Hindawi Publishing Corporation
International Journal of Antennas and Propagation
Volume 2016, Article ID 5950472, 7 pages
http://dx.doi.org/10.1155/2016/5950472

*Research Article*

# The Analysis of a Wideband Strip-Helical Antenna with 1.1 Turns

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Received 8 September 2015; Revised 15 November 2015; Accepted 20 December 2015

Academic Editor: Ahmed T. Mobashsher



A wideband strip-helical antenna with 1.1 turns is analyzed numerically and experimentally. By replacing the traditional wire helix with wide metallic strip, the forward traveling current on the strip helix with about one turn smoothly decays to the minimum value at the open end of the helix. Therefore, the strip helix can excite a wideband circular polarization (CP) wave with 50-ohm impedance matching. The proposed antenna is printed on a hollow-cylinder with a substrate relative permittivity of $\varepsilon_r = 2.2$ and a thickness of $h = 0.5$ mm. A 50 Ω coaxial cable is directly connected to excite the strip-helical antenna without any additional impedance matching section. The ground plane is placed below the antenna in order to provide a directional radiation pattern. To demonstrate this method, a prototype of 1.1-turn strip-helical antenna is tested. The test shows that the proposed antenna can reach an overlapped bandwidth of 46% with height of $0.52\lambda_0$, where $\lambda_0$ is the wavelength in free space at the center operation frequency.

## 1. Introduction

Conventional axial-mode helical antennas are one of excellent candidates for achieving circular polarizations in wireless communications due to their advantages such as high gain and wide axial ratio (AR) bandwidth [1, 2]. However, the large profile limits their applications in wireless terminals. Some low-profile wire helical antennas have been proposed to tackle this disadvantage [3, 4]. However, the reported AR bandwidths are not wide enough, and their characteristic impedances are relatively high, which may require an additional impedance transformer for transferring the high impedance to 50 Ω feed. In the last twenty years, the spherical and hemispherical helical antennas, both can improve the AR bandwidth up to 15%, have been designed by Cardoso and Hui [5, 6], respectively. Nevertheless, the AR bandwidth of these antennas still cannot meet the requirement of the modern high speed transmission. In addition, a series of tapered strip-helical antennas have been presented in [7, 8]. A tapered metallic strip is introduced to further increase the AR bandwidth to 24% with antenna height of $0.28\lambda_0$ [7]. Recently, some helical/spiral excited circularly polarized dielectric resonator antennas (DRAs) with compact size have been proposed in [9–11]. For example, the helical excited DRA in [10] has an AR bandwidth of ~13%, and the square spiral excited DRA in [11] has an AR bandwidth of ~16%.

In our previous work [12], a wideband strip-helical antenna with circular polarization has been reported. But the principles and the performances of the strip-helical antenna are not fully considered in [12]. In this paper, a detailed analysis of the strip-helical antenna is carried out numerically and experimentally, which includes radiation mechanism, parameter investigation, and performance comparisons. The proposed helix is made of metallic strip with uniform width, which is different from the traditional wire helix. This change leads to a reduction in reflected current at the end of the helix over a wide frequency range due to the less numbers of turn design. This gives advantages to both input impedance and CP radiation characteristics of the proposed helical antenna. The antenna obtains a 3 dB AR and 7.5 ± 0.5 dB gain bandwidth of 46% using the proposed strip helix with 1.1 turns. More importantly, the proposed antenna has

