6×6 Array of Four-arm Spiral Antennas for High-gain Satellite Receiver Applications at Low Elevation

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***Abstract*— A 6×6 array of four-arm spiral antennas is presented for satellite receiver applications at 18 GHz. The array provides a wide-angle elevation scanning with a high gain right handed circularly polarized (RHCP) radiation beam. Each spiral element has four spiral arms with four feeding ports. The four arms are arranged symmetrically with respect to the center of the antenna. When one of the four ports are excited and other ports are open-circuited, the spiral element provides an RHCP tilted beam ($\theta_{max} = 51^o$) with a gain of 8.4 dBi. By switching the excitation among the four feeding ports, the spiral element can switch the beam in four different quadrants in space. It is demonstrated that by combining these four unit-patterns, the 6×6 array of four-arm spirals provides an elevation scanning range of $-70^o \leq \theta \leq 70^o$ with a maximum gain up to 20.6 dBi.**

Keywords*— *Four-arm spiral antenna, tilted beam, circularly polarized beam, array antenna, scanning range, low elevation angle.

I. Introduction

In recent years, a satellite communication system has been widely used for broadcasting and information sharing networks such as satellite phone, television, digital radio and broadband internet services. Due to the world-wide availability and high data rate most of these systems function in Ku-band (12-18 GHz). During the last decade, various configuration of antenna arrays have been investigated for satellite communication applications, such as microstrip patch antenna [1]-[2], helical antenna array [3], two-arm spiral array [4], aperture-coupled dipole antenna array [5], and slot array antenna [6]. However, these antennas provide a narrow elevation scanning range and the gain of these antennas drops significantly in low elevation angles ($\theta > 60^o$). The array system could enhance its scanning range if it deploys antenna elements capable of providing switchable tilted radiation beams. In addition to the amplitude and phase of the excitation signal, these beam switchable antennas as elements can offer an additional (third) degree of freedom in the form of switchable element pattern. This additional degree of freedom enables the array antenna to achieve a wider scanning range [7].

In this paper, a 6x6 array of beam switchable four-arm spiral antennas is presented for Ku-band satellite communication applications at 18 GHz. Each four-arm spiral antenna provides four switchable RHCP beams in four different quadrants of space. The array provides an elevation scanning range of $-70^o \leq \theta \leq 70^o$ with a maximum gain up to 20.6 dBi.

II. 6X6 Spiral Antenna Array

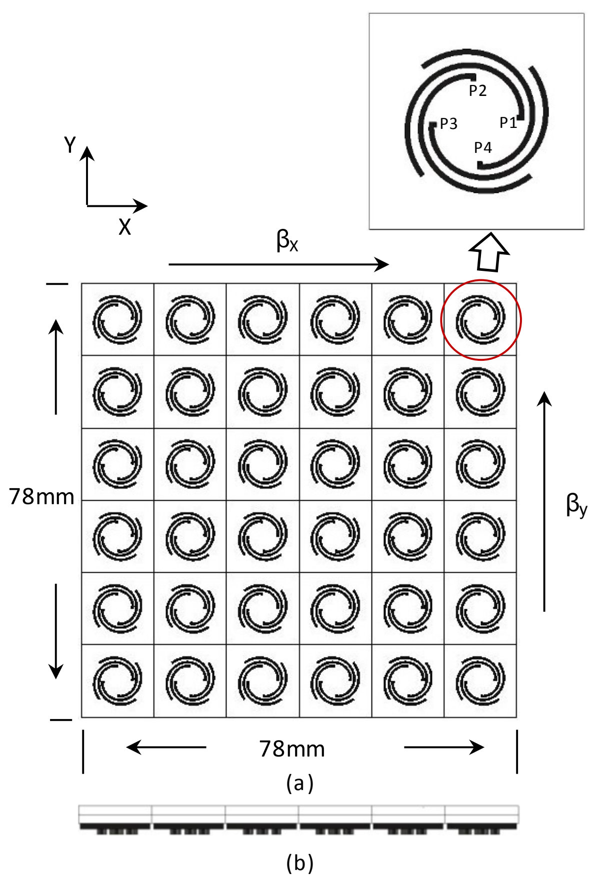

Fig. 1. The structure of spiral antenna array. (a) Top view. (b) Side view.

Fig. 1 shows a 6 x 6 array of the four-arm spiral antennas. The spirals are printed on the top of a two-layered combined substrate. The upper substrate of FR-4 (relative permittivity, $\varepsilon_{r1} = 4.3$ and loss tangent, $\tan \delta = 0.025$) has a thickness of 1.6 mm and the bottom substrate of RO3035 ($\varepsilon_{r2} = 3.5$ and $\tan \delta = 0.015$) has a thickness of 1.5 mm. Hence, the antenna total height is 3.1 mm ($\approx \lambda_0/5.3$, where λ_0 is the free space wavelength at 18 GHz). The overall planar size of the array is 78 mm x 78 mm. The distance between two spiral antenna elements is $0.78\lambda_0$. Each antenna element has four switchable excitation ports (P_1, P_2, P_3, and P_4) and there are 144 ports in the array configuration. β_x and β_y is the phase shift between two spiral elements in the x and y directions, respectively.

