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Design of a Wideband Sleeve Antenna with Symmetrical Ridges

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Abstract—In this letter, a novel sleeve antenna with wideband characteristic is presented for wireless communication applications. By employing a sleeve structure, impedance bandwidth of the antenna is improved through exciting a new resonant point. To obtain an impedance bandwidth enhancement further, four symmetrical ridges are introduced between the sleeve and the main radiator. An excellent wideband impedance bandwidth for VSWR ≤ 2 of 148.45% is achieved, covering the frequency range from 1.04 to 7.03 GHz, and good monopole-like radiation patterns are obtained where the un-roundness in the H-plane is less than 1.49 dB. It is very suitable for recent wireless communication services such as DCS, PCS1900, UMTS, IMT2000, WLAN, WiMAX2350/3500, WiBro, etc.

1. INTRODUCTION

Owing to the rapid development of modern wireless communication systems, wideband antennas with omnidirectional radiation patterns, light weight, simple structure, and easy fabrication are receiving much more attention nowadays. Considering various types of antennas, monopole antenna is an attractive choice to meet most of the requirements [1–5], such as a staircase-shaped patch with a modified ACS-fed structure [1], a folded monopole antenna with an inverted "S"-type structure [2], a spider-shaped monopole antenna consisting of a dielectric sleeve, a bulb-like metal body, and eight arc metal pipes [3], a CPW single-layer printed antenna with a rectangular monopole radiator etched with a half-elliptical slot [4], etc.

It is known that a common drawback of the monopole antenna is its narrow bandwidth, which is insufficient for many applications, and therefore, many attempts and studies have been implemented to broaden its bandwidth. Configurations of sleeve antennas have been demonstrated with broadband operation and monopole-like radiation patterns. And various novel sleeve antennas have been researched and proposed recently, such as dual-sleeve, open sleeve, conical sleeve, capacitive annulus loaded, and top loaded [6–11]. Shorted to the ground plane through four shorting probes, the disc-conical sleeve proposed in [6] has a thickness of 0.1λ and an impedance of about 50% for VSWR $\leqslant 2$. By introducing the dual-sleeve structure, bandwidth performance of the antenna is enhanced further, providing an operating bandwidth of 137% ranging from 730 to 3880 MHz (VSWR $\leqslant 2$) [7]. The printed dipole antenna with dumbbell-shaped open sleeve structure, which is presented in [8], achieves an impedance characteristic of 91.4% for VSWR $\leqslant 2$. However, it is seen that these designs all suffer from configuration complication and difficulties in fabrication.

This letter presents a novel wideband antenna design with sleeve structure and symmetrical ridges. Without altering the overall configuration and physical dimensions, four symmetrical ridges are employed between the sleeve and the main radiator, which improve the impedance bandwidth of the antenna significantly. A prototype of the proposed sleeve antenna has been fabricated, and its performance has been tested to verify the design methodology. The measured results show that

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the antenna exhibits an excellent bandwidth of about 148.45% for VSWR $\leqslant 2$, ranging from 1.04 to 7.03 GHz, and good radiation characteristics for both E-plane and H-plane. Due to these performances, the antenna has wide wireless communication applications such as DCS, PCS1900, UMTS, IMT2000, WLAN, WiMAX2350/3500, WiBro, etc.

2. ANTENNA DESIGN AND DISCUSSION

The configuration and coordinate system of the proposed antenna are depicted in Fig. 1, with detailed design parameters shown in Table 1. As shown in Fig. 1(a), the antenna generally consists of four parts: a main radiator, a sleeve, four symmetrical ridges, and a ground plane. The main radiator is composed of a lower cylinder with a radius of r_1 and an upper hollow one with an outer radius of r_2 and a thickness of $t = 1.5$ mm. The sleeve, which is also a hollow cylinder, has a height of h_3, an outer radius of r_3, and a thickness of t. In comparison with the normal sleeve monopole antenna, the proposed antenna adds four symmetrical metal ridges between the main radiator and the sleeve structure, which are cuboids and connected to the sleeve and the ground plane. These cuboids all have a height of h_4, a width of r_4, and a thickness of t. The height of the sleeve antenna is 72.5 mm, approximately $0.25\lambda_0$, where λ_0 is the wavelength at the low frequency in the free space.

Table 1. Dimensions of proposed antenna.

