A small-size and multi-band wearable antenna with coplanar structure

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Abstract. A small-size multi-band wearable antenna with coplanar coupling of radiation patch and ground plane for 4G mobile communication is proposed and discussed in this paper. A coupling strip, a C-shaped slot made of copper foil and a shorting strip are combined to form the proposed wearable antenna with a simple structure and small size of 25×32 mm². The proposed antenna operates over two frequency ranges, 2308-2841 MHz and 5092-5887 MHz suitable for LTE 2300/2500 MHz, WLAN 2.4/5.2 GHz and ISM 5.8 GHz applications. In addition, the proposed antenna has better stability and it also can cover five frequency bands when the curvature radius is 45 mm and 25 mm in comparison with traditional conductive fabric wearable antennas. The designed antenna is easy to fabricated, small in volume and wide in frequency band that is applicable to most wearable electronic devices in the future.

1. Introduction

With the rapid development of human centric communication technology and the rise of the wearable electronics market, the research on wearable electronic communication devices has become a hot issue [1]. One of the most important components of wearable electronic devices is the wearable antenna. Compared with the ordinary undeformable printed antenna, the wearable antenna has outstanding advantages of flexibility and wearability [2-4]. The wearable antenna is inevitably subjected to repeated bending and deformation owing to human body during movement. Therefore, it is required that the wearable antenna in practical applications must be highly stable. In addition, driven by fierce competition in the wireless body area network market, more and more devices in wearable electronic equipment integration realize multiple functions. Meanwhile, wearable antennas also must be lightweight and portable which squeeze greatly the design space of the wearable antenna. Accordingly, it is of great challenge and high application value to design wearable antennas which cover multi-band, low profile and small size, especially when the high stability requirements of the wearable antenna is considered in repeated large deformation.

In recent years, many researches have been done on wearable antennas, especially for the design of wearable antennas with multi-band and high stability [5-12]. Reference [5] utilizes the advantage of dismountability of flexible material, and realizes the multi-band by replacing the radiation patch. Finally, a reconfigurable wearable antenna is designed. However, it is inconvenient to replace the radiation patch to realize the multi-band antenna. Reference [6] uses shorting probes to secure the flexible material. To some extent, the stability of the wearable antenna is improved, but as the shorting probes and the antenna
can not achieve the coincident optimally, the retention of air at the fixed position results in a significant reduction in the effectiveness of the antenna in experimental measurements. The RFID antennas in [7] and [8] are small size, easy to disassemble and highly stable. But because of the limitation of the antenna structure, it can not cover many frequency bands. Some wearable antennas, such as cavity antennas [9], EBG antennas [10] and aperture coupling technology [11,12], have good stability and are easy to integrate, but the manufacturing process is too complicated and leads to high cost for the antenna which realizes common communication frequency bands. Besides, flexible materials are usually chosen as dielectric layer for wearable antennas whose physical properties have a direct influence on the stability of antenna. Therefore, the selection of flexible materials as substrate is also an important part of the design of wearable antennas. Textile material is widely used in the design of wearable antennas as a flexible substrate because it has good flexibility and ideal dielectric constant [5,13,14]. Unfortunately, the density of textile is low and rough surface resulting in a large gap between radiation patch and ground plane and the stability of antenna greatly reduces. Therefore, for wearable antennas, achieving multi-band coverage while improving stability has become the key issue of future wearable antenna design.

In this paper, latex is used as substrate [15]. A compact wearable antenna with stable performance and multi-band frequency is designed by coplanar coupling of radiation patch and ground plane. The antenna can work at 2440 MHz, 5220 MHz and 5800 MHz three resonant modes by using extend strips to realize radiation patch and ground plane coplanar coupling. At the same time, the antenna material is simple and easy to manufacture. Although the antenna covers multiple frequency bands, the substrate area is only 25×32 mm². In other words, multi-frequency and miniaturization are realized at the same time. When the radius of curvature is 45 mm and 25 mm, antenna also can cover five target bands effectively and has good stability.

2. Antenna design and simulation

![Figure 1. Geometry of the proposed antenna. (a) front view; (b) back view; (c) side view](image)

The front and back figures of the wearable antenna and the detailed size parameters of the antenna are shown in Figure 1 (units are mm). The dielectric substrate of the antenna is made of 0.75 mm thick latex with size of 25×32 mm², relative dielectric constant of 3.31 and dielectric loss tangent of 0.028. The copper foil on two sides of the antenna is the radiation patch and the ground plane respectively. The radiation patch with C-shaped motivates low-order resonant mode by extending the current of the radiation patch. Shorting strip A is a copper sheet with size of 1×0.75 mm² which is connected from the central part of the radiation patch to the ground on the back of the antenna. The ground plane of antenna
adopts defected ground structure, as shown in Figure 1 (b), only by the size of 32×8.5 mm² copper foil composed of ground. The coupling strip B made by two rectangular strips which are extended from ground plane to radiation patch, is used to expand the bandwidth of WLAN 5.2/ISM 5.8 bands.

In order to analyze the design process of the antenna, the High Frequency Structure Simulator (HFSS) simulation tool is used. Figure 2 compares simulated reflection coefficients of the proposed antenna and the antenna without shorting strip. According to Figure 2, the proposed antenna has a resonant mode at 2.5 GHz and 5.5 GHz respectively without shorting strip A. However, the simulation frequency can not fully cover low-frequency WLAN 2.4 and high-frequency WLAN 5.2/ISM 5.8 bands with a 3:1 VSWR. Thus, the high frequency and low frequency bands are motivated two resonant modes simultaneously by introducing shorting strip A, which effectively extends high frequency and low frequency bands, the new antenna can completely cover WLAN 2.4 and WLAN 5.2/ISM 5.8 bands. The shorting strip A is equivalent to adding a current path to the center of the antenna, as shown in Figure 1 (a). A current path on the back of the antenna is added to the center of the antenna because the surface current of conventional patch antenna is cut off by a rectangular copper strip. Therefore, the distribution of current is cut into two completely different distributions. Moreover, the high frequency resonant modes can also be effectively extended by the blessing of the defected ground structure, thereby improving antenna performance.

