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A Novel Low-Profile Quadripod Kettle Antenna with Enhanced Bandwidth

Long Yang*, Zhi-Ya Zhang, Guang Fu, Yong-Xia Zhang, and Yang Li

Abstract—The design of a novel low profile antenna is presented in this paper. By a cross-shaped structure shorted to the ground plane through shorting probes, the size reduction is achieved. A top-loading ring-disc is successfully employed to broaden the impedance bandwidth. Moreover, with the uniformly-arranged shorting pins and a circular sleeve structure placed on the ground, a good omnidirectional performance in the horizontal plane is obtained. An antenna prototype has been implemented and characterized. A measured impedance bandwidth for VSWR $\leq$ 2 of about 135% ranging from 1500 to 7800 MHz is achieved, and a monopole-like radiation pattern is also produced. The height of the proposed antenna is very low with 0.07λ tall. The proposed antenna is very suitable for indoor base station and the UWB applications.

1. INTRODUCTION

In recent years, wireless communication services have attracted more and more attention due to their wide use in different applications. In the era of wireless communications, wide band, small size and ease of fabrication are appreciated in the antenna design. The demand of future communication systems that require high data rates over short distances makes UWB technology a promising solution. Ultra wide bandwidth, constant gain, high radiation efficiency, low profile and directional or omnidirectional radiation patterns are the desirable factors for UWB antennas [1–4]. Monopole antennas are probably one of the most frequently used antennas in wireless communication systems which can be found on the roof of many buildings and malls. However, most of these places have strict physical size and bandwidth requirements [5, 6]. In order to broaden the bandwidth, more complicated geometries and techniques are used, like using cone structure [7], applying folded L-slots to feeding [8], and utilizing sleeve structure [9]. Meanwhile, in order to reduce the size especially their height, many kinds of approaches are put forward, such as using a top-loading patch shorted to the ground, introducing meander strip patch and using slots on the patch [9, 10]. Recently, the demand for a vertically polarized and low-profile omnidirectional antenna with wide bandwidth reminds the authors of the prospective features of the Quadripod Kettle Antenna (QKA). The concept of QKA was first introduced in 1976 [11]. Although the antenna performs an omnidirectional radiation pattern, it shows a narrow bandwidth of 25% and a relatively large size. Over a long period of time, the antenna had not been of concern to people until a further study on the QKA antenna was proposed in the mid-nineties [12]. By further more study [13], this antenna has a 90% relative bandwidth which is much wider than before, but it is not wide enough for future communication systems.

In this paper, we propose a novel design of the quadripod kettle antenna for bandwidth enhancement. The simulation with HFSS 13 shows that the proposed antenna can achieve an enhanced operating bandwidth of about 140% ranging from 1450–8220 MHz (VSWR $\leq$ 2) by introducing the taped top-loading structure. In particular, the height of the proposed antenna is 0.07λ that corresponds

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to the free-space wavelength of the lowest frequency. Furthermore, omnidirectional radiation patterns and stable peak gain are also achieved over the whole operating frequency band. With this low profile and wide bandwidth characteristics, it is an excellent candidate for the UWB applications and indoor base station applications such as DCS1800, PCS1900, UMTS, IMT2000, WiMAX2350, and WLAN (IEEE802.11b). Finally, the proposed antenna has been successfully fabricated, and experimental results are discussed.

2. ANTENNA DESIGN AND DISCUSSION

The geometry of the proposed antenna and the coordinate system are shown in Figure 1. The proposed antenna mainly consists of a two-plate structure, and the lower plate, fed by the inner conductor of the coaxial in the middle point, is a cross-shaped structure connected to the ground by supporting probes in the end point. The upper plate, in the form of a ring-disc, is connected with the lower plate by a hollow cylinder. The ring-disc and the hollow cylinder which connects the two plates have a crucial impact on bandwidth enhancement because they effectively improve the matching condition of the high operating frequency edge. The size reduction is achieved with the utilizing of the shorting probes. The diameter (R_d) of the ring-disc and the antenna height are about 0.36 times and 0.07 times the free-space wavelength of the low operating frequency, respectively. By dividing the four supporting probes into eight probes, which placed uniformly on each side of the planar, a good omnidirectional performance in the horizontal plane is achieved. Furthermore, a sleeve structure is placed on the ground in order to further improve the omnidirectional performance and enhance the impedance matching. The detailed parameters of the lower plate with divided shorting probes are shown in Figure 1(b). The final optimal antenna parameters are shown in Table 1.

