space. The dashed horizontal line marks the criterion for VSWR=2.5. The frequency bandwidth of the simulated results for this criterion is from 2.4 GHz to 2.7 GHz. The bandwidth of the measured result for this criterion is from 2.33 GHz to 2.71 GHz. The calculated and measured values are in good agreement. The reflection coefficient curves of the L-shape PIFA with the parasitic lossy PCB panel are shown in Fig. 10 (b). The frequency bandwidth of the simulated and measured results for the VSWR=2.5 criteria, is from 2.43 GHz to 2.73 GHz and from 2.3 GHz to 2.82 GHz, respectively. It can be noticed that the antenna bandwidth is wide enough to cover the 2.4-2.5GHz industrial, scientific, and medical (ISM) band. It is also noted that better matching is attained for the antenna with the lossy PCB panel due to the reduced Q factor of the antenna system.

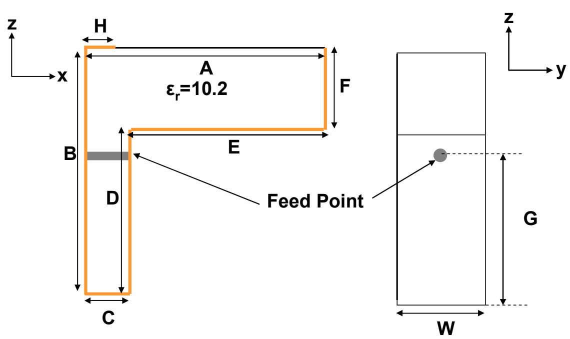
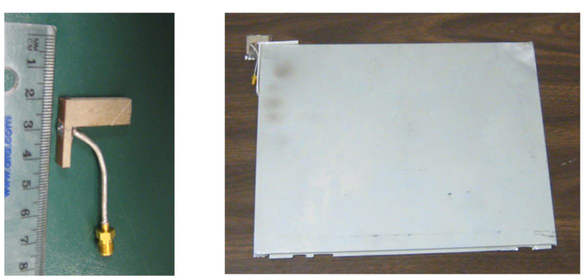


Fig. 8. Geometry of L-shape PIFA.



(a) (b)

Fig. 9. Photo of fabricated antenna: (a) alone; (b) with lossy PCB panel.

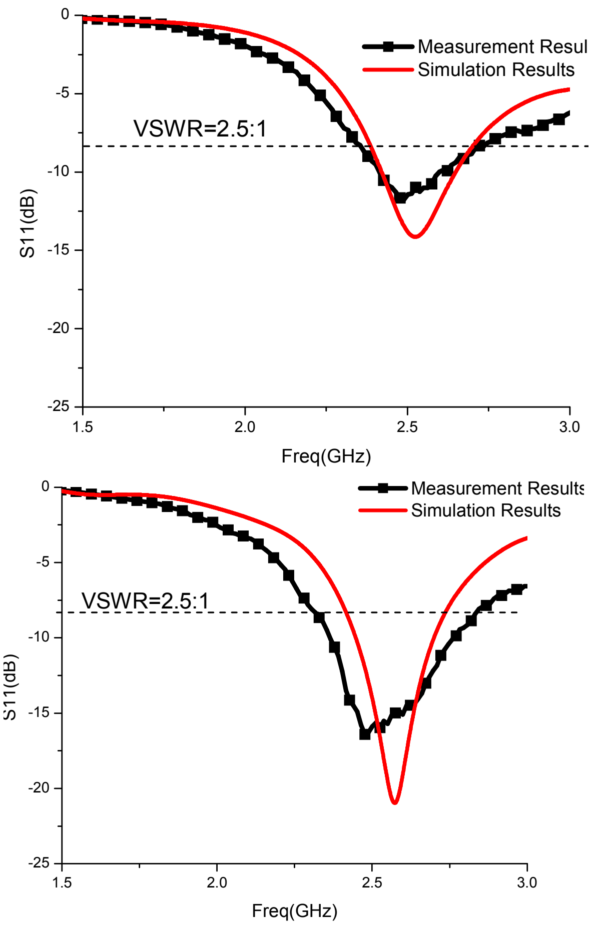
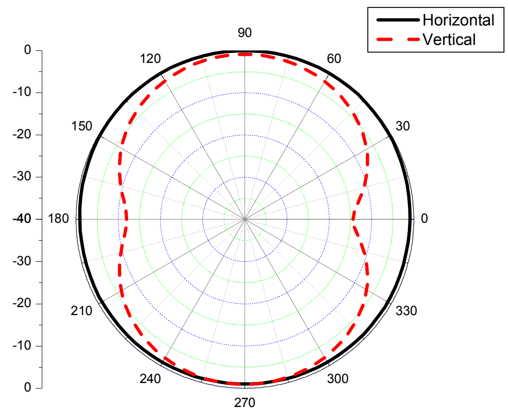
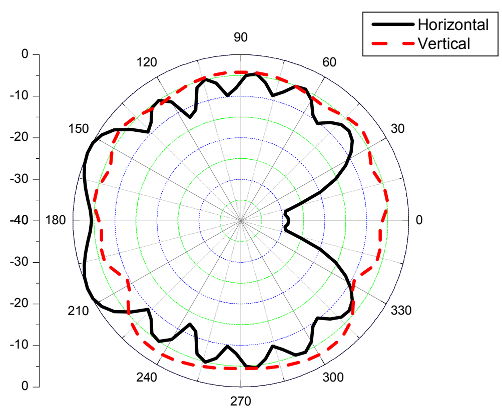


Fig. 10. Simulated and measured S_{11} for antenna (a) alone (b) with lossy PCB panel.

Figure 11 (a) and (b) provide the simulated far-field gain patterns of L-shape PIFA alone and with lossy PCB panel at 2.5 GHz in the horizontal plane (xy-plane) and vertical (yz-plane) plane, separately. It is shown that the total gain pattern is almost omnidirectional in the horizontal plane for antenna alone case. For antenna with lossy PCB panel, as we expected, the deformation of the radiation patterns is occurred. But the antenna radiates most of the energy away from the front, back, and left side of the display. The vertical plane radiation pattern is almost omnidirectional for both cases.



(a)



(b)

Fig. 11. Simulated total far-field gain patterns at 2.5GHz: (a) antenna alone; (b) antenna with lossy PCB panel.

IV. CONCLUSIONS

A button wearable antenna and an L-shape PIFA antenna were designed for medical eHealth system. The multi-band spiral top button antenna was designed, fabricated and tested for WLAN application. A spiral top was implemented into the antenna structure to obtain additional inductance. The button antenna was fed by a 50 Ohm coaxial probe with the ground plane underneath. Both simulated and measured reflection coefficients were presented. Three resonance bands were achieved at 2.4-2.6 GHz, 3.3-3.4 GHz, and 4-5.25 GHz, respectively, which cover both the 2.4-2.5GHz and 5.15-5.825 GHz ISM bands. Simulated far-field total gain patterns were also obtained. Good omnidirectionality was achieved at x-y plane for all three bands. A compact L-shape PIFA antenna was designed and fabricated for laptop WLAN application. The antenna was formed to L-shape to minimize the ground plane size, so that it can be fitted into the top corners of a laptop display. A parasitic lossy PCB panel was used to mimic laptop LCD panel. Both the cases of antenna alone and with display panel were simulated and measured. A full coverage of 2.4-2.5GHz ISM band was achieved for both cases. Simulated far-field total gain patterns were also presented. The effect of the presence of display panel was discussed.

ACKNOWLEDGEMENT

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