Progress In Electromagnetics Research Letters, Vol. 45, 45–50, 2014

A Spiral Antenna with Integrated Parallel-Plane Feeding Structure

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Abstract—In practical applications, the low-profile spiral antennas suffer from the lack of proper planar feeding ways. The vertical balun always has a significantly long length, inconsistent with the requirements of the low profile spiral antenna geometry. A spiral antenna with integrated parallel-plane feeding structure is proposed in this paper. The antenna used has obviously improved axial ratio compared to the equiangular spiral antenna at low frequencies. And the traditional balun in the third dimension is moved to the planar plane. The antenna and the Dyson-style balun have been integrated into a multi-layer structure. The resulting structure maintains the typical radiation behavior and the broadband operation of the spiral antennas, but the vertical balun is integrated at the same plane with the antenna. The overall size of the spiral antenna is largely reduced.

1. INTRODUCTION

Planar spiral antennas have the advantages of great performance on circular polarization, easy impedance matching, and superior radiation efficiency. However, the conventional feeding structure for planar spiral antennas is situated in the center of the spiral and extends into the third dimension [1]. The vertical feeding structure always has a significantly long length, inconsistent with the requirements of the low-profile spiral antenna geometry. This three-dimensional feeding way is well studied in the past [2, 3].

Many efforts have been made to feed spiral antennas in the planar plane, but the radiation behavior always becomes worse at the same time. Feeding the spiral from the terminations on the perimeter is proposed. This method achieves a completely planar spiral antenna at the cost of limited band width [4]. The coplanar waveguide (CPW)-fed slot antenna has received considerable attention [5–7]. Despite the advantages of completely planar structure, the CP (circularly polarization) bandwidth is also limited. Holes were etched from the metal arms of the equiangular spiral antenna to feed the antenna in the planar plane [8], but the structure only exhibits an elliptical polarization at operation frequencies.

Feeding the spiral with a transmission line that follows the metal layer beneath the spiral arm to the center point is proposed [9]. This method is used to feed equiangular spiral antenna and achieves axial ratio below 5 dB over the frequency range of 3–10 GHz, but it is impossible to feed the Archimedean spiral antenna in the same way because of its long and thin arms. However, the Archimedean spiral antenna has a noticeable advantage at axial ratio bandwidth over its equiangular counterparts. On this condition, this paper uses the similar feeding way to feed a newly designed spiral antenna. The antenna designed has largely improved axial ratio compared to the equiangular spiral antenna at comparable size, and the arms are wider and largely shorter than the Archimedean spiral antenna to make it possible to feed the antenna in similar way with [9]. The spiral antenna and a Dyson-style balun have been integrated into a multi-layer structure. The resulting structure maintains the typical radiation behavior and broadband operation of spiral antennas, and achieves good axial ratio performance without the vertical balun. The overall size of the spiral antenna is largely reduced.

Received 27 January 2014, Accepted 14 February 2014, Scheduled 18 February 2014
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2. ANTENNA DESIGN

Figure 1 shows the conventional equiangular spiral antenna, Archimedean spiral antenna and the newly designed antenna. The new spiral antenna edge is described by (1).

$$r(\varphi) = r_0 * A * \left[\frac{\arctan(\varphi - B)}{C} + D\right] \tag{1}$$

where r is the radial distance, φ the winding angle, and r_0 the inner radius. A, B, C and D are constants related to the defining geometrical parameters of the antennas. The formula defines the edge of the first arm. The other edge is obtained by rotating the first edge by 90°. The second arm is created by rotating the first arm by 180°.

As shown in Figure 1, the Archimedean spiral has thin and long arms and is impossible to be fed in the new way mentioned in [9]. However, Archimedean spiral has an obvious advantage of axial ratio bandwidth at comparable size. On this condition, the new kind of spiral antenna is designed to achieve improved axial ratio and shorted arm length. The design process of the new antenna is well explained in our former work [10]. With the wider and largely shorter arm, feeding the antenna using a transmission line that follows the metal layer beneath the spiral arm to the center point is feasible.

Figure 2 shows the newly designed antenna with integrated parallel-plane feeding structure. Compared with the feeding way mentioned in [9], the new feeding way in this paper is modified to avoid unnecessary connecting between the spiral arms and feeding structure. So in this paper the two arms of the spiral antenna are printed on different sides of the substrate for planar feed. A Dyson-style balun is designed to match the antenna input port and 50 Ω transmission line. The balun and the antenna are integrated together at the border. The spiral antenna uses one arm of the spiral antenna as ground of the stripline feed network and the center conductor of the strip line provides the other spiral arm.