Figure 2 shows the simulated VSWR against frequency for the proposed antenna, indicated as Ant.3. It can be noticed that the impedance bandwidth for VSWR ≤ 2 is about 140% (1.45–8.22 GHz). Meanwhile, in order to explore the effects of the connecting structure that connects the lower plate and the upper disc on the antenna's matching condition, the simulated results of VSWR for the proposed antenna with rectangle connector and hollow cylinder connector are also plotted in Figure 2. For Ant.1, only 80% impedance bandwidths for VSWR ≤ 2 can be achieved. For Ant.2 with hollow cylinder connector, it is clearly seen that an impedance performance for VSWR ≤ 2 is from 1450 to 4000 MHz

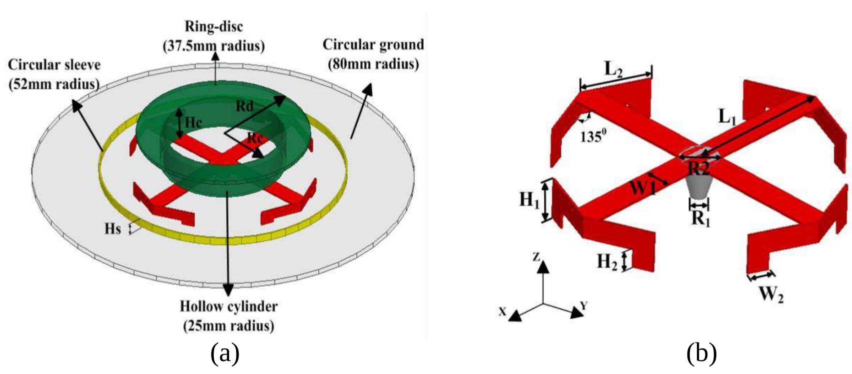


Figure 1. Geometry of proposed design. (a) 3-D view of proposed antenna. (b) Detailed view of the lower plate structure.

Table 1. Dimensions of proposed antenna.

Parameters	R_1	R_2	R_c	R_d	L_1	L_2
Values/mm	1.5	5	25	37.5	44	18.4
Parameters	H_1	H_2	H_c	H_s	W_1	W_2
Values/mm	5	1.5	11.5	3	7.2	5.5

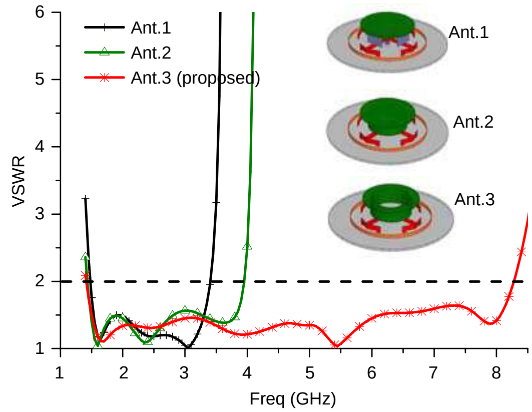


Figure 2. Simulated VSWR of Ant.1, Ant.2, and Ant.3 (proposed).

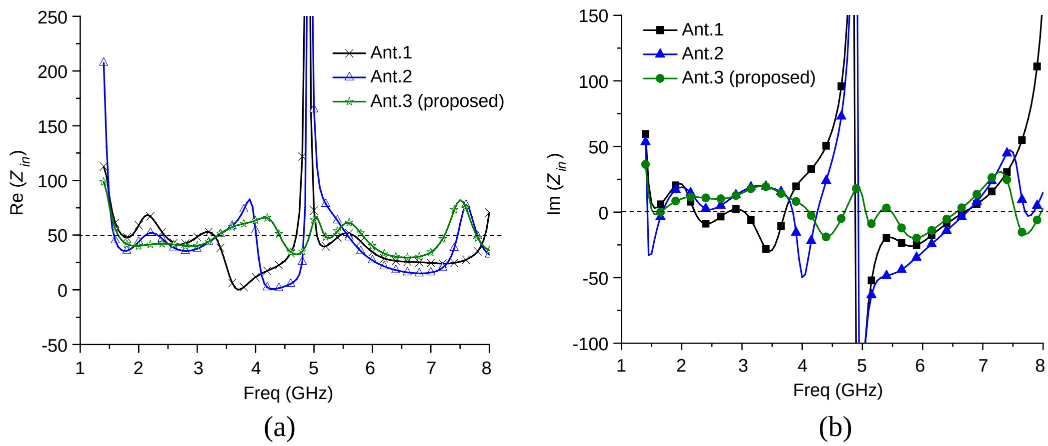


Figure 3. The impedance of the Ant.1, Ant.2, and Ant.3. (a) Real part. (b) Imaginary part.

which is wider than Ant.1.

