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Polarization Ratio Improvement in a Spiral Element Array¹

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Abstract

A technique is presented for generating high quality circularly polarized radiation from an array of spiral elements by applying a mechanical rotation and a compensating electric phase shift to each element so as to steer the cross-polarized pattern into the grating lobe region. The technique is illustrated by simulations and measurements on a linear four-spiral array.

Introduction

An antenna with a high circular polarization (CP) ratio and wide bandwidth is desirable for target discrimination and suppression of clutter and multipath effects. An array of two-arm Archimedean spiral antennas could meet those requirements and provide higher gain. The basic description of an Archimedean spiral is given by Bawer and Wolfe [1] in which they point out that a spiral antenna radiates from a circular region of effective diameter λ/π . When this diameter is only slightly smaller than the overall spiral diameter, D , there will be reflections from the end of each arm. The reflected wave has the opposite polarization sense compared to the outward traveling wave, resulting in a degraded polarization ratio. In a linear phased array of spiral elements, if D is increased to minimize these reflections, the inter-element spacing, d , may also have to be increased. However, when $d > \lambda/2$, the scan volume will be reduced by grating lobes. Steyskal *et al.* [2] noted that requiring $\lambda/2 > d > \lambda/\pi$ limits the bandwidth of an array of spiral elements.

In this paper we revisit a technique for suppressing the opposite polarization by mechanically rotating the elements in the array. Kaiser [3] pointed out that a mechanical rotation of a spiral antenna produces a corresponding change in phase by the same amount. Teshirogi *et al.* [4] proved that by applying a mechanical rotation and an equal phase shift to the elements in an array, the polarization ratio at broadside becomes independent of the element polarization. Hall and others [5, 6, 7] considered arrays of dual linear patch elements wherein the elements were sequentially rotated by exactly 90 degrees. An improvement in polarization ratio was noted, but no explanation was given. In this paper we will provide an explanation and show that there is a range of mechanical rotation angles that will improve the polarization ratio.

Theory

We first consider the pattern of an individual spiral element in the $\phi = \pi/2$ plane. We assume the element is mechanically rotated by an angle $n\phi_m$ as illustrated in Fig. 1. The right-hand (RH) electric field $E_R(\theta)$ and left-hand (LH) electric field,

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$E_L(\theta)$ can be expressed in terms of calculated or measured orthogonal components $E_\phi(\theta)$ and $E_\theta(\theta)$

$$\begin{aligned} \begin{bmatrix} E_R(\theta) \\ E_L(\theta) \end{bmatrix} &= \begin{bmatrix} 1 & j \\ 1 & -j \end{bmatrix} \begin{bmatrix} \cos n\phi_m & -\sin n\phi_m \\ \sin n\phi_m & \cos n\phi_m \end{bmatrix} \begin{bmatrix} E_\theta \\ E_\phi \end{bmatrix} \\ &= \begin{bmatrix} (E_\theta + jE_\phi) \exp(jn\phi_m) \\ (E_\theta - jE_\phi) \exp(-jn\phi_m) \end{bmatrix} \quad -\pi/2 \leq \theta \leq \pi/2. \end{aligned} \quad (1)$$

This transformation confirms that a mechanical rotation of an element shifts the phase of RH polarization in one direction and the phase of LH polarization in the opposite direction.

We now consider a uniform linear array of N identical elements as described by Eq. (1) with differential mechanical rotation ϕ_m and differential electrical phase shift α_e . The RH and LH polarized array patterns, $P_R(\theta)$ and $P_L(\theta)$, are given in terms of the array factor

$$P_R(\theta) = (E_\theta + jE_\phi) \frac{\sin(N\psi_R/2)}{\sin(\psi_R/2)} \quad \text{where} \quad \psi_R = \frac{2\pi d}{\lambda} \sin \theta - (\alpha_e + \phi_m) \quad (2)$$

$$P_L(\theta) = (E_\theta - jE_\phi) \frac{\sin(N\psi_L/2)}{\sin(\psi_L/2)} \quad \text{where} \quad \psi_L = \frac{2\pi d}{\lambda} \sin \theta - (\alpha_e - \phi_m). \quad (3)$$

Let us assume that we would like to choose ϕ_m and α_e to maximize the polarization ratio $|P_R/P_L|$ over the mainlobe of the RH pattern. This can be accomplished by steering the desired RH pattern to broadside, i.e., by choosing the mechanical and electrical phase shift in Eq. (2) to be equal and opposite

$$\phi_m = -\alpha_e \quad (4)$$

and by choosing the electrical phase shift α_e so that the LH pattern given by Eq. (3) has a null on broadside

$$\alpha_e = \frac{\pi k}{N} \quad \text{where} \quad k = 1, 2, \dots, N/2. \quad (5)$$

Eq. (4) and (5) turn out to be equivalent to those postulated by Hall *et al.* [5] and provide an explanation for the observed polarization error cancellation. However, pattern nulls tend to be narrow and not well defined in an array with imperfect elements. More generally, we would like to steer the undesired LH pattern as far away from broadside as practical. The maximum electrical phase shift α_e is readily derived from the grating lobe condition

$$\alpha_e = \pi \left(1 - \frac{d}{\lambda} \right). \quad (6)$$

When the element spacing $d = \lambda/2$ then $\alpha_e = 90^\circ$, which is the same result that could be obtained from Eq. (5) with $k = N/2$.

