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REVIEW ARTICLE

Circularly Polarized Arrays of Sequentially Crossed Dipoles

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Abstract

Usual configurations of dipoles that radiate circularly polarized fields consist of elements arranged in crossed pairs, with one component of each pair in top of the other component. As an alternative to this, in a previous work it was presented an array composed of 4 separate and sequentially rotated dipoles, with uniform and out-of-phase feeding distribution. Here we generalize the concept and analyze the behavior of analogous setups composed of up to 20 elements, showing the variation of copolar/crosspolar gains, and axial ratio, in terms of the array elements number.

Keywords

Bidirectional Radiation Patterns, Circularly Polarized Arrays, Circularly Polarized Dipoles.

INTRODUCTION

In the technical community, dipoles have always been the prototypical linear wire antenna models that radiate linearly polarized electromagnetic waves [1]. Such a behavior has led to their customary use in linearly polarized arrays [1-3]. Nevertheless, they can also be used for generating circularly polarized waves. It is well known that two linear mechanical oscillators that have the same frequency are capable of generating a circular Lissajous curve if their spatial movements are perpendicular to each other and have the same amplitude and their phases differ by 90º [4]. That simple concept can be naturally extended to 2 dipoles in order to generate a circularly polarized field. This is achieved by placing the dipoles perpendicular to each other, and feeding them with excitations that have the same amplitude and whose phases differ by 90º. Such a configuration of crossed dipoles [5] has been previously investigated and employed with success [6-7], in some cases by modifying, for example, the geometry of the dipole arms (thus changing their impedance phases) [8], by designing relatively sophisticated profiles [9-11], or with a sequential phase feeding variation (0º, 90º, 180º, and 270º) in a four-arm model [12]. Crossed dipoles models have also been used in linear and planar arrays [12-15], mainly representing arrangements that pursue the same ideas applied on the abovementioned single models.

In a recent work [16], an alternative array of dipoles whose crossed arms do not overlap has been presented. In that work, 4 dipoles are assembled along a line with an inter-element distance equal to $\lambda/4$ (being λ the wavelength at the design frequency) in a way that contiguous components are perpendicular to each other. In this case, the elements excitations phases alternate between 0 and 180º, giving a phase shifting of 180º instead of 90º, something that takes into account,for the combined field, the time delay of the waves hitting the elements as they travel along the array. In view of these last main features, such a structure could be called Array of Sequentially Crossed Dipoles (ASCD). The ASCD represents an easy-to-design antenna that radiates two opposite circularly polarized main lobes (a bidirectional radiation pattern), with an excellent axial ratio vs frequency performance. The antenna array also exhibits good input impedance vs frequency behavior [16].

In this paper, the concept of ASCD is extended to analogous arrays with any finite number of elements. In order to have a better insight of general ASCDs, the behaviors of some of its parameters as functions of elements number are analyzed and discussed.

The paper is organized as follows. Next section (Design) describes the ASCD configuration that is based upon an array model in which, for simplicity, the feeding network is disregarded. The following section (Results) introduces the computed parameters, and shows the corresponding results obtained with the combined help of two commercial software tools [17,18]. The conclusions are presented in the last section.

DESIGN

Consider, see Fig. 1, an ASCD composed of N centrally fed dipoles whose arms have length $L/2$ and diameter $d<<L/2$. The arms of a given dipole are separated a small distance (gap) g apart (such a g could be taken to be of the order of d). The dipoles of the ASCD are distributed along the x axis with an inter-element spacing equal to D.

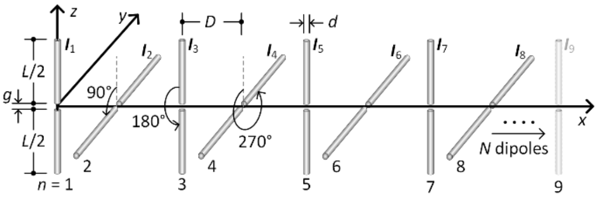
Fig. 1 shows that odd-numbered elements (n = 1, 3, 5, …) are aligned along the z axis, whereas even-numbered elements are aligned along the y axis. Notice that the orientations of dipoles 2, 3 and 4 are represented by their rotations (90º, 180º, 270º) with respect to element 1. The rotational sequence starts again on element 5, and repeats itself up to the last element of the array. The relative excitation of the n-th element is represented by the complex number $\mathbf{I}_n = I_n e^{j\phi n}$, where $I_n = |\mathbf{I}_n|$ is the corresponding excitation amplitude, and ϕ_n represents its relative phase. In order to obtain a circularly polarized radiated electric field $\mathbf{E}(\theta,\varphi)$, being θ and φ the usual spherical coordinates, the following assumptions must be made [16]:

$$\begin{gathered} I_n = 1 \quad \forall n \in \{1,2,\ldots,N\}, \\ \phi_n = \begin{cases} 0^\circ & \text{if } n = 1,3,5,\ldots \\ 180^\circ & \text{otherwise,} \end{cases} \\ D = \frac{\lambda}{4}, \end{gathered} \tag{1}$$

where λ is the wavelength at the design frequency.

After having established the setup, we proceed to analyze the behavior of some of the ASCD electrical parameters as we vary the number of array elements N from 2 to 20. We begin with the computation of the copolar and crosspolar components of the ASCD gain, which, according to the configuration given in Fig. 1, correspond to the right- and left-handed circularly polarized waves, respectively [17]. Those components will be measured along the x axis (which corresponds to the spherical coordinates θ = 90º, φ = 0º), since, as it will be seen, such an axis corresponds to the direction of the maximum radiation density of the antenna for increasing values of N. We will also compute the axial ratio along that direction. After that, we will analyze the behavior of the complex-valued scattering parameters amplitudes $|\mathbf{S}_{mn}| = S_{mn}$ through which we can have an insight about the performance of the input impedance and mutual coupling of any of the elements of the ASCD [1]. Those last parameters will be analyzed by considering a reference impedance $\mathbf{Z}_0$ = 73 [Ω], which represents the theoretical input impedance of a single dipole whose length equals $\lambda/2$ [1].

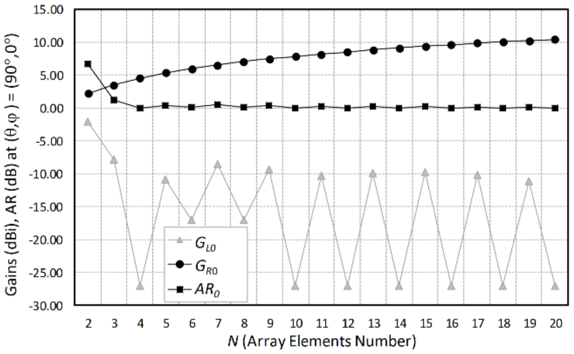
Figure 1: Array general configuration



RESULTS

As a concrete example, we establish a design frequency value f = 2.4 GHz, that corresponds to the usual S frequency band. In such a case, the wavelength λ equals 124.914 mm. We then set $d = g = 0.02\lambda$ = 2.498 mm, and D = L/2 = λ / 4 = 31.228 mm. After that, we perform the numerical simulations by making N vary from 2 to 20. Fig. 2 shows the copolar and crosspolar components of the gain –G_{R0} and G_{L0}, respectively (measured in dBi)–, together with the axial ratio –A_{R0} (in dB)–, all of them obtained along the x axis, in terms of the number of array elements. It can be seen that the copolar gain component increases steadily with N up to reaching 10.04 dBi. Moreover, if G_{R0} is computed as a real absolute value (not in dBi), then such a gain is found to be practically proportional to N.

