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Alzahraa H. Nosier, Mohamed E. Nasr, Nessem M. Mahmoud, amr Hussein

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A novel optimized conical antenna array structure for back lobe cancellation of uniform concentric circular antenna arrays

Alzahraa H. Nosier [1], Mohamed E. Nasr[1], Nessem M. Mahmoud[1], and Amr H. Hussein[1, 2]

[1] Electronics and Electrical Communications Engineering Dept., Faculty of Engineering, Tanta University, Tanta, Egypt.
[2] Electronics and Communications Engineering Dept., Faculty of Engineering, Horus University Egypt, New Damietta, Egypt.

***Abstract*- In wireless communication systems, the existence of the antenna array back lobe represents a significant source of interference, which causes degradation of the signal-to-interference ratio (SIR), and power loss. In this paper, a novel optimized conical antenna array (O-CONAA) structure is proposed for back lobe cancellation of concentric circular antenna arrays (CCAA). Based on the CAA, It is considered to be made up Of several concentric circular antenna arrays (CCAA) which are placed in the X-Y plane. Firstly a non-optimized CONAA is constructed, by arranging these concentric CAAs with uniform vertical spacing along the Z-axis. Consequently, the CONAA seems to be treated as a combination between uniform CAAs and a linear antenna array (LAA). It has been noted that the CONAA radiation pattern has a back lobe amplitude the same as the main beam amplitude. The O-CONAA structure is suggested as a solution to this problem, which provides back lobe cancellation while maintaining the CONAA pattern characteristics like half power beamwidth (HPBW) side lobe level (SLL). The genetic algorithm(GA) approach is used in the O-CONAA structure to optimize the values of both CONAA inter-element spacing around the perimeter of each circle, and vertical spacing along the Z-axis to generate the desired radiation pattern.**

***Keywords*- Circular Antenna Array (CAA), Concentric Circular Antenna Array (CCAA), Side Lobe Level (SLL), Half Power Beamwidth (HPBW), Genetic Algorithm (GA).**

I. INTRODUCTION

Antenna arrays in wireless communication systems provide advanced capabilities for signal shaping, interference mitigation, and improved system performance as they can enable higher data rates, better coverage, and enhanced user experience. They are the most critical components in present-day wireless communication systems, such as satellite communication [1], mobile networks, and wireless sensor networks.[2] .The utility of antenna arrays comes from their radiation patterns, which let wireless devices serve the targeted receiver while minimizing interference to unwanted receivers. As a consequence of this, the received signal to interference (SINR) is improved, which results in overall enhancement in wireless communication systems performance. [3].

The antenna array elements are arranged in several geometrical configurations such as linear, elliptical, cylindrical, planer, co-centric planer, circular, and concentric circular, and the main challenge in antenna array design is to minimize both its side lobe level (SSL) and back lobe to reduce the interference, and this can be accomplished by adjusting the number of elements, inter-element spacing, excitation coefficients, relative phases, and the geometrical configuration. [4] .

However, liner arrays are the most popular configuration due to the simplicity in construction, and the increased directivity of the main beam in a particular direction. As they suffer from ineffective radiation in all 360-degree azimuthal directions. [5] .Contrariwise, in circular arrays, because there are no edge elements, the array can be electronically rotated 360°without the radiation pattern being deformed, allowing the main beam to be focused and channeled in any direction throughout the entire space. [6].

A concentric circular antenna array (CCAA) consists of several concentric circular rings with different radii where each ring contains a specific number of antennas.[7]. The CCAA has several noteworthy advantages, such as 360°azimuth scanning, invariant angle coverage, simplicity of pattern synthesis, efficient spectrum utilization, and low mutual coupling sensitivity. [4] , and because of their strength compared to the linear and planer array, it is widely utilized in contemporary wireless

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communication systems, particularly for satellite, sonar, and radar-related applications.

For side lobe level (SLL) reduction and back lobe minimization, several research and optimization methods have been introduced in this issue.[8]. There are typically two approaches to lowering a CCAA's SLL. The first approach is to use radially tapered amplitude distribution across the array elements while maintaining the elements uniformly spaced, but using this approach makes the feed network more complex and lowers the maximum power input. [9]. Another approach is to vary the spacing between array elements in the circle, and therefore varying the radius of circles, taking on the assumption that each array element's excitation is uniform.[10]. The ALO-SQP approach which combines ant lion optimizer (ALO) and sequential quadratic programming (SQP) is introduced in [11]. It is proposed for the concentric circular antenna array (CCAA) to reduce the SLL by controlling the antenna elements' excitation coefficients of the 3-ring structure of a non-uniform CCAA design having two sets of elements(4, 6, 10), and (8,10,12) with and without central element and the distance between the adjacent elements is assumed to be constant being 0.55 λ, 0.606 λ, and 0.75 λ for the first, second, and third rings, respectively. When compared to symbiotic organisms search (SOS) in [13], The Firefly Algorithm (FA) in [14], the Evolutionary Programming (EP) algorithm in [15], the Biogeography-Based Optimization algorithm (BBO) in [16], Cat Swarm Optimization (CSO) in [17], and Advanced Marine Predator Algorithm (AMPA) in[2], the ALO-SQP yielded the lowest MSL (−45.79 dB), FNBW (96.2°), and DRR (15.748) for all considered cases. Another optimization algorithm Ant Lion Optimizer (ALO) is introduced in [12], This ALO algorithm has produced a reduction in SLL to $-35.64\ dB$ and narrowing the first null beamwidth (FNBW) to be taking into consideration the effect of the mutual coupling. In [18], Moth Flame Optimizer (MFO) , reduced the SLL and perform also main beam thinning by performing optimization on both the current excitation for every antenna array element and the interelement spacing between the elements in each circle.

