Concentric Ring Array of Connecting Spirals with Interleaved WAVES

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***Abstract*— In a previous work, a concentric ring array (CRA) of spiral antennas was designed. Its specifications were a bandwidth of 2:1, the capability to scan up to 30°, dual circular polarization with an axial ratio (AR) < 3dB, relative sidelobe level (RSLL) < -10 dB and reflection coefficient (S_{11}) < -10dB. By connecting the arms of the neighboring spirals we were able to expand the S_{11} bandwidth in the low frequencies. In order to expand the RSLL bandwidth in the higher frequencies, we used the WAVES (Wideband Array with Variable Element Size) technique by interleaving the concentric ring array (CRA) rings of spirals with rings of spirals with half their size. By combining those techniques, we achieved a bandwidth of 15:1.**

***Keywords*— phased array, variable element size, genetic algorithm**

I. Introduction

Dual circularly polarized wideband arrays are required for several applications, including weather radar and synthetic aperture radar. A cavity backed CRA of spiral antennas was developed for wideband, circular polarization applications [1][2]. The array used spiral antennas because of its large bandwidth and used interleaved spirals of opposite polarization to obtain the dual polarization characteristics. Because we interleaved the spirals, the array was sparse, causing the appearance of grating lobes, which were reduced by the use of non-uniformly spaced concentric rings with radii optimized by genetic algorithms. To ensure a good AR, we used the sequential rotation technique, which means we rotated the elements and add phases proportionally to the negative of its angular position in the array [3]. The resulting design had a 2:1 bandwidth for steering up to 30°, RSLL < -10dB, AR < 3dB, dual circular polarization and S_{11} < -10dB. In order to reduce the reflection coefficient of the spiral antennas in the low frequencies, we connected the arms of adjacent spirals in a ring [4]. This approach reduces the reflections from the ends of the spiral which in turn decreases the lowest operating frequency. Then, to reduce the RSLL in the higher frequencies, we used the WAVES technique [5] by interleaving the CRA rings of large spirals with rings of smaller spirals with connected arms. The resulting array operates from 1-15 GHz.

II. Array Geometry

The array consists of rings of large spirals interleaved with rings of small spirals (Fig. 1). The large spirals are 3.18 cm in diameter and form a CRA that operates in the low end of the bandwidth. This low frequency CRA is interleaved with rings of spirals with a diameter of 1.59 cm that operate at the high frequency end of the band. The spacing between spirals of the same polarization in each ring is $d_{el} = 7.37$ cm and, for the interleaved rings, $d_{el\,W} = 3.69$ cm.

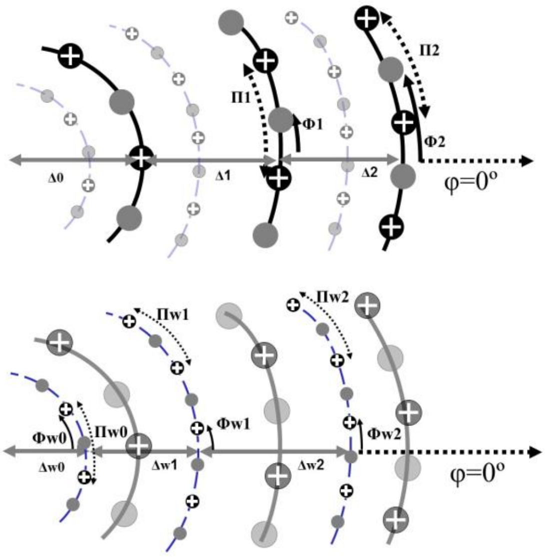

Fig.1 Array geometry. In the top figure CRA of spirals with a diameter of 3.18 cm and its corresponding parameters highlighted. In the bottom figure interleaved rings of spirals with a diameter of 1.59 cm and its corresponding parameters highlighted. Circles with crosses represents right handed circular polarized spirals and filled circles represents left handed circular polarized spirals.

The array is parametrized by the distance between rings and their rotations ($[\Delta_i, \phi_i]$ for the rings of larger spirals and $[\Delta_{W\,i}, \phi_{W\,i}]$ for the rings of small spirals). The rotations in each ring are limited to the angular distance between two spirals of the same polarization ($0 \leq \phi_i \leq \Pi_i$ and $0 \leq \phi_{W\,i} \leq \Pi_{W\,i}$), except for the first ring of the CRA that is not rotated. To avoid having the spiral connections and cavities of the different rings superimposed on each other, we set the minimum distance between rings in the CRA to 7.6 cm (so we can fit the interleaved rings), and minimal distance between the CRA rings and the interleaved rings to 3.8 cm. The maximum radius of the array is limited to 32.5 cm (so that, when accounting for connections and cavities, the arrays radius is limited to 35 cm).

III. Optimization Strategy

In this section we will present the optimization procedure, which is composed of two steps. First, we will optimize the CRA of spiral antennas with a diameter of 3.18 cm. Then we will optimize the rings of scaled down spirals.

