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A Novel Wideband Sleeve Antenna with Capacitive Annulus for Wireless Communication Applications

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Abstract—A novel wideband sleeve antenna with capacitive annulus for wireless communication applications is presented in this paper. A sleeve structure is introduced to improve the impedance bandwidth through exciting a new resonate point. By loading capacitive annulus at the center of the sleeve, an impedance bandwidth enhancement is achieved at the upper frequency band. The measured impedance bandwidth for VSWR $\leq$ 2 about 142.8% ranging from 1.01 to 6.06 GHz is achieved, and monopole-like radiation patterns are presented. A prototype has been fabricated and tested, and the experimental results validate the design procedure. It is sufficient for accommodating recent wireless communication services such as DCS1800, PCS1900, IMT2000, WLAN, WiMAX2350/3500, etc.

1. INTRODUCTION

With the rapid development of wireless communication and the complicacy of the fabricating environment of antennas, wideband antennas attract more and more attention. Various antennas with planar configuration, such as diamond-shaped patch [1], triangular monopole [2], tapered monopole [3] and rectangular patch with loaded plates [4], are studied for wireless communication applications. They are all derived from monopole. Monopole is an attractive choice because of its simple structure, easy fabrication and good radiation characteristic, but the narrow bandwidth of monopole limits its applications, and many useful methods for broadening its bandwidth have been studied in recent years. Sleeve antenna is a conventional form because it has the advantages of monopole and also has wideband characteristic with monopole-like radiation patterns. Many methods for analyzing the input impedance and radiation characteristic of sleeve antennas are proposed [5–9], and their theoretical analyses are useful references in designing sleeve antennas. In the past years, many novel configurations, such as conical sleeve, dual-sleeve and open sleeve, have been researched and analyzed [10–14]. Dual-sleeve antennas are candidates for many designers who are interested in sleeve antennas because dual-sleeve configuration can further broaden the impedance bandwidth [10–12]. A novel dual-sleeve antenna unrelated with ground is presented, and the transverse dimension is miniaturized [10]. A top loaded dual-sleeve antenna covering 0.5–2.1 GHz [11] and a low profile dual-sleeve antenna with an impedance bandwidth of about 137% [12] are proposed, but they are complicated in configurations and difficult to fabricate.

In this paper, a novel wideband sleeve antenna with capacitive annulus for wireless communication applications is proposed. Addition of the capacitive annulus can further improve the bandwidth without changing the physical dimension of the sleeve antenna. The simulated results show that the proposed antenna can achieve an enhanced impedance bandwidth for VSWR $\leq$ 2 about 141.8% ranging from 1.04 to 6.12 GHz by introducing the capacitive annulus at the center of sleeve. Moreover, good radiation patterns in E- and H-planes are achieved. With this omnidirectional radiation and wideband characteristics, it is an excellent candidate for recent wireless communication services such as DCS1800, PCS1900, IMT2000, WLAN, WiMAX2350/3500. Results of the constructed prototype are presented and discussed. Design considerations of the proposed antenna are described in the paper.

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2. ANTENNA DESIGN AND DISCUSSION

The geometry and composition of the proposed antenna are shown in Figure 1. The proposed antenna consists of a main radiator, a sleeve with capacitive annulus, an SMA connector and a ground plane. The main radiator is fed by an inner conductor of the SMA connector and is composed of a cylinder and a hollow cylinder. The outer conductor of the SMA connector is fixed at the bottom of the ground plane. The sleeve structure, a hollow cylinder with an outer radius of r_2 and a thickness of 1 mm, is introduced to improve the impedance bandwidth. A capacitive annulus, which has an inner radius of r_4 and deviates from the ground plane with a distance of h_4, is loaded at the center of the sleeve. By loading the capacitive annulus, the impedance bandwidth will be enhanced at the upper frequency band apparently. All parameters of the proposed antenna are optimized using the Ansoft HFSS 13. The detailed parameters of the proposed antenna are shown in Figure 1, and the values are given in Table 1.