Also, many array thinning techniques for enhancing the performance of CCAA, array thinning is executed either by making the placements of the elements fixed while their states alternate between "on" and "off." as traduced in [19] using Improved Binary Invasive Weed Optimization Algorithm (IBIWO), or in addition to the change in the element activity between "on" and "off.", the interelement spacing between elements in the ring is optimized as introduced in binary Slap Swarm Algorithm (BSSA) in [20], In terms of reduced SLL, minimum number of array elements, and a higher percentage of array thinning, (IBIWO) and (BSSA) introduced good results with the other algorithms like Firefly Algorithm (FA) used in [14], Biogeography Based Optimization (BBO) used in [16], and Teaching-Learning-Based Optimization (TLBO) presented in [21]. However, the array thing technique has a drawback which is the increase in HPBW, The (IBIWO) could achieve array thinning with a significant reduction in SLL while maintaining the HPBW like the fully occupied arrangement of array elements.

Whereas CCAA is considered a type of planner antenna array(PAA), there are several approaches used for SLL reduction and array thinning. By adjusting the excitation coefficients of the antenna elements, the improved chicken swarm optimization (ICSO) algorithm is introduced in [22] to decrease the SLL of a planar antenna array (PAA). The ICSO produced the lowest SLL if compared to the biogeography-based optimization (BBO), and particle swarm optimization (PSO), in [16], a new optimized quadrant pyramid antenna array (O-QPAA) structure is proposed for back lobe minimization and side lobe level (SLL) reduction of planar antenna arrays (PAA) and this by perform optimization on both excitation coefficients and interelement spacing. For array thinning, the modified binary-coded GA (MBC-GA) introduced in [23], generates SLL reduction in addition to array thinning by performing optimization on the array elements that will be "on" and the rest that will be "of" with maintaining the position of the elements, in comparison the MBC-GA offers less SLL than the Boolean PSO (BPSO) technique.

In this paper, the optimized conical antenna array (O-CONAA) construction is presented for back lobe cancellation of uniform concentric circular antenna arrays (CCAAs). First, the non-optimized CONAA is constructed from L decreasing radius circular antenna arrays CAAs, and the L is equal to M that represents

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the number of rings of CCAA with radii $r_{ms}, m = 1,2,\dots,M$, and number of elements N_{ms}, $m = 1,2,\dots,M$, they are uniformly fed, positioned in the X-Y plane, and aligned around the Z axis with uniform vertical spacing d_L. As a result, each m^{th} CAA is regarded as an l^{th} antenna element in a linear antenna array (LAA) made up of L elements with the previously indicated vertical element spacing d_L aligned along the Z-axis. The uniform CONAA will be constructed in the case of uniform feeding CAAs an LAA with uniform excitations $\mathfrak{I}_{(mn)_l}$ and e_l, respectively, and with uniform inter-element spacing $d_{n_m}, m = 1,2,\dots,L$, for the m^{th} CAA and uniform vertical spacing d_L.But, the resultant radiation pattern of uniform CONAA has a main beam and back lobe with the same amplitude.

Consequently, the optimized conical antenna array O-CONAA is suggested to minimize the amplitude of the back lobe but still make the other parameters of CONAA radiation pattern such as SLL and HBPW be adjusted, and this is by using the GA approach to optimize the value of both d_{n_m} and d_L, and for simplicity in feeding network design the excitation coefficients $\mathfrak{I}_{(mn)_l}$ of each CAA are maintained uniform and the synthesized excitations $£_l$ of the LAA are typically non-uniform.

The paper is arranged as follows; Part II presents the problem formulation in detail, Part III introduces the proposed Conical antenna array (CONAA), the proposed O-CONAA for back lobe cancellation is introduced in Part IV, and the simulation results and discussions are introduced in Part V.

II. PROBLEM FORMULATION

In a concentric circular antenna array, all antenna elements are arranged in multiple concentric rings on the X-Y plane. Fig. 1 shows the general configuration of CCAA with M concentric circular rings, where the $m^{th}(m = 1,2,\dots,M)$. The ring has a radius r_m and the corresponding number of elements is N_m. Assuming that all the array elements are isotropic sources, then the beam pattern can be described by its array factor, which is given as follows:

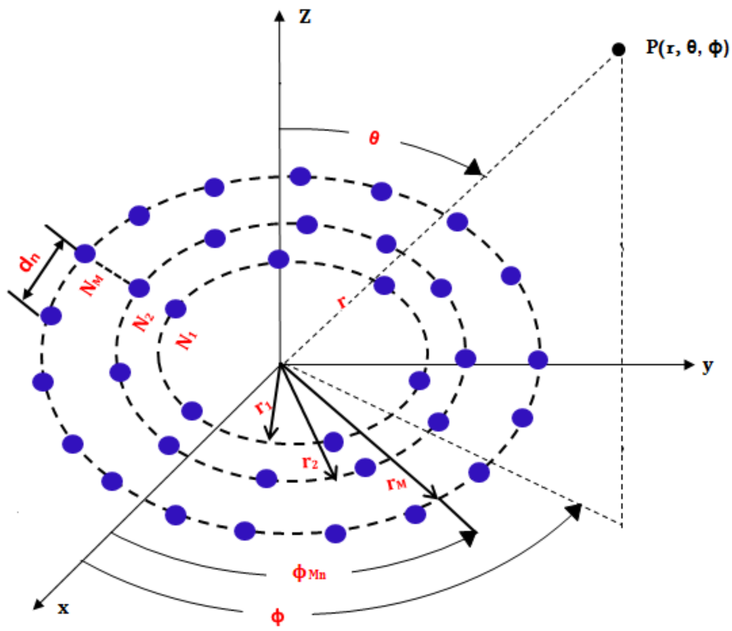

Figure 1. The geometrical configuration of the concentric circular antenna array CCAA.