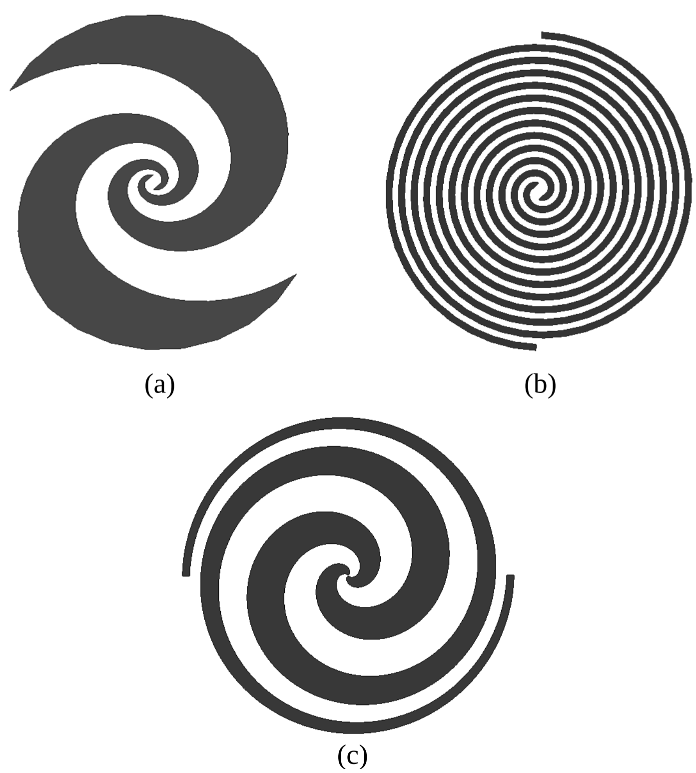

Figure 1. The antennas discussed in this paper. (a) Equiangular spiral. (b) Archimedean spiral. (c) New spiral.

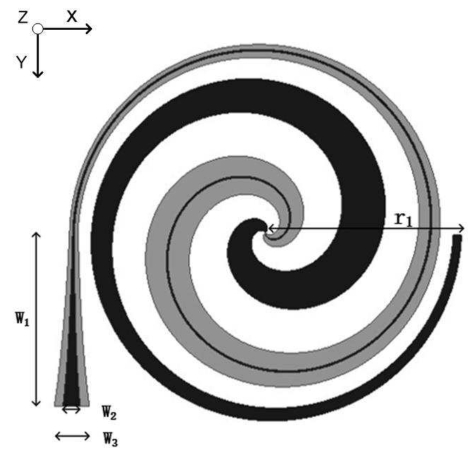

Figure 2. The geometry of the proposed antenna. Metal on the front side (black) and metal on the back side (gray).

The parameters A, B, C, D, r_0, $\varphi_{\max}$, W_1, W_2, and W_3 are illustrated in Table 1. The antenna is constructed on the F4B substrate with the dielectric constant of 2.2, the loss tangent of 0.0009 and the thickness of 0.8 mm, occupying an area of $70 \times 70\,\text{mm}^2$.

Table 1. Parameters of the antennas.

A	B	C	D	r_0	$\varphi_{\max}$	W_1	W_2	W_3
64.1	4.6	3	1	0.2 mm	3.75π	25 mm	2.5 mm	5 mm

3. SIMULATIONS AND MEASUREMENTS

The antenna performance is investigated by HFSS simulation software [11], using lumped port. The antennas are fabricated on a 0.8 mm thick F4B ($\varepsilon_r = 2.2$) substrate. The axial ratio of the new spiral antenna and equiangular spiral antenna are compared in Figure 3. The new antenna has a noticeable advantage of axial ratio at low frequencies compared to equiangular spiral antenna at even smaller size. The parameters of the equiangular spiral antenna are described in [9], and the radium is 32.5 mm. The radium of the new spiral antenna is only 28 mm, and the axial ratio is largely improved at low frequencies. In this simulation, no balun is used and we have assumed matched conditions at the input port. The excitation source impedance is set to 160 Ω in accordance with the simulated input resistance.

Figure 4 is the prototype of the spiral antenna integrated with the planar feeding structure. The $|S_{11}|$ of the antenna is measured by Advantest R3770 network analyzer. Figure 5 shows measured and simulated results of $|S_{11}|$ for the developed spiral antenna with feeding structure, and good reflection coefficient is achieved throughout the desired bandwidth. The discrepancies between the measured and simulated results are due to fabrication and measurement deviations.

