A Comparison of Various Hybrid Elliptical Antenna Arrays

R. A. Sadeghzadeh, A. A. Lotfi Neyestanak, M. Naser-Moghadasi, and M. Ghiamy

Abstract—In this paper, novel types of antenna arrays constructed from combination of linear and elliptical antenna arrays, are presented. These types are called EA, CEA, ECA, ECCA, HA, CHA, HCA, HCCA, HCCA, ECOA, ECCOA, HCOA and HCCOA where only the array factors are considered. The effect of the element factor can be considered separately and combined to the array factor. The expressions for all array factors have been obtained. HA is treated as consisting of two concentric N-element elliptical arrays of different semi-major and semi-minor axes and ECOA is treated as EA’s that are placed one above another, so that the semi-major and semi-minor axes of each EA decrease linearly. The directivities and side lobe levels of them are simulated and compared for various ellipse eccentricity, element spacing and number of elements. Simulations show that CHA has the best directivity and ECOA has the lowest SLL.

Index Terms—Antenna Array, directivity, elliptical, SLL.

I. INTRODUCTION

United the radiation pattern of a single element is relatively wide and each element provides low values of directivity. Antenna arrays increases the directivity without enlarging the size of single elements.

Generally, the overall array properties as directivity and gain, direction of maximum directivity, side lobe level (SLL), half power beam-width, … can be controlled and optimized by adjusting the number of elements, the spacing between them, their excitation coefficients, their relative phase, the geometrical configuration of the overall array (linear, circular, elliptical, …) and the relative pattern of the individual elements [1].

Now a days, one of the most recent innovations to overcome the problem of increasing demand for capacity is to deploy smart antennas for wireless communications [2]. Narrower main-beam and more nulls in the pattern can resolve the Signals-Of-Interest (SOI) more accurately and allow the smart antenna system to reject more Signals-Not-Of-Interest (SNOI).

A linear array has excellent directivity and it can form the narrowest main-lobe in a given direction, but it does not work well in all azimuth directions. Since a circular array does not have edge elements, directional patterns synthesized with a circular array can be electronically rotated in the plane of the array without a significant change of the beam shape [3]. And, circular array pattern has not any nulls in azimuth plane [1]. In smart antenna applications to reject SNOI the array pattern should be has several nulls in the azimuth plane. This can be implemented by the use of elliptical arrays instead of circular arrays [4].

The circular array is a high side-lobe geometry. If the distance of array elements is decreased to reduce the side lobes, the mutual coupling influence becomes more significant. For mitigating high side-lobe levels, concentric arrays are utilized in [5]. Also concentric circular array antennas have several advantages including the flexibility in array pattern synthesis and design both in narrowband and broadband beam forming applications [6]. The other suitable array type to reduce the side lobe level, the hexagonal array which may has the better performance from concentric arrays [7].

Antenna array arrangement has considerable effect on spatial correlation properties of multiple input multiple-output wireless communications channels. In [8], the effects of different antenna array geometries such as uniform linear, uniform circular, uniform rectangular and uniform cubic array on MIMO channel properties are investigated.

In [9], a method of beam steering and scanning using linear mechanical motion of circular array elements in a way to always form an elliptical array is presented. In [10], the radiation characteristics of a uniform circular array with linear centrally-fed dipole elements, used for smart antenna systems, are analyzed. The radiation patterns of the array and the gain of the array over a single element are derived based on the thin-wire model.

In [11], the radiation field of an end-fed elliptical array, whose main beam points toward the array normal and whose elements are equally-spaced in the ellipse, is considered.

An improved spherical antenna array has been presented in [12]. A number of attractive properties for antenna arrays are discussed such as electric beam scanning in the whole three-dimensional space leading to reduce the effects of mutual coupling.

In [13], the authors propose a method to reduce the maximum side lobe level of an array with a given number of elements on concentric rings.