Figure 2(a) shows the simulated VSWR against frequency for the proposed antenna (Ant1). It can be noticed that the impedance bandwidth for VSWR ≤ 2 is about 141.8% (1.04–6.12 GHz). Moreover,

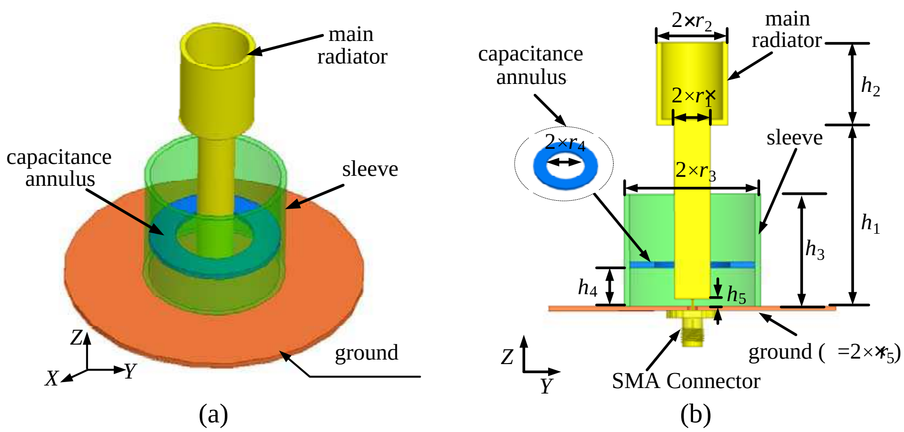

Figure 1. Geometry of the proposed antenna. (a) 3-D view. (b) Section view.

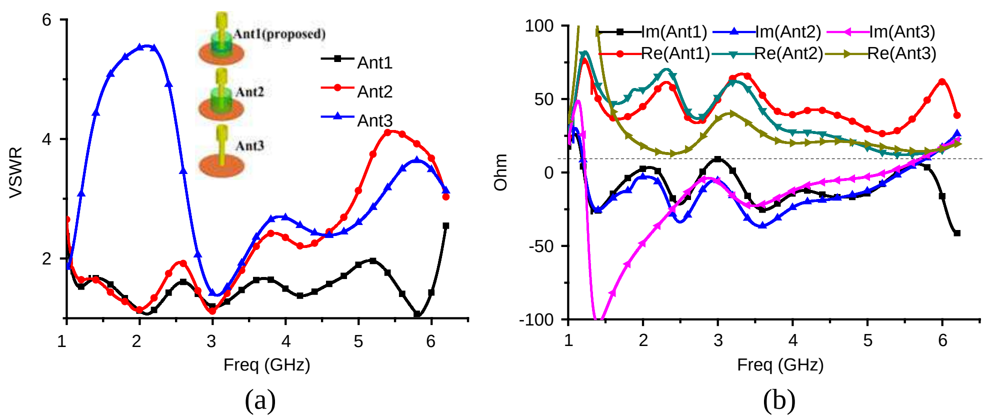

Figure 2. (a) Simulated VSWR and (b) input impedance of Ant1 (proposed), Ant2 and Ant3.

Table 1. Dimensions of the proposed antenna.

Parameters	h_1	h_2	h_3	h_4	h_5
Values/mm	50	23	31	10.5	2
Parameters	r_1	r_2	r_3	r_4	r_5
Values/mm	5	10	19	8.5	40

in order to study the influence of the capacitive annulus and the sleeve on matching, the simulated results of VSWR for the proposed antenna without capacitive annulus (Ant2) and the simple monopole (Ant3) are also plotted in Figure 2(a). For Ant3, three resonate points at 1, 3 and 4.5 GHz are excited. For Ant2, the impedance bandwidth is 106.8% (1.06–3.49 GHz) for VSWR ≤ 2 by introducing the sleeve, and the resonant point excited by the sleeve appears at about 2 GHz. It is clearly seen that the sleeve significantly affects matching in the lower frequency band, and the capacitive annulus affects matching especially in the upper frequency band. The input resistance and reactance for Ant1, Ant2 and Ant3

