Two-arm microstrip spiral antenna for multi-beam pattern control

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A two-arm microstrip spiral antenna with a circular aperture on the ground plane for multi-beam pattern control is presented. Several beam shapes can be selected by controlling the phase difference of the two spiral arms with the *pin* diode phase shifters located on each feedline. At the operating frequency band, the antenna has four different radiation patterns: the normal beam, the conical beam, and the two tilted beams. The multi-beam pattern control is confirmed with measurements.

Introduction: The spiral antenna shows characteristics of frequency independence where radiation pattern, impedance, and polarisation are not changed appreciably over a wide range of frequency. Additionally, spiral antennas maintain the advantage of being able to attain various radiation patterns according to the number of spiral arms and feeding techniques. For such radiation characteristics, the spiral antenna has been used in many fields such as direction finding systems, military surveillance systems, and commercial communication systems.

The number of useful radiation modes that can be attained with a conventional N-arm spiral antenna is N-1. This is because the conventional spiral antenna is fed from the central part of the spiral and generates radiation from the feedline when all spiral arms are fed in-phase [1]. Therefore, it is difficult to attain a second mode pattern with a conventional two-arm spiral antenna. However, a two-arm microstrip spiral antenna that is composed of the external feeding structure using the inward travelling wave [2–4] yields very little interference between the two separated feedlines positioned oppositely. This characteristic allows the two spiral arms of the antenna to be fed a variety of phase differences. In this Letter, we propose an antenna that can control four different beam types using a two-arm spiral line. Various beam patterns can be achieved according to the spiral mode, which is altered by controlling the phase difference between two feedlines that are connected to the outer end of the spiral through the phase shifter.

Antenna structure and characteristics: Fig. 1 shows photographs of the proposed two-arm microstrip spiral antenna with switched beam capability. A circular aperture with a radius of r_o is located on the circular ground plane with a radius of r. Spiral radiators, phase shifters, and feedlines are located on the other side of the substrate. Two spiral arms are of the Archimedean spiral type, and one of the spiral arms is represented as

$$r(\varphi) = a\varphi + r_a, \quad (\varphi_s \le \varphi \le \varphi_e) \qquad (1)$$

Here, $r(\varphi)$ is the radial distance from the origin to the arbitrary point on the centreline of the spiral, a is the spiral constant, φ is the winding angle, φ_s is the spiral start angle, φ_e is the spiral end angle, and r_a is the radial distance from the origin to the initial point of the spiral line. The second spiral arm is situated at a 180° rotation from the first spiral arm relative to the origin. A 50 Ω microstrip line is divided into two 100 Ω microstrip lines that feed the spiral antenna through the phase shifter from the outer end of the spiral arms. The phase shifter is composed of two lines, and a series diode switched line type switching circuit [5] was realised by using two HPND 4028 *pin* diodes at each line. Phase shifters are operated by DC bias of ±1.6 V, and they are designed to feed the spiral antenna with four phase differences; 360°, 180°, 90°, and −90° at 10.5 GHz.

The antenna was fabricated on a substrate with a dielectric constant of 2.2 and a thickness of 0.508 mm (RT Duroid 5880). Since this antenna has a circular aperture, it radiates to both sides of the antenna. To attain unidirectional radiation, a conductor backed 19 mm-thick AN-74 electromagnetic wave absorber manufactured by Emerson & Cuming is placed, along with a 10 mm styrofoam spacer, under the backside of the antenna. The design parameters of the antenna are: $r = 28$ mm, $r_o = 11.5$ mm, $w_f = 1.55$ mm, $w = 0.45$ mm, $a = 0.61275$ mm/rad, $r_a = 0.75$ mm, $\varphi_s = 0$ rad, and $\varphi_e = 17.6$ rad. The polarisation sense of the spiral is the same as that of the spiral winding direction from the outer to the inner arm as seen from the side of the circular aperture. For this antenna structure, right-hand circularly polarised (RHCP) waves radiate to the upper half of the plane.

