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A Compact Flexible Printed Monopole Antenna with Embedded Periodic H-Shaped Slots for WLAN Applications

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Abstract—In this paper, a compact printed monopole antenna with periodic H-shaped slots for WLAN application is proposed, designed, and fabricated with standard flexible printed circuit board process. By cutting four H-shaped slots in the radiation patch of the printed monopole antenna, the resonant frequency of the monopole antenna can be reduced; therefore, a compact antenna is realized. The radiator size of the antenna is $0.07\lambda_g \times 0.19\lambda_g$, which is much smaller than that of a traditional printed monopole antenna. By utilizing electromagnetic simulation software CST, the antenna is simulated and optimized. Moreover, the performance of the proposed antenna is discussed taking into consideration the possible effects of deformations due to the flexibility of the substrate. A sample antenna is manufactured and measured to prove the predicted performance of our proposed antenna. The measured results agree well with the simulations. Hence, the proposed method in this paper is a promising candidate for the design of compact antennas.

1. INTRODUCTION

With the rapid development of wireless communication systems, antennas as their key component face increasing challenges in terms of light weight, small size, low cost, and ease of fabrication [1, 2]. With the development of integrated circuit and component technology, the size of these devices is decreasing, and the demand for antenna integration and miniaturization is increasing. Various techniques for designing compact monopole antennas based on different structures have been proposed [3–5], such as tape meander line [6], folded meandering branches [7], bent folded [8], embedded slots [9], meandered split-ring slot [10], loading rectangular parasitic elements [11], and coplanar waveguide (CPW)-fed slot antenna [12, 13].

In [14], a multi-folded tapered monopole antenna is proposed. By the space between the folded strips, impedance matching of antenna is obtained. However, its structure is 3-D, not 2-D, which increases manufacturing difficulty and cost. In [15], a compact monopole antenna is realized by half-cutting method; however, its volume is still too large. Meandering techniques [16, 17] are used to miniaturize a printed monopole antenna, which enables the antenna to reduce size more flexibly both physically and electrically. However, the resulting antenna has a narrower bandwidth than other compact monopoles realized by other techniques.

Recently, metamaterial has been widely used to design compact antennas [18–20]. In [21], transmission line metamaterial (TL-MTM) provides a design method for realizing compact antennas. However, the bandwidth of a traditional TL-MTM antenna is narrow. In [22], by utilizing the property of metamaterial, different feeding modes and monopole structure composed of single split ring resonator

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(SRR) and double SRR have been adopted to realize a compact antenna. Although miniaturization of antenna is realized, the design process is complex, which leads to narrow bandwidth and low radiation efficiency.

In this paper, a novel compact flexible printed monopole antenna with periodic H-shaped slots is proposed. By cutting four H-shaped slots in the patch of a monopole antenna, the resonant frequency of the antenna can be reduced. The antenna design and simulated results have been carefully examined and discussed in detail. Furthermore, the proposed antenna is fabricated and measured. The measurement is in good agreement with the predicted results, which verify our design method.

2. ANTENNA DESIGN AND DISCUSSION

The proposed compact monopole antenna is illustrated in Figure 1. The antenna consists of a printed monopole and four H-shaped slots cut on the patch of the printed monopole. The entire monopole antenna is connected to a $50\,\Omega$ microstrip feeding line through an impedance transformation section. In our design, the antenna is built on a flexible substrate polyimide (PI) with a thickness of 0.1 mm, and relative dielectric constant and loss tangent are 3.5 and 0.0027, respectively.

