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Connected Spiral Antennas for Wideband Circularly Polarized Antenna Array, Experimental Investigations

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***Abstract*—A cavity backed array of 5 connected spiral antennas is presented. The circular polarization is generated using mono polarized spirals in an alternating configuration RHCP and LHCP. Due to the connection between spirals, the currents in the arms of one spiral flow into the arms of the adjacent spirals. The currents transmitted to the opposite polarized neighboring spiral radiate the same polarization. The proposed antenna array allows more than 500MHz bandwidth while being dual polarized and steerable +/- 30deg. The performance of the constructed array is presented and validated using electromagnetic simulations and radiation pattern measurements.**

Index Terms— antenna array, circular polarization

I. INTRODUCTION

RADAR applications and synthetic aperture radar mapping require wideband phased arrays. For these applications, spiral antenna is an interesting broadband structure since its working principle is governed by simple rules.

In fact, the spiral antenna bandwidth minimum frequency (VSWR<2) is directly related to its diameter [1]. The spiral polarization depends on the direction of the spiral winds (clockwise or counter clockwise direction). For these reasons the use of the spiral antenna as an array elementary structure is a promising technique. In a recent paper [2], authors, present a technique based on the connection of adjacent spirals antennas to enhance the lower limit of dual polarized array. This configuration allows avoiding the reflections that usually occur at the end of the arms. These reflections are responsible for the lower frequency of the antenna bandwidth.

The concept used in the present work has been introduced and studied from the electromagnetic simulation point of view in [2]. Nevertheless, the experimental validation was still under investigations. The question of the spiral antenna feeding system rises when trying to practically implement the concept proposed in [2]. Indeed, the spiral antenna being symmetrical structure needs a wide band balanced excitation. For self-complementary spiral antenna, the symmetrical excitation load must be matched to 188Ω, while the classical feeding system based on coaxial cable is non-symmetrical and is matched to 50 Ω (or 75 Ω). In the present work the excitation of the antenna array is presented and experimentally implemented.

In addition, an important point which was not addressed in [2] is detailed in this paper. The spiral array performances are presented when it is backed by a simple rectangular cavity that gives a unidirectional beam with significant gain all over the bandwidth.

The paper is organized as follows. Section II develops the antenna array description. Simulation and measurement data results are depicted and commented in Section III. Finally, some concluding remarks summarizing the antenna array performances are outlined in section IV.

II. ANTENNA ARRAY DESCRIPTION

The circularly polarized array, we propose here, is constructed using 5 spiral antennas (self-complementary Archimedean spirals) alternating right hand circularly polarized spiral and left hand circularly polarized spiral as shown in fig. 3 (left, right, left, right, left). These antennas are separated by a distance of 80 mm which corresponds to the spiral diameter and only two antennas are excited (Fig. 1).

The idea is to construct the array by adding straight connections between neighboring spirals where only right hand circularly polarized spirals are excited (ports 2 and 4). In the other ports a lumped resistive loads of 120Ω are placed.

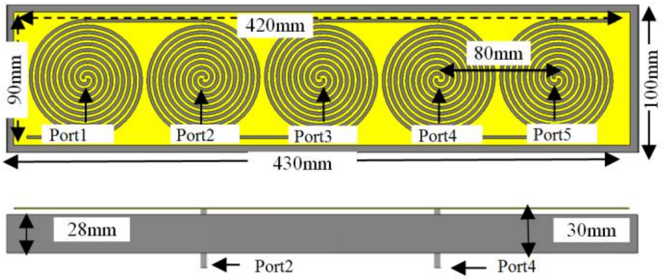


Figure 1. (up) the fabricated antenna array prototype considered for our investigations. The micro strip lines width is 2mm. (down) the cavity is placed at 30mm from the bottom of the substrate (yellow part).