Figure 6 is the simulated and measured axial ratio performances of the new antenna with the transmission line balun. As seen in Figure 6, the axial ratio of new spiral has been largely affected by the transmission line balun, but the whole structure still exhibits a circular polarization at operation frequencies.

The measured and simulated gains of the new structure is shown in Figure 7. The gain of the new structure is not much reduced by the long transmission line because of the low loss of the substrate.

Figure 8 shows comparison between simulated and measured results of normalized radiation patterns for the total gain at 3 GHz, 6 GHz, and 9 GHz. As shown, because of the transmission line the

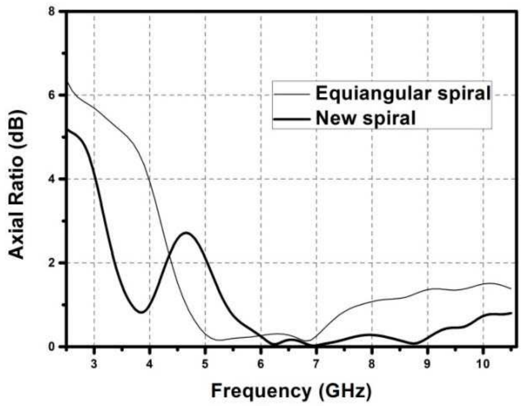

Figure 3. Simulated axial ratio for the new spiral and equiangular spiral.

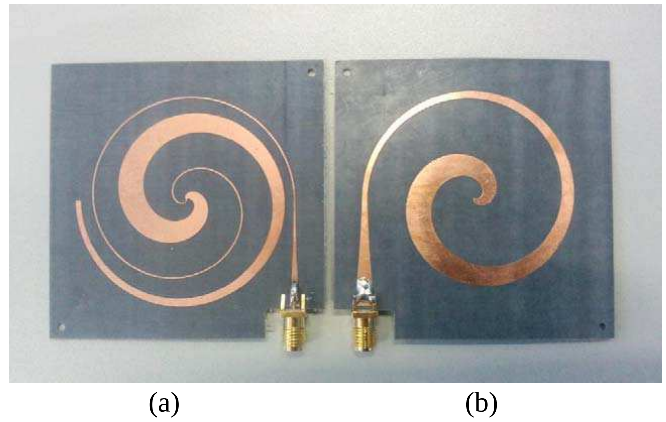

Figure 4. (a) Top view and (b) bottom view of fabricated antenna with spiral-shaped microstrip line.

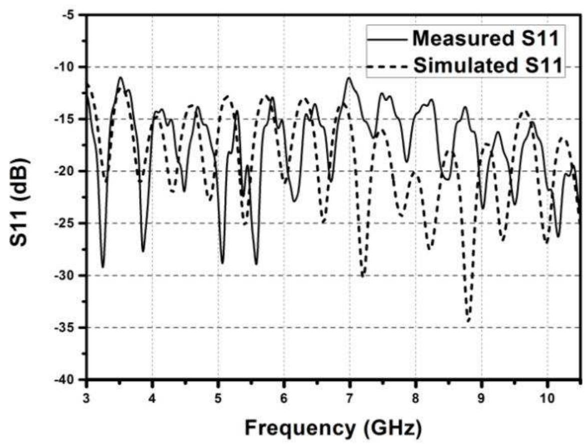

Figure 5. Measured and simulated $|S_{11}|$.

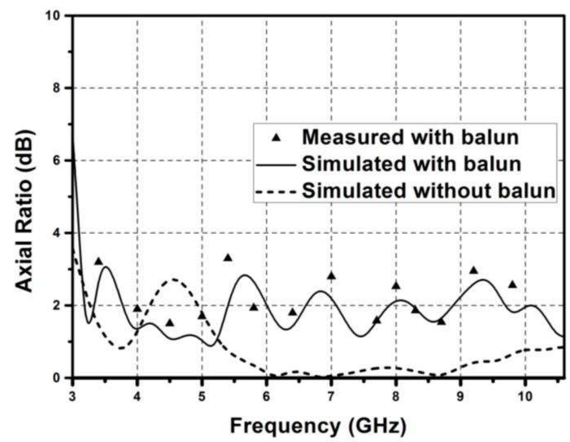

Figure 6. Measured and simulated axial ratios at front side.

