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Miniaturized Annular Ring Slot Antenna for Small/Mini UAV Applications

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Abstract—A miniaturized annular ring slot antenna is presented. The antenna consists of an annular ring slot structure and a novel folded matching structure. The annular ring slot structure is printed on a substrate and shorted concentrically with a set of conductive vias. The additional matching structure is a ring cavity attached to the back of the annular ring slot structure. Firstly, the diameter of the proposed antenna is reduced by using the folded matching structure comparing with traditional annular ring slot antennas. Secondly, the impedance matching of the proposed antenna is achieved by optimizing the size of the matching structure. A prototype of the proposed antenna with a height of 3.048 mm (0.03λ) and a radius of 47.2 mm (0.4λ) is designed, fabricated and measured. The antenna resonates at 2.67 GHz and has a monopole-like radiation pattern, which shows that the antenna is suitable for the applications of taking off, landing, and long distance communications for a small or mini UAV.

1. INTRODUCTION

Unmanned aerial vehicles (UAVs) play an increasingly important role in military, civilian and scientific missions [1]. It is critical to have reliable communication link between ground control station and an aircraft because there is no pilot in the aircraft. As one of the most important parts of the communication system, a suitable antenna for UAV communications is of great significance. The antenna mounted on a UAV usually has a low profile to meet the aerodynamic requirements. In addition, other desirable features for the UAV antenna also include compact size, light weight and firm configuration.

There are a variety of antennas which can be installed on a UAV [2–5]. B.-H. Sun [2] developed an antenna which is similar to a dipole antenna with a reflector. The antenna in [2] is very simple in structure, and it can be matched by adjusting the coupling of the feeding strip to the radiating strip. An annular ring coupled to a shorted circular patch is studied in [3]. A shorting pin was added to reduce the size of the patch and the annular ring was used to extend the bandwidth to 6.6%. Both of the antennas in [2, 3] are low in profile, and they can provide a unidirectional radiation pattern in elevation plane which is similar to the radiation pattern of a dipole with a reflector or a microstrip antenna. As shown in Fig. 1, these antennas are very useful when a UAV is flying high above the ground control station (case1 in Fig. 1). When a UAV is taking off, landing or far away from the ground station, these antennas may not be suitable for the communication scenario as shown in case 2 in Fig. 1 since their azimuthal radiation is too weak to meet the demands of low elevation communications. In [4, 5], Sharawi et al. proposed antenna arrays embedded in the UAV wing structures. The antenna arrays use the beam-forming technique to enhance the communication link throughput. The antenna arrays seem to be suitable candidates for relatively large UAVs, but the complex systems of antenna arrays and communication equipment may restrict their applications in small or mini UAVs.

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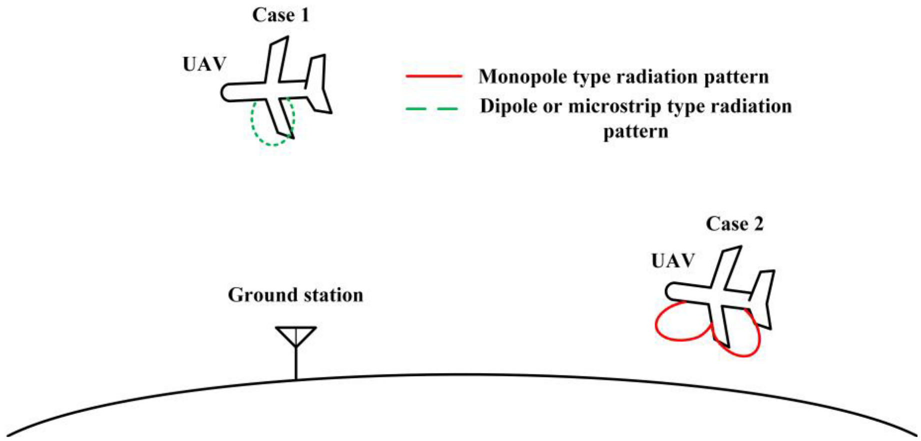


Figure 1. The description of the scenarios discussed in Section 1.