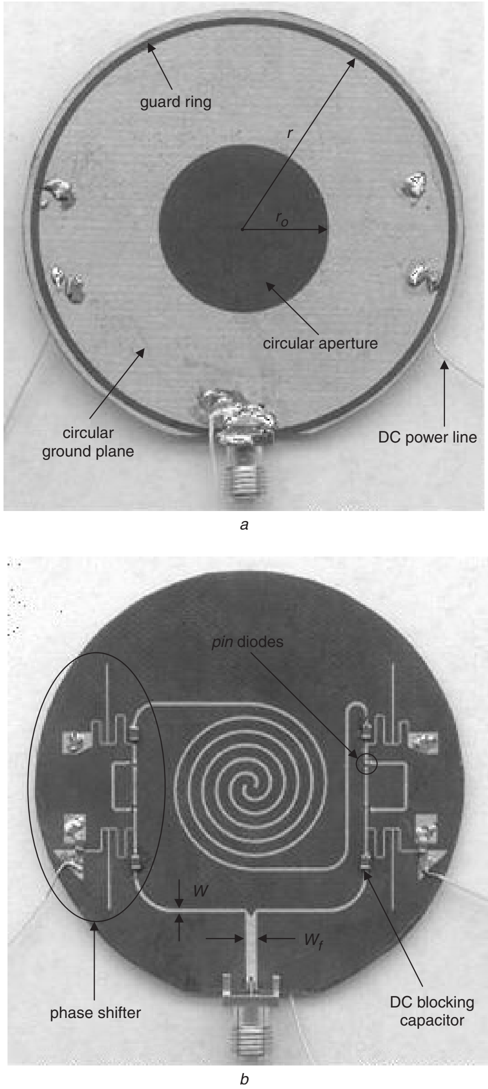

Fig. 1 *Proposed two-arm microstrip spiral antenna structure*
a Front side *b* Back side

Table 1: Beam characteristics for four different phase shift cases

	Phase difference	Beam type	Measured gain [dB]
Case 1	180°	Normal beam	1.3
Case 2	360°	Conical beam	−1.0
Case 3	+90°	Tilted beam	0.3
Case 4	−90°	Tilted beam	0.1

Table 1 shows beam characteristics of the spiral antenna under four different cases of phase shift, and Fig. 2 shows their measured radiation patterns at 10.5 GHz, with an axial ratio lower than 3 dB being met for all measured cases. The radiation pattern measurement was performed using the phase-amplitude method [6] in an anechoic chamber (7 × 4 × 3 m) with the capability of gain error within 0.5 dB. Case 1 shows a radiation pattern with out-of-phase feed (180° phase difference between the two feedlines) and exhibits a normal beam pattern that corresponds to the first mode of the spiral antenna. Case 2 shows a radiation pattern with in-phase feed (360° phase difference between the two feedlines: we used a phase difference of 360° instead of 0° to ease phase shifter design) and exhibits a conical beam pattern that corresponds to the second mode of the spiral antenna. Cases 3 and 4 display radiation patterns with phase differences of +90° and −90°, respectively, and exhibit tilted beams that maintain opposite directions with respect to the vertical axis. The measured gains for the normal beam, the conical beam, and the two tilted beams are 1.3, −1.0, 0.3 and 0.1 dB, respectively. The gain of the antenna is about 2–3 dB lower than expected [4] due to loss in the *pin* diode present at a high frequency. This problem can be improved by using low-loss RF or MEMS switches. Fig. 3 shows the measured VSWR of the spiral antenna for four different cases of the phase shift. The measurement result was taken from an HP8510C network analyser with an MCP-3010D (MC Technology) dual DC power supply. In all cases, a VSWR less than 2 is attained for the frequency range of 10.18 and 11.39 GHz. We have also tested for three identically fabricated designs and they all provided very similar results.

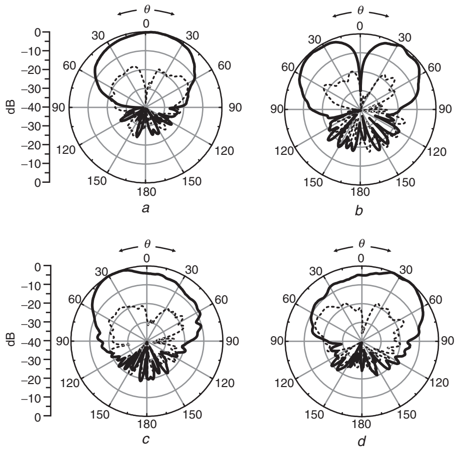

Fig. 2 *Normalised radiation pattern for four different phase shift cases*

a case 1 *b* case 2 *c* case 3 *d* case 4
—— RHCp ····· LHCP

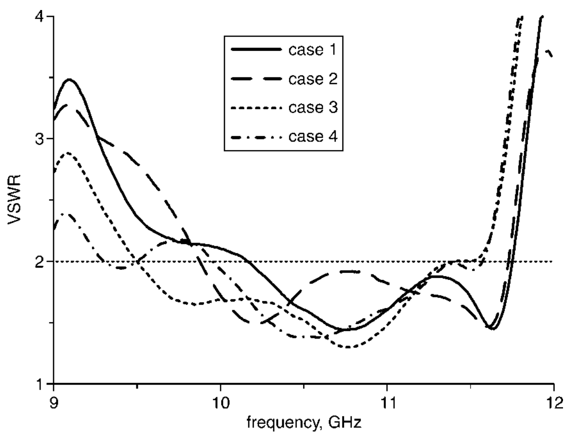

Fig. 3 *VSWR for four different phase shift cases*

Conclusion: We have proposed a two-arm microstrip spiral antenna for multi-beam pattern control. With this antenna, a normal beam, a conical beam, and two tilted beams can be obtained by using phase shifters that are designed for use at the outer end of the spiral lines. This two-arm microstrip spiral antenna has an advantage of increasing efficiency of transmitting and receiving in a rapidly changing electromagnetic communication environment, as it can radiate various beam patterns selectively.

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