$$AF(\theta,\varphi) = \sum_{m=1}^{M}\sum_{n=1}^{N} \mathfrak{I}_{mn}\, exp\,[jk\, r_m(cos\,\varphi_{mn} U + sin\,\varphi_{mn} V)] \quad (1)$$

Where

$$\begin{cases} U = sin\,\theta\, sin\,\varphi - sin\,\theta_0\, sin\,\varphi_0 \\ V = sin\,\theta\, cos\,\varphi - sin\,\theta_0\, cos\,\varphi_0 \end{cases} \quad (2)$$

The pair (θ_0, φ_0) indicates the steering direction, and the pair (θ, φ) indicates the arrival direction and θ and φ are the azimuth and elevation angle, respectively. $k = 2\pi/\lambda$ is the wave number, $r_m = N_m d_{n_m}/2\pi$ is the radius of the m^{th} ring, d_{n_m} is the interelement spacing of the m^{th} ring, and $\varphi_{mn} = 2(n-1)/N_m$ is the angular position of the n^{th} element of the m^{th} ring. Finally, $\mathfrak{I}_{mn}$ is the excitation amplitude of the n^{th} element on the m^{th} ring.

To enhance the performance of the antenna array with regards to minimizing the interference and raising optimal power utilization. Whereas, a significant cause of interference and power loss throughout transmission and reception is the presence of both the CCAA's back lobe and side lobes. So it is imperative to control the ratio between the main beam and back lobe amplitudes

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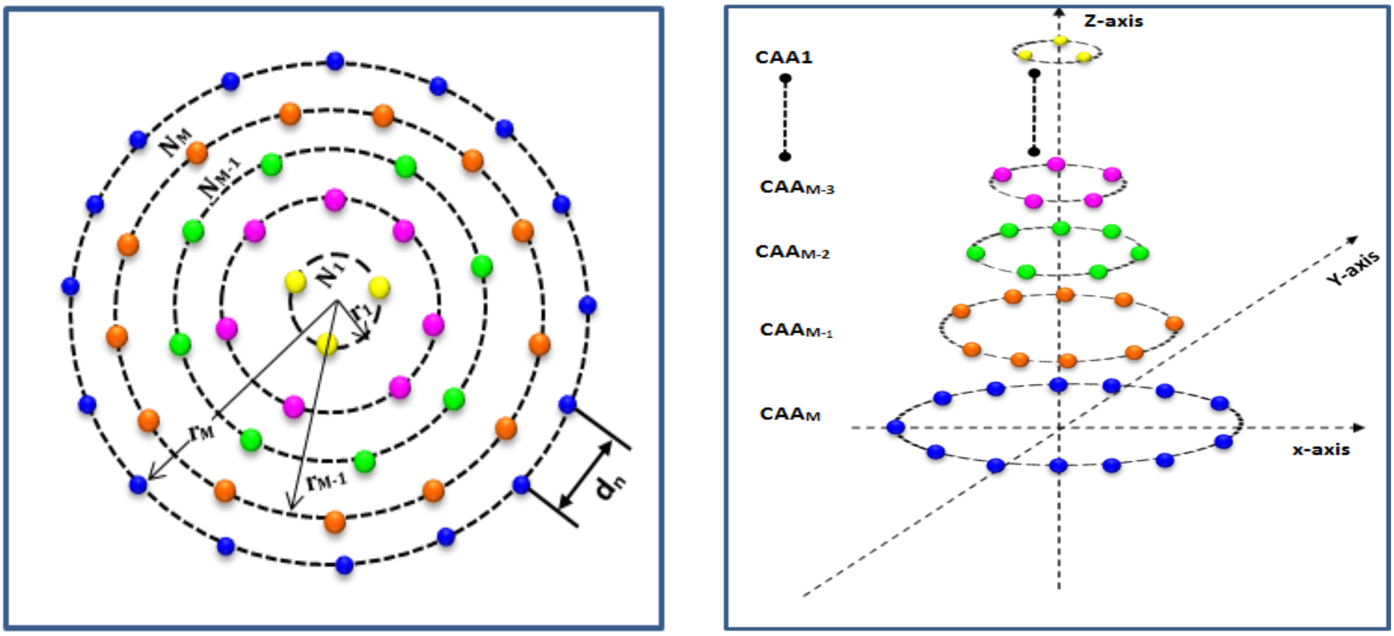

(a)

(b)

(b)

Figure 2. The elements distribution: (a) *M* rings traditional CCAA, (b) Equivalent CONAA.

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to decrease it as much possible as. This ratio is defined as :

$$\frac{\mathcal{F}}{\mathcal{B}} = \frac{\text{Main beam amplitude}}{\text{Back lobe amplitude}} \quad (3)$$

III. PROPOSED CONICAL ANTENNA ARRAY (CONAA)

In this part, from L decreasing radius CAAs, and the L is equal to M that represents the number of concentric circular antenna array CCAA rings with radii $r_{ms}, m = 1,2,\dots,M$, and the number of elements N_{ms}, $m = 1,2,\dots,M$, with uniform feeding, they are positioned in the X-Y plane, and the circles then aligned around the Z axis with uniform vertical spacing d_L as shown in Fig. 2 . As a result, each m^{th} CAA is regarded as an l^{th} antenna element in a linear antenna array (LAA) made up of L elements with the previously indicated vertical element spacing d_L along the Z-axis.

