Ultra-Wideband Circularly Polarized Spiral Antenna Using Integrated Balun

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1. Introduction

With the increasing demands for high-quality wireless communication system, circularly polarized antennas have attracted significant attention, since they can suppress multipath interference and require no polarization tracking. Furthermore, ultra-wideband (UWB) electromagnetic pulses of nanosecond duration are of considerable interest to communication industry, and have been widely explored for military and biotechnological applications. Therefore, the broadband circularly polarized antennas have emerged as a new and viable alternative to narrowband circularly polarized elements such as microstrip patches.

The spiral antenna with a thin metal foil spiral pattern etched onto a substrate is typically employed for broadband circular polarization owing to its inherent frequency-independent characteristic. Compared to the Archimedean spiral antenna, which relies on the spiral with closely spaced turns for successful operation, an equiangular spiral antenna can be built with only 1.5 or 2 turns in a fairly loose spiral. Thus, the equiangular spiral antenna generates low circuit losses at low frequencies, and stimulates fewer high-order modes at high frequencies [1]. Furthermore, the spiral antenna normally requires a broadband balun for the balanced configuration of spiral antenna [2]. The microstrip-to-coplanar stripline (CPS) balun vertically connected to the spiral antenna is usually adopted as a feed network [3]. However, this configuration is bulky and difficult for microwave circuit integration.

This investigation develops a novel wideband circularly polarized equiangular spiral antenna fed by an integrated microstrip-to-CPS balun. Notably, the required balun is realized in a low-profile conformal structure by printing the tapered microstrip line on the substrate, enabling the antenna to be implemented by planar technology [4]. Hence, this balanced-fed spiral antenna reduces the induced currents on the conducting environment, and thus prevents the antenna performance from being degraded [5]. Additionally, the frequency- and time-domain properties of the UWB circularly polarized spiral antennas are explored in terms of return loss, gain, radiation pattern, and pulse responses. Moreover, the radiation pattern is bidirectional, and is capable of providing the right-hand circular polarization (RHCP) and the left-hand circular polarization (LHCP) near the axis of the main lobe over 3 to 12 GHz.

2. Antenna Design and Characterization

The geometry of 1.5-turn equiangular spiral antenna shown in Fig. 1 is given by

$$\rho_1 = ke^{a\phi} \tag{1}$$

and

$$\rho_2 = ke^{a(\phi-\delta)} \tag{2}$$

where ρ_1 and ρ_2 are the outer and inner radii of the spiral, respectively, ϕ is the angular position, k and $ke^{-a\delta}$ are the initial outer and inner radii, and a corresponds to the tightness of the spiral arms [6]. The antenna is constructed on the both sides of RT/Duriod 5880 substrate with thickness

0.787 mm and relative permittivity 2.2. The spiral antenna is optimized with the dimensions a = 0.45, k = 0.11 mm and δ = 90° to obtain the radiation pattern and input impedance with broad bandwidth. The ends of the two spiral arms are truncated to produce the smallest physical construction. Specifically, a tapered microstrip line integrated into one spiral arm is used for balun implementation, and its characteristic impedance is made from 50 to 130 Ω [1]. The current flow on the ground plane are mostly concentrated beneath the signal strip of microstrip line, which is on the center of the spiral arm, and hence the radiation property of the spiral antenna contributed by the edge current of the spiral arms would not be disturbed significantly. This is the advantage of the proposed spiral antenna with integrated balun and can be demonstrated by the broadband return loss, radiation pattern, and axial ratio.

3. Frequency-Domain Characterization

In Fig. 2, the measured return loss of the spiral antenna is illustrated, which indicates that $|S_{11}|$ is below -10 dB from 3.75 to 18.6 GHz. The radiation characteristics of the proposed antenna are also presented in Figs. 3 and 4. Fig. 3 shows the measured axial ratio and circularly polarized peak gain over the entire operating region. The circularly polarized gain varies from 3.5 to 7 dBic, and the axial ratio is below 3 dB from 3 to 14.5 GHz. The measured RHCP and LHCP radiation patterns on XZ- and YZ- plane at 3, 6, 9, and 12 GHz are shown in Fig. 4, demonstrating that the bidirectional radiation with opposite polarization is achieved.