As can be seen from Fig. 1, a monopole-type antenna seems more suitable for the scenario of the Case 2 in Fig. 1. But the traditional monopole antenna is not recommended for the UAV applications, since it has a relatively large height (0.25λ) [6]. A low-profile, electrically small antenna with omnidirectional vertically polarized radiation is presented in [7]. The antenna is outlined for very low profile (0.03λ) and monopole-like radiation. Nonetheless it requires a relatively large ground plane, which may restrict its application in a small nonmetallic UAV.

The cavity-backed annular ring slot antenna is commonly used on aircraft because it produces a radiation pattern almost equal to a quarter-wave monopole [8]. This type of antenna has been studied theoretically and experimentally. The input impedance and radiation pattern of the antenna can be predicted by the methods proposed in [9, 10]. In [11], a thin printed annular ring slot antenna is presented. The antenna is promising owing to its simple structure, compact size and low profile. It offers omni-directional radiation patterns.

A compact annular ring slot antenna is proposed in this paper. The antenna is based on the previous experience of [11]. The diameter of the proposed antenna is further reduced by using a novel matching structure. The antenna resonates at the operating frequency without the need of a large ground plane. Thus the proposed antenna in this paper is much smaller than the antenna in [11]. Moreover, the antenna has a relatively low elevation compared with traditional annular ring slot antennas due to its small ground size [12]. Details of the design and principle of the proposed antenna are described. A prototype for UAV operation at 2.67 GHz is fabricated, simulated and tested. The simulated and measured results are presented and discussed.

2. ANTENNA DESIGN CONCEPT AND STRUCTURE

The geometry of the proposed antenna is shown in Fig. 2. The antenna consists of two layers. The top layer is an annular ring slot structure, and the bottom layer is a novel matching structure. The proposed antenna is fed by an SMA at the center of the annular ring slot structure. The annular ring slot structure is a circular patch with a ring slot cut out. It is printed on a substrate and shorted concentrically with a set of conductive vias. The circular metallic patch has a radius of $R2 = 47.2$ mm. And the ring slot is located at 41 mm ($R1$) from the center of the circular patch and has a width of $t = 3.2$ mm. The matching structure is a ring cavity attached to the back of the annular ring slot structure with its one terminal connected to the annular ring slot structure, and the other terminal shorted to the ground plane through two sets of conductive vias. This ring cavity has an outer radius of 47.2 mm (equal to $R2$) and an inner radius of $R3 = 25.3$ mm. Both of the substrates used in the proposed antenna are Arlon AD250A (relative permittivity 2.5, loss tangent 0.002 and thickness of $h1 = h2 = 1.524$ mm). All the conductive vias in the antenna have a radius of $r = 1$ mm. And the number of the vias is $n = 45$ for both sets. It should be noted that there is an identical ring slot cut out on the ground plane.

In order to illustrate the evolution procedure of the proposed antenna clearly, Fig. 3 shows the

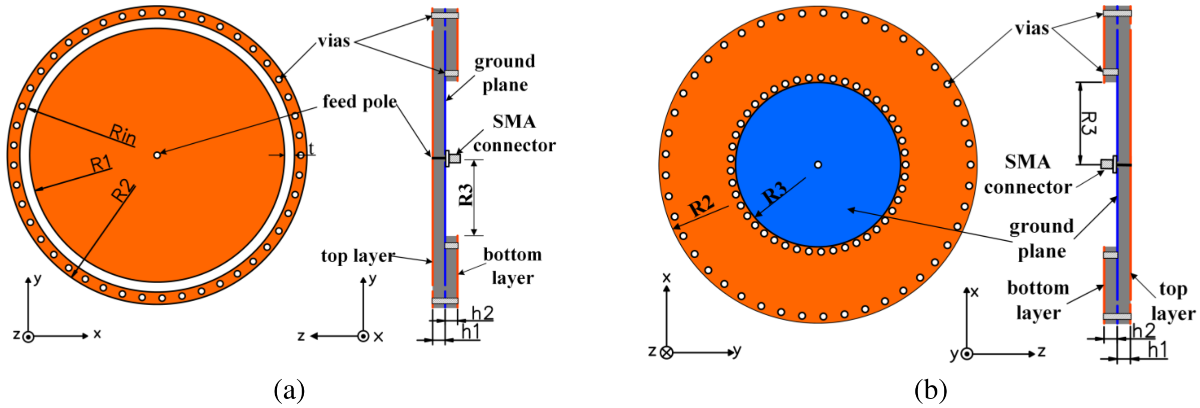


Figure 2. Geometry of the proposed antenna. (a) Top view and sectional view. (b) Bottom view and sectional view.