The elementary spiral antenna used in the array construction is shown in Fig. 2. This 4 turns two arms self-complementary Archimedean spiral has a diameter of 80 mm and is printed over FR4 substrate characterized by a relative permittivity value of $\epsilon_r=4.2$. As demonstrated in [3], the input impedance Z_{in} of spiral antenna printed over a substrate with $\epsilon_r=4.2$ is 120Ω.

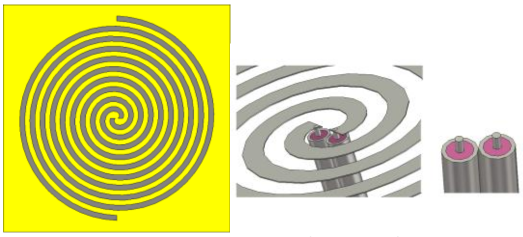


Figure 2. The elementary spiral antenna (left) and its feeding system (right)

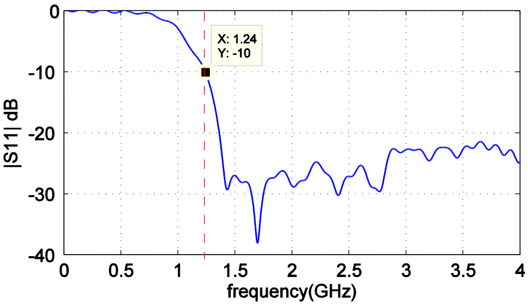


Figure 3. Calculated reflection coefficient of the elementary spiral

The elementary spiral antenna feeding system is made of two RG-10 coaxial cables soldered together where the inner conductor of each cable is connected to the spiral arms. Doing this, the impedance between inner conductors (seen by the antenna) is also about 100Ω. On the other coaxial cables end a 180° hybrid coupler is used to generate two opposed-phase signals. This versatile excitation technique can be generalized to any symmetrical structure for which the input impedance is around 100Ω. Using the electromagnetic simulation software CST Microwave Studio [4] we calculate the spiral antenna reflection coefficient as a function of the frequency when it is excited by the feeding system described above.

As it can be seen from Fig. 3, the antenna S11<-10dB for frequencies greater than 1.24 GHz. The axial ratio of this spiral antenna is less than 3dB for frequencies beyond 1.5GHz.

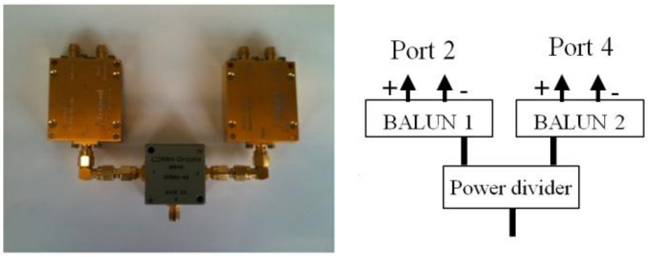


Figure 4. Antenna array excitation circuit composed of two pulse lab PSPL BALUNs and a power divider in the middle of the photography.

In order to give the antenna array unidirectional beam with significant gain all over the bandwidth, we have used a rectangular metallic cavity. The cavity is placed at the height of 30mm from the bottom of the antenna array substrate (Fig.1).

In this paper we use a modified definition of the antenna array bandwidth. We are interested in a circularly polarized antenna array. The antenna array must have a VSWR less than 2 (20log10(|S11|)<-10dB) and an axial ratio (AR) less than 3 dB. The antenna array frequency bandwidth is defined when both conditions are met simultaneously.

III. RESULTS

The circularly polarized array is built based on the 5 self-complementary Archimedean spiral antennas printed over FR4 substrate with a thickness of 0.8mm. As shown in Fig. 1, only the right hand circularly polarized spirals are fed (port2 and port4) and the feeding system is presented in the photography shown in Fig. 4. The simultaneous excitation of port2 and port4 of the antenna array is guaranteed by the use of wideband power divider (Fig.4).