4. Time-Domain Characterization

In addition to these frequency-domain results, the transient property of the UWB antenna is further investigated in terms of its temporal characteristics. Two identical antennas, which point each other along Z-axis, are in a line-of-sight position to examine the time-domain performances [5]. The S-parameters are measured using an HP8720C vector network analyzer and transformed to the time domain to obtain the pulse response of antenna. The Gaussian pulse with a pulse width of 400 ps, as shown in Fig. 5(a), corresponding to -10 dB power bandwidth from 3.5 to 12.3 GHz, is used for transmitting signal. The measured impulse responses of the transmitting/receiving antenna system with different separations D = 25, 50, and 70 cm are shown in Fig. 5(b). The signal fidelity [5] of the transmitting signal and receiving signal is calculated and the results are 0.898, 0.894, and 0.896 for D = 25, 50, and 70 cm, respectively. Therefore, the proposed UWB antenna possessing the insignificant pulse distortion is quantitatively verified the high fidelity for transmitting and receiving signals (> 0.89).

5. Conclusion

The proposed equiangular spiral antenna has been investigated theoretically and experimentally. The spiral antenna and the tapered microstrip balun printed onto one spiral arm are successfully integrated to achieve circular polarization with broad bandwidth. The measured results show $|S_{11}|$ < -10 dB from 3.75 to 18.6 GHz and axial ratio < 3 dB from 3 to 14.5 GHz. This antenna radiates both RHCP and LHCP waves on each side of the antenna plane with 3.5 to 7 dBic gain within the operating band. The presented antenna can be backed by an absorber-loaded cavity for some applications when unidirectional operation is required. The insignificant pulse response of the proposed antenna is validated by the measured results with high fidelity (> 0.89). The proposed spiral antenna is suitable for numerous applications, such as the high resolution and object identification radar sensor.

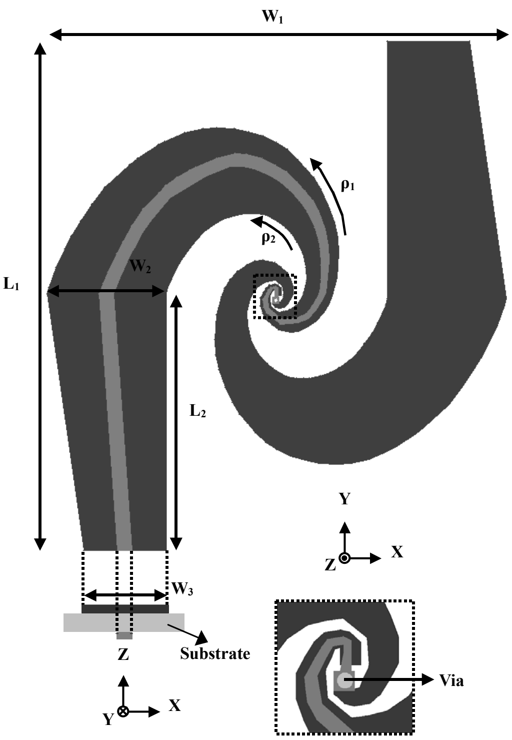

Fig. 1. Layout of the proposed equiangular spiral antenna. (W_1 = 75.8 mm, W_2 = 19.6 mm, W_3 = 13.65 mm, L_1 = 84.26 mm, L_2 = 43.6 mm)

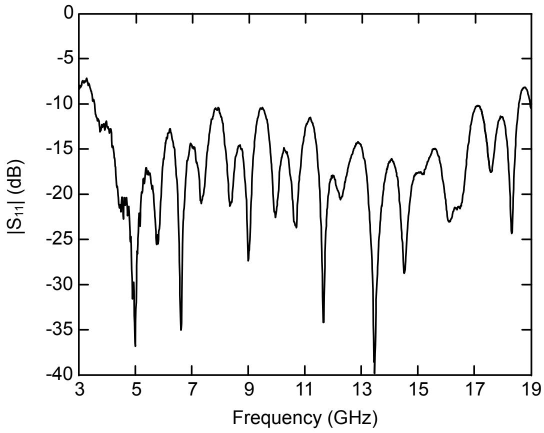

Fig. 2. Measured return loss of the spiral antenna.