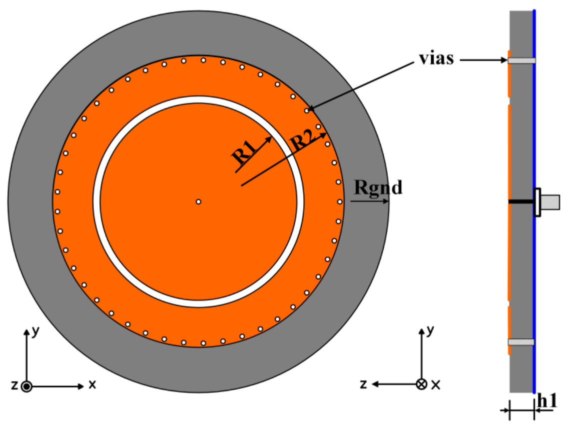


Figure 3. Geometry of the antenna in [11].

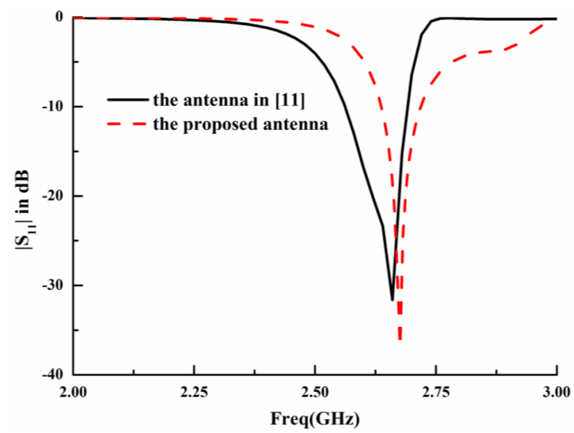


Figure 4. Simulated reflection coefficients $|S_{11}|$ of the antenna in [11] and the proposed antenna.

Table 1. Detailed dimensions of the antenna in [11] and the proposed antenna (unit: mm).

	$R1$	$R2$	$R3$	$Rgnd$	t	$h1$	$h2$
Fig. 3	44	65.2	\	20	3.2	1.524	\
Fig. 2	41	47.2	25.3	\	3.2	1.524	1.524

structure of a traditional printed annular ring slot antenna based on the previous experience [11]. The detailed dimensions of the antenna in reference [11] and the proposed antenna are proposed in Table 1. The antenna in reference [11] consists of a circular patch with a coupled annular ring. It is shorted with a set of conductive vias. The overall size of the antenna is too big to be installed on a small UAV. In order to reduce its size, $R1$ is reduced from 44 mm to 41 mm, and $R2$ is reduced from 65.2 mm to 47.2 mm. Thus the outer part of the antenna became a very slim ring. Its width is only a little bigger than the diameter of the vias. Moreover, the radius of the ground plane is decreased to be equal to the outer radius of the annular ring slot structure ($R2$). By doing so, the antenna size is greatly reduced. However, as the size of the coupled annular ring and the ground plane is reduced, the impedance of the antenna is changed, which results in impedance mismatch. A novel matching structure is introduced for the sake of improving the impedance matching of the antenna. This matching structure is a ring cavity attached to the back of the antenna, which comprise the antenna proposed in this paper. Its final structure is shown in Fig. 2.

Figure 4 shows the corresponding performance of the antenna geometries, in terms of reflection coefficient. The simulated results are obtained by Ansoft HFSS ver.12. It can be seen from the above analysis that the antenna has been miniaturized comparing to the antenna in [11] while maintaining its resonating characteristic. Thus it can be used for a small UAV or mini UAV.

For quarter-wave monopole antenna with disk ground plane in free space, the directivity on horizon increases approximately with decreasing disc radius [12]. Small ground size is effective in reducing the elevation angle of peak directivity [12]. Based on this, the elevation of the proposed antenna is relatively lowered by decreasing the ground size. Fig. 5 shows the simulated elevation patterns of the antenna in [11] and the proposed antenna.