Parameters	h_1	h_2	h_3	h_4	h_5	r_1	r_2	r_3	r_4	r_5
Values/mm	50	21	31.5	24.5	3	5.5	8.5	23	8.5	45

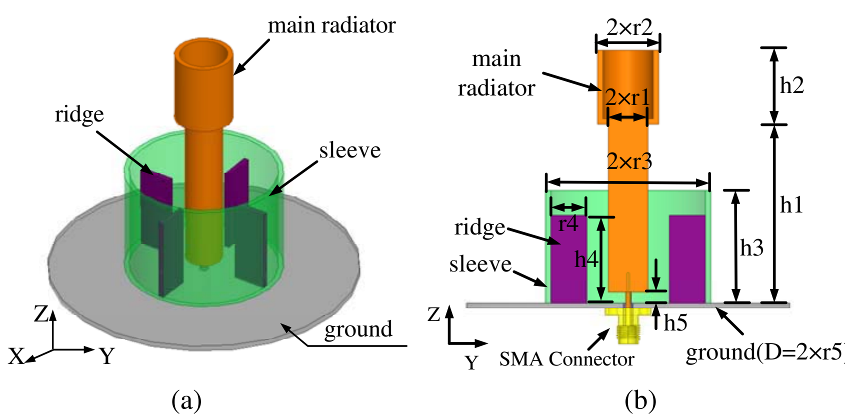


Figure 1. Configuration of the sleeve antenna with symmetrical ridges. (a) Perspective view. (b) Side view.

To investigate the effects of the sleeve and ridges on the characteristic of the antenna, different antenna structures have been designed and studied as shown in Fig. 2. The first antenna, denoted by Ant. 1, is a simple monopole without the sleeve and ridges. The next one, denoted Ant. 2, is designed by adding the sleeve structure to Ant. 1. Denoted Ant. 3, the last one is indeed the proposed antenna in this paper. Fig. 2(a) and Fig. 2(b) show the simulated frequency response of the VSWR and input impedance $Z_{in} = R_{in} + jX_{in}$ of different antenna designs, respectively. It is observed that four resonant points at 1, 3.2, 5.1, and 7.5 GHz are excited for Ant. 1, and the impedance curves of Ant. 1 fluctuate greatly, especially in the lower band, which lead to its narrow operation bandwidth. By introducing the sleeve structure, the impedance curves are much smoother at lower band, and a new resonant point at about 1.8 GHz is excited for Ant. 2, which broadens its impedance bandwidth. And by employing four symmetrical ridges between the main radiator and the sleeve, the real part of the input impedance

(R_{in}) of Ant. 3 gets larger in higher band and smaller in lower band, separately. While R_{in} approaches to $50\,\Omega$, the imaginary part of impedance (X_{in}) approaches to $0\,\Omega$, which provide the Ant. 3 with great impedance match over the whole operation band. This is due to the fact that parasitic capacitance between the ridges and the main radiator is introduced along with the ridge structure. It is noted that the sleeve structure affects the impedance matching of the lower band significantly, and the symmetrical ridges enhance the overall match without changing any physical dimensions of the sleeve antenna.

In order to further study the influence of the sleeve structure on the impedance bandwidth of the antenna, the radius (r_3) and height (h_3) of the sleeve are analyzed quantitatively. Theoretically, with the raise of r_3 and h_3, the resonant point excited by the sleeve at about 1.8 GHz moves to lower frequency due to the increase of the electrical length. But since the sleeve and ridges are connected together, the variation of r_3 not only affects the impedance match of the lower band, but also changes the interaction between the ridges and main radiator, which can be confirmed by the simulated results shown in Fig. 3(a). It is found that, as r_3 decreases, the impedance matching of the antenna becomes better in higher band and worse in lower band, and there is a good match when r_3 equals 23 mm. Additionally, the VSWR variation with h_3 is shown in Fig. 3(b). It is seen that the resonance at 1.8 GHz moves to low frequency band as h_3 raises, which validates the basic theory, and a good impedance match is achieved when $h_3 = 32$ mm.