To design The CONAA, each of the following parameters should be evaluated: the number M of CAAs and the number of antenna elements N_m at each one, the interelement spacing d_{n_m} for each m^{th} CAA, and the vertical spacing d_L between the adjacent CAAs along the Z-axis.

And as for the N_m , we consider that the antenna elements distribution over the CAAs takes the form of an arithmetic series as follows:

$$N_m = N_1 + (m-1)d, m = 1,2,\dots,M \quad (4)$$

where, its initial term N_1 represents the number of antenna elements of the innermost ring, m represents the number of m^{th} CAA of CCAA, d represents the common difference of successive CAAs, and N_m represents the number of antenna elements in m^{th} CAA. Accordingly, the total number of antenna elements can be calculated as follows:

$$N_{tot} = \begin{cases} \frac{m(N1+Nm)}{2}, CCAA\ with\ out\ central\ element \\ 1 + \frac{m(N1+Nm)}{2}, CCAA\ with\ central\ element \end{cases} \quad (5)$$

In order to better understand this, for example, assume CCAA with four rings ($M = 4$) without a central element, has 3 antenna elements in the innermost ring, while each succeeding ring has six more elements on the outside. Fig. 3, clarifies how the traditional CCAA in Fig. 2 . (a), with ($M = 4$) rings is placed around the Z axis with uniform vertical spacing to build up the proposed conical antenna array CONAA, and its equivalent LAA with $L = 4$ elements vertical element spacing d_L along Z-axis.

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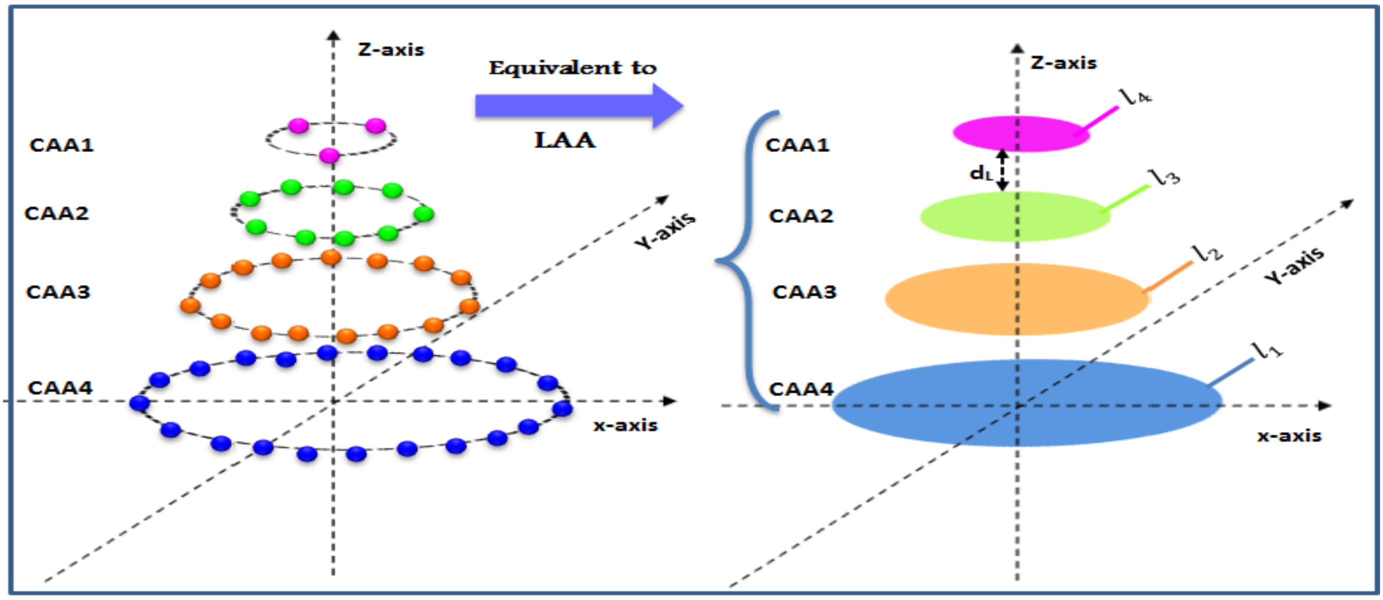

And Table 1, lists the number of rings of CCAA, the number of elements in each m^{th} CAA, the total number of elements, and the number of elements L of LAA.

Table 1. The parameters M, L, N_{tot}, N_m of the proposed CONAA for 4 rings CCAA.

$M = 4$	
$L = 4$ and $N_{tot} = 48$	
N_1	3
N_2	9
N_3	15
N_4	21

To derive a formula for the array factor of the proposed CONAA $AF_{CONAA}(\theta,\varphi)$. Considering, the CONAA as a combination of L CAAs, every single one of which serves as an antenna element in an L-elements LAA. At first, the array factor $AF_{CAA_m}(\theta,\varphi)$ of an (N_m) CAA can be determined from the array factor of the traditional (N) CAA such that:

$$AF_{CAA_m}(\theta,\varphi) = \sum_{n=1}^{N_m} \mathfrak{I}_{mn} \exp\left[jk\, r_m(\cos\varphi_{mn}(\sin\theta \sin\varphi - \sin\theta_0 \sin\varphi_0)) + \sin\varphi_n(\sin\theta\cos\varphi - \sin\theta_0\cos\varphi_0))\right] \quad (6)$$