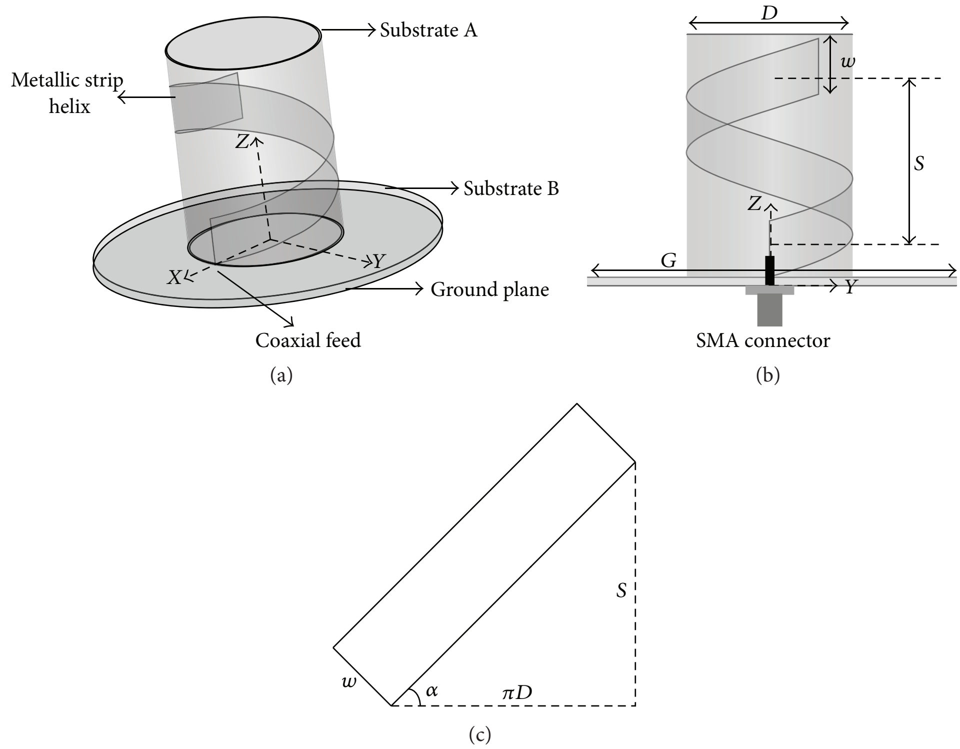


Figure 1: Geometry of the proposed strip-helical antenna. (a) 3D view. (b) Side view. (c) Unrolled strip helix of one turn.

an impedance bandwidth ($S_{11} < -10$ dB) of 77%, which can completely cover the AR bandwidth.

## 2. Antenna Structure

The structure of the strip-helical antenna is depicted in Figure 1. It consists of a circular ground plane and a cylindrical helix, which is made of vertical strip with uniform width ($w$). For convenience of fabrication, it is printed on Substrate A with a relative permittivity of $\varepsilon_{r1} = 2.2$ and a thickness of $h_1 = 0.5$ mm. The helix is rolled in right-hand direction for right-hand circular polarization (RHCP). The detailed dimensions of the helix are given as follows: $D$ is the diameter of the helix, $S$ is the spacing between the turns (center-to-center), $\alpha$ is the pitch angle ($\alpha = \arctan(S/\pi D)$), $C$ is the circumference of the helix ($C = \pi D$), and $n$ is the number of turns. The circular ground plane (diameter of $G$) is printed on the bottom layer of substrate B ($\varepsilon_{r2} = 2.2$, $h_2 = 3$ mm) and placed below the helix to depress back radiation. The detailed dimensions of the antenna structure are as follows: $D = 72$ mm, $S = 65$ mm, $\alpha = 16^{\circ}$, $C = 226$ mm, $n = 1.1$, and $G = 160$ mm. With the aim of reducing the height of the proposed antenna, the numbers of turns ($n$) are designed to be around 1. It is precisely optimized to be 1.1 for achieving maximizing AR bandwidth. The diameter of the ground plane ($G$) is set to be about one wavelength. In fact, the variation of its size contributes little to the change of impedance and axial ratio of the proposed antenna as long as $G$ reaches one wavelength. A 50 Ω SMA connector is placed under the ground plane. The inner of the SMA connector with a diameter of 1 mm is soldered to the strip helix.

