LINEAR ARRAY DESIGN USING COMPLEX CURRENT AND IMPROVED PARTICLE SWARM OPTIMIZATION FOR WIMAX APPLICATIONS

[1]NOOR SALEM ALSHDAIFAT, [2]MOHAMMED HUSSEIN BATAINEH

[1,2]Department of Communication. Hijjawi Faculty of Engineering Technology Yarmouk University Irbid, Jordan
E-mail: mohbat@yu.edu.jo

Abstract- In this paper particle swarm optimization (PSO) and an improved particle swarm optimization (IPSO) will search for the optimum solution to achieve the desired requirements, the complex current excitation of each element is used as the optimization factor, with an aim to suppress the side lobe level (SLL), maintain the desired half power beam width (HPBW) with prescribed nulls. This paper also includes a design of a ten inset feed micro strip antenna array at operating frequency (2.5 GHz), which is suitable for WiMAX applications, the array is designed and simulated using a High Frequency Structure Simulator Software HFSS.

Keywords- Linear array;Complex current; PSO; IPSO; SLL suppression; HPBW; Inset feed micro strip antenna; WiMax; HFSS.

I. INTRODUCTION

Wireless communication demands for more directive antenna with higher gain, to minimize the interference from surrounding application [1,2], this necessitate a precise directional antenna to concentrate the energy in the desired direction. To increase the gain one needs to construct array by combining a number of antenna elements in certain geometry, its performance is improved by proper current and/or phase excitation. Recently the optimization for solving antenna synthesis has revived with nature inspired algorithms [3,4], In recent studies, the researchers focus on various types of optimization to synthesis different array geometries [5-7]. In this article the aim is to optimize the phase and the current, so instead of optimizing current by itself and phase by itself the complex current is optimized in order to optimize current and phase at the same time in one step. In theory when dealing with array elements they are assumed to be isolated, i.e., there is no effect of the elements on each other [8], but in practice this is not true because the elements will receive some portion of the energy radiated by nearby elements in the array which is called mutual coupling, as a result the current and the input impedance of each element will be affected, some studies on linear array for the effect of mutual coupling have been presented [9,10]. In this paper the case of active array will be designed in HFSS [11], where each element has its own separate generator, this will result in reducing the coupling caused by feeding networks, and the degradation in the radiation pattern is caused only by interaction of the complex current excitation of the array elements.

II. CHEBYSHEV DISTRIBUTIONS FOR LINEAR ANTENNA ARRAY SYNTHESIS

A uniform linear array antenna as shown in Figure 1 lies in the x-axis with equal spacing between elements d is considered. Figure 1 illustrate the array configuration for even or odd number of elements uniformly spaced along the x-axis.

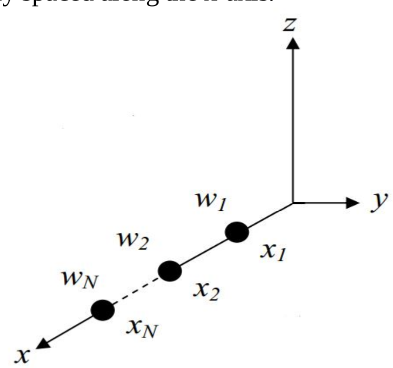

Fig 1. Asymmetric uniformly spaced, x-axis linear array for N number of elements.

For identical isotropic elements with equal spacing (d) between the elements and a uniform phase excitation β between array elements the normalized far field radiation pattern for any number of elements N is given by [12]

$$AF(\theta,\phi) = \sum_{n=1}^{N} w_n e^{jn(kd\sin\theta+\beta)} \quad (1)$$

Where w_n is the complex weight of the n^{th} element, k is the wave number $= \frac{2\pi}{\lambda}$, λ is the wavelength, d is the spacing between array elements measured in terms of wavelength, θ is the elevation angle, $0^\circ \le \theta \le 180^\circ$, and β is the phase excitation.

The next step in the design process is to formulate the objective function. The fitness function is formulated such that the maximum peaks of the SLL of the obtained array factor are restricted not to exceed a predefined level (ζ), this fitness function may provide the solution to have the desired SLL but it may affect the desired HPBW [13], so the difference between the desired beamwidth (BW_d) and the obtained one (BW) is calculated, and it set nulls in the interference angles θ_n and make them equal to (q) a desired null depth

$$\text{Cost function} = \sum_m (AF(\theta_{msl}) - \zeta)^2 + (BW - BW_d)^2 + \sum_n (AF(\theta_n) - q)^2 \quad (2)$$

m is the number of the SLL peaks and θ_{msl} is the angles at these local maxima of the AF and θ_n is the angles of the nulls, BW_d is calculated using a formula given by Safaai-Jazi [14] where he found a relation between the number of elements, SLL, and the smallest HPBW is given, this formula is used to find the minimum HPBW.

III. PARTICLE SWARM OPTIMIZATION & IMPROVED PARTICLE SWARM OPTIMIZATION

Particle swarm optimization (PSO) [15] is a robust heuristic multidimensional global optimization method, which is based on swarm intelligence. PSO starts by randomly distributing the agents within the search space, then evaluating the fitness of each agent using the fitness function where each particle knows its best value (p_{best}), and each particle knows the best value so far in the entire group (g_{best}) among all p_{best}. After that each particle tries to modify its position based on the distance between the current position and p_{best} and the distance between the current position and g_{best}. Figure 2 summarizes the steps used in PSO and IPSO algorithms.