Simulations and Measurements

The technique was demonstrated with a four-element array of commercial spiral elements operating at 6.5 GHz, at the lower end of its usable frequency range. At that frequency, the element centers were spaced 0.67λ apart. The elements were modeled

as two-armed Archimedean spirals as shown in Fig. 1. Each arm consisted of 3 turns, making the element diameter about 0.5λ . Feed line radiation was ignored by assuming the spirals were center-fed from a balanced source. We used the Numerical Electromagnetic Code (NEC) to simulate the array. A comparison of a simulated and a measured element pattern, in Fig. 2, proved that the model was satisfactory.

Array patterns were calculated by combining measured dual-polarized element patterns. In Fig. 3 we show simulated and measured RH and LH polarization array patterns without phase shift, $\alpha_e = \phi_m = 0$. The polarization ratio is not significantly better than that of an individual element. For the array geometry in Fig. 1 and from Eq. (6), the maximum electrical phase shift is $\alpha_e \approx 60$ deg. This phase shift corresponds to an array scan angle of 34 deg. In Fig. 4 we show an RH and LH pattern synthesized from four measured element patterns, each sequentially rotated by $\phi_m = 60$ deg and numerically combining the element patterns with a phase shift $\alpha_e = -60$ deg. A significant improvement in the polarization ratio is evident. Fig. 5 summarizes the simulated and measured polarization ratios over the array pattern mainlobe. The best polarization ratio was obtained with a mechanical rotation $\phi_m = 60$ deg, however, the polarization ratio for $\phi_m = 90$ deg is also quite good. Both results are much better than the polarization ratio without mechanical rotation.

Conclusions

A technique has been presented for improving the polarization ratio of an array of spiral antennas by differential mechanical rotation and opposing electrical phase shift in such a fashion as to steer the cross-polarized pattern into the grating lobe region. Simulations and experimental results confirm that the technique has a beneficial effect on the polarization ratio.

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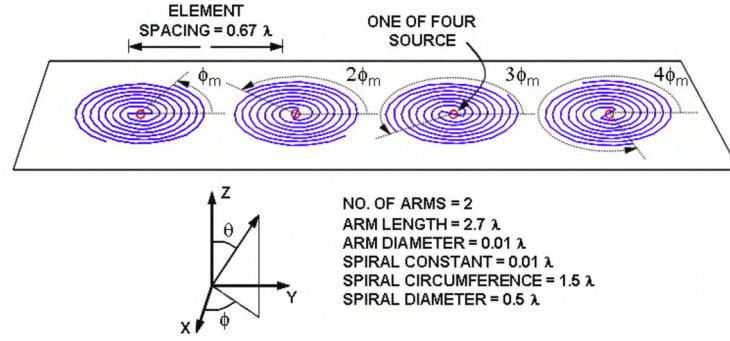


Fig. 1. Spiral Array Geometry

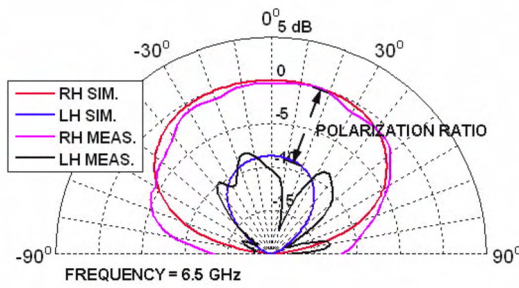


Fig. 2. Simulated and Measured Spiral Element Pattern

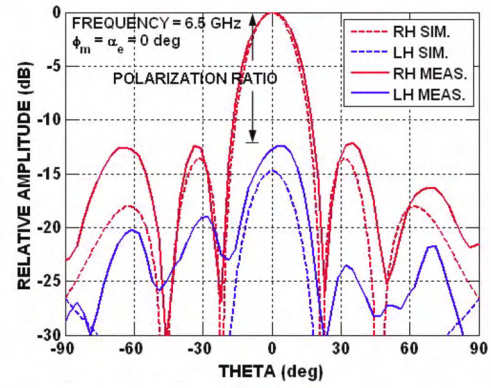


Fig. 3. Simulated and Measured Array Pattern with $\phi_m = 0 \text{ deg}$

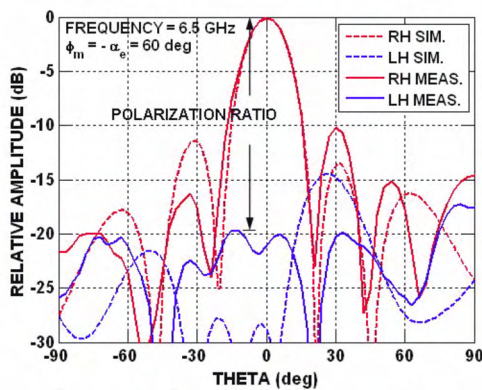


Fig. 4. Simulated and Measured Array Pattern with $\phi_m = 60 \text{ deg}$

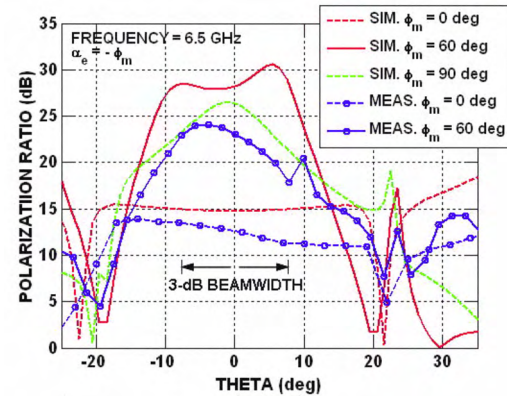


Fig. 5. Mainlobe Polarization Ratio by Simulation and Measurements