The other way to improve the performance of circular, concentric, elliptical and hexagonal arrays is the combination of properties of linear arrays with mentioned arrays. Also the use of conical arrays [14], [15] may results...
the better performance. The properties of linear and circular array combination were discussed in [16]. The linear and elliptical array combinations were introduced in [4].

In this paper, the expressions for the array factor of linear, circular, elliptical and hexagonal arrays (respectively called: LA, CA, EA and HA) are reviewed. Then, the combination of linear array with other mentioned arrays in radial and/or vertical directions are considered. These array types are called: concentric circular array (CCA), circular cylindrical array (CCYA), circular coaxial cylindrical array (CCCCA), concentric elliptical array (CEA), elliptical cylindrical array (ECA), elliptical coaxial cylindrical array (ECCA), concentric hexagonal array (CHA), hexagonal cylindrical array (HCA), hexagonal coaxial cylindrical array (HCCA). Similar to above arrays, the array factor of conical array (COA) can be obtained by applying some modifications to array factor of CCYA. Also by exchanging the cross-section of COA to ellipse or hexagon, the elliptical conical array (ECOA) or hexagonal conical array (HCOA) can be constructed, respectively. Finally the combination of linear array with COA, ECOA and HCOA in radial direction concludes the coaxial conical array (CCOA), elliptical coaxial conical array (ECCOA) and hexagonal coaxial conical array (HCCOA), respectively. In all array geometries and cross-sections, array elements lie on an ellipse with eccentricity (e) and e = 0 leads to circular case (i.e. the peripheral curve of cross-section is ellipse).

Since this paper is a theoretical study of arrays of isotropic elements, mutual coupling between radiating elements is not considered.

In section II the array factor of mentioned arrays (LA, CA, EA, HA, CCA, CCYA, …) are reviewed and derived. In section III the directivity and SLL definitions of an array are reviewed and a numerical method to directivity calculation is presented. Section IV shows the numerical results. In this section the directivity and side lobe level of all mentioned arrays versus ellipse eccentricity, element spacing and number of elements are simulated and discussed. Numerical results show that HCOA and HCCOA have the maximum and minimum directivities, respectively. Also COA and HCCOA have minimum and maximum SLL, respectively for given number of elements and element spacing. Finally section V presents conclusion remarks.

II. ARRAY FACTORS

The total field of an array, according to pattern multiplication principle, can be formed by multiplying the field of a single element at a selected reference point and the array factor. The array factor can be formulated by replacing the actual elements with isotropic (point) sources. The array factor of an array in general can be written as [17]

\[ AF(\theta, \phi) = \sum_{n=1}^{N} A_n e^{j(n-1)kz \cos \theta \sin \phi} \]

(1)

where \( N \) is the number of elements, \( A_n \) is the relative amplitude of \( n \) th element, \( \alpha_n \) is the relative phase of \( n \) th element, \( \alpha_n \) is the position vector of \( n \) th element depends on array geometry, \( a_n \) is the unit vector of observation point in spherical coordinates and \( k \) is the wave number.

From (1) the array factor of arrays can be derived. For the \( N \) -element linear array (LA) with equal element spacing \( d \) along \( z \) axis, the array factor is given by [1]:

\[ AF = \sum_{n=1}^{N} A_n e^{j(n-1)kd \cos \theta \sin \phi} \]

(2)

The array factor of a circular \( N \)-element array (CA) with its center in origin of \( x - y \) plane, is [1]

\[ AF(\theta, \phi) = \sum_{n=1}^{N} A_n e^{j n \sin \theta \cos \phi} \]

(3)

where \( a \) is the radius of the circle, \( \phi \) is the angle between positive section of \( x \) axis and the observation point in the space, \( \theta \) is the angle between positive section of \( z \) axis and the observation point in the space and \( \phi_\theta = 2\pi(n-1)/N \) is the angle in the \( x - y \) plane between the \( x \) axis and the \( n \) th element.