As critical parameters to the impedance bandwidth, the length (r_4) and height (h_4) of ridges are also investigated. As depicted in Fig. 4(a), when r_4 is small, the interaction between the main radiator and ridges is weak, and there exists impedance mismatch over the operation band. As r_4 increases, the

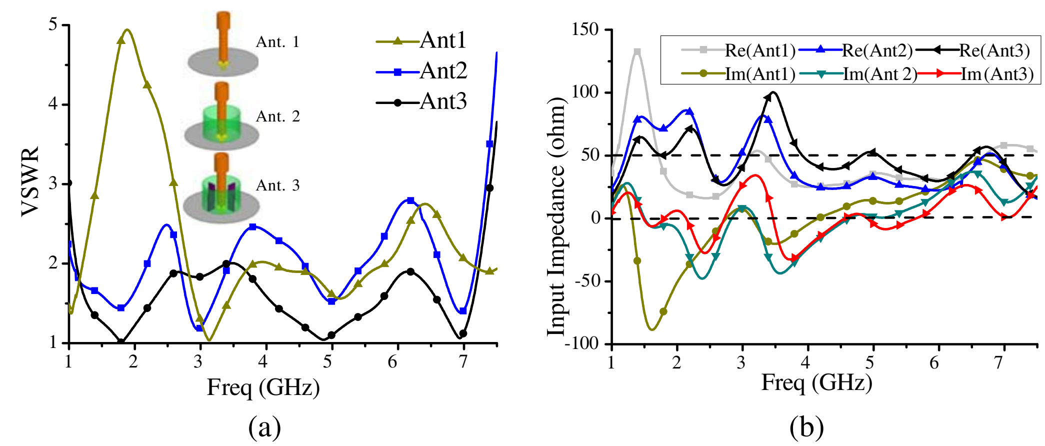


Figure 2. (a) Simulated VSWR and (b) input impedance of different antenna prototypes.

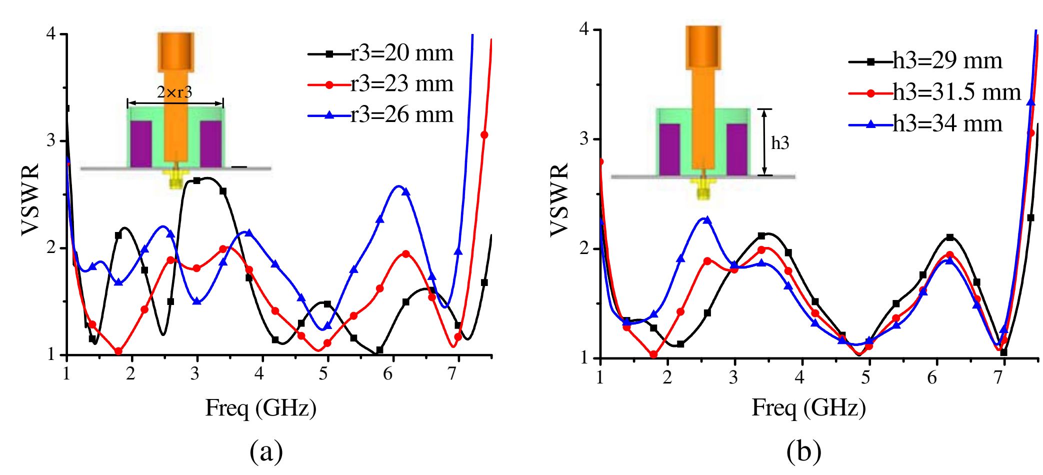
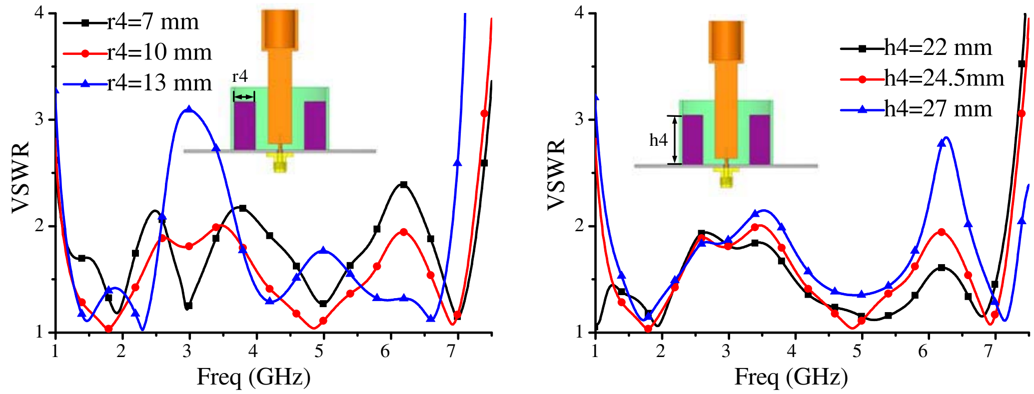