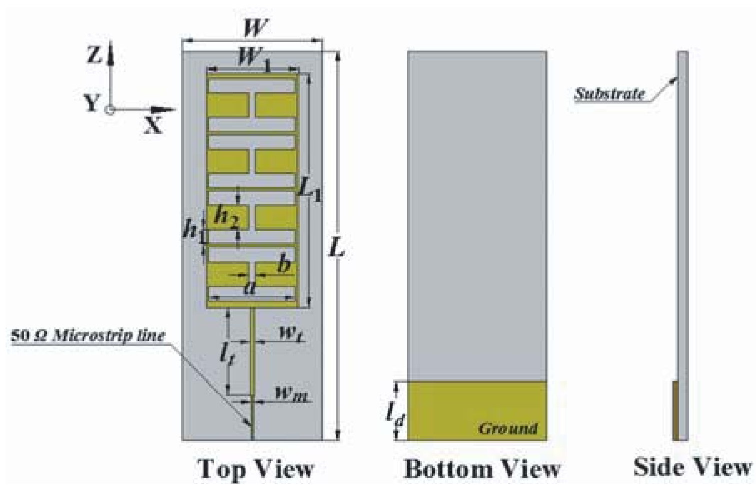


Figure 1. Physical layout of the proposed compact monopole antenna.

In order to understand the design method of the proposed compact monopole antenna, Figure 2 depicts the design evolution process. In Figure 2, an I-shaped slot, single H-shaped slot, double H-shaped slots, and four H-shaped slots are gradually added on the patch of the printed monopole antenna. Figure 3 shows the simulated S_{11} corresponding to the design evolution process demonstrated in Figure 2.

Under simulation, the size parameters are set as: $W = 14.48\,\text{mm}$, $W_1 = 9.51\,\text{mm}$, $L = 40.49\,\text{mm}$, $L_1 = 24.36\,\text{mm}$, $h_1 = 1.49\,\text{mm}$, $h_2 = 2.50\,\text{mm}$, $a = 8.95\,\text{mm}$, $b = 0.72\,\text{mm}$, $w_t = 0.42\,\text{mm}$, $w_m = 0.26\,\text{mm}$, $l_t = 9.12\,\text{mm}$, and $l_d = 6.15\,\text{mm}$.

As shown in Figure 3, the corresponding resonant frequencies of the antennas presented in Figure 2 are 2.53 GHz, 2.49 GHz, 2.44 GHz, and 2.42 GHz, respectively. Obviously, the resonant frequency of the antenna decreases gradually with the increase of the quantity of the slots. On the other hand, it can be observed in Figure 2 that the current path of the printed monopole antenna increases with the increase of the number of H-shaped slots; therefore, the frequency can be significantly reduced. In addition, S_{11} of a conventional printed monopole antenna (without embedded slots) is also plotted in Figure 3. Compared with the original printed monopole antenna, the resonant frequency of the proposed printed monopole antenna with embedded slots is obviously reduced.

To further illustrate the design evolution process of the antenna, the surface current distributions at center frequency of antenna I, antenna II, antenna III, antenna IV, and the conventional printed monopole antenna are plotted in Figure 4. As can be seen from Figure 4, the current of the conventional printed monopole antenna just concentrates on both sides of the antenna radiation patch at the

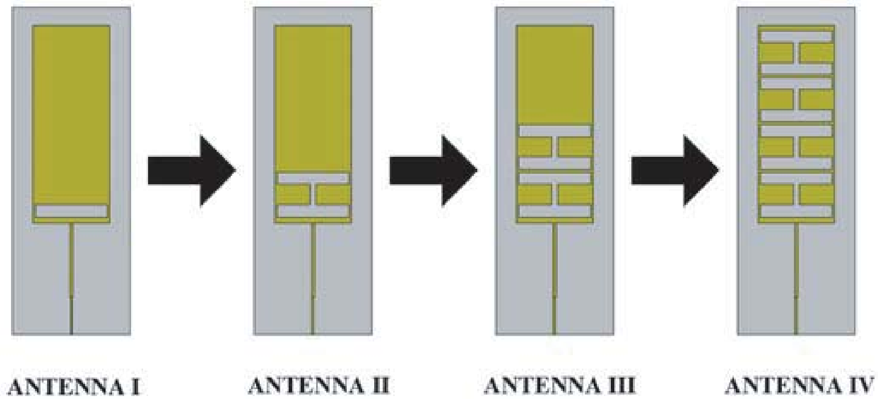


Figure 2. Design evolution process of the proposed monopole antenna.