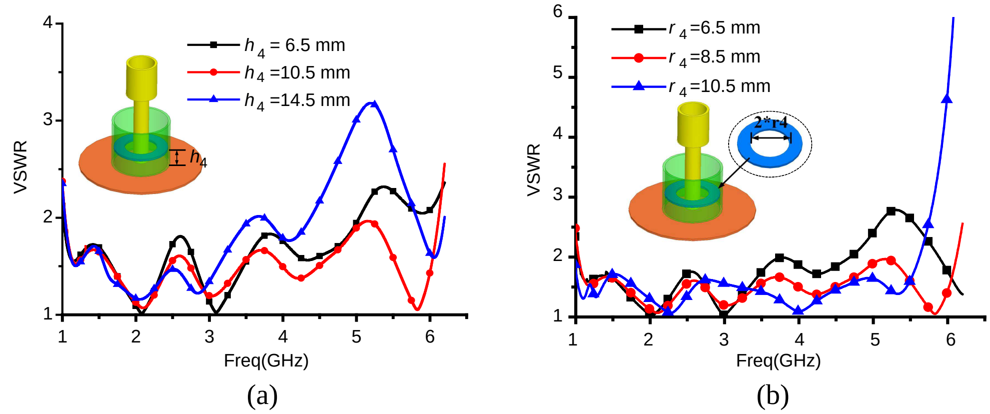

Figure 3. The variation of VSWR with h_4 and r_4. (a) h_4. (b) r_4.

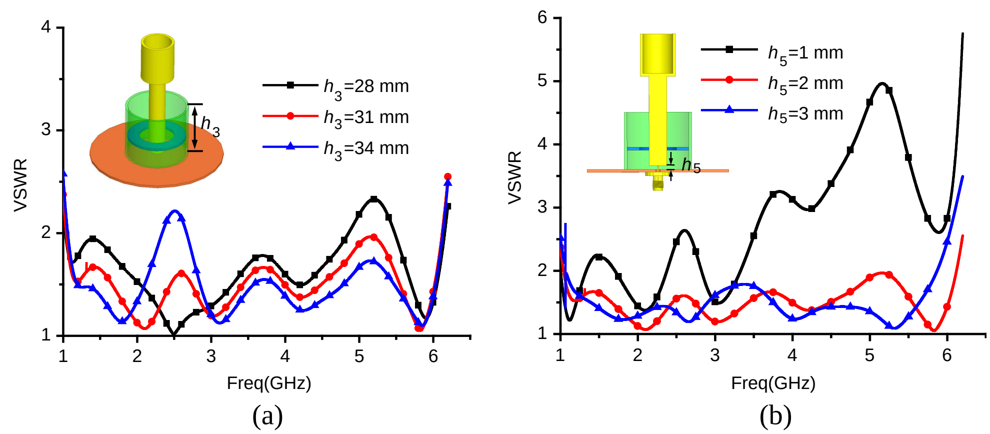

Figure 4. The variation of VSWR with h_3 and h_5. (a) h_3. (b) h_5.

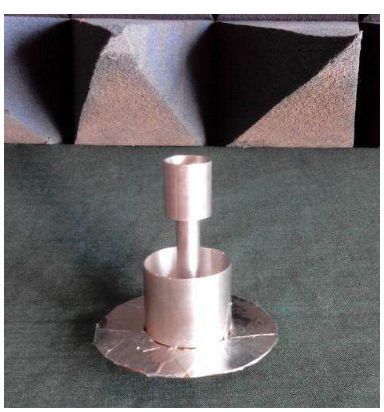

Figure 5. Photograph of the proposed antenna.

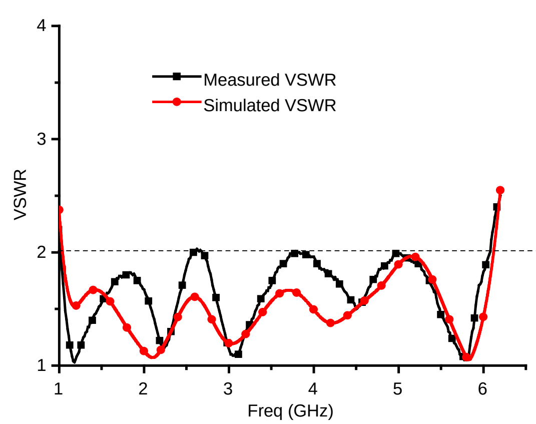

Figure 6. Simulated and measured VSWR.

are plotted in Figure 2(b). By introducing the capacitive annulus, there will be parasitic capacitance between the ground and the capacitive annulus, and the proposed antenna's input resistance can be increased to 50 ohm in the upper frequency band, which is perfect for matching with the SMA connector. At the same time, the loading capacitive annulus does not change the inherent physical dimension of the sleeve antenna, so the input resistance and reactance in the lower frequency band are almost unchanged.