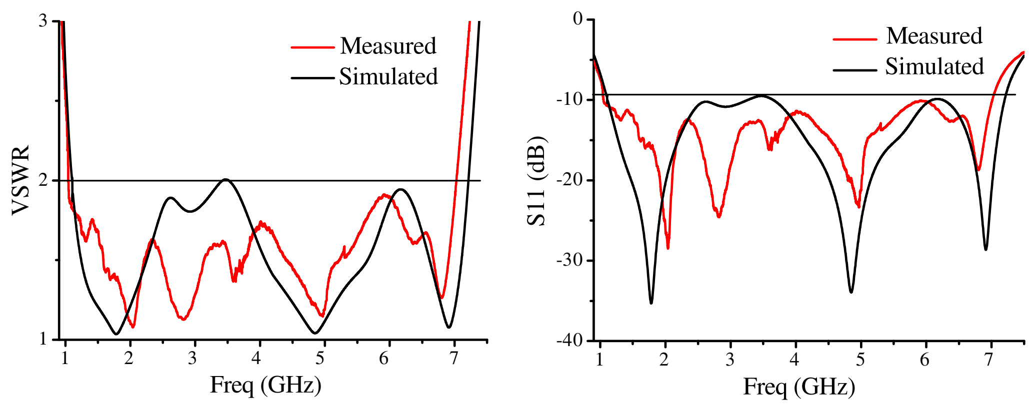
Figure 3. Simulated VSWR variation of proposed antenna versus (a) r_3 and (b) h_3.



(a) (b)

Figure 4. Simulated VSWR variation of proposed antenna versus (a) r_4 and (b) h_4.

Figure 5. Photograph of the fabricated sleeve antenna.



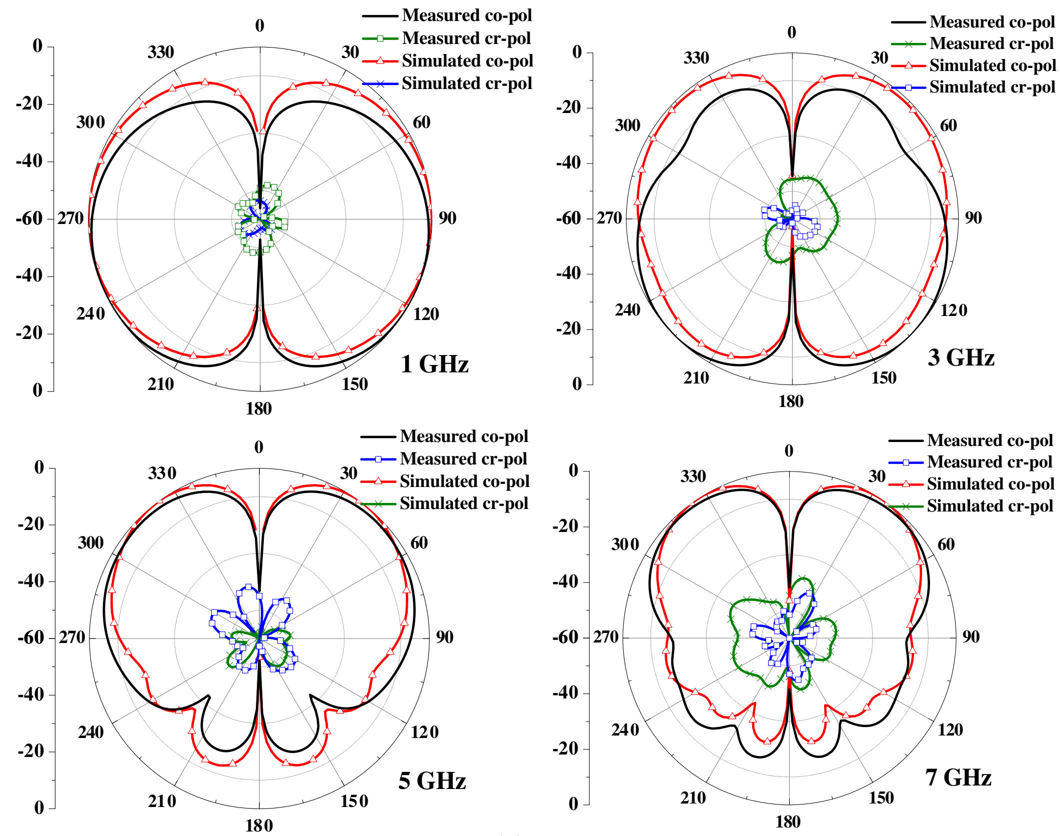
(a) (b)

Figure 6. Simulated and measured VSWR and S_{11} of the proposed antenna.