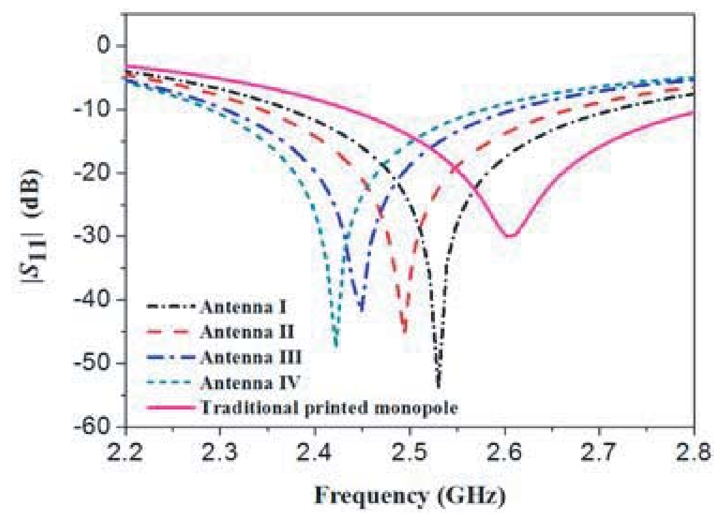


Figure 3. Simulated S_{11} of antennas involved in the evolution process.

resonance frequency. Because of the embedded slots, the current concentrates on both sides of the H-shaped slot. With the increases of embedded slots, the current path gradually becomes longer, thus, the resonance frequency decreases. The study on the current distributions also validates the analysis above.

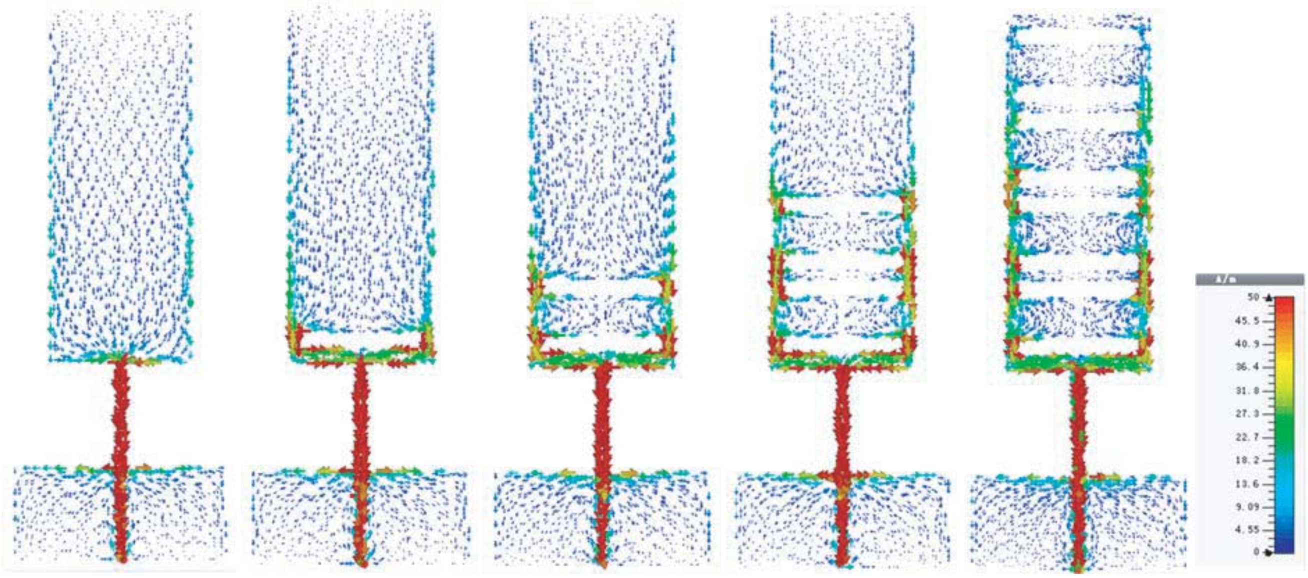
Several simulations on the key size parameters of antenna IV have been carried out to explain this phenomenon. Figure 5 shows the simulated return loss varied with the length of the H-shaped slot (a). Under simulation, the other size parameters are kept as: $W = 14.48$ mm, $W_1 = 9.51$ mm, $L = 40.49$ mm, $L_1 = 24.36$ mm, $h_1 = 1.49$ mm, $h_2 = 2.50$ mm, $b = 0.72$ mm, $w_t = 0.42$ mm, $w_m = 0.26$ mm, $l_t = 9.12$ mm, and $l_d = 6.15$ mm.