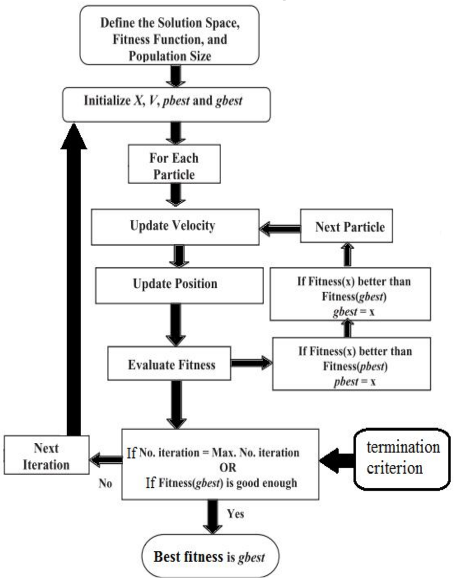

Fig 2. Flow chart of PSO and IPSO algorithm.

Improved particle swarm optimization [16] is a modification to the original PSO to enhance its searching ability; it has the same strong features of PSO but has a better searching procedure which consequently makes the algorithm converges faster.

IV. SIMULATION RESULTS

A. Linear Antenna Array Design using IPSO

Example 1: linear array with N=10 element and uniform spacing of d=0.5λ is considered, the desired SLL is - 40dB with a HPBW of 14.5°, and two nulls are placed at $\theta_{n1} = -30^{\circ}, \theta_{n2} = 30^{\circ}$, the cost function of Eq.(2) is used. The improved particle swarm was implemented using MATLAB where the design parameters used for 10 element linear array for PSO and IPSO algorithm are presented in Table 1.

TABLE 1 PSO and IPSO design parameter for symmetric linear array

Symbol	*Quantity*	*Value*
N	Number of elements	10
P_{size}	Number of particles	100
$iter_{max}$	Number of iteration	250

Table 2 summarizes the optimized asymmetric complex current using IPSO and PSO. The results are shown in Figure 3 and Figure 4 for the radiation pattern resulting from IPSO and PSO respectively, the average fitness (mean value of p_{best} in red line) and the fitness (g_{best} in blue line) of each iteration for IPSO and PSO are illustrated in Figure 5 and figure 6. In Table 2 the magnitude of the current is set in the first and second row while the phase in degree is set in the third and fourth row, the magnitude of the current and the phase are ordered such that the symmetric elements around the origin are on top of each other to make it easier to compare their values.

TABLE 2 Magnitude and phase of asymmetric complex current excitation of λ/2-spacing for 10 element linear antenna array synthesis with predefined nulls using IPSO and PSO (the desired SLL=-40dB and the desired HPBW= 14.5°, with two nulls at $-30^{\circ}, 30^{\circ}$).

Algorithm	*SLL*	*Null Angle*	*Null depth*	*HPBW*	*Magnitude and phase of current excitation*				
					w_5	w_4	w_3	w_2	w_1
					w_6	w_7	w_8	w_9	w_{10}
					β_5	β_4	β_3	β_2	β_1
					β_6	β_7	β_8	β_9	β_{10}
IPSO	-40dB	-30°	-97dB	13.2°	7.69	6.27	4.22	2.13	0.78
					7.82	6.73	4.65	2.51	1
		30°	-63dB		38.1	35.4	33.8	29.7	22.7
					40.5	42.2	44.1	45.6	49.6
PSO	-40dB	-30°	-71dB	14.8°	10.61	9.07	6.25	3.43	1.34
					10.26	8.40	5.63	2.70	1
		30°	-84dB		39.1	39.7	39.9	40.5	40.2
					38.4	37.6	36.5	35.7	34.1

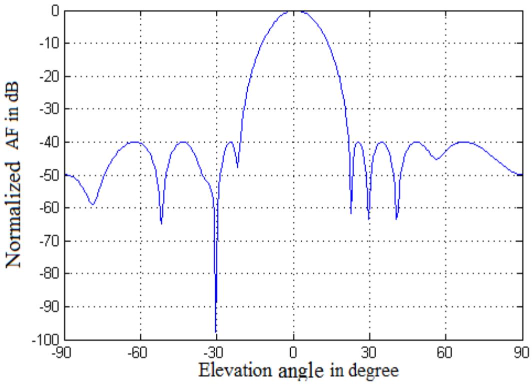

Fig. 3. Synthesized radiation pattern of 10-element array synthesized using IPSO for asymmetric current with two nulls at $-30^{\circ}, 30^{\circ}$

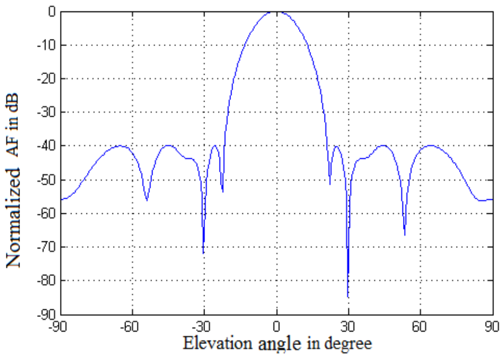

Fig. 4. Synthesized radiation pattern of 10-element array synthesized using PSO for asymmetric current with two nulls at $-30^{\circ}, 30^{\circ}$

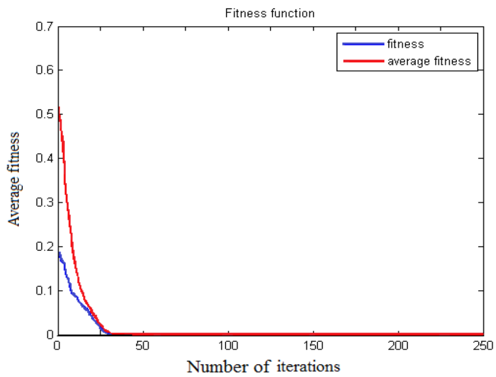

Fig. 5. The average fitness of the global best value for each iteration using IPSO