The antenna array prototype and the cavity have been fabricated and measured in an anechoic chamber in the frequency band [0.6GHz, 1.5GHz]. The measured reflection coefficients (S11) of the antenna array are presented as a function of the frequency in Fig. 5. As it can be seen, the antenna array minimum frequency corresponding to S11<-10dB is less than 1.24GHz which is the minimum frequency (S11<-10dB) for a single spiral. We recall here that the effect of the excitation circuit has been compensated by a de-embedding procedure to reach the intrinsic S11 of the antenna array.

In addition we have characterized the antenna radiation far field pattern over a sphere surrounding the antenna. The antenna boresight direction corresponds to θ=0 of the considered coordinate system. Using tangential components of the measured far-field components E_θ and E_φ we calculate the Axial Ratio (AR) of the antenna array.

In Fig. 6 we present the AR calculated from simulation and measurement data respectively determined in the broadside direction (θ=0°) for the frequency band of interest([0.6GHz 1.5GHz]). As shown, a good behavior agreement is noticed between simulation and measurement results.

A. *The Axial Ratio enhancement*

The use of resistive loads at the end of the spiral arms enhances the frequency region for which the AR is less than 3.

In fact, the introduction of resistive loads further improves the current dissipation at the end of the spiral arms. Being connected, the current can travel from a spiral to a neighboring one. This current radiates through the straight connection in a linear polarization. Consequently, by attenuating these currents using resistive lumped loads the AR is greatly enhanced. The other solution to enhance the spiral array performances is based on the connection optimization as presented in [2].

As a matter of facts, we have added lumped resistive loads (120Ω) to the proposed array as presented in the photography in Fig. 7. Then, we have measured the far-field radiation pattern in order to determine the AR.

In Fig. 8 we present a comparison between AR in the antenna boresight direction (θ=0) determined from measured and simulated far-field radiation pattern resulting from the prototype presented in Fig. 7. As it can be seen a good behavior agreement is noticed. Based on measurement data, the spiral array has a **650MHz bandwidth** from 0.85GHz to 1.5GHz. This bandwidth is confirmed by a good S11 (below-10dB).

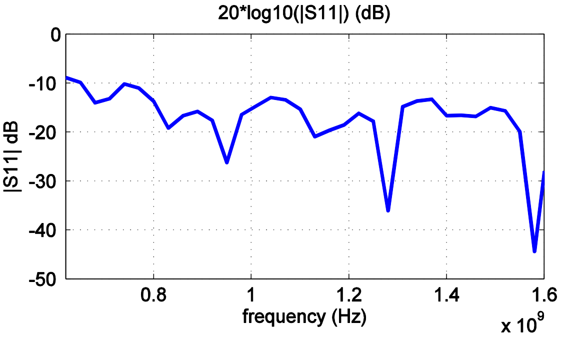


Figure 5. Measured S11 coefficients as a function of the frequency

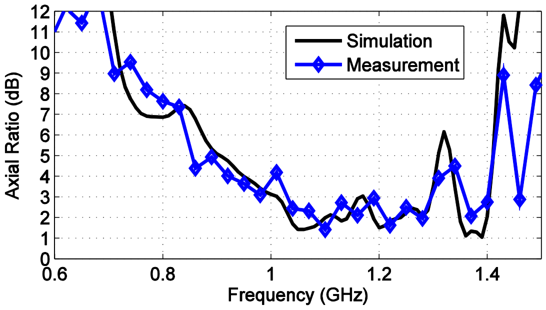


Figure 6. Comparison of the simulation and measurement Axial Ratio as a function of the frequency in the broadside direction (θ=0°).

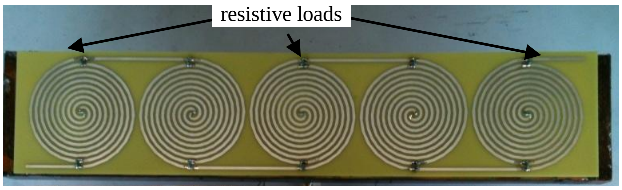


Figure 7. The antenna array with lumped resistive loads.