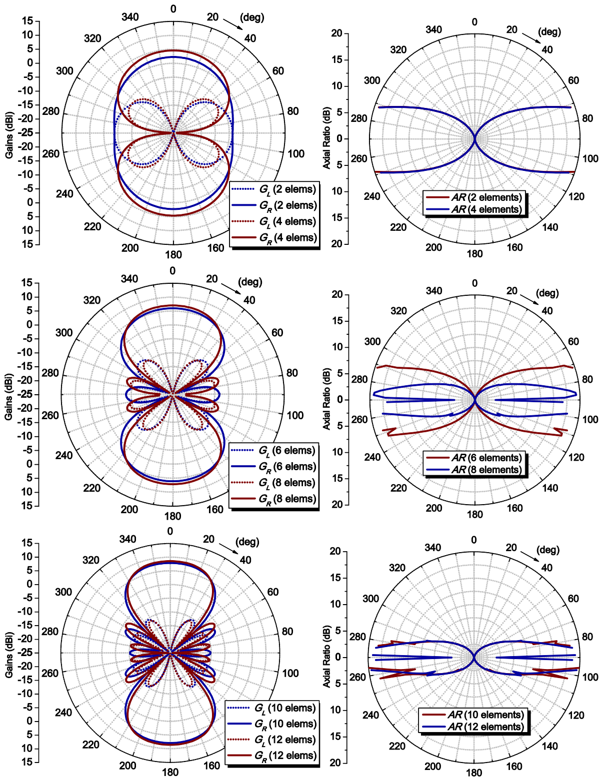
Figure 2: Gains and axial ratio vs number of elements

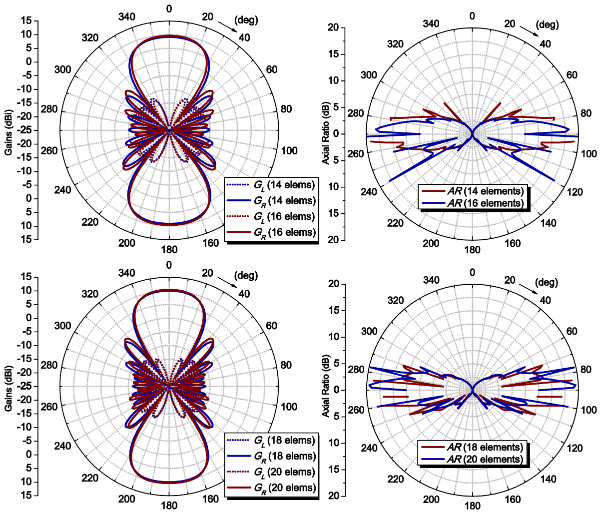


It can be seen that the axial ratio decreases and keeps its value approximately near the ideal value (0 dB) for N>4. Therefore, if relatively low copolar gain values are required, a 4-element ASCD will be enough to obtain a radiation pattern with good circular polarization [16].

The crosspolar component has a relatively unstable variation, keeping low values, but oscillating between, approximately, –10 dBi (for N odd) and –27 dBi (for N even) when N>4. This plot shows that it is preferable to have an even number of elements in order to reduce the crosspolar component gain level to the minimum.

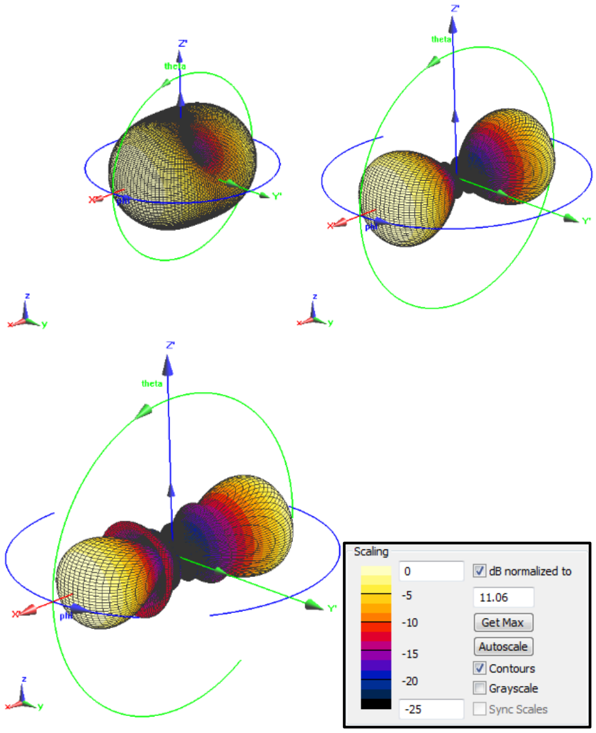
Figure 3: Plots of copolar G_R and crosspolar G_L gain components, together with the axial ratio, at θ = 90º (xy plane, see Fig. 1) cuts for the array with even number of elements