It can be obviously seen from Figure 4 that as length a increases, the resonant frequency continuously moves to the lower frequency band, which can be used to tune the resonant frequency of the monopole antenna.

Figure 6 depicts the simulated return loss under different slot widths (h_1). Under simulation, the other size parameters are kept as: $W = 14.48$ mm, $W_1 = 9.51$ mm, $L = 40.49$ mm, $L_1 = 24.36$ mm, $h_2 = 2.50$ mm, $a = 8.95$ mm, $b = 0.72$ mm, $w_t = 0.42$ mm, $w_m = 0.26$ mm, $l_t = 9.12$ mm, and $l_d = 6.15$ mm.

As can be seen from Figure 6, with the increases of h_1, the resonant frequency of the antenna moves to the lower frequency band. By tuning parameter h_1, the resonant frequency can also be changed.

In addition, Figure 7 depicts S-parameters of the antenna under different bending angles ($\alpha = 180°$,



(a) (b) (c) (d) (e)

Figure 4. Simulated surface current distribution: (a) The original printed monopole @ 2.60 GHz; (b) Antenna I @ 2.53 GHz; (c) Antenna II @ 2.49 GHz; (d) Antenna III @ 2.44 GHz; (e) Antenna IV @ 2.42 GHz.

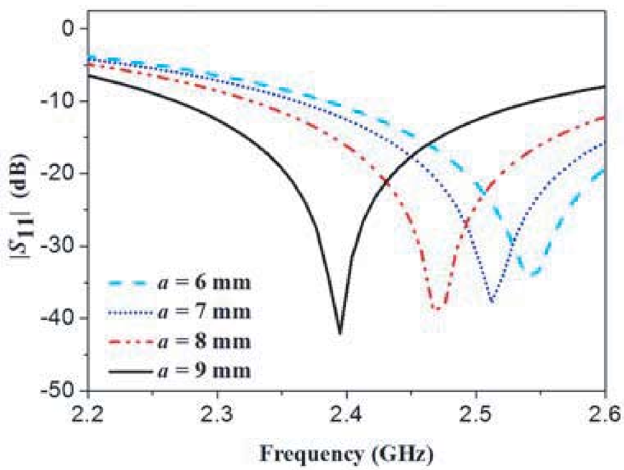


Figure 5. Simulated S_{11} varies with a.

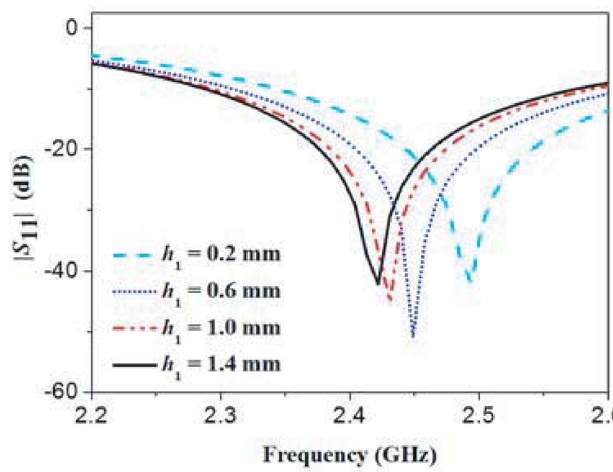


Figure 6. Simulated S_{11} varies with h_1.

30°, 45°, 60°, and 90°) of the flexible substrate.

As seen from Figure 7, with the variation of the bending angle from 30° to 90°, the resonance frequency shifts slightly.