Motivated by the fact that a strip monopole has much larger operation bandwidth than a wire monopole for linear polarization, [13, 14], we use a strip helix instead of the traditional wire helix in this paper. The reflected current from the open end of the helix can deteriorate the axial ratio of the helical antenna [3]. The current densities (Jsurfs) on the center of the strip along the proposed helix at three normalized circumferences of $C/\lambda = 0.94$, $C/\lambda = 1.28$, and $C/\lambda = 1.66$ are obtained with the aid of the commercial software "HFSS", as illustrated in Figure 2. It is clear that that the smoothly decaying Jsurfs obtain minimum value with less reflected current at the open end of helix when $C/\lambda$ varies from 0.94 to 1.66. This indicates that the proposed strip helix with 1.1 turns can generate circularly polarized radiation over a wide frequency range. Moreover, the input impedance of the strip-helical antenna stays stable over the corresponding range, since the reflected current at the open end of the helix is negligible. As a result, substantial improvement in both input impedance and radiation characteristics with circular polarization is achieved with the proposed technique.

Figure 3 shows the axial ratio against frequency of the strip-helical antennas with different turn numbers. The AR bandwidth with turn numbers of 2 and 3 is 43% from 1.1 GHz to 1.7 GHz and 43% from 1 GHz to 1.55 GHz. As the turn number decreases to 1 (black curve), a w-shaped axial ratio curve is obtained between 1.35 GHz and 2.5 GHz. Thus, the increase in turn numbers does not improve the AR performance. Given that the maximum value of axial ratio

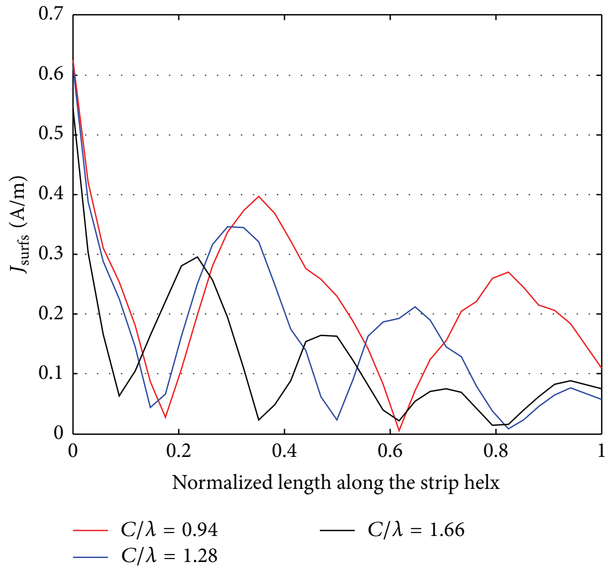


FIGURE 2: Current densities on the center of the strip along the helix at three $C/\lambda$ ratios.

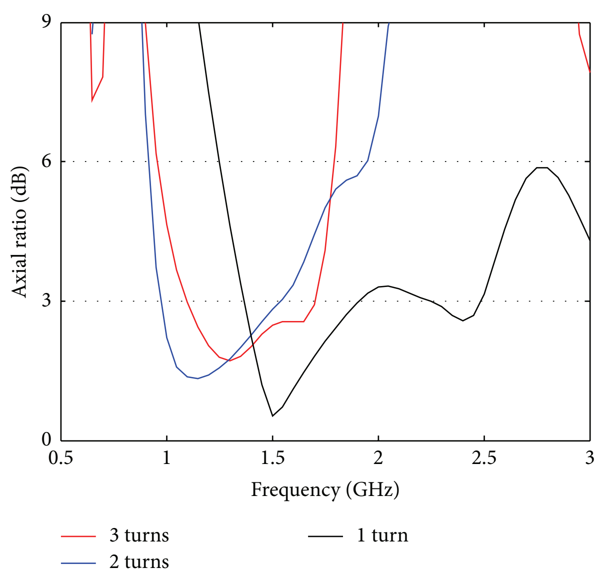


FIGURE 3: Axial ratio against frequency of the strip-helical antennas with different turn numbers.

between 1.35 GHz and 2.5 GHz is 3.3 dB, the proposed turn numbers in this design are optimized to be 1.1 in order to achieve a wide 3 dB AR bandwidth.