Where The pair (θ_0, φ_0) indicates the steering direction, the pair (θ, φ) indicates the arrival direction and θ and φ are the azimuth and elevation angle, respectively. $k = 2\pi/\lambda$ is the wave number, $r_m = N_m d_{n_m}/2\pi$ is the radius of the m^{th} ring, d_n is the interelement spacing of the m^{th} ring, and $\varphi_{mn} = 2(n-1)/N_m$ is the angular position of the n^{th} element of the m^{th} ring. Finally, $\mathfrak{I}_{mn}$ is the excitation amplitude of the n^{th} element on the m^{th} ring, and by the way it is the same excitation amplitude $\mathfrak{I}_{(mn)_l}$ of each l^{th} CAA that composes CONAA structure as illustrated previously, Consequently, the total array factor $AF_{CONAA}(\theta,\varphi)$ of the CONAA is obtained by merging the L number of CAA array factors through the LAA. The array factor $AF_{LAA}(\theta)$ of the LAA is given by:

$$AF_{LAA}(\theta) = \sum_{l=1}^{L} \pounds_l \exp\left[j\, k(l-1)\, d_L((\cos\varphi - \cos\varphi_0) + (\cos\theta - \cos\theta_0))\right] \quad (7)$$

where $\pounds_l$ is the excitation coefficient of the l^{th} antenna element of the LAA. Then the $AF_{CONAA}(\theta,\varphi)$ is obtained as follows:

$$AF_{CONAA}(\theta,\varphi) = AF_{LAA}(\theta) \times AF_{CAA_m}(\theta,\varphi) \quad (8)$$

Thus, it can be written as:

$$AF_{QPAA}(\theta,\varphi) = \sum_{l=1}^{L} \mho_l * \left[\sum_{n=1}^{N_m} \mathfrak{I}_{(mn)_l} \exp\left[jk\, r_m(\cos\varphi_{mn}(\sin\theta \sin -\right.\right.$$

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$\sin\theta_0 \sin\varphi_0)) + \sin\varphi_n(\sin\theta\cos\varphi - \sin\theta_0\cos\varphi_0))]\Big]$ (9)

where $\mho_l$ is defined as:

$$\mho_l = £_l \exp\,[j\,k(l-1)\,d_L(\left(cos\varphi - cos\varphi_0\right) + (cos\theta - cos\theta_0))] \quad (10)$$

IV. PROPOSED O-CONAA FOR BACK LOBE CANCELLATION.

In this part, the suggested optimization technique of the O-CONAA for back lobe cancellation is introduced. Control the radiation pattern parameters of the CONAA like HPBW, SLL, and back lobe amplitude, This can be done via performing optimization of its' key parameters ($\mathfrak{T}_{mn_l}, d_{n_m}, d_L$, and $£_l$). In this study, to facilitate the implementation of antenna array feeding m the excitation coefficients $\mathfrak{T}_{mn_l}$ are kept uniform as the original CCAA. While the GA technique is used to evaluate the optimal values of the other parameters (d_{n_m}, d_L, and $£_l$).

To manage the characteristics of the CONAA pattern, such as SLL, HPBW, and back lobe amplitude, the optimal values of the inter-element spacing of CAAs and their vertical spacing in the LAA are generally determined using the GA. Additionally, the LAA elements' optimized non-uniform excitation coefficients, which manage the excitations of each uniform feeding CAA, have a significant influence on the CONAA's overall pattern. The three parameters (d_{n_m}, d_L, and $£_l$). of the CONAA pattern AF_CONAA. The optimization process is illustrated as follows:

To obtain the desired pattern, $AF_d(\theta,\varphi)$, all the side lobes of the $AF_{COAA}(\theta,\varphi)$ pattern in Eq. (9) is nulled as follows:

$$AF_d(\theta,\varphi) = \begin{cases} 0, & 0 \le \theta < \theta_{NL1} \\ AF_{CONAA}(\theta,\varphi), & \theta_{NL1} \le \theta \le \theta_{NL2} \\ 0, & \theta_{NL2} < \theta \le 2\pi \end{cases} \quad (11)$$

where θ_{NL1} and θ_{NL2} are the first null angles of the $AF_{CONAA}(\theta,\varphi)$ pattern. Thereby, the synthesized pattern of the optimized CONAA, $AF_{O-CONAA}(\theta,\varphi)$, can be determined according to:.

$$AF_{O-CONAA}(\theta,\varphi) \cong AF_d(\theta,\varphi) \quad (12)$$

Using Eq. (9), Eq. (12) can be refourmuled as follows:

$$\sum_{l=1}^{L} \mho_l * \left[\sum_{n=1}^{N_m} \mathfrak{T}_{(mn)_l} \exp\,[jk\,r_m(\cos\varphi_{mn}(\sin\theta\sin - \sin\theta_0\sin\varphi_0)) + \sin\varphi_n(\sin\theta\cos\varphi - \sin\theta_0\cos\varphi_0))]\right] \cong AF_d(\theta,\varphi) \quad (13)$$

Then, assume we have $W(\theta,\varphi)$ parameter can be defined as follows:

$$W(\theta,\varphi) = exp\,[j\,k(l-1)\,d_L(\,(cos\varphi - cos\varphi_0) + (cos\theta - cos\theta_0))] \times AF_{CAA}(\theta,\varphi) \quad (14)$$

Then, Eq. (13) can be reformulated as follows:

$$\sum_{l=1}^{L} £_l \times W(\theta,\varphi) \cong AF_d(\theta,\varphi) \quad (15)$$

The values both of d_L and d_{n_m} are optimized using the GA within an assigned range of 0.5λ to 0.9λ to make the mutual coupling between the elements as minimal as can and avoid the existence of the grating lobes in the O-QPAA pattern. These values are used to determine the synthesized excitation coefficients of the LAA, $£_l$, to minimize the designed cost function CF given below:

$$CF = min\left(\frac{|SLL_{CCAA} - SLL_{O-CONAA}|}{\mathcal{F}/_{\mathcal{B}}}\right) \quad (16)$$

But, with a condition that $HPBW_{O-CONAA} \le HPBW_{CCAA}$.