The outer radius of the proposed antenna is reduced from 65.2 mm (0.6λ) to 47.2 mm (0.4λ) without changing its resonant frequency. Moreover, the elevation of the radiation of the proposed antenna is lowered because the ground size is reduced, too. The antenna can be installed on some mini or small UAVs due to its miniaturized antenna size. The proposed antenna increases the flexibility of the installation on UAVs. Furthermore, the proposed antenna can be the element of an antenna array because its radius is less than 0.5λ.

A conceptual TL model (transmission line model) is introduced to explain the fundamental operations of the proposed antenna and to demonstrate the novel matching structure. As shown in Fig. 6, the slot is modeled as a capacitance C in parallel with a radiation resistance R_{rad}, the circular patch and the matching structure are modeled as two transmission lines, which are connected to the parallel circuit. The matching structure is conceptually equivalent to a transmission line which is terminated in a short circuit. It is used to transform the input impedance of the proposed antenna Z_{in} to $50 + j0$ (Ohm). The impedance of the proposed antenna is very sensitive to the parameter $R3$ due to the fact that the impedance of a shorted transmission line changes quickly when its length is close to 0.25λ. By optimizing the parameter $R3$, good impedance matching can be achieved. A parametric study of $R3$ is provided in Fig. 7.

According to the above analysis, the proposed antenna has three advantages. Firstly, the diameter of the antenna (including its ground plane) is reduced, thus suitable for installation on small UAVs or mini UAVs. Secondly, the elevation of the proposed antenna is lowered. The directivity on horizon increases and the communication quality will be improved when a UAV is taking off, landing, or far away from the ground station. Thirdly, the antenna contains a novel matching structure. Resonance and impedance matching can be easily achieved by optimizing the parameter $R3$ of the matching structure.

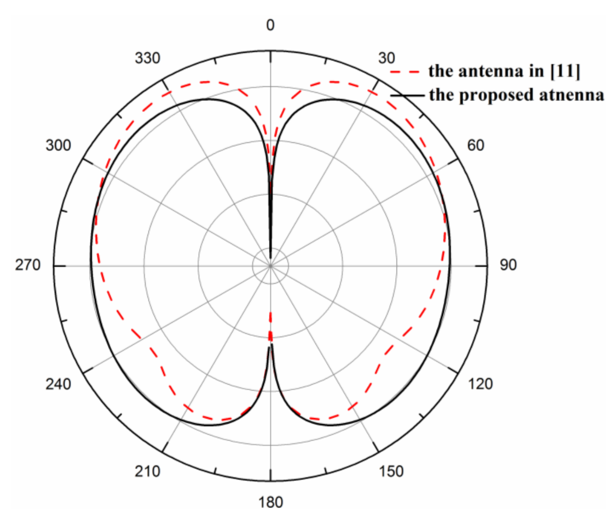


Figure 5. Simulated radiation patterns of the antenna in [11] and the proposed antenna.

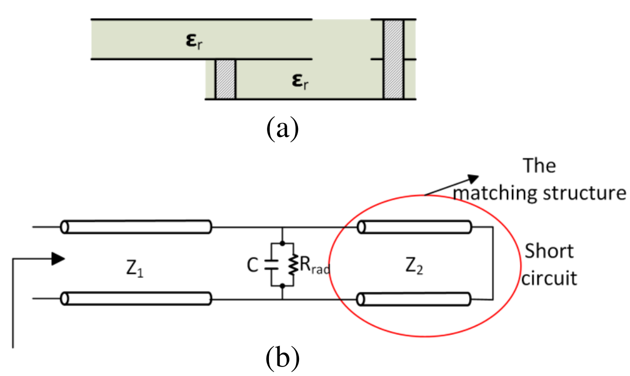


Figure 6. Conceptual transmission line model. (a) Sectional view of the proposed antenna (partial). (b) Conceptual transmission line model of the proposed antenna.