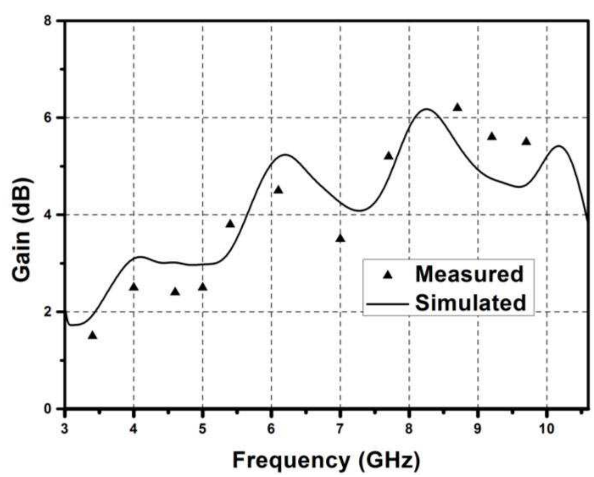

Figure 7. Measured and simulated gains of the antenna.

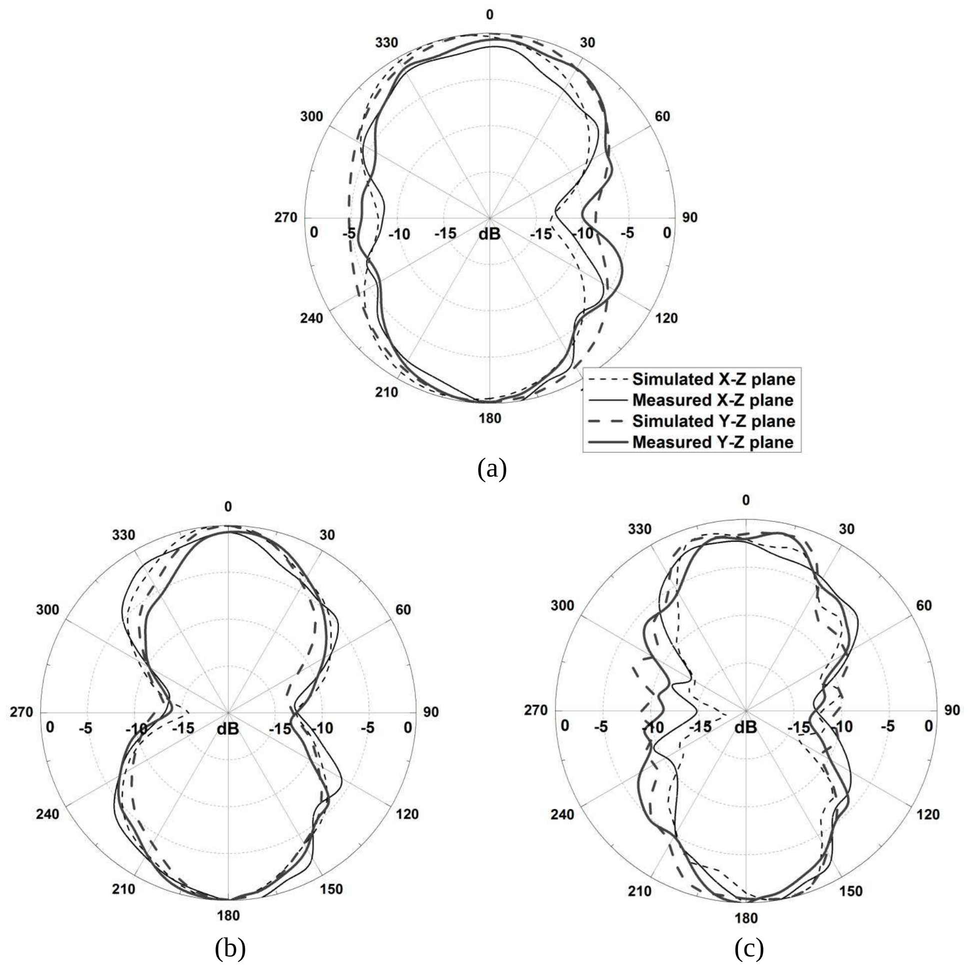

Figure 8. Measured and simulated radiation directivity. (a) 3 GHz. (b) 6 GHz. (c) 9 GHz.

radiation pattern is not symmetrical any more. Discrepancies between measurements and simulations are due to the physical difference between the computational models.

4. CONCLUSIONS

A new spiral antenna with a parallel-plane feeding structure is proposed in this paper. The antenna used has a noticeable advantage of axial ratio over equiangular spiral antenna. And the traditional vertical balun has been replaced by integrated parallel-plane feeding structure. The resulting structure maintains the typical radiation behavior and broadband operation of spiral antennas, and achieves good axial ratio performance without the vertical balun. The overall size of the spiral antenna is largely reduced.

ACKNOWLEDGMENT

This work is supported by the National Natural Science Foundation of China under Grant 61071056.

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