To further explore the effect of the connector and the upper plate on the proposed antenna's bandwidth performance, the input resistance and reactance for the three antennas are also discussed, shown in Figure 3. It can be seen that five resonant modes of Ant.1 are excited at about 1.4, 2.3, 3.2, 5 and 8.5 GHz. It is observed that the first three modes are coupled together and form a smooth bandwidth. The difference between the impedance characteristics of Ant.2 and Ant.1 is that the third resonant mode of Ant.2 is shifted to a higher mode (about 4 GHz) which leads to a wider bandwidth with the use of the hollow cylinder. For Ant.3, the ring-disc structure with hollow cylinder is successfully applied to improve the impedance matching and enhance the impedance bandwidth through achieving another resonant point at about 5.6 GHz. These results clearly indicate that the existence of the hollow connector and ring-disc can significantly improve impedance matching through changing resonant point and achieving another resonant mode, respectively.

Figure 4 introduces the variation of the simulated VSWR with R_c varies from 19 to 25 mm. R_c is the radius of the circle which is cut away in the center of the upper plate. With increasing R_c, the upper plate decreases in size, the middle-band impedance performance is fast shifted to the matching condition, and the upper band impedance characteristic becomes better, whereas that of the lower band remains almost unchanged. To make a qualitative discussion, we analyze the novel structure of the proposed antenna. It is noted that the reason that the ring-disc and hollow connector significantly affects the whole operating band is that the upper ring-disc, hollow cylinder, lower plate and inner conductor of the coaxial comprise a conical tapered structure, as the red line shown in Figure 5, which maintains nearly constant impedance over a wide bandwidth for the proposed antenna. Namely, the proposed antenna can be viewed as another kind of shorted top-hat cone antenna, and the difference is that the shorted pins are not loaded from top plate but from the lower plate. When it comes to the current distribution, it is noticed that the current flows from ring-disc to the lower plate, then it flows through two different paths to ground. One flows through the feed pin to ground, and the other flows through the shorted probs. Thus the hollow cylinder is used not only as a part of the radiator, but also as a part of the shorted pins. This special structure makes a broadband impedance characteristic and a low profile performance realizable.

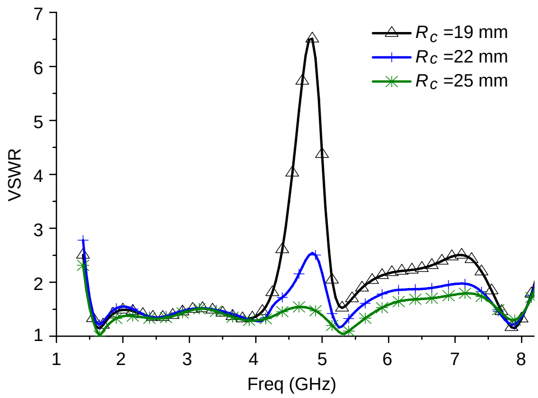


Figure 4. The variation of VSWR with R_c.

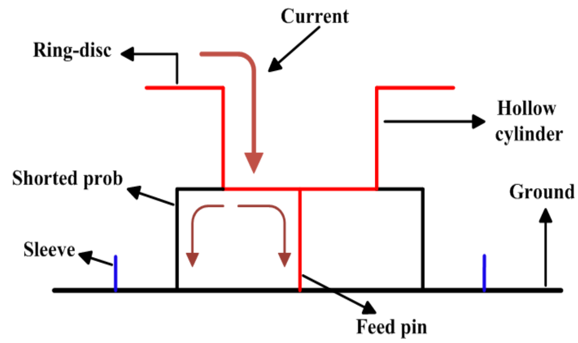


Figure 5. The sectional view of the proposed antenna.