## 3. The Effect of the Strip Helix

In Section 2, the difference between the proposed strip-helical antenna and the traditional wire helical antenna has been discussed. In this section, the performance of the strip helix is investigated. Specifically, the width of the strip helix that effects both impedance matching and CP radiation is discussed. The remaining dimensions of the antenna structure are identical to the dimensions given in Section 2.

*3.1. Impedance Matching.* Figure 4 depicts the input impedance and the corresponding reflection coefficient when helix is made of strip with a width ($w$) of 22 mm and 10 mm and wire with a diameter of 1 mm, respectively. It can be seen from the black curves that the input impedance varies rapidly with different frequencies and $S_{11}$ is larger than −10 dB when the helix is made of wire. However, as wire is substituted with strip with a width of 10 mm (sky-blue curves), the input impedance varies within a narrow range and $S_{11}$ drops to about −10 dB. As the width of the strip is increased to 22 mm (red curves), the input impedance is slightly changed and $S_{11}$ is less than −10 dB from 1.2 GHz to 3 GHz and beyond. Moreover, it is observed that the input impedance becomes steady with the increase of the strip width (wire can be considered as strip with a width of 1 mm). Thus, a wide impedance bandwidth ($S_{11} < -10$ dB) of over 85% is achieved with $w$ = 22 mm. The minimum value of $S_{11}$ within the impedance bandwidth is about −14 dB.

*3.2. Radiation with Circular Polarization.* Figure 5 demonstrates the axial ratio against frequency when helix is made of strip with width ($w$) of 22 mm and 10 mm and wire with a diameter of 1 mm, respectively. It is noticed that the performance of CP radiation is significantly enhanced when the wire helix is replaced by the strip helix. Furthermore, a much wider AR bandwidth (AR < 3 dB) of 56% can be obtained when the width of the strip is increased from 10 mm to 22 mm.

The proposed strip-helical antenna has an impedance bandwidth of over 80% and an AR bandwidth of 56%, while the wire helical antenna has neither an impedance bandwidth nor an AR bandwidth with the same number of turns. This indicates that the strip helix introduced in this paper considerably improves the antenna characteristics on both impedance matching and CP radiation.

## 4. Simulation and Experiment Results

In order to demonstrate the good performance of the proposed strip-helical antenna, a prototype is fabricated and shown in Figure 6. The width of the strip ($w$) is chosen to be 22 mm. The remaining dimensions of the prototype are the same as the one described in Section 3. Measurement is obtained with the aid of the E5071C Network Analyzer and the Near Field Antenna Measurement System, Satimo. Measurement results of reflection coefficient ($S_{11}$), axial ratio, gain, and radiation patterns are presented and compared with the corresponding simulated results.

The reflection coefficient ($S_{11}$) of the proposed strip-helical antenna against frequency is plotted in Figure 7. As can be seen from Figure 7, the input impedance of the proposed strip-helical antenna is stable across a wide frequency ranges with a matching impedance of 50 ohm, and hence it obtains a wide impedance bandwidth. The simulated impedance bandwidths ($S_{11} < -10$ dB) are more than 85% from 1.18 GHz to 3 GHz and beyond (we tested only within 1 GHz–3 GHz), while the measured impedance bandwidths are about 77% from 1.22 GHz to 2.76 GHz.