The height (h_4) of the capacitive annulus apart from the ground plane and the inner radius (r_4) of the capacitive annulus are critical to the impedance bandwidth. Different values of h_4 and r_4 are analyzed, and the results are plotted in Figure 3. The resonant point excited by the capacitive annulus is determined by the parasitic capacitance between the ground and the capacitive annulus. The parasitic capacitance will decrease when the value of h_4 increases, and the resonant frequency will shift to the

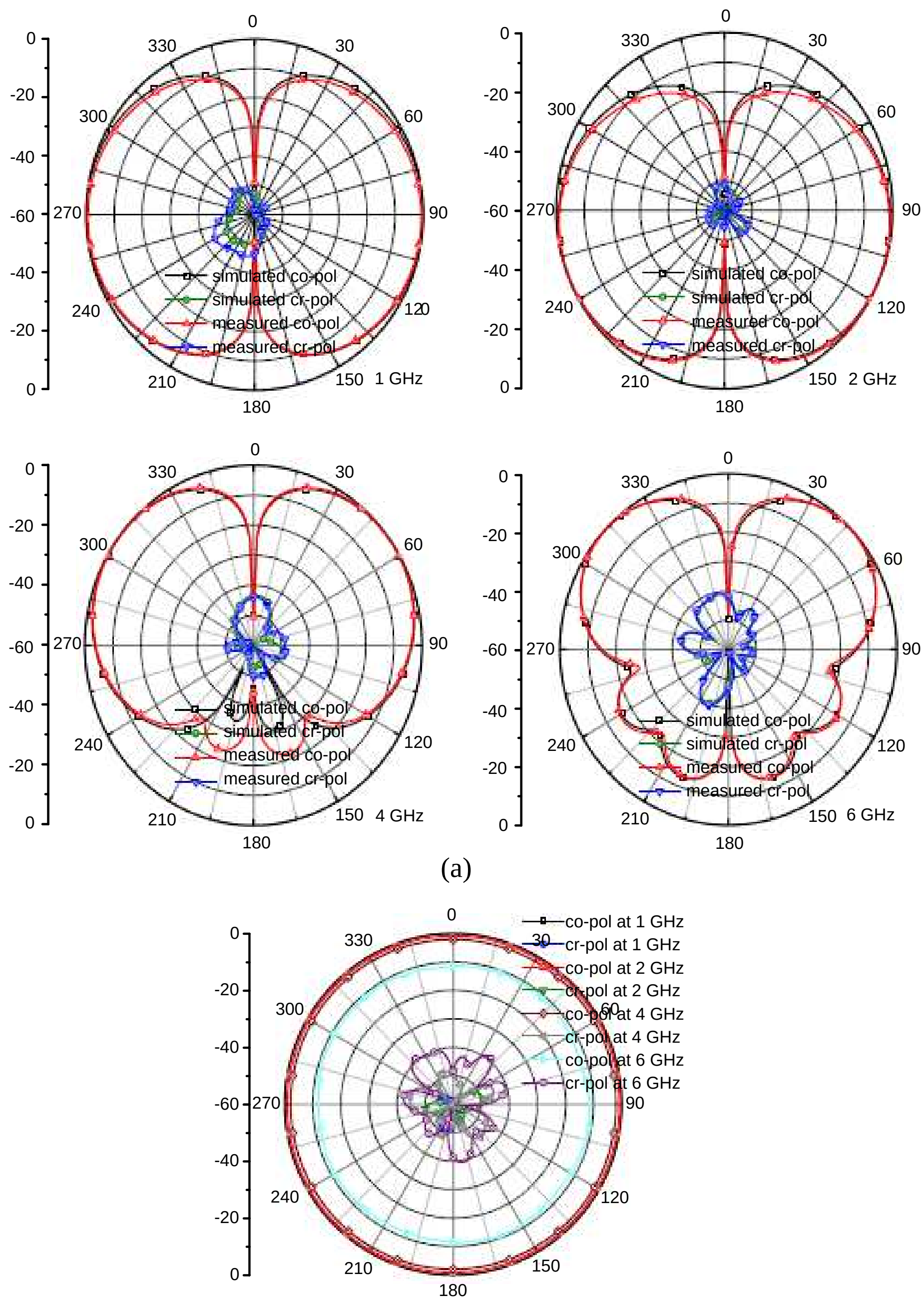

Figure 7. Radiation patterns at 1,2,4,6 GHz of proposed antenna. (a) *E*-plane. (b) *H*-plane.

upper frequency band as shown in Figure 3(a). By choosing a proper value of h_4, the new resonant point can be connected to the original operating band of the sleeve antenna, thus wideband impedance characteristic can be obtained. When the inner radius of the capacitive annulus (r_4) changes, the impedance will move to the matching point at the range of 4 to 6 GHz as shown in Figure 3(b). With the increase of r_4, the influence of the capacitive annulus gradually reduces. The reason is that the area of the capacitive annulus decreases, and the resonant point in the upper frequency band will disappear. It can be concluded that the capacitive annulus mainly decides the impedance matching at the upper frequency band.