All array configurations analyzed here are shown in Fig. 1. The array factor of an elliptical \( N \)-element array (EA) with its center in origin of \( x - y \) plane (Fig. 1(a)), is [4]

\[ AF(\theta, \phi) = \sum_{n=1}^{N} A_n e^{j n \sin \theta \cos \phi - b_n \sin \phi_\theta \sin \phi_\phi} \]

(4)

where \( a, b \) are semi-major axis and semi-minor axis, respectively, \( \phi \) is the angle between positive section of \( x \) axis and the observation point in the space, \( \theta \) is the angle between positive section of \( z \) axis and the observation point in the space, \( \phi_\theta = 2\pi(n-1)/N \) is the angle in the \( x - y \) plane between the \( x \) axis and the \( n \) th element and \( e = \sqrt{1-b^2/a^2} \) is the ellipse eccentricity. Assuming \( e = 0 \) results the circular array factor.

The polygonal array (PA) which the peripheral curve of it’s vertices is an ellipse, can be treated as consisting of two concentric \( N \)-element elliptical arrays of different semi-major and semi-minor axes \( a_1, b_1 \) and \( a_2, b_2 \), respectively. Fig. 1 (e), give a simple example of polygonal array with \( 2N \) elements \( (N = 6) \), \( N \) of which are located at the vertices of the polygon and the other \( N \) elements are placed at the middle of each line of the polygon, respectively. Using (4) and above explanation, the array factor of polygonal array is

\[ AF(\theta, \phi) = \sum_{n=1}^{N} \left[ A_n e^{j n \sin \theta \cos \phi - b_n_1 \sin \phi_\theta \sin \phi_\phi} + B_n e^{j n \sin \theta \cos \phi - b_n_2 \sin \phi_\theta \sin \phi_\phi} \right] \]

(5)

where \( \phi_\theta = 2\pi(n-1)/N \) is the angle in the \( x - y \) plane between the \( x \) axis and the \( n \) th element at the vertices of the polygon, \( \phi_\theta = \phi_\theta + \pi/N \) is the angle in the \( x - y \) plane between the \( x \) axis and the \( n \) th element at the middle of each line of the polygon, \( A_n, B_n \) are the relative amplitude of \( n \) th element placed at the vertices and the middle of the polygon, respectively. And both ellipses have the same eccentricity \( e = \sqrt{1-b_1^2/a_1^2} = \sqrt{1-b_2^2/a_2^2} \). Considering, \( N = 6 \), results a 12 element hexagonal array (HA).

The array factor of the concentric elliptical array (CEA), as shown in Fig. 1(b), is [4]
AF(θ, φ) = \sum_{m=1}^{N} C_{mm} e^{j \theta m} e^{j \phi m} \sin(\theta m \cos \phi m + \phi m \sin \phi m) \sin(\theta m \cos \phi m + \phi m \sin \phi m)

(7)

where, \( N \) is the number of elements lie on ellipses, \( M \) is the number of concentric ellipses, \( B_{mm} \) is the amplitude of excitation current, \( a_m, b_m \) are semi-major axis and semi-minor axis of \( m \) th elliptical array, respectively. They are obtained from following equations for a given eccentricity.

\[ a_m = a + (m - 1)d \]
\[ b_m = a_m \sqrt{1 - e^2} \]

(8)

In (8), \( a \) is the smallest semi-major axis and \( d \) is the spacing between ellipses.