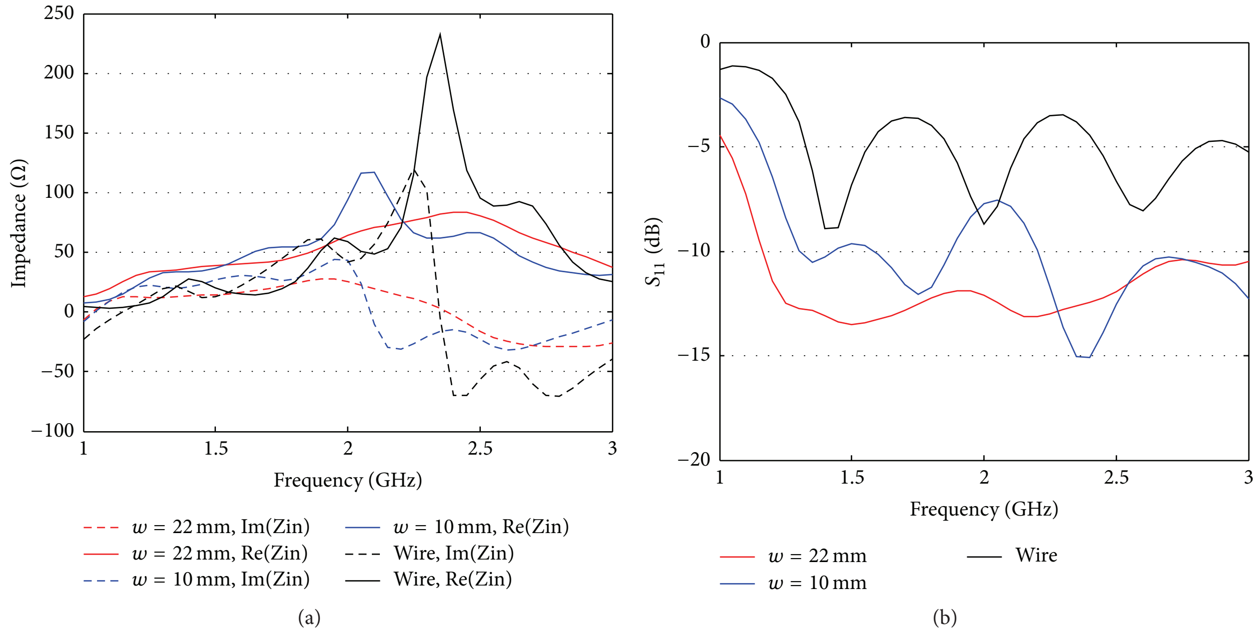


FIGURE 4: Input impedance and reflection coefficient ($S_{11}$) against frequency when the helix is made of strips and wire. (a) Input impedance. (b) $S_{11}$.

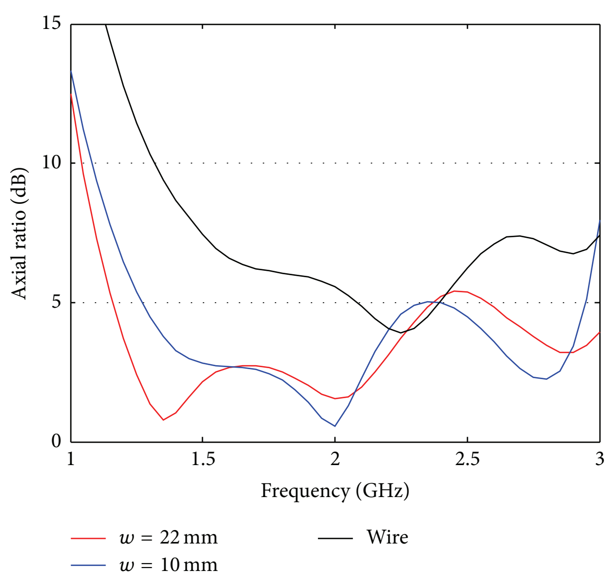


FIGURE 5: Axial ratio against frequency when the helix is made of strips and wire.

