A novel class of broad band full scan coverage polarization agile spherical conformal array antennas

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1. Introduction

In this contribution a novel phased array concept [1], which exploits a random spherical conformal arrangement of circularly polarized radiating elements, is presented. Indeed, to ensure the possibility of beam-forming to any desired direction, it is more convenient to randomly disperse the radiators on a spherical surface, rather than positioning them on a periodic lattice, such that the elements distribution looks nearly identical from each aspect angle and there is no scan blindness due to the element patterns. This non-periodic arrangement, according to several theoretical studies [2], [3] corroborated by experimental results [4], [5] eliminates grating lobes and results in an average sidelobe level that is inversely proportional to the number of elements. Moreover, as a result of the cancellation of grating lobes, the array can possibly take full advantage of broad band radiating elements.

The advantage of polarization agility is achieved by using circularly polarized elements, such as spiral antennas, which produce very wide band, almost perfectly circular polarized radiation [6]. Thus, the two components of the total far field radiated from the array can be phased in turn without distinction and the array is expected to have good performance in both polarizations for all scan angles of interest.

A wide range of wireless communication systems may benefit from employing broad band antennas with steerable dual polarized pencil-beam radiation patterns, including WWLAN (Wideband Wireless Local Area Network), multi-function monostatic and bistatic radar systems, and high mobility cellular systems. Furthermore, this kind of antennas is very suitable for integration onto inflatable space structures to fit out satellites, manned and unmanned modules, vehicles and smart robots [7].

The radiation characteristics of the array are investigated by resorting to the active element pattern approach [8]. The active pattern of each element is determined by means of the method of moments (MoM), so that mutual coupling between the antenna elements, which can be significant and cause scan anomalies or blindnesses within the desired bandwidth and scan volume, is accurately accounted for.

2. Antenna configuration

A sample sketch of the spherical conformal array is depicted in Fig. 1. The array consists of many Archimedian spiral antennas randomly distributed on a spherical surface with uniform spatial density. The antennas can be fed through micro-coaxial cables or flexible coplanar waveguides.

The design parameters of the array are essentially: *i*) the number of elements N and *ii*) the minimum interelement spacing d_{min}. This latter is bounded below by the array element size to prevent the elements from overlapping. Once these two parameters are set, the radius of the spherical envelope of the array R_S is easily obtained by the following rule of thumb:

$$R_S \cong \frac{1}{4}\sqrt{N}\ \overline{d_{min}} = \frac{1}{4\sqrt{N}} \sum_{\substack{n,m=1 \\ n\neq m}}^{N} \min\left[d(n,m)\right], \tag{1}$$

where *d(n, m)* denotes the distance between the *n*-th and *m*-th elements.

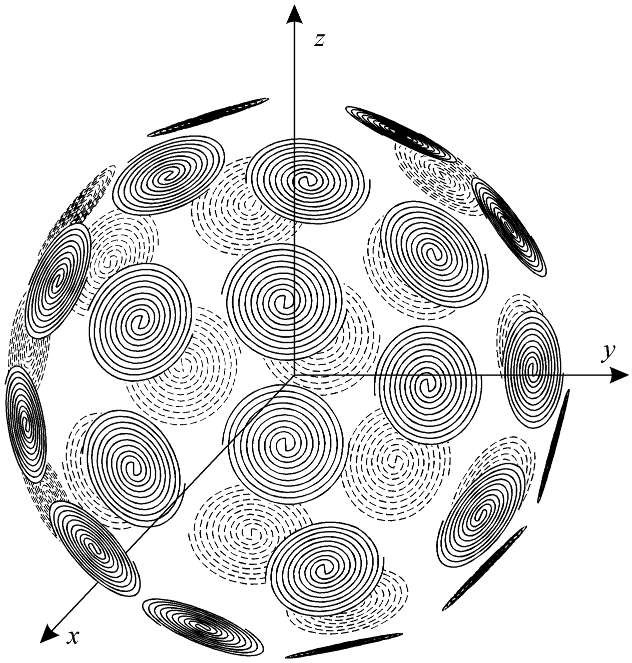

Fig. 1. Sample geometry of a random spherical conformal array antenna.