For elliptical cylindrical array (ECA), all ellipses are of equal semi-major axis and semi-minor axis \( a, b \) and they are placed one above the other, with an equal vertical spacing \( d \) between them (Fig. 1(c)). Thus, the elements along a vertical line on the cylinder surface form a linear array and those in a transversal plane constitute an elliptical array. For the \( M \) identical elliptical arrays, the total array factor is obtained by the summation of the \( M \) elliptical array factors given by (4) as in [4]

\[ AF(\theta, \phi) = \sum_{m=1}^{N} C_{mm} e^{j \theta m} e^{j \phi m} \sin(\theta m \cos \phi m + \phi m \sin \phi m) \]

(9)

In (9), considering the far field region, the array factor of each elliptical array in Fig. 1(c) is the same as that of the elliptical array in the \( x - y \) plane. However, in the vertical direction there is a phase difference between the elements of a linear array, hence in (9)

\[ C_{mm} = A_m e^{j \alpha m} B_m e^{j (m-1)kd \cos \theta + \beta} \]

(10)

where \( d \) is spacing between elements lied in vertical direction, the term \( B_m e^{j (m-1)kd \cos \theta + \beta} \) comes from \( m \) th vertical element and \( A_m e^{j \alpha m} \) is the excitation coefficient of \( n \) th element of elliptical array.

In elliptical coaxial cylindrical array ECCA (Fig. 1(d)), the elements along a vertical line on the cylinder surface form a linear array, while those laid in a transversal plane constitute a concentric elliptical array (CEA). The total array factor is the summation of the array factors of \( P \) cylindrical arrays, each with a different semi-major axis and semi-minor axis. Using (9) and (10), the array factor of \( P \) coaxial cylinders is given by [4]

\[ AF(\theta, \phi) = \sum_{m=1}^{N} C_{mm} e^{j \theta m} e^{j \phi m} \sin(\theta m \cos \phi m + \phi m \sin \phi m) \sin(\theta m \cos \phi m + \phi m \sin \phi m)
\]

(11)

where

\[ a_p = a + (p - 1)d \]
\[ b_p = a_p \sqrt{1 - e^2} \]

(12)

and \( a_p, b_p \) are semi-major axis and semi-minor axis of \( p \) th elliptical cylinder, respectively. \( d_r \) is spacing between two elements in the radial direction and \( d_v \) is spacing between two elements in the vertical direction and \( e \) is the all ellipses eccentricity.

In (4) to (12), assuming \( e = 0 \), leads to circular case.

The array factor of the concentric hexagonal array (CHA), as shown in Fig. 1(f), can be found by summation of the array factors of \( M \) concentric HA

\[ AF(\theta, \phi) = \sum_{m=1}^{N} \sum_{n=1}^{N} [A_{nn} e^{j \theta n} e^{j \phi n} \sin(\theta n \cos \phi n + \phi n \sin \phi n) + B_{nn} e^{j \theta n} e^{j \phi n} \sin(\theta n \cos \phi n + \phi n \sin \phi n)] \]

(13)

where, \( 2N \) is the number elements on each hexagon, \( M \) is the number of concentric hexagons, \( A_{nn}, B_{nn} \) is the amplitude of excitation currents, \( a_{nm}, b_{nm} \) are semi-major axis and semi-minor axis of \( m \) th element placed at the vertices of the hexagon, respectively. \( a_{2m}, b_{2m} \) are semi-major axis and semi-minor axis of \( m \) th element placed at the middle of each line of the hexagon which are obtained from following equations for a given eccentricity \( e \).

\[ a_{nm} = a + (m - 1)d, \quad b_{nm} = a_{nm} \sqrt{1 - e^2} \]
\[ a_{2m} = a_{nm} \cos(\gamma), \quad b_{2m} = b_{nm} \cos(\gamma) \]

(14)

In (14), \( a \) is the smallest semi-major axis of the ellipse.
they are placed one above another, so that the semi-major and semi-minor axes of each EA decrease linearly by increasing \( m \). Then ECCOA array factor is similar to ECCA equations and comments.