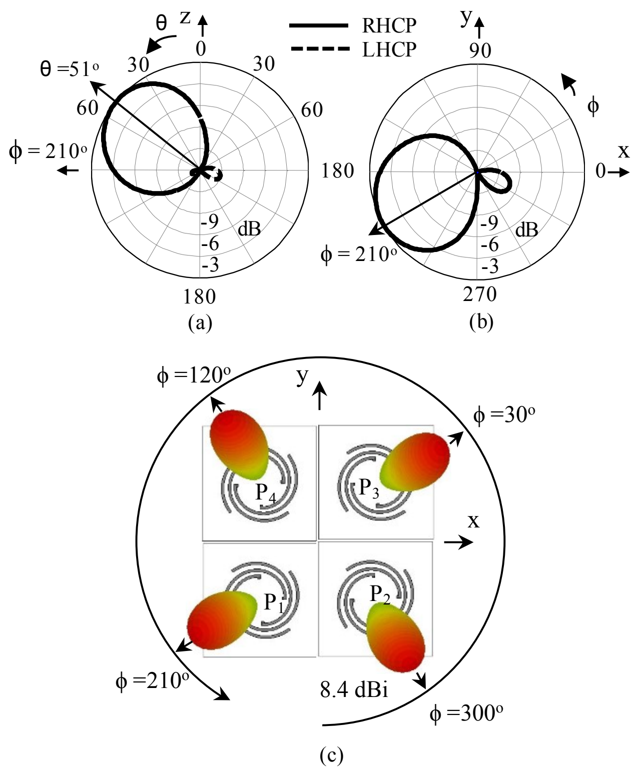

Fig. 2. Radiation patterns for the single four-arm spiral antenna at 18 GHz. (a) Polar plane at $\phi = 210°$. (b) Polar plane at $\theta = 51°$. (c) Demonstration of beam steering with tilted beams.

III. Results

Fig. 2 (a) and (b) show the elevation and azimuth plane radiation patterns of a single element four-arm spiral antenna at 18 GHz. When port P_1 is excited and the other ports are open-circuited, the spiral antenna provides a tilted RHCP beam in the direction of $(\theta, \phi) = (51°, 210°)$. Similarly, when P_2, P_3 and P_4 ports are excited and remaining ports are open circuited, the spiral forms tilted RHCP beams in the direction of $\phi = 300°$, $30°$ and $120°$, respectively. All these beams have the same tilt of $\theta = 51°$ in the elevation plane. Therefore, the antenna radiation pattern is switchable when the excitation port is changed by switching circuits. A demonstration of beam switching is shown in Fig. 2 (c).

Fig. 3 shows the elevation scanning range at $\phi = 210°$ for the 6×6 spiral antenna array at 18 GHz. When all the P_1 ports are excited with $\beta_x = 42.2°$ and $\beta_y = 24.4°$, the array provides an RHCP radiation beam with a gain of 20.67 dBi in the direction of $(\theta, \phi) = (10°, 210°)$. The array also obtains an RHCP beam in the direction of $(\theta, \phi) = (70°, 210°)$ with a gain of 17.3 dBi when $\beta_x = 228.5°$ and $\beta_y = 131.9°$. Similarly, by exciting all P_3 ports the array can scan the other half (0 ° to -90°) of the elevation plane. Therefore, the excitation of all P_1 and P_3 ports can scan the beam across a range of $-70° \leq \theta \leq 70°$ in the elevation plane under the condition that the antenna gain must not drop more than 3 dB from the maximum gain. It is found that, compared to the conventional 6×6 array of microstrip patch antennas, the 6×6 array of four-arm spiral antennas provides a 6 dB higher gain at low elevation angles of $\theta = \pm 70°$.

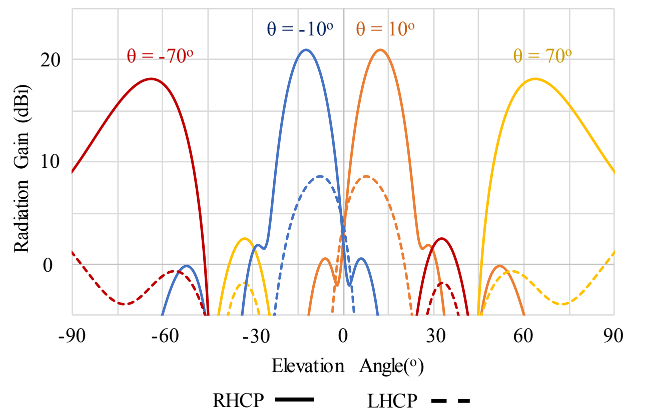

Fig. 3. Spiral antenna array elevation scanning range at $\phi = 210°$.

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