Figure 6. Photograph of the proposed antenna.

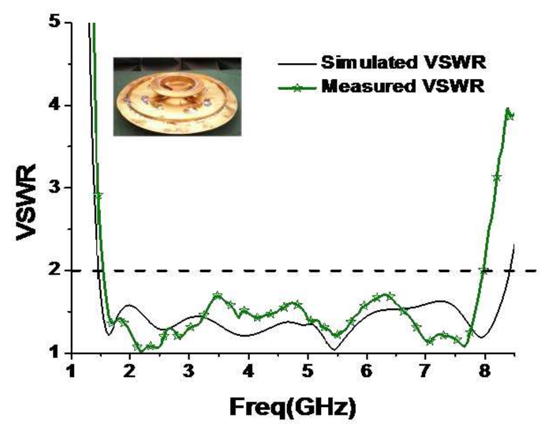
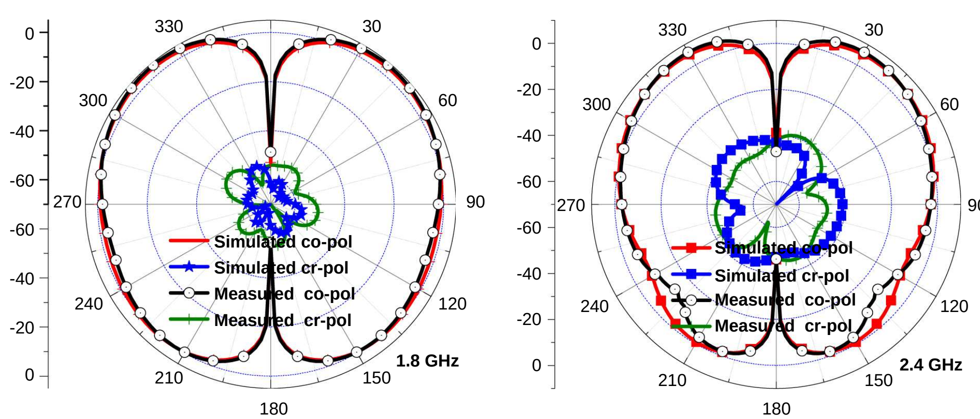
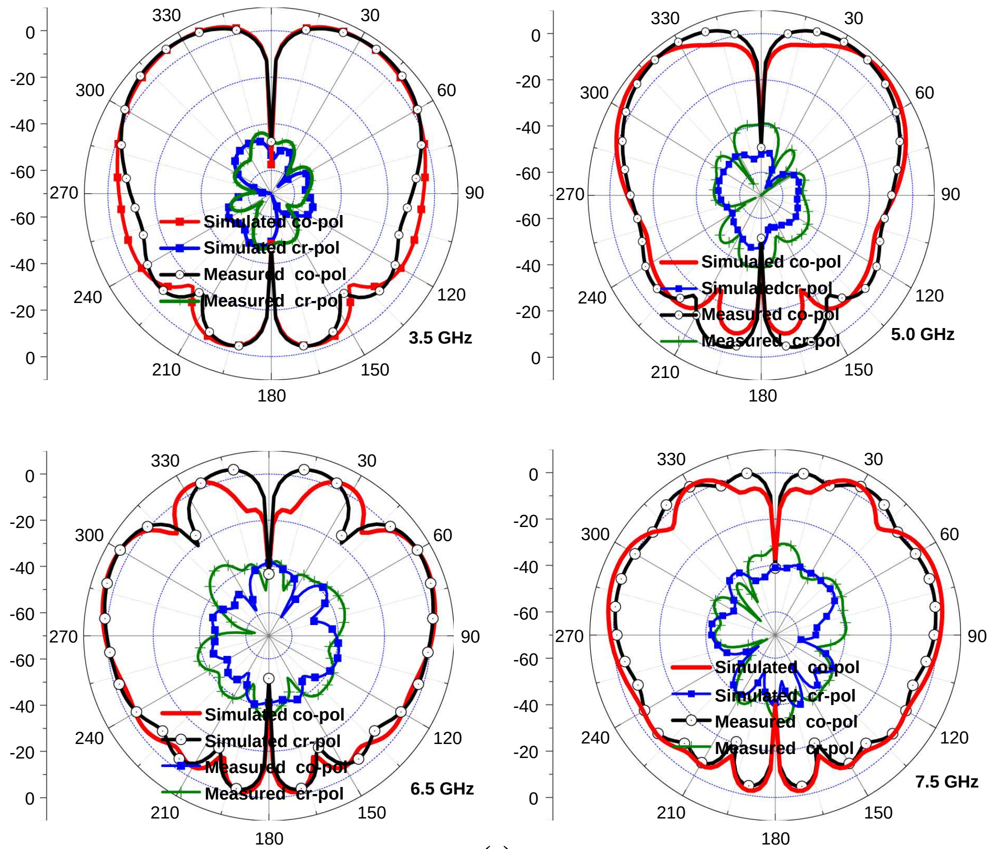
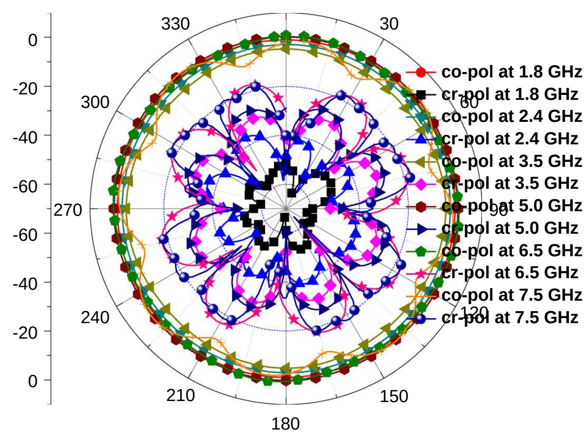