We optimize the 3 ring CRA (Fig. 1) using the same procedure as in [2]. The sidelobe level of the array factor in the inner sidelobe (ISL) region defined by $(u\ d_{el}/\lambda)^2 + (v\ d_{el}/\lambda)^2 \leq 1.85^2$ is minimized using a genetic algorithm. Optimization results can be seen on Table 1.

Table 1. Optimization optimal values

	Δ0 (cm)	Δ1 (cm)	Δ2 (cm)	-	Φ1 (rad)	Φ2 (rad)
CRA	10.65	11.10	10.69	-	0.17	0.22
	Δw0 (cm)	Δw1 (cm)	Δw2 (cm)	Φw0 (rad)	Φw1 (rad)	Φw2 (rad)
Interleaved rings	5.28	10.57	10.94	0	0.22	0.06

At this point, we calculate the constraints on the interleaved rings radii so that the WAVES rings do not touch the rings of the low frequency spirals. Then, we optimize the interleaved rings using the same way, except we look at the AF in the region of $(u\ d_{el\,W}/\lambda)^2 + (v\ d_{el\,W}/\lambda)^2 \leq 1.85^2$. This corresponds to the ISL region, but for a different distance between elements. Optimization results can be seen on Table 1.

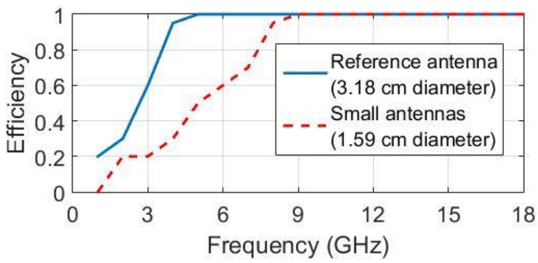

Fig. 2 Efficiency of the antennas versus Frequency (GHz) – In the continuous blue line the spirals with D=3.18 cm and in the dashed red line spirals with D=1.59 cm. The low frequency data was obtained by scaling the simulated results from [6].

IV. Optimization Results and Analysis

Before analyzing the optimization results, we will define how to calculate the radiated fields of the array. Consider a simple radiating pattern for the spiral elements obtained by comparison with the embedded element pattern obtained from a FEKO simulation of a one ring array with 8 spirals (4 per polarization) [3].

$$E_{spiral} = \sqrt{\cos\left(\frac{\pi}{2}\ |\sin\theta|\right)} \qquad (1)$$

By scaling the results in [3], we can expect the spirals with a diameter of 3.18 cm to have a $|S_{11}| \leq -10\ dB$ starting at 1 GHz, and the spirals with a diameter of 1.59 cm to have a $|S_{11}| \leq -10\ dB$ starting at 2 GHz. By scaling the results in [6], we can obtain the efficiency of the spiral antennas at low frequencies (Fig. 2). It should be noted that for the rings of larger spirals the cavity height at 10 GHz equals $\lambda/2$ [3]. To estimate the gain and the RSLL of the array, we assume that:

- 1 to 2 GHz: original array receives 100% of the power
- > 2 GHz: 50% of the power goes to the original array and 50% to the interleaved WAVES rings

Under those assumptions, we get the plots of gain and RSLL vs Frequency (Fig. 3). The results show that the RSLL is under -10 dB over a bandwidth from 1-15 GHz. The array gain increases from 1 to 8 GHz then remains constant over the rest of the bandwidth.

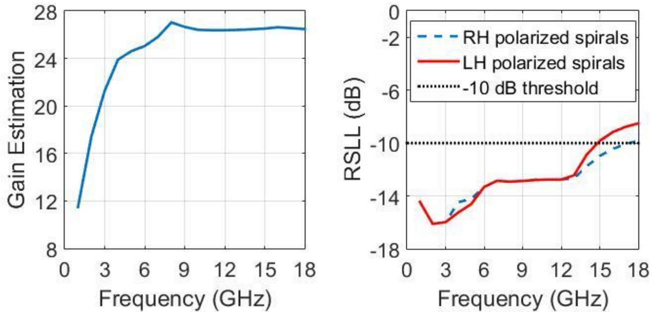

Fig. 3 Concentric Ring Array with interleaved rings of smaller elements. In the left we have the Gain Estimation vs Frequency. In the right we have the RSLL estimation vs Frequency. In dashed-blue we have the results for RH polarized spirals and, in red, for the LH polarized spirals.

V. Conclusions

In this work, we designed a concentric ring array of connecting spirals from 1-15 GHz with dual circular polarization and scanning out to 30 degrees. In order to achieve this bandwidth, we incremented the cavity backed CRA of spirals design [1][2] by the use of connections between spirals [4] in order to enhance the S_{11} at the lower frequencies. For the higher frequencies, the bandwidth was extended by sequentially optimizing the concentric rings and the WAVES [5] rings by genetic algorithms, which allowed the reduction of the RSLL. The low efficiency of the connections causes a reduced realized gain at lower frequencies.

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