A 54-element array has been developed to operate over an octave bandwidth at the frequency range from 1.5 to 3 GHz. The radiating element consists of a wire Archimedian spiral antenna that has been designed to work at this same frequency range. To achieve an effective spherical scan coverage each spiral antenna lies in the plane orthogonal to the vector from the centre of the spherical surface describing the array envelope to its feed point. The spiral is loaded with a distributed resistance along the last three quarters of the outer windings of its arms. This resistive loading reduces the reflections from the antenna terminations, which are significant especially at the lower frequency, thus providing for a trade-off between the need to obtain unit axial ratio over the entire bandwidth and the advantage of keeping the antenna size as small as possible. As a result, the loaded spiral has good circularly polarized radiation patterns over the entire frequency band [1].

3. Method of analysis

The array far-field pattern may be suitably formulated by resorting to the active element pattern approach [8]. All mutual coupling effects are accounted for through the so called active element, whose pattern is obtained by exciting only the *n*-th element and loading all other elements with the generator impedance. The active element pattern for each element is calculated by the MoM.

Assuming a standard spherical coordinate system, the array pattern in this formulation is given by the expression:

$$\overline{F}(\theta,\phi) = F_\theta(\theta,\phi)\hat{\theta} + F_\phi(\theta,\phi)\hat{\phi} = \sum_{n=1}^{N} \overline{g}^n(\theta,\phi) e^{j\xi^n_{\theta,\phi}(\theta_0,\phi_0)} e^{jkR_S\left[\sin\theta_n \sin\theta \cos(\phi-\phi_n)+\cos\theta_n \cos\theta\right]}, \quad (3)$$

where $\overline{g}^n(\theta,\phi) = g^n_\theta(\theta,\phi)\hat{\theta} + g^n_\phi(\theta,\phi)\hat{\phi}$ denotes the n-th active element pattern, which in general exhibits elliptical polarization, and $P_n \equiv (R_S, \theta_n, \phi_n)$ represents the element position on the spherical surface of radius R_S. The excitations are intended to be of equal unit amplitude with phases $\xi^n_{\theta,\phi}$ that must be adjusted to steer the main beam to a given direction (θ_0, ϕ_0). By properly choosing these phase terms

$$\xi^n_{\theta,\phi}(\theta_0,\phi_0) = -\left[\gamma^n_{\theta,\phi}(\theta_0,\phi_0) + \alpha_n(\theta_0,\phi_0)\right], \quad (4)$$

where $\alpha_n(\theta_0,\phi_0) = kR_S\left[\sin\theta_n \sin\theta_0 \cos(\phi_0-\phi_n) + \cos\theta_n \cos\theta_0\right]$ represents the phase shift due to the n-th element position and $\gamma^n_{\theta,\phi}(\theta_0,\phi_0) = \angle g^n_{\theta,\phi}(\theta_0,\phi_0)$ is the n-th element far field phase, either the θ- or ϕ-component could be phased without distinction.

4. Samples of numerical results

To illustrate the performance of the array main beam patterns have been synthesised at several directions both in the azimuthal and elevation planes at different frequencies. In particular, Fig. 2 shows the patterns computed for the 54-element array at 2.25 GHz, in the azimuthal plane. The average interelement spacing is set equal to 0.75 λ_0, with λ_0 denoting the wavelength at 1.5 GHz, and the array radius R_S is 2.4 λ_0. These graphs have been obtained by superimposing the plots of the array patterns scanned at different directions, with a step of 45° between two next scan angles. Figs. 2 (a) and 2 (b) are relevant to the θ- and ϕ-component, respectively, and have been obtained by using suitable different phases for the excitations accordingly to (4). As apparent, the array has the ability to scan the main beam to each direction with negligible changes in directivity and beamwidth, whose average 3 dB value settles around 10°. The SLL slight more noticeably depends on the look direction, nonetheless its peak value hardly exceeds –10 dB.