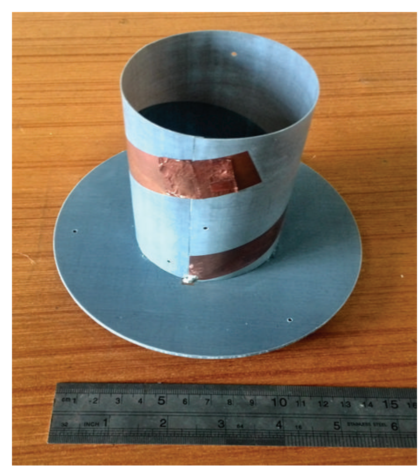

FIGURE 6: View of the prototype of the proposed strip-helical antenna.

Figure 8 shows both the simulated and measured results for AR and gains of the helix in the axial direction. A good agreement between the simulated and measured results is observed. From the AR curves, it is found that the proposed strip-helical antenna has simulated and measured AR bandwidths (AR < 3 dB) of 56% (1.23–2.19 GHz) and 55% (1.25–2.2 GHz), respectively. Within the measured AR bandwidth, the normalized length of $L/\lambda$ varies from 0.98 to 1.72, where $\lambda$ is the wavelength in free space. The simulated and measured peak gain are 9 dB and 8.5 dB, respectively. From 1.8 GHz to 2.2 GHz, both the simulated and measured gain decrease fast, since the direction of maximum radiation deviates from the axial direction with tilt angle $\tau$ in higher frequency band. Therefore, an overlapped bandwidth of 46% (1.25–2 GHz) is defined, where $S_{11}$ is below −10 dB, AR is smaller than 3 dB, and the gain is stable with $7.5 \pm 0.5$ dB. The axial height of the proposed antenna ((65 × 1.1 + 22 + 3) mm) and the size of the ground plane are $0.52\lambda_0$ and $0.87\lambda_0$, respectively, at the center operation frequency of 1.625 GHz.

Table 1: Performance of helical antennas.

| References | Impedance matching section | Numbers of turns | Height | AR bandwidth | Gain, dB |
|---|---|---|---|---|---|
| [6] | Required | 5 | $0.27\lambda_0$ | 15% | $9 \pm 1$ |
| [7] | Required | 4.5 | $0.28\lambda_0$ | 24% | $9 \pm 1$ |
| [9] | Not required | 7.25 | $0.23\lambda_0$ | 6% | $7 \pm 1$ |
| [10] | Not required | 8 | $0.3\lambda_0$ | 13% | $4 \pm 1$ |
| [11] | Required | — | $0.23\lambda_0$ | 16% | $7 \pm 0.5$ |
| Proposed | Not required | 1.1 | $0.52\lambda_0$ | 46% | $7.5 \pm 0.5$ |

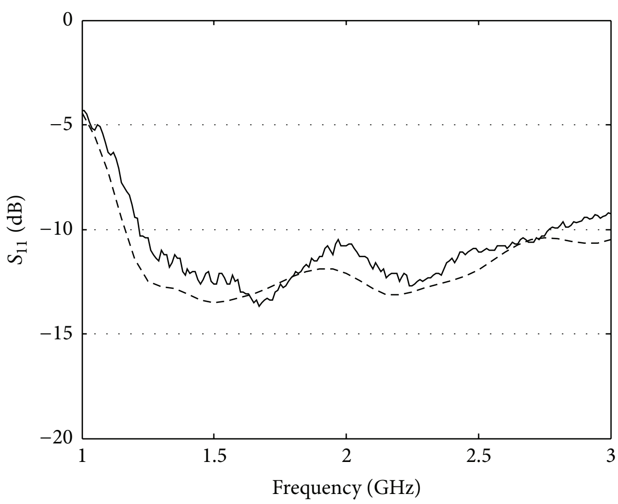


Figure 7: Reflection coefficient ($S_{11}$) against frequency of the proposed strip-helical antenna. Solid line: measured data; dashed line: simulated data.