3. MEASURED RESULTS

In order to verify our design, a sample monopole antenna is fabricated and measured. After optimization carried out by electromagnetic simulation software CST STUDIO SUITE, the size parameters of the antenna are determined as follows: $W = 14.48\,\text{mm}$, $W_1 = 9.51\,\text{mm}$, $L = 40.49\,\text{mm}$, $L_1 = 24.36\,\text{mm}$, $h_1 = 1.49\,\text{mm}$, $h_2 = 2.50\,\text{mm}$, $a = 8.95\,\text{mm}$, $b = 0.72\,\text{mm}$, $w_t = 0.42\,\text{mm}$, $w_m = 0.26\,\text{mm}$, $l_t = 9.12\,\text{mm}$, and $l_d = 6.15\,\text{mm}$. A photograph of the fabricated antenna is illustrated in Figure 8. In addition, it

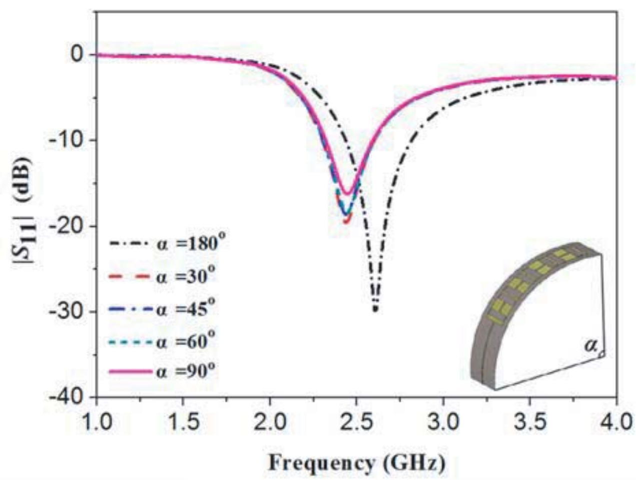


Figure 7. Simulated S_{11} varies with α.

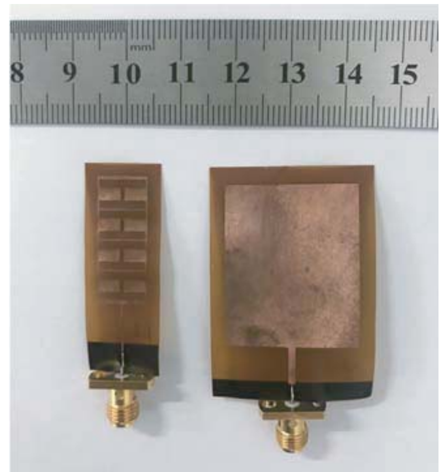


Figure 8. Photograph of the proposed monopole antenna.

can be observed in Figure 6 that the size of the proposed antenna is significantly smaller than that of a traditional printed monopole antenna. The measured reflection coefficient and radiation pattern are obtained by Keysight E5071C vector network analyzer and SATIMO near-field antenna measurement system, respectively.

Both the simulated and measured S-parameters are shown in Figure 9. The center frequency of the manufactured antenna is about 2.4 GHz, and the corresponding value of S_{11} at 2.4 GHz is about −19.8 dB. The nuances between the simulation and measurement might be caused by manufacture tolerance.

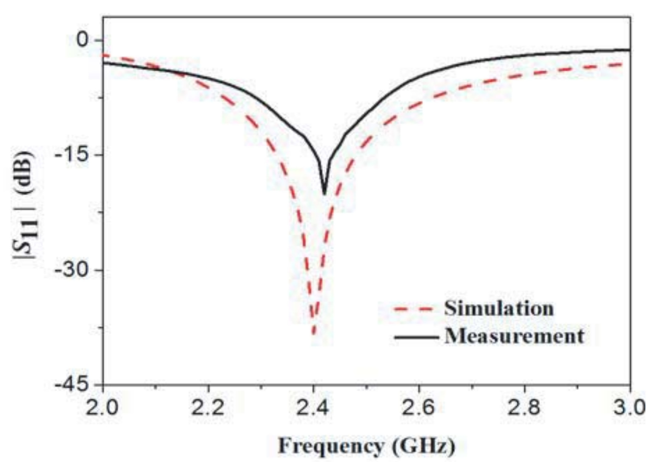


Figure 9. Simulated and measured refection coefficients of the proposed compact monopole antenna.