Figure 7. Simulated and measured VSWR.





(a)



(b)

Figure 8. Radiation patterns at 1.8, 2.4, 3.5, 5, 6.5, 7.5 GHz. (a) E-plane. (b) H-plane.

3. EXPERIMENTAL RESULTS

A prototype of the proposed antenna was fabricated according to the design parameters in Table 1, as shown in Figure 6. The measurements were carried out using Agilent E8363B network analyzer and an anechoic chamber. Figure 7 presents the measured and simulated VSWRs against the frequency for the proposed antenna. Wideband performance was achieved. The measured impedance bandwidth is about 135% (1500–7800 MHz) for VSWR ≤ 2. The bandwidth clearly covers the required bandwidths for the indoor base station applications and the UWB applications.

Figure 8 shows the simulated and measured far-field radiation patterns at frequencies of 1800, 2400, 3500, 5000, 6500 and 7500 MHz of the proposed antenna. Both the azimuth plane cut and elevation plane cut of the pattern look quite monopole-like. The unevenness in the horizontal plane is good with the help of the sleeve and the divided shorting pins. The measured peak antenna gain versus frequency maintains stable which is from 2.0 to 7.6 dBi approximately and shown in Figure 9. From Figure 9, it can also be observed that the peak gain decreases as the frequency increases, because the main lobe splits into multi-lobes when frequency increases.

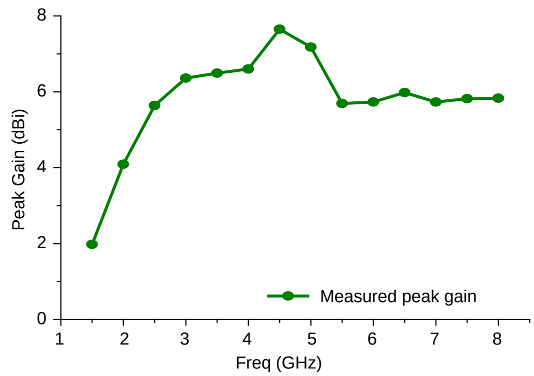


Figure 9. Peak gain against frequency for proposed antenna.

4. CONCLUSION

A novel low profile wideband quadripod kettle antenna has been presented with experimental and simulated results. Through using another kind of conical shape with the hollow connector and ring-disc, the impedance bandwidth is enhanced. A 135% input impedance bandwidth for VSWR ≤ 2 is obtained. By a top-loading ring-disc shorted to the ground plane by divided shorting probes, the size reduction for the antenna is achieved. The total size of the proposed antenna is small. Stable monopole-like radiation patterns across the impedance bandwidth are also provided. The measured peak antenna gain versus frequency is stable. Due to these performances, the antenna has wide and potential applications for wireless communication and UWB applications.

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