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where SLL_{CCAA} and $SLL_{O-CONAA}$ are the SLLs of the uniform CCAA and the O-CONAA, respectively. While $HPBW_{CCAA}$ and $HPBW_{O-CONAA}$ are the HBPWs of the uniform CCAA and the O-CONAA, respectively. In Fig. 4. The summary of the synthesis steps of the O-CONAA.

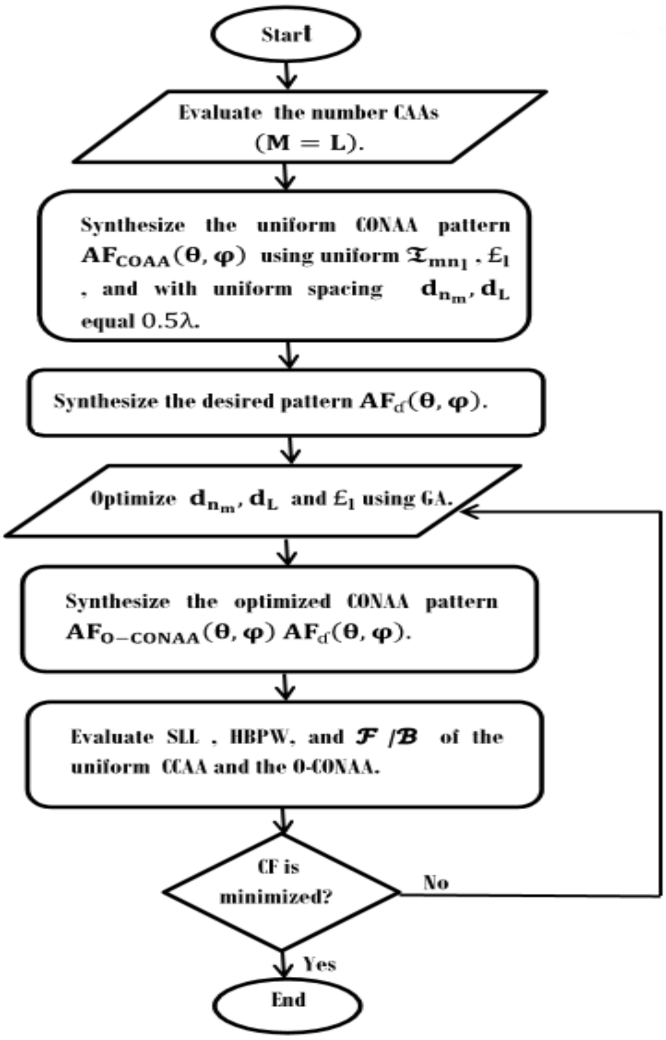

Figure 4. The flow chart of the proposed O-CONAA synthesis steps.

V. SIMULATION RESULTS.

In this part, with the aid of the MATLAB R2013a tool, simulations to verify the effectiveness of the proposed O-CONAA in comparison to the CCAA are carried out.

1- Non-optimized CONAA.

Initially, we will begin with non-optimized CONAA simulations, assuming a CCAA with $(M = 10)$ rings without a central element, with uniform feeding and uniform interelement spacing $d_{n_m} = \lambda/2$, then, 10-rings are distributed to build up the COAA, with uniform spacing $d_L = \lambda/2$, $I_{(mn)_l} = 1$, and $£_l = 1$. The rectangular and the polar charts of the uniform CONAA compared to the uniform PAA, respectively are shown in Fig. 5 and Fig. 6.

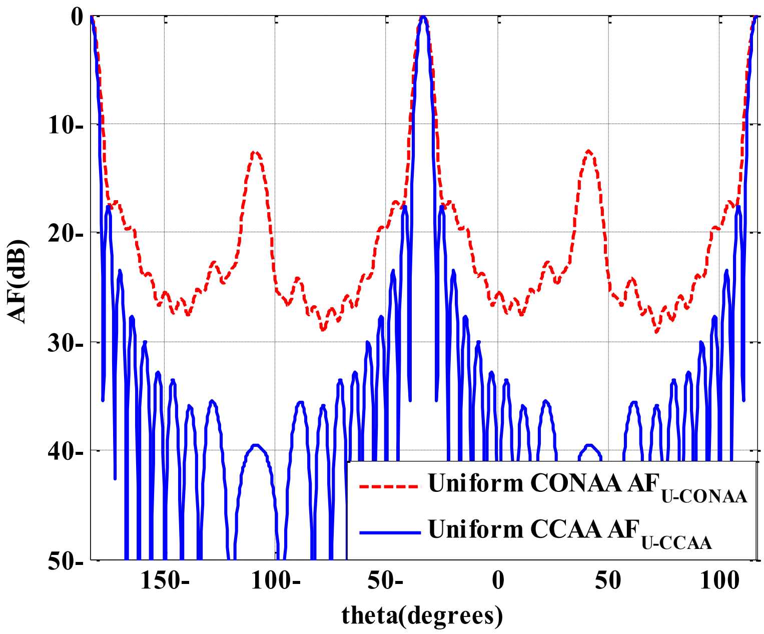

Figure 5. Rectangular plot of the uniform CONAA pattern compared to the uniform (M = 10) CCAA patterns.