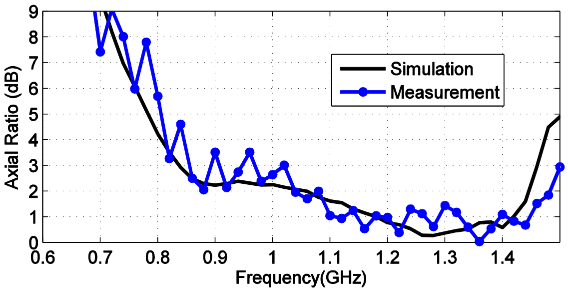
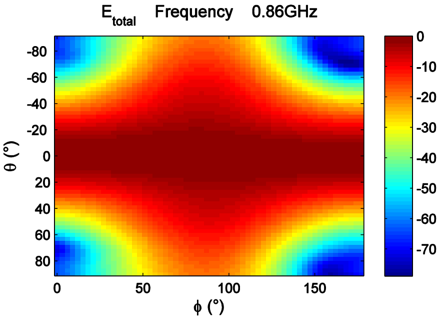
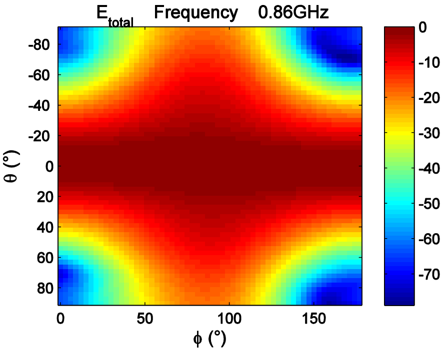


Figure 8. Axial Ratio issued from simulation and measurement data as a function of the frequency in θ=0° direction for spirals with resistive loads.

In Fig. 9, the measured electric field over a hemisphere (-90°≤θ≤90° and 0≤φ≤180) is presented for frequencies inside the antenna array bandwidth ([0.85GHz 1.35GHz]). As shown, in Fig. 9, the use of the lumped resistive loads does not affect drastically the radiation pattern.



without resistive loads



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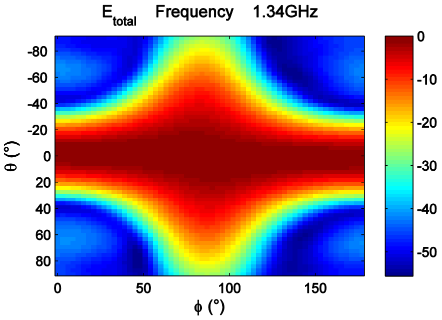
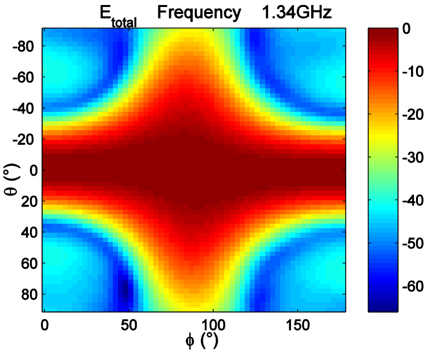


without resistive loads



with resistive loads

Figure 9. Radiation pattern of the spiral array in two different frequencies 0.86GHz and 1.34GHz.

IV. CONCLUSION

A versatile and efficient cavity backed circularly polarized array of spiral antenna has been presented. This spiral antenna array guarantees 500MHz bandwidth where the VSWR is less than 2 and the axial ration less than 3dB. In this paper we have excited port2 and port4 to reach the right hand circularly polarized array (RH). To achieve the left hand circular polarization (LH) port 1, port 3 and port 5 have to be excited.

Consequently this antenna array structure allows us to realize LHCP and RHCP polarization. The minimum frequency of the array is less than the minimum frequency of a single spiral antenna composing the array structure.

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