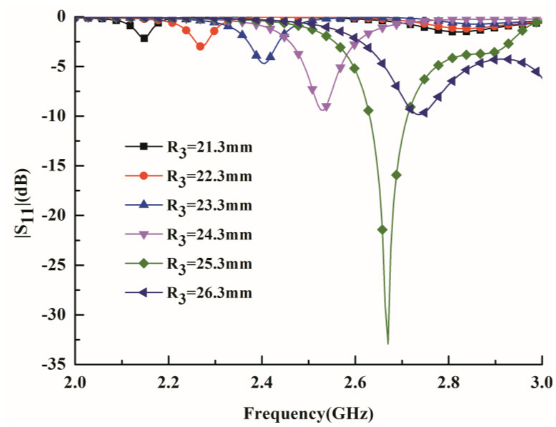
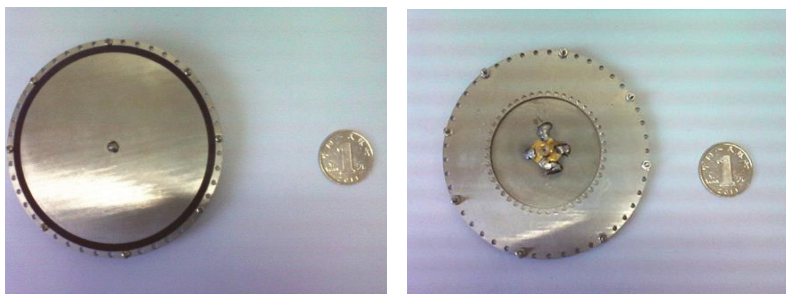


Figure 7. Simulated reflection coefficient of the antenna with different $R3$.



(a) (b)

Figure 8. Photograph of the proposed antenna. (a) Top view. (b) Bottom view.

3. RESULTS AND DISCUSSION

The antenna is simulated using the commercial software Ansoft HFSS. To verify the simulation performance of the antenna, a physical prototype was fabricated and measured. The photo of the prototype is illustrated in Fig. 8. The simulated and measured VSWR of the proposed antenna is shown in Fig. 9. From these results, it can be clearly seen that the resonant frequency occurred at 2.67 GHz in both simulation and measurement. The antenna achieves an impedance bandwidth of 2.62%, covering frequency spectrum from 2.64 GHz to 2.71 GHz for the criterion VSWR less than 2. The obtained results show a good agreement between the measured and the simulated results with an acceptable frequency discrepancy. The discrepancy can be attributed to the use of bolts in the prototype and the fabrication errors.

Figure 10 shows the current distribution of the proposed antenna. As can be seen, the current distribution is symmetrical. Thus the antenna provides an omni-directional radiation patterns on H-plane.

The far-filed radiation patterns of the proposed antenna at 2.67 GHz are plotted in Fig. 11. Other frequencies in the operating frequency band have also been investigated and show similar radiation performances. As can be seen, monopole-like radiation patterns are observed. Fig. 11(b) indicates that the elevation angle of the radiation pattern is quite small due to a small ground plane adopted in the proposed antenna. The measured peak gain of the proposed antenna at 2.67 GHz is 2.5 dBi. It is stable and varies little in the whole operating frequency band.

The proposed antenna can be installed on the wing structure or the head of a UAV. In our scenario, the small UAV used is made of foam. Thus it has little effect on the radiation performance of the proposed antenna.