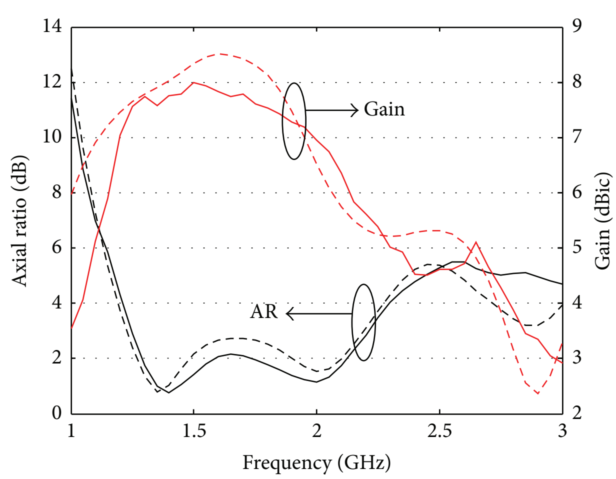


Figure 8: Axial ratio and gain against frequency of the proposed strip-helical antenna. Solid line: measured data; dashed line: simulated data.

Figure 9 shows the simulated and measured radiation patterns at 1.25 GHz, 1.625 GHz, and 2 GHz, respectively. The proposed strip-helical antenna is right-hand circularly polarized. The measurement shows that the radiation patterns are symmetric with respect to the axial direction at 1.25 GHz and 1.625 GHz. The corresponding half power beamwidths (HPBWs) are both about 70° at two principal planes. As the operation frequency increases to 2 GHz, the direction of maximum radiation deviates from the axial direction. The tilt angles are −15° at $\phi = 0°$ plane and 10° at $\phi = 90°$ plane. The varieties of the radiation patterns may be caused by the significant change of $C/\lambda$ across the whole CP bandwidth. When the proposed antenna works at 1.25 GHz, the ratio of $C/\lambda$ is 0.94, where the maximum radiation lies in the axial direction. However, the increase of $C/\lambda$, for example, from 0.94 at 1.25 GHz to 1.5 at 2 GHz, will lead to an asymmetry of the current distribution on the strip helix and the tilt of the maximum radiation from the axial direction. In fact, adding more turns of strip helix is a solution to the deviation of the maximum gain away from the axial direction. In this design, it compromises to achieve the minimum numbers.

Table 1 shows the comparison between the proposed strip-helical antenna and other designs of helical antenna in [6, 7, 9–11]. Although the proposed antenna has an axial height of half a wavelength, its overlapped bandwidth is about 2 times that proposed in [7].

## 5. Conclusion

A wideband strip-helical antenna for circular polarization is introduced and investigated. Utilizing the proposed strip helix with 1.1 turns, the reflected current at the open end can be significantlly reduced over a wide frequency range. An overlapped bandwidth of 46%, where $S_{11}$ is below −10 dB, AR is smaller than 3 dB, and the gain is stable with 7.5±0.5 dB, has been obtained. Comparing with the traditional wire helical antenna, the proposed strip-helical antenna has much better impedance characteristic and needs fewer turns to achieve a wide AR bandwidth. A prototype of the proposed antenna is fabricated and measured. Generally speaking, there is a good agreement between the simulated and measured results. The proposed antenna has a potential application in high data rate wireless communication systems owing to its wide bandwidth and convenience of fabrication.

## Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

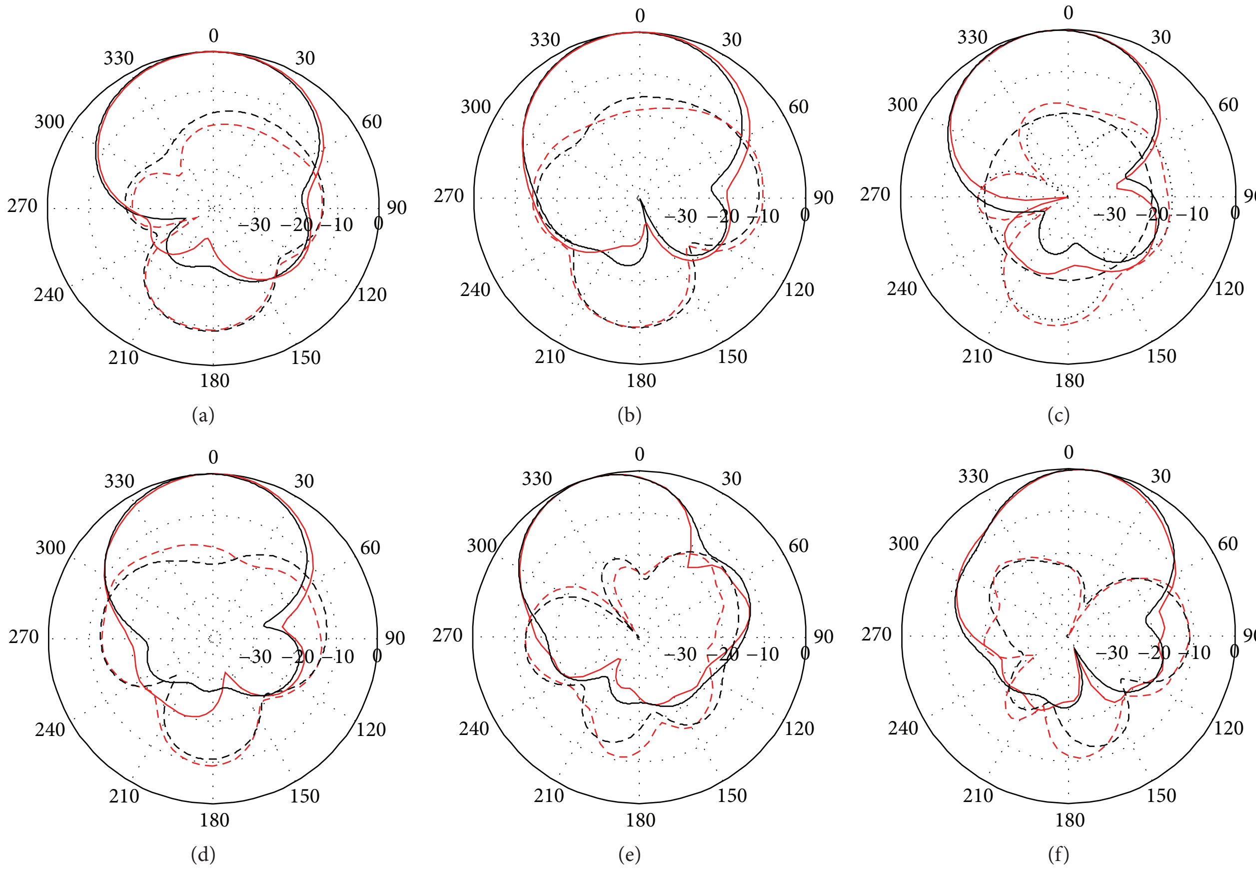


Figure 9: Radiation patterns of the proposed strip-helical antenna at 1.25 GHz, 1.625 GHz, and 2 GHz, respectively. Black line: measured data; red line: simulated data. Solid line: RHCP; dashed line: LHCP. (a) $f = 1.25$ GHz, $\phi = 0^\circ$ plane, (b) $f = 1.25$ GHz, $\phi = 90^\circ$ plane, (c) $f = 1.625$ GHz, $\phi = 0^\circ$ plane, (d) $f = 1.625$ GHz, $\phi = 90^\circ$ plane, (e) $f = 2$ GHz, $\phi = 0^\circ$ plane, and (f) $f = 2$ GHz, $\phi = 90^\circ$ plane.


## Acknowledgments

This work is supported by the Natural Science Foundation of China (61301075) and the Shenzhen Fundamental Research Project (JCYJ20120613165052982).


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