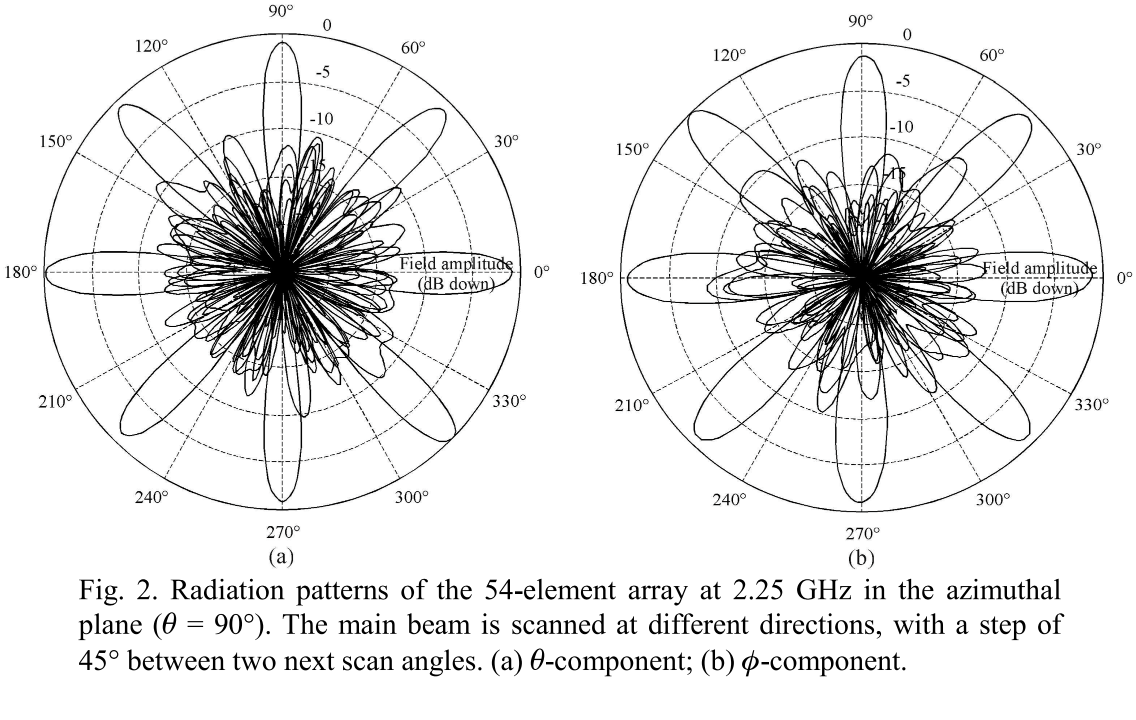

Fig. 2. Radiation patterns of the 54-element array at 2.25 GHz in the azimuthal plane (θ = 90°). The main beam is scanned at different directions, with a step of 45° between two next scan angles. (a) θ-component; (b) ϕ-component.

The polarization cross coupling, which is equally important as spatial decorrelation effects for space diversity systems, has been analysed as well. It is found that the cross-polarized patterns are much below the level of the co-polarised patterns with peaks at most raising to the maximum SLL. A similar behaviour is obtained by phasing either the θ- or ϕ-component of the far field and for any look direction. These results testify for the possibility of polarization agility, which is accomplished by using only one phase shifter for each element, and thus for the effectiveness of spiral antenna as radiating element.

The dependence on frequency of the performance of this kind of conformal arrays was also investigated. It turned out that, accordingly to the theory of random spherical arrays, the most apparent effect produced by the increasing of frequency and, hence, of array size with respect to wavelength, consists in an almost linear decrease of the beamwidth.

5. Conclusions

A novel spherical conformal phased array of spiral antennas has been developed by randomly dispersing the radiating elements on a spherical surface with uniform spatial density. The scan performances of a 54-element development model array have been analysed by means of the MoM so as to accurately account for mutual coupling between the antenna elements. It has been checked that this kind of array shows two main advantages: *i*) full scan coverage; *ii*) linear polarization agility. The beamwidth and average side lobe level turn out to be almost independent from the look direction and mainly related to the electrical size of the antenna and the number of elements through an almost inversely proportional relationship, respectively. Comparison with the results obtained from the analysis of spherical conformal pseudo-uniform arrays will be presented at the conference.

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