Ultra-Wideband Circularly Polarized Antenna and Applications to Target Detection

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Abstract

A wideband circularly polarized (CP) equiangular spiral antenna is proposed. Contrary to the conventional spiral antenna using the coaxial line or the vertically connected feeding structure, a tapered microstrip balun is fully integrated into one spiral arm of the proposed antenna and hence this construction can be realized completely planar. The experimental results reveal that the characteristics of the proposed circularly polarized antennas are useful in the application of ground penetrating radar (GPR), and by using time-frequency analysis, the information concerning the targets, including position and dielectric constant, can be obtained easily.

Keywords: Ultra-wideband spiral antenna circular polarization transmitting/receiving antenna system

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]. Additionally, the application of the spiral antenna for UWB bistatic radar system is presented. A brick is used as a target to test the radar detecting system, and the position and dielectric constant of the brick can be identified clearly.

2. Antenna Characterization

The geometry of 1.5-turn equiangular spiral antenna shown in Figure 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 [5]. 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.

In Figure 2 (a), 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 Figure 2 (b). Fig. 2 (b) 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.

3. UWB Radar Systems

The experimental setup is based on a brick with area of 10 cm × 22 cm and thickness of 5.3cm. The brick is analysed by the UWB bistatic radar system shown in Figure 3, and the result of time-frequency analysis is shown in Figure 4. It can be observed that signal arises by the reflections on both the top and the bottom surfaces of the brick. The first impulse reflected on the top surface of the brick only through air, resulting in no dispersion. This causes a contour distribution parallel to the frequency axis of the time-frequency representation, and the length of the contour distribution reflects the bandwidth of the pulse. The pulse travels through the brick is subjected to dispersion which depends upon the moisture content, meaning that the lower-frequency spectral components are delayed more significantly than the higher-frequency spectral components. Furthermore, the higher frequency tends to be attenuated. In the time-frequency analysis, this results in a skewing of the impulse trace and a reduction of its length. For the sake of simplicity, we use for the first trials only the skewing to demonstrate the influence of moisture. The joint time-frequency approach offers new and interesting methods for more penetrating observations and analysis.

Moreover, relative permittivity of the detected object can be estimate by calculating phase velocity of the signal in the object. The phase velocity is obtained by the formula as [6]:

$$v_p = \frac{c}{\sqrt{\varepsilon_r}} = \frac{z}{t} \tag{3}$$

v_p is the phase velocity of the material with relative permittivity ε_r. c is the velocity of light. z and t are path length and spent time of the signal travelled within the detected object. So, the relative permittivity of the detected object can obtain by (4)

$$\varepsilon_r = (\frac{t \times c}{z})^2 \tag{4}$$

On the calculation, the effect of incident angle is neglected, because the distance from the antenna to the detected object H = 25.5 cm, is greater than the half-space between two antennas $D/2$ = 7.25 cm. Hence, the signal path length is treated as the double thickness of brick, and the spent time is the interval between two peaks of reflected signals. The relative permittivity of the brick can be found ($\varepsilon_r = 5.255$). The calculated result is very close to the value, 5.31, presented in the paper [7]. Therefore, it is demonstrated that the relative permittivity of detected object can estimate in rough when its dimension is known.

4. 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. Furthermore, a brick is used to test the spiral antenna radar system, and according to the experiment results, the pulse arises when the signal is passing through the object surface. By performing the time-frequency analysis, the characteristics of the detected object can be observed in details. The proposed UWB CP antenna is suitable for various applications, such as high resolution and object identification radar sensor.