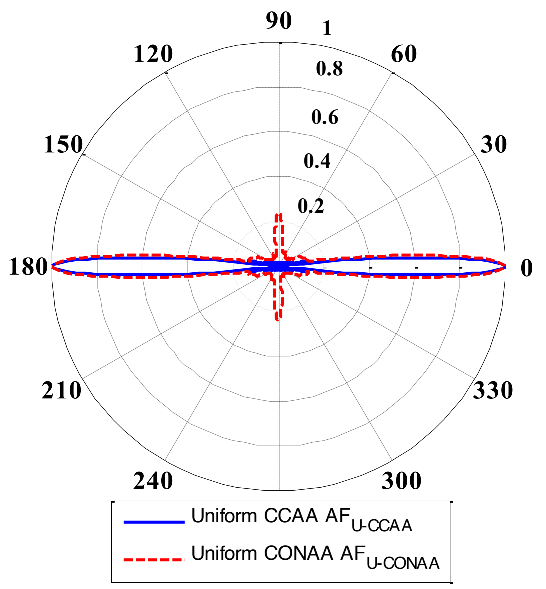

Figure 6. Polar plot of the uniform CONAA pattern compared to the uniform (M = 10) CCAA patterns.

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It is evident from the analysis of the findings that the uniform CONAA pattern produces broader HPBW and greater SLL than the uniform PAA pattern. Where it raises the SLL by 5.03 dB and the HPBW by 1.44°. while, the uniform CONAA still offers the same $\mathcal{F}/\mathcal{B}$ as the uniform PAA, The uniform CCAA and the uniform PAA are contrasted in Table 2. in terms of HPBW, SLL, and F/B.

Table 2. A comparison of HPBW, SLL, and $\mathcal{F}/\mathcal{B}$ between the uniform CONAA and the uniform M = 10 CCAA patterns.

Parameter	*Uniform CONAA*	*Uniform CCAA*
HPBW	7.74°	6.3°
SLL	−12.5236dB	−17.5628dB
$\mathcal{F}/\mathcal{B}$	0 dB	0 dB

2- Optimized CONAA.

The O-CONAA will be introduced in this section to address the problems in the preceding section. Consider a CCAA without a central antenna element that consists of (M=10) uniform rings. The innermost ring contains three elements, while each subsequent ring contains six more elements on the outside, The elements are fed uniformly and are arranged around the rings perimeters with uniform interelement spacing$d_{n_m} = \lambda/2$. In this part, the suggested O-CONAA is in comparison with the uniform feeding M = 10 CCAA. In terms of HPBW, SLL, and $\mathcal{F}/\mathcal{B}$, the O-QPAA is compared to the uniform-feeding CCAA.

To begin, the elements of the (M = 10) CCAA are rearranged to construct the proposed O-CONAA. And as a result, an O-CONAA composed of $L = 10$ CAAs with $N_{tot} = 300$ elements is constructed. The number of elements $N_{m=l}$ of the l^{th} CAA, the optimized interelement spacing d_{n_m}, and the optimized vertical CAA spacing d_L are listed in Table 3. The excitation coefficients $I_{(mn)_l}$ remain uniform as the uniform CCAA. While LAA excitations $£_l$ is optimized and the optimum values of it are listed in Table 4.

Table3. The parameters M, L, N_{tot}, d_L, N_m and d_{n_m} of the proposed O-CONAA for a uniform M = 10 CCAA.

M = 10	
L = 10, d_L = 0.8 λ, N_{tot} = 300	
$N_1 = 3$	$d_{n1} = 0.54\,\lambda$
$N_2 = 9$	$d_{n2} = 0.58\lambda$
$N_3 = 15$	$d_{n3} = 0.66\,\lambda$
$N_4 = 21$	$d_{n4} = 0.57\lambda$
$N_5 = 27$	$d_{n5} = 0.55\,\lambda$
$N_6 = 33$	$d_{n6} = 0.65\,\lambda$
$N_7 = 39$	$d_{n7} = 0.56\,\lambda$
$N_8 = 45$	$d_{n8} = 0.51\,\lambda$
$N_9 = 51$	$d_{n9} = 0.54\,\lambda$
$N_{10} = 57$	$d_{n10} = 0.53\,\lambda$

Table4. The optimized excitation coefficients $£_l$ of $L = 10$ LAA elements.

l	$£_l$
1	0.1058∠ − 0.0060
2	0.0831∠ + 0.0040
3	0.0577∠ + 0.0280
4	0.1358∠ − 0.0103
5	0.1428∠ − 0.0315
6	0.1062∠ − 0.0209
7	0.1337∠ + 0.0291
8	0.1137∠ − 0.0160
9	0.0607∠ + 0.0033
10	0.0152∠ + 0.0125

Fig. 6. and Fig. 7 Indicate the rectangular and polar plots of the proposed O-CONAA pattern versus the uniform CCAA pattern.