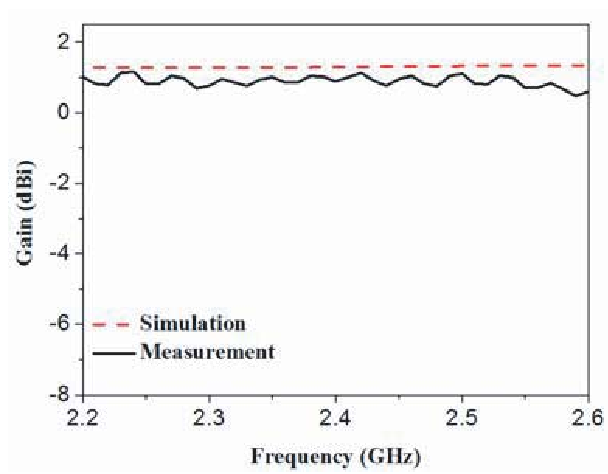


Figure 10. Simulated and measured radiation gain of the proposed compact monopole antenna.

The simulated and measured antenna gains are presented in Figure 10. The measured results show that the antenna achieves a stable gain over the operating frequency range, and the gain is about 1.4 dB, which agrees well with the simulated result.

The radiation patterns on E-plane and H-plane at 2.4 GHz are given in Figures 11(a) and (b), respectively. As can be seen from Figure 11, the antenna has excellent omnidirectional radiation characteristics as well as low cross polarization.

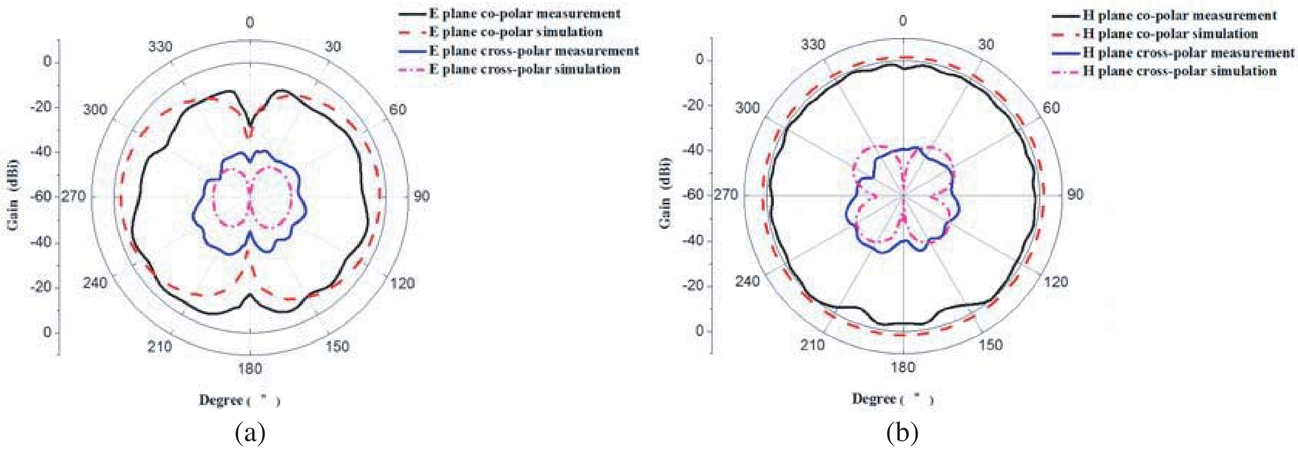


Figure 11. Simulated and measured radiation patterns of the proposed compact monopole antenna at 2.4 GHz: (a) E-plane; (b) H-plane.

4. CONCLUSION

In this paper, a compact flexible printed monopole antenna with periodic H-shaped slots is presented. By cutting four H-shaped slots in the radiation patch of a printed monopole, the current path of the antenna is lengthened; therefore, the resonant frequency can be reduced. Since the periodic H-shaped slots are cut on the printed monopole, the overall size of the antenna does not increase, and a compact monopole antenna can be realized. The proposed antenna presents good performance such as omnidirectional radiation patterns and stable gain. Finally, a prototype monopole antenna is designed, manufactured, and measured. The simulation is in good agreement with the measurement, which provides a valuable verification for our proposed design method.

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