Value of h_3, which is the height of the sleeve, determines the coupling area between the sleeve and the main radiator as shown in Figure 4(a). With the increase of h_3, the resonant point generated by the sleeve at 2 GHz will move towards low frequency band due to the increase of the electrical length. The gap of the main radiator apart from the ground plane (h_5) significantly impacts the impedance matching [11]. The effect of various values of h_5 is shown in Figure 4(b). When choosing h_5 as 1 mm, the input resistance will be too small and far away from the matching point in the whole band. On the contrary, if h_5 is larger than 2 mm, poor matching appears in the upper frequency band. This is attributed to the fact that when the value of h_5 increases, the sleeve's effect on the performance of the main radiator is weakened, and the sleeve antenna works as a simple monopole antenna. These results clearly indicate that all the parameters have great effects on the impedance matching of the antenna. However, the upper resonance and lower resonance are mainly affected by the capacitive annulus and sleeve structure, respectively, which correspond to the results obtained in Figure 3 and Figure 4. By selecting $h_4 = 10.5$ mm, $r_4 = 8.5$ mm, $h_3 = 31$ mm and $h_5 = 2$ mm, better impendence characteristic which can meet the requirement for wireless standards are achieved.

3. EXPERIMENTAL RESULTS

As shown in Figure 5, a prototype of the proposed antenna is fabricated according to the design dimensions in Table 1. The measurements are carried out using Agilent E8363B network analyzer and an anechoic chamber. Figure 6 presents the simulated and measured VSWRs against frequency for the proposed antenna. Obviously, wideband performance is achieved. The measured impedance bandwidth is about 142.8% (1.01–6.06 GHz) for VSWR $\leq$ 2. The slight difference between the simulated and measured results is due to the influence of fabricated errors.

The measured and simulated far-field radiation patterns at frequencies of 1, 2, 4 and 6 GHz for the proposed antenna are shown in Figure 7. The proposed antenna has a stable monopole-like radiation patterns in the elevation planes (E-plane) and azimuth plane (H-plane). Unevenness in the azimuth plane at 1, 2, 4, 6 GHz for the proposed antenna is 0.05, 0.12, 0.21 and 1.4 dB, respectively, which shows good omnidirectional characteristic across the whole operating band. The measured peak gain at discrete frequencies over the operating band is shown in Figure 8, and the gain of the antenna varies

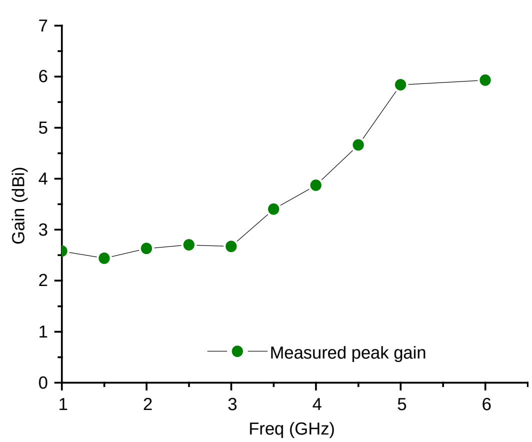

Figure 8. Measured peak gain of the proposed antenna.

from 2.4 to 6.1 dBi. Excellent radiation patterns and wideband impedance characteristics of proposed antenna make it suitable for wireless communications.

4. CONCLUSION

A novel sleeve antenna with capacitive annulus for wireless communication applications has been presented with simulated and measured results. By loading capacitive annulus at the center of the sleeve, enhanced impedance bandwidth is achieved, and a measured input impedance bandwidth of about 142.8% ranging from 1.01 to 6.06 GHz for VSWR ≤ 2 is obtained. The influence of the loading capacitive annulus on impedance matching is analyzed and verified. Stable monopole-like radiation patterns across the impedance bandwidth are provided. Measured results agree well with the simulated ones, and the performance proves that the proposed antenna has wideband characteristics and good radiation patterns, making it suitable for wireless communication services such as DCS1800, PCS1900, IMT2000, WLAN, and WiMAX2350/3500.

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