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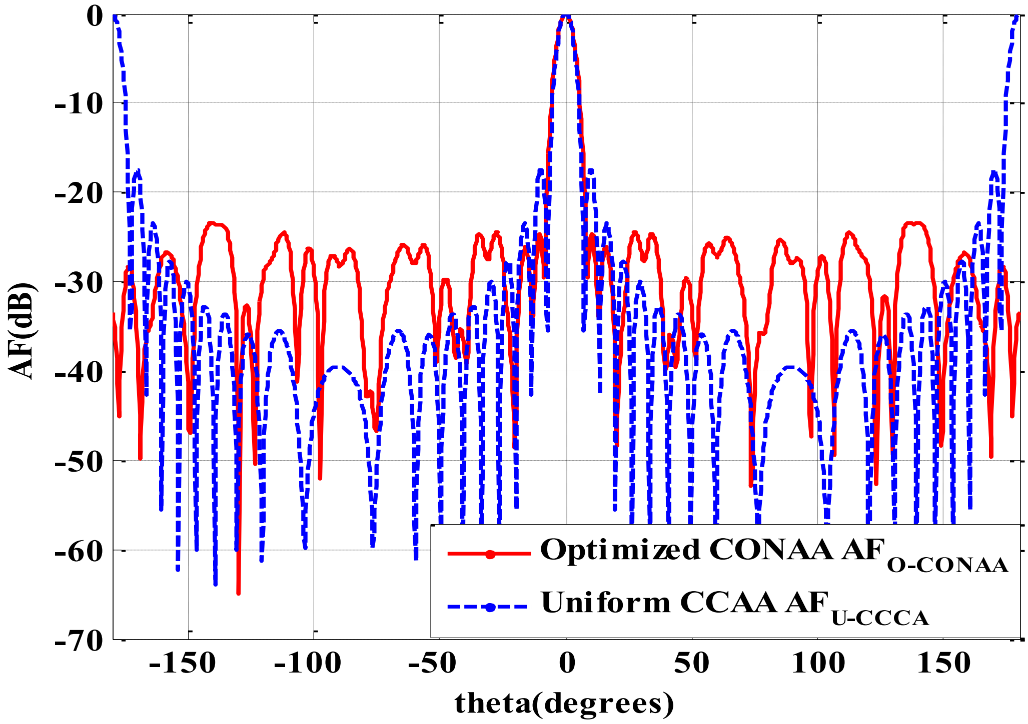

Figure 6. Rectangular plot of the optimized CONAA pattern compared to the uniform (M = 10) CCAA patterns.

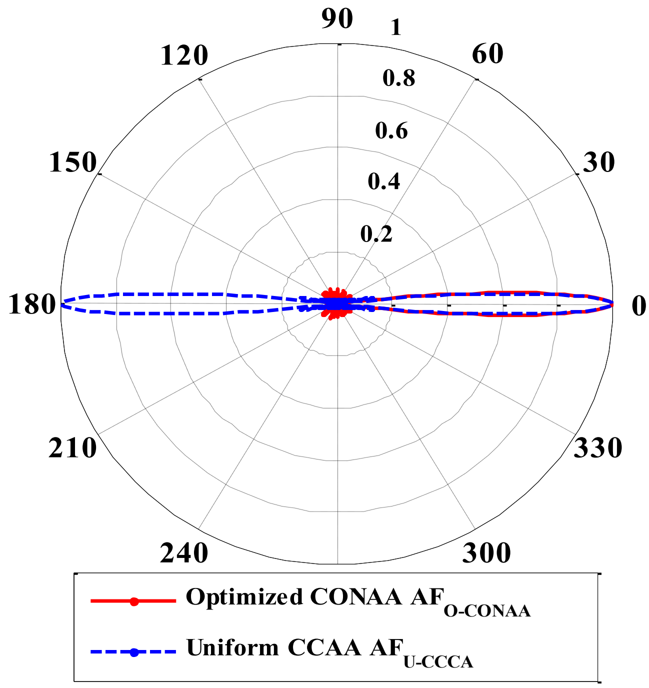

Figure 7. Polar plot of the optimized CONAA pattern compared to the uniform (M = 10) CCAA patterns.

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Analyzing the results reveals that, the O-CONAA gives almost the same HBPW as the uniform CCAA, While, it provides SLL reduction by 6.85 dB if it is compared with the uniform CCAA. Furthermore, the O-CONAA radiation pattern provides very high $\mathcal{F}/\mathcal{B} = 33.53\,dB$ when compared to the uniform CCAA which has $\mathcal{F}/\mathcal{B} = 0\,dB$, which means that the O-CONAA reduces the back lobe by $33.53\,dB$. Table 5. provides a summary of the O-CONAA, uniform CCAA, and uniform CCAA in terms of the key parameters HBPW, SLL, and $\mathcal{F}/\mathcal{B}$.

Table5. A comparison between the O-QPAA, and the uniform (M = 10) CCAA pattern in terms of HPBW, SLL, and $\mathcal{F}/\mathcal{B}$.

Parameter	*O-CONAA*	*Uniform CONAA*	*Uniform CCAA*
HPBW	6.4°	7.74°	6.3°
SLL	−24.4201 dB	−12.5236dB	−17.5628dB
$\mathcal{F}/\mathcal{B}$	33.53 dB	0 dB	0 dB

VI. Conclusion

Firstly, the non-optimized uniform CONAA is proposed in this paper; nevertheless, it delivers a back lobe with the same amplitude as the main beam. Secondly, to solve the back lobe existence problem, the O-CONAA is introduced, which greatly reduces the back lobe of the CONAA and provides a high $\mathcal{F}/\mathcal{B}$, in addition to achieving SLL reduction compared to the uniform CCAA with the same number of antenna elements. The O-CONAA achieves full back lobe cancellation and very high $\mathcal{F}/\mathcal{B}$ ratios in MATLAB simulations. It provides an $\mathcal{F}/\mathcal{B} = 33.53$ dB. While the uniform CCAA provides $\mathcal{F}/\mathcal{B} = 0$ dB.

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Conflicts of Interest: The authors declare no competing interests.

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