![Figure 2. The simulated comparison between the proposed antenna and the referenced antenna.](image1)

![Figure 3. The reflection coefficients are simulated with different values of g.](image2)

Then, Figure 1 analyses the influence of the distance g from coupling strip B to the feed port. G is a key parameter that affects the performance of the antenna. By changing the distance g (range of 1 mm -10 mm) and keeping the other dimensional parameters unchanged in Figure 1, the S-parameters simulation curve is shown in Figure 3. The change of g has no significant influence within certain range at the first resonance peak of the antenna, but it has a very obvious influence at the second resonant peak for the center frequency of 5.5 GHz. With the increase of g, the central resonant peak at high frequency shifts gradually to low frequency and the bandwidth becomes narrower. Therefore, in order to cover the high-frequency section better, 4 mm is the optimal selection of parameter g.

3. Experiment results and discussion
The antenna has been manufactured and measured, and the fabricated antenna is shown in Figure 4. In order to facilitate the measurement, a plastic with a relative dielectric constant of approximately 1 is used to support the antenna. The contrast of the reflection coefficients of the antenna simulation and measurement is shown in Figure 5 and Agilent N5230C Vector Network Analyzer is used in measurement. From experimental results in Figure 5, it can be found that the frequency range is 2308 MHz - 2841 MHz and 5092 MHz - 5887 MHz with a 3:1 VSWR. Thus, the fabricated antenna covers both low-band and high-band with a 3:1 VSWR bandwidth of 533 MHz and 795 MHz respectively, which is sufficiently wide for the WLAN 2.4/5.2/LTE 2300/2500/ISM 5.8 bands operation. Since the
two central frequencies are separated by a great distance, in order to measure the result accurately and reliably, lower and higher central frequencies to be measured step by step. That is to say, the whole frequency bands are measured by two times in Figure 5. The experimental results of the reflection coefficient are partially shift compared to the simulated result due to some difficulties from the flexibility of substrate. However, experiment and simulation results covered all of the actual operating frequency bands within the target frequency range.

In order to validate the practicability of the antenna, the radiation patterns of the fabricated antenna are measured in SATIMO anechoic chamber. First, Figure 6 shows the measured radiation patterns at 2400 MHz, 5200 MHz and 5800 MHz. For 2400 MHz in Figure 6 (a), the radiation has a good omni-directional in x-z, x-y and y-z at 2400 MHz, which indicates that the radiation characteristic of the proposed antenna is relatively stable for WLAN 2.4/LTE 2300/2500 operation. While for high-band at 5200 MHz and 5800 MHz in Figure 6 (b) and (c), some variations can be seen in the radiation patterns, which are owing to high-order resonant modes. In fact, a large area of current distribution is close to coupling strip at high-frequency section, which has a certain influence on the radiation pattern of the high frequency antenna.

Figure 7 shows the measured gain and radiation efficiency of the antenna. Over the lower band LTE 2300/2500/WLAN 2.4 and upper band WLAN 5.2/ISM 5.8, the measured gain and radiation efficiency is more than 35% and 1 dBi in most frequency. Only around 2300 and 5150 MHz there are two traps with the bandwidth of less than 50 MHz below 35%, but the lowest point is still more than 30%. The radiation characteristics show that the antenna meets the requirements in the wearable electronic communication device.

4. Stability analysis of antenna
For flexible wearable antennas, a key index is the measurement of the stability of the antenna at different bending degrees. As shown in Figure 8, the antenna is fixed on a flexible plastic whose dielectric constant is approximately 1. From the knowledge of the radius of curvature, we know that when R is smaller, the antenna bends more. The coefficient of reflection of the antenna simulation and measurement are shown in Figure 9 when select 45 mm and 25 mm as R respectively. It can be seen from Figure 9 (a) when the R is 45 mm, the reflection coefficient of the antenna is simulated and measured with small deviations. But, in the case of larger bending, that is, when R is 25 mm, the frequency deviation of the antenna at the low frequency is small while a large frequency deviation at high frequency. But overall, the antenna still covers the designed target band very well, and can meet the needs of the actual operating frequency band in the two typical bending modes.
Figure 6. Measured two-dimensional radiation patterns for the proposed antenna at (a) 2400 MHz; (b) 5200 MHz; (c) 5800 MHz.

Figure 7. The measured gain and efficiency of antenna.

Figure 8. The state of wearable antenna under bending.
Figure 9. Simulated and measured reflection coefficient of antenna under different bending conditions. (a) R=45 mm; (b) R=25 mm.

5. Conclusion
In this paper, a compact wearable antenna covering a wide range of frequencies is designed by coplanar coupling of radiation patch and ground plane. The proposed antenna achieves two wide operating bands of 2308 - 2841 MHz and 5092 - 5887 MHz to cover the LTE 2300/2500/WLAN 2.4/5.2/ISM 5.8 bands with a 3:1 VSWR. The test results show that the above parameters can meet the actual requirements of the future wearable antenna. Moreover, the antenna may be in a larger degree of bending in practical use. Therefore, two typical bending modes are selected and measured, and it is found that the antenna can still satisfy the coverage of target frequency band and has high stability. Therefore, a small-size and multi-band wearable antenna with coplanar structure designed in this paper is very competitive in the practical application of wearable electronic devices in the future.

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