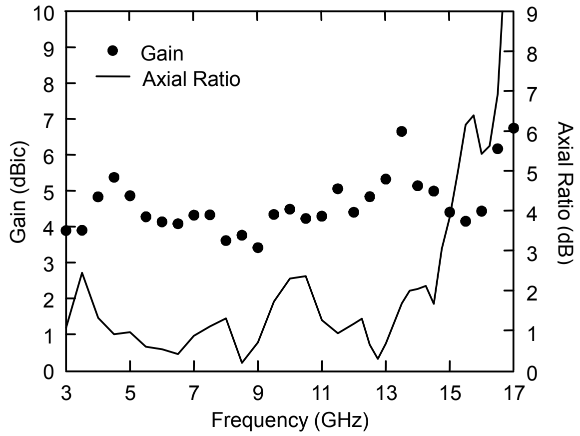

Fig. 3. Measured axial ratio and circularly polarized gain of the spiral antenna.

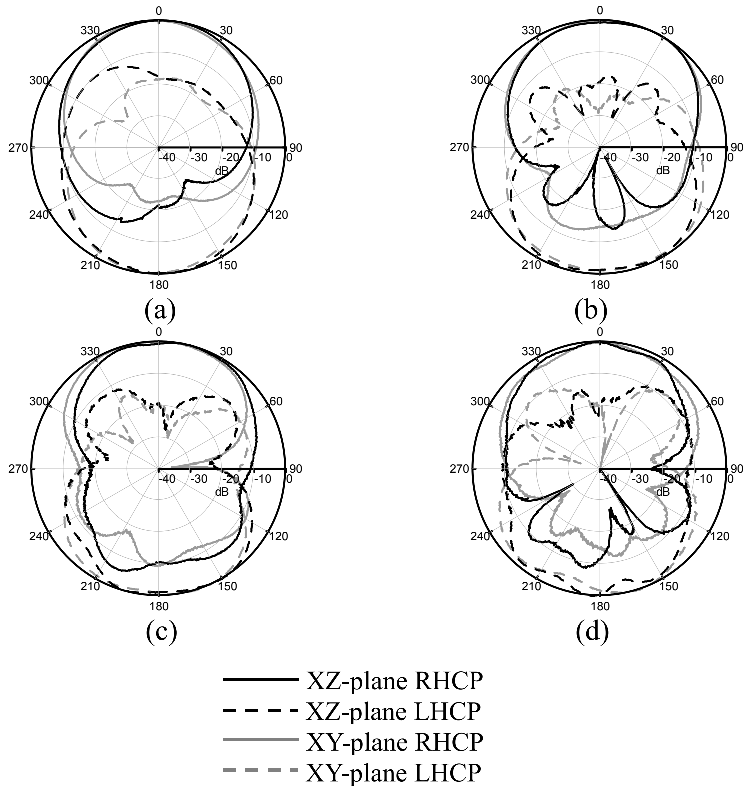

Fig. 4. Measured circularly polarized radiation patterns on XZ- and YZ-plane at (a) 3, (b) 6, (c) 9, and (d) 12 GHz.

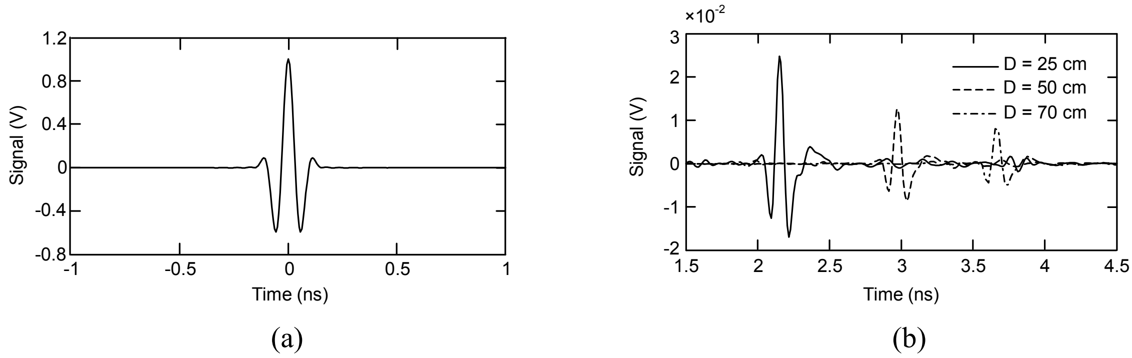

Fig. 5. (a) The transmitting signal impulse response and (b) the measured impulse responses of the transmitting/receiving antenna system with different separations, D = 25, 50, and 70 cm.

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