The array factor of hexagonal conical cylindrical array HCCA (Fig. 1(h)) can be obtained by applying some modifications to array factor of ECA in (9) and the array factor of HCOA (Fig. 1(l)) becomes

\[
AF(\theta, \varphi) = \sum_{p=1}^{M} \sum_{m=1}^{N} \sum_{n=1}^{N} \left\{ A_{pm} e^{jk \sin \theta \alpha_{pm} \cos \varphi b_{pm} \sin \varphi_{pm} \sin \varphi} + B_{pm} e^{jk \sin \theta \alpha_{pm} \cos \varphi b_{pm} \sin \varphi_{pm} \sin \varphi} \right\}
\]

where, \( d \) is spacing between elements lied in vertical direction, and similar \( a_{1}, b_{1}, a_{2}, b_{2} \) to ECA equations and comments.

The elliptical conical array (ECOA) can be treated as M, CEA and semi-minor axes of each EA decrease linearly by increasing \( m \) (Fig. 1(i)). Then, the array factor of ECA and they are placed one above another, so that the semi-major factor, this array can be treated as M, CEA and HCA (Fig. 1(g)) can be obtained as

\[
AF(\theta, \varphi) = \sum_{p=1}^{M} \sum_{m=1}^{N} \sum_{n=1}^{N} \left\{ A_{pm} e^{jk \sin \theta \alpha_{pm} \cos \varphi b_{pm} \sin \varphi_{pm} \sin \varphi} + B_{pm} e^{jk \sin \theta \alpha_{pm} \cos \varphi b_{pm} \sin \varphi_{pm} \sin \varphi} \right\}
\]

The elliptical conical array (ECOA) can be treated as M, CEA and HCOA (Fig. 1(i)) can be derived as

\[
AF(\theta, \varphi) = \sum_{m=1}^{M} \sum_{p=1}^{N} A_{pm} e^{jk \sin \theta \alpha_{pm} \cos \varphi b_{pm} \sin \varphi_{pm} \sin \varphi} + B_{pm} e^{jk \sin \theta \alpha_{pm} \cos \varphi b_{pm} \sin \varphi_{pm} \sin \varphi}
\]

where, \( a_{pm} = a + (p - 1)d, b_{pm} = a_{pm} \sqrt{1 - e^{2}} \)

The elliptical conical array (ECOA) can be treated as M, CEA and they are placed one above another, so that the semi-major and semi-minor axes of each EA decrease linearly by increasing \( m \). Then, the array factor of the conical array (ECOA) can be obtained by applying some modifications to array factor of ECA in (9)

\[
AF(\theta, \varphi) = \sum_{m=1}^{M} \sum_{p=1}^{N} C_{pm} e^{jk \sin \theta \alpha_{pm} \cos \varphi b_{pm} \sin \varphi_{pm} \sin \varphi}
\]

where, \( C_{pm} \) is described by (10), and \( a_{pm}, b_{pm} \) are semi-major and semi minor axes of \( m \) EA:

\[
a_{pm} = \frac{M - m + 1}{M} a_{1}, b_{pm} = \sqrt{1 - e^{2}} a_{pm}
\]

and assuming \( e = 0 \) results the COA array factor.

To obtain the elliptical coaxial array (ECOA) (Fig. 1(j)) factor, this array can be treated as M, CEA and they are placed one above another, so that the semi-major and semi minor axes of each EA decrease linearly by increasing \( m \). Then ECOA array factor is similar to ECCA array factor in (11) and only needs some modification.

\[
AF(\theta, \varphi) = \sum_{p=1}^{M} \sum_{m=1}^{N} \sum_{n=1}^{N} A_{pm} e^{jk \sin \theta \alpha_{pm} \cos \varphi b_{pm} \sin \varphi_{pm} \sin \varphi} + B_{pm} e^{jk \sin \theta \alpha_{pm} \cos \varphi b_{pm} \sin \varphi_{pm} \sin \varphi}
\]

where, \( a \) is the smallest semi-major axis of the first elliptical array (\( m = 1 \)), and \( d \) is the element spacing in radial direction for \( m = 1 \). The \( e = 0 \) case is CCOA.