Radiation diagrams of the abovementioned gains and axial ratio for N even are given in Fig. 3, where θ = 90° cuts were taken (*xy* plane, see Fig. 1). Those plots show that the steady grow of copolar component gain not only corresponds to the (θ,φ) = (90°, 0) direction, but to the whole *xy*plane, with a marked symmetry with respect to the φ = 0, 180º axis. In all cases, the crosspolar gain component level remains below –15 dBi. As expected, for increasing values of N, the array becomes more and more directive. The lower values of the axial ratio (near 0 dB) are located within the main lobe angular coverage zone, thus establishing an excellent circular polarization behavior.

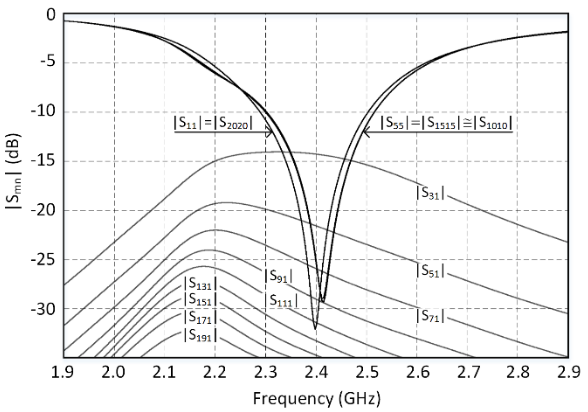
Figure 4: Top left: normalized copolar gain radiated by an array composed of 2 elements. Top right: normalized copolar gain radiated by the 10-element array. Bottom left: copolar gain by the 20-element array. Bottom right: scaling, which represents the absolute normalization value (11.06, or 10.44 dBi) that corresponds to the maximum gain of the 20-element array radiation pattern.



The increasing axial symmetry along the x axis can be observed from Fig. 4, which represents the copolar gain component of the ASCD for N = 2, 10 and 20, which represent the most significant samples to show the evolution of the power pattern as N increases. Those 3D patterns were normalized with respect to 11.06,which corresponds to the 20-element ASCDmaximum G_R. Finally, the S_{mn} parameters (m and n ranging from 1 to N) are analyzed when the frequency varies from 1.9 to 2.9 GHz. Fig. 5 shows the S_{mn} amplitudes, expressed in dB. We first observe the $|\mathbf{S}_{mm}| = S_{mm}$ parameters, which represent the reflection coefficient at the m-th dipole input [1](and thus its matching with the theoretical reference impedance $\mathbf{Z}_0$ = 73 [Ω]). The figure shows that the reflection coefficients are not significantly affected by their positions inside the array, and elements 1, 5, 10 15 and 20 have all almost the same S_{mm} vs frequency curve, all of them reaching the resonance near 2.4 GHz, the design frequency. The S_{mm} are below –10 dB within approximately 2.3 and 2.5 GHz, which represents a good fractional bandwidth [1] of about 8.33%.

The transference coefficients S_{mn} show that the influence that dipole m has on dipole n ($m \neq n$) is relatively small. The most relevant influence corresponds to the electromagnetic coupling between elements 1 and 3, showing an S_{31} below –10 dB. As the separation between elements increases, their mutual influence decreases, as expected, see S_{51}, S_{71}, etc. Notice that those behaviors correspond to the influence between odd elements, i.e., m, n = 1, 3, 5, 7, …, 19. Such behaviors are expected to be the same than the ones corresponding to even elements, as it certainly happens, and for that reason their curves were omitted. On the other hand, the coupling between even and odd elements is really low (the simulations showed values below –60 dB in all cases), as expected, since they are perpendicular to each other, something that minimizes their interactions.

Figure 5: The most significant S_{mn} (dB) vs frequency curves from N = 20.



CONCLUSIONS

Circularly polarized arrays of sequentially crossed dipoles are easy to design models that show excellent polarization and input impedance characteristics. The numerical simulations performed here reveal that, for arrays composed of more than 3 elements and up to 20, good input impedance matching and pattern stability are guaranteed.

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