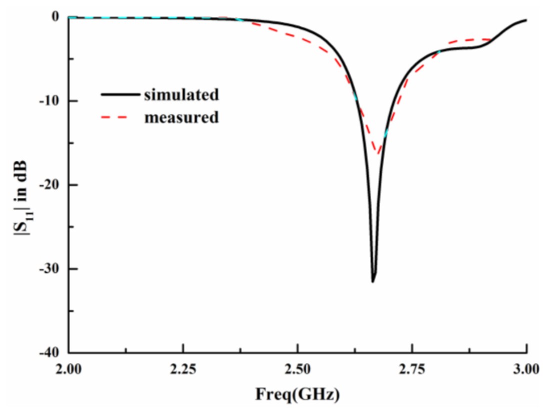
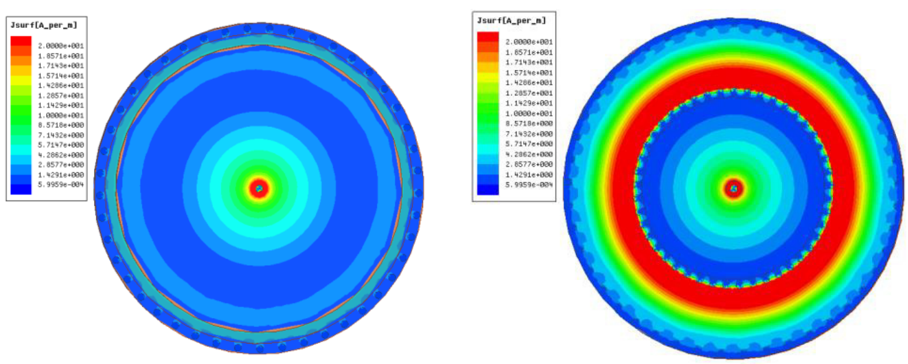
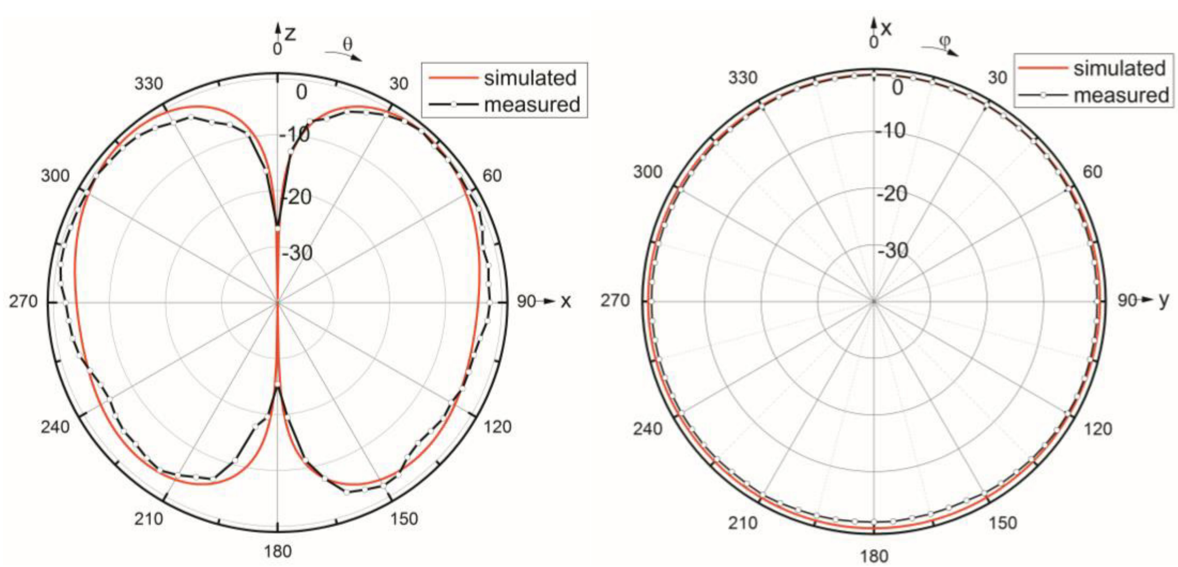


Figure 9. Simulated and measured VSWR of the proposed antenna.



(a) (b)

Figure 10. The current distribution of the proposed antenna. (a) Top view. (b) Bottom view.



(a) (b)

Figure 11. Simulated and measured radiation patterns. (a) *E*-plane. (b) *H*-plane.

4. CONCLUSION

A miniaturized annular ring slot antenna with a novel matching structure is presented and extensively investigated in this paper. By using a novel folded matching structure, the proposed antenna is miniaturized and does not need a large ground plane. Compared with traditional annular ring slot antennas, the proposed antenna is much smaller in size and it has a relatively low elevation. Moreover, impedance matching can be easily achieved by optimizing the size of the matching structure. These attractive characteristics make it potentially suitable for the applications of taking off, landing, and long distance communications for a small UAV.

The UAV used in our scenario is made of foam, and it has little effect on the radiation performance of the proposed antenna. The influence of the UAVs made of other materials on the proposed antenna is being investigated and will be reported in the near future.

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