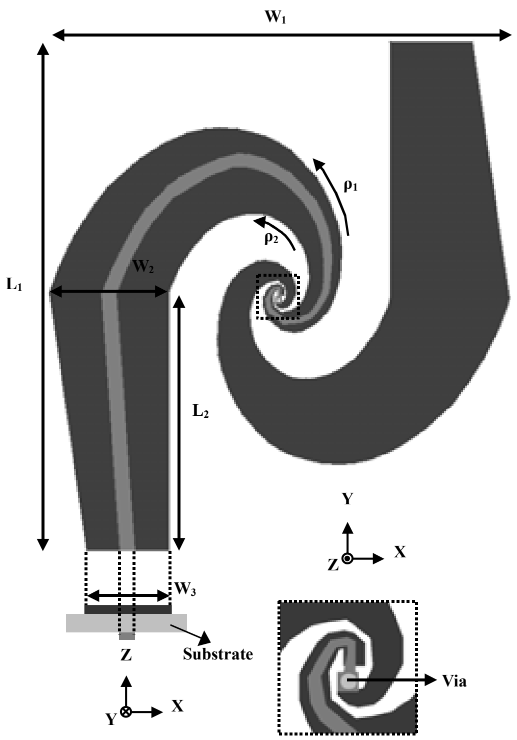
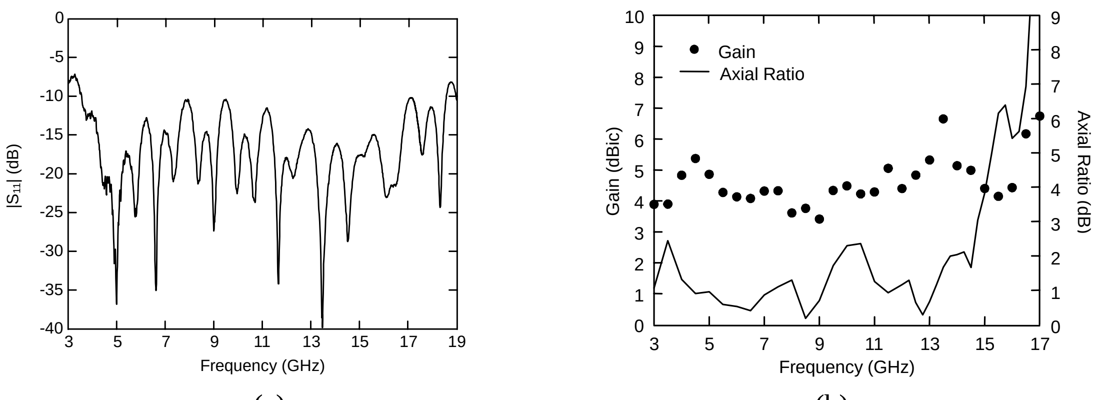


Figure 1: Layout of the proposed equiangular spiral antenna. (W1 = 75.8 mm, W2 = 19.6 mm, W3 = 13.65 mm, L1 = 84.26 mm, L2 = 43.6 mm)



(a) (b)

Figure 2: Measured (a) return loss, (b) gain and axial ratio of the spiral antenna.

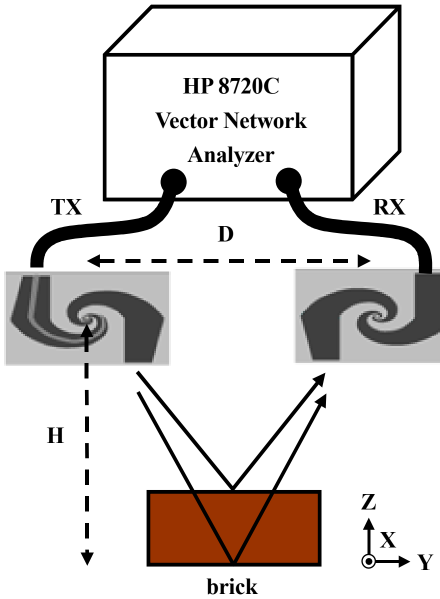


Figure 3: Setup configuration of radar system detected a brick with an area 10 cm x 22 cm and thickness is 5.3 cm. (D=14.5 cm, H=25.5 cm)

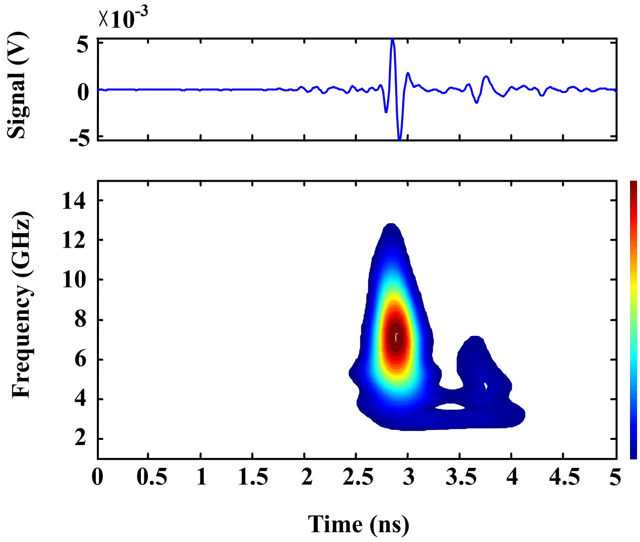


Figure 4: Time-frequency analysis and impulse response of the measured signal of Figure 3.

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