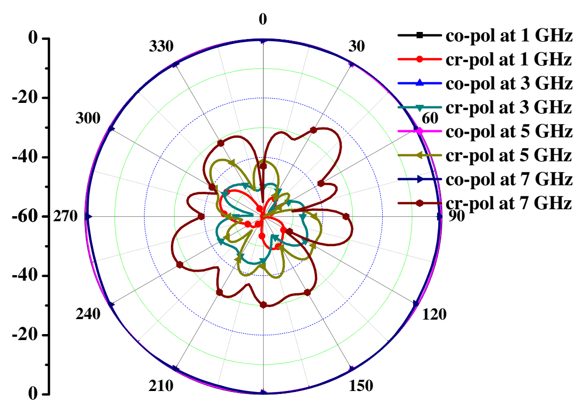
interaction between the ridges and the main radiator becomes stronger, thus the impedance match of the lower and higher band has been improved. However, the antenna presents a dual-band performance when r_4 becomes large. With $r_4 = 10\,\text{mm}$, the optimal results are obtained. In addition, variation of h_4 mainly affects the impedance match of the higher band, as shown in Fig. 4(b). The case of $h = 24.5\,\text{mm}$ is the proposed optimal design.

3. EXPERIMENTAL RESULTS

The proposed antenna is designed and simulated with the commercial software Ansoft High Frequency Structure Simulator (HFSS 13.0). To confirm the design, a prototype of the sleeve antenna has been fabricated following the design parameters, the photograph of which is shown in Fig. 5. The frequency response of the VSWR and S_{11} for the antenna are presented in Fig. 6 separately, and obviously, the simulated data and measured result match well with each other. The measured impedance bandwidth for VSWR $\leqslant 2$ is approximately 148.45% ranging from 1.04 to 7.03 GHz, which can cover the recent



(a)



(b)

Figure 7. Simulated and measured radiation patterns of the proposed antenna at 1, 3, 5, and 7 GHz. (a) YOZ plane. (b) XOY plane.

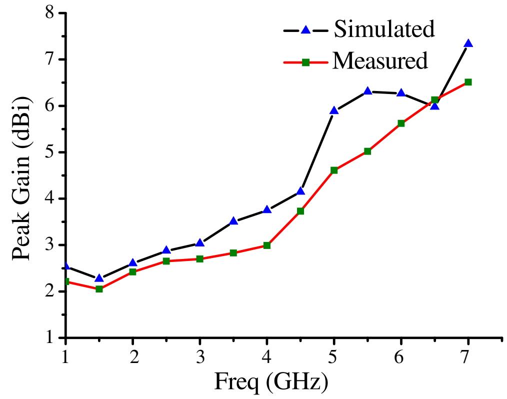


Figure 8. Simulated and measured peak gain against frequency.

wireless communication services such as DCS, PCS1900, UMTS, IMT2000, WLAN, WiMAX2350/3500, WiBro, etc. Note that the slight difference between the measured and simulated results is due to the influence of fabricated errors.

Simulated and measured results of radiation patterns at 1, 3, 5, and 7 GHz are plotted in Fig. 7 respectively. The radiation pattern results of the azimuth plane (XOY-plane) present that the proposed antenna is featured by omnidirectional pattern for overall band with low cross polarization, while there are stable monopole-like radiation patterns in the elevation plane. It is observed that the measured un-roundness of the antenna in the azimuth plane are 0.07, 0.14, 0.39, 1.49 dB at 1, 3, 5, and 7 GHz, respectively. Note that as frequency rises, the electrical length of the ground plane gets larger, which causes the tilting up of the radiation pattern in high frequency. There is reasonable agreement between the simulated and measured results.

Referring to the gain performance, the simulated and measured results for the antenna are shown in Fig. 8. Over the operating band of 1.04–7.03 GHz, the measured peak gain is varied from 2.05 to 6.51 dBi, which indicates a similar varying trend in comparison with the simulated result.

4. CONCLUSION

A novel sleeve antenna with wideband characteristic is presented for wireless communication applications. By employing four symmetrical ridges between the sleeve and the main radiator, the proposed antenna obtains an impedance bandwidth enhancement without changing any physical dimensions. The antenna performs an excellent impedance bandwidth for VSWR $\leq$ 2 of 148.45%, covering the frequency range from 1.04 to 7.03 GHz, and good monopole-like radiation patterns where the un-roundness in the H-plane is less than 1.49 dB. It is sufficient for accommodating recent wireless communication services such as DCS, PCS1900, UMTS, IMT2000, WLAN, WiMAX2350/3500, WiBro, etc.

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