Finally, with a similar way the array factor of HCOA (Fig. 1(k)) can be derived as

\[
AF(\theta, \varphi) = \sum_{m=1}^{M} \sum_{p=1}^{N} \left\{ A_{pm} e^{jk \sin \theta \alpha_{pm} \cos \varphi b_{pm} \sin \varphi_{pm} \sin \varphi} + B_{pm} e^{jk \sin \theta \alpha_{pm} \cos \varphi b_{pm} \sin \varphi_{pm} \sin \varphi} \right\}
\]

where, \( a_{pm} = a_{m} + (p - 1)d_{m}, b_{pm} = a_{pm} \sqrt{1 - e^{2}} \)

The general formula of directivity is given by (23). In denominator of (23) there is a double integral and it is
discredited along 

\[
D(\theta_{0}, \varphi_{0}) = \frac{4 \pi F(\theta_{0}, \varphi_{0})}{\int_{0}^{2 \pi} F(\theta, \varphi) \sin \theta d \theta d \varphi}
\]

If array elements are isotropic, then:

\[
F(\theta, \varphi) = A^{2} F(\theta, \varphi) F^{*}(\theta, \varphi)
\]

where \( * \) denotes the complex conjugate [1]. The gain is equal to product of the directivity and radiation efficiency depending on the antenna type. By controlling the progressive phase difference \( \alpha_{i} \) between the elements, the maximum radiation can be squinted in any desired direction to form a phased array.
Fig. 2. Comparison of our simulation with the results of [9]
$N = 32, a = 2\lambda, \varphi_0 = 30^{\circ}, 49.1^{\circ}$. (a) and (b) are the results of [9] for $t = 1, 2$, respectively, and (c) and (d) is results of our simulations for $t = 1, 2$, respectively.

B. Side Lobe Level (SLL)

The side lobe level (SLL) is the ratio of the maximum amplitude of the major lobe to maximum amplitude of the greatest minor lobe.

If the amplitude of excitation currents of elements is equal, array has a large directivity and the SLL is considerably great. To overcome this disadvantage, non-uniform current distribution so used that the amplitude of current from center to edges of array is gradually reduced. As the current amplitude is tapered more toward the edges of the array, the side lobes tend to decrease while the beam width increases resulting in decreasing the directivity. This directivity/SLL trade off can be optimized [18].

IV. NUMERICAL RESULTS

To verify our simulations (Fig. 2), an elliptical array (EA) which analyzed in [9] is considered and obtained results with the same parameters is in good agreement with the results of [9] depicted in Fig. 3 of [9]. In this verification, $N = 32, a = 2\lambda$, the axial ratio $t = 1, 2$ and the peak direction of array in $z = 0$ plane is $\varphi_0 = 30^{\circ}, 49.1^{\circ}$, respectively for given values of $t$ (the axial ratio $t = \%$ in [9] is related to eccentricity $e$ by $e = \sqrt{1 - \%}$).

In numerical analysis, EA, CEA, ECA, ECCA, ECOA and ECCOA, with $N = 12, M = 4, P = 4$ and HA, CHA, HCA, HCCA, HCOA and HCCOA with $N = 6, M = 4, P = 4$ are considered. Consequently, all array types have the same number of elements in peripheral direction. In all cases the element spacing has been assumed $\lambda/2$ in three directions of peripheral, radial and vertical and exciting current distribution is uniform.

Figure 3 shows the radiation pattern of EA, HA, HCOA with $e = 0.5$ in $\varphi = 0$ and $\theta = \pi/2$ planes, for instance. Regarding to this figure, EA, HA and ECOA have nulls in some directions of azimuth plane ($\theta = \pi/2$). This can be employed in smart antenna design to steer the maximum of beam toward SOI and nulls of beam to SNOI.

Figure 4 illustrates the Directivity and SLL of EA, CEA, ECA and ECCA versus ellipse eccentricity $e$. For these array types, the directivity and SLL do not vary considerably by incrementing eccentricity, except the SLL of ECCA. CEA has the highest Directivity and ECA has the lowest SLL. Also EA, ECA and ECCA have approximately similar directivities, EA and ECA have the worse SLL.

In Fig. 5, the directivity and SLL of HA, CHA, HCA and HCCA versus ellipse eccentricity are shown. CHA has the best directivity and HCCA has the lowest SLL among them. The SLL of HCA has significant variation by eccentricity and is the worse case. The directivity and SLL of ECOA, ECCOA, HCOA and HCCOA are depicted in Fig. 6. ECCOA and ECOA have the best directivity and ECCOA has the lowest SLL. HCCOA and HCOA have not good directivity and SLL.

Figure 7 shows the directivity and SLL variations of EA, CEA, ECA and ECCA versus number of elements $N$. In all cases the directivity increases versus incrementing $N$, but this increment for CEA is considerably with high slope. The SLL of EA approximately independent from $N$ and SLL of ECA oscillates by $N$. The SLL of ECA and ECCA
become 0 for large number of elements. It is due to occurring grating lobes in large $N$.

In Fig. 8, the directivity and SLL of HA, CHA, HCA and HCCA versus ellipse eccentricity are shown. In all cases the directivity increases versus incrementing $N$, but this increment for CHA is considerably with high slope. The SLL of HA and CHA do not vary considerably by $N$ and the SLL of HCA and HCCA oscillate versus $N$. HCA has grating lobes in some element numbers $N$.

The directivity and SLL of ECOA, ECCOA, HCOA and HCCOA have significant variations versus $N$. This fact is shown in Fig. 9.

In Figs. 10 to 12, the directivity and SLL variations versus element spacing are illustrated. In all cases the directivity and SLL oscillate versus $N$ except the SLL of EA, CEA, HA and CHA.

Among mentioned array types, CHA and CEA have the largest directivity and HCOA and HCCOA have the lowest directivity, for a given number of elements, $N$, $M$ and $P$, ellipse eccentricity $e$ and element spacing. Also ECOA and HCCA have the lowest SLL and HCOA and HCCOA have the worse SLL.

V. CONCLUSION

In this paper elliptical and hexagonal arrays and their combination with linear arrays in peripheral, vertical and radial directions and conical and pyramidal arrays with ellipse cross-section were considered. These array types were, EA, CEA, ECA, ECCA, HA, HCA, HCCA, ECOA, ECCOA, HCOA, and HCCOA. The expressions for array...
Fig. 7. Directivity and SLL of EA, CEA, ECA, ECCA versus Number of Elements ($N$) for $M = 4$, $P = 4$ elements, $d_r = d_e = d_i = \lambda / 2$ and $\epsilon = 0.5$.

Fig. 8. Directivity and SLL of HA, CHA, HCA, HCCA versus Number of Elements ($N$) for $M = 4$, $P = 4$ elements, $d_r = d_e = d_i = \lambda / 2$ and $\epsilon = 0.5$.

Fig. 9. Directivity and SLL of ECOA, ECOA, HCOA and HCOA versus Number of Elements ($N$) for $M = 4$, $P = 4$ elements, $d_r = d_e = d_i = \lambda / 2$ and $\epsilon = 0.5$.

Fig. 10. Directivity and SLL of EA, CEA, ECA, ECCA versus Element Spacing as a fraction or coefficient of $\lambda$ for $N = 12$, $M = 4$, $P = 4$ elements, $d_r = d_e = \lambda / 2$ and $\epsilon = 0.5$.
factor of them were obtained. The hexagonal array was treated as consisting of two concentric \(N\) element elliptical arrays of different semi-major and semi-minor axes and the elliptical conical array (ECOA) was treated as \(M\), EA and they are placed one above another, so that the semi-major and semi-minor axes of each EA decrease linearly.

The directivity and SLL of all arrays versus ellipse eccentricity, number of elements and element spacing were simulated and obtained. Among them, CHA and CEA had the largest directivity and HCOA and HCCOA had the lowest directivity and ECOA and HCCA had the lowest SLL and HCOA and HCCOA had the worse SLL. Also combining linear arrays with other arrays instead of single arrays, leads to smaller array size with the same directivity and SLL.

The radiation pattern in some cases as HA, EA and ECOA had nulls in azimuth plane to reject the SNOI in smart antenna applications.

Finally it can be seen that the best array type, may be obtained by means of calculations mentioned in this paper, [4] and [16].

REFERENCES

R. A. Sadeghzadeh received the B.Sc. degree in Communication Engineering from University of Khajeh Nasir Tousi in 1984. He received his M.Sc. and Ph.D. degrees both in Communication Engineering from the university of Bradford UK, in 1987 and 1990, respectively. From 1980 to 1984, he worked with Iran Telecommunication Company. During 1990-1998 he served as a Post-Doctoral research Assistant in the Electrical and Electronic Engineering Dept. at the university of Bradford, UK.

Dr. Sadeghzadeh has been with University of Khajeh Nasir Tousi, since 1998. His research interests include Antenna, propagation, Electromagnetics, Numerical Analysis, Electromagnetic wave exposure and wireless communication.

A. A. Lotfi Neyestanak was born in Tehran, Iran in Jun. 1971. He received B.Sc. degree in Communication Eng. (1993) and M.Sc. degree in Electronic Engineering (1997) and Ph.D. degree in communication Engineering (2004) from Iran University of Science and Technology (IUST) Tehran, Iran, respectively. From 1995-1998 he was a microwave links designer and a TV Engineer in IRIB Tehran, Iran. Since 1999 he has been teaching in the Department of Electrical Engineering at Islamic Azad University, Tehran-Iran. Since 1999 has been a Research Assistant at the Iranian Research Institute for Electrical Engineering (IRIEE).

His main areas of interest in research are microstrip antenna, microwave passive circuits, RF circuit design, EMC, radio networks design, optimization methods in electromagnetic, radio wave propagation, radar and RF MEMS.

M. Naser-Moghadi was born in Saveh, Iran, in 1959. He received the B.Sc. degree in Communication Eng. in 1985 from Leeds Metropolitan University (formerly Leeds Polytechnic), UK.

Between 1985 and 1987 he worked as an RF design engineer for the Gigatech Company in Newcastle Upon Tyne, UK. From 1987 to 1989, he was awarded a full scholarship by the Leeds educational authority to pursue an M.Phil. studying in CAD of Microwave circuits. He received his Ph.D. in 1993, from the University of Bradford, UK. He was offered then a two years Post Doc. to pursue research on Microwave cooking of materials at University of Nottingham, UK.

From 1995, Dr. Naser-Moghadi joined Islamic Azad University, Science & Research Branch, Iran, where he currently is the head of postgraduate studies and also a member of Central Commission for Scientific Literacy & Art Societies. His main areas of interest in research are Microstrip antenna, Microwave passive and active circuits, Optimization methods, RF MEMS. Dr. Naser-Moghadi is a member of the Institution of Engineering and Technology, MIET and he has so far published 31 papers in different journals and conferences.

M. Ghiamy was born in Ardabil, Iran in 1976. He received the B.Sc. degree from Sharif University of Technology, Tehran, in 1998 and M.Sc. degree from Amirkabir University of Technology, Tehran in 2001, both in electrical engineering and now is a Ph.D. candidate in electrical engineering in Islamic Azad University, Science and Research Branch, Tehran.

In 2003, he was employed as a Faculty of Islamic Azad University, Branch of Ardabil in Electrical Engineering group. His research interests include numerical techniques in electromagnetics, micro-strip antennas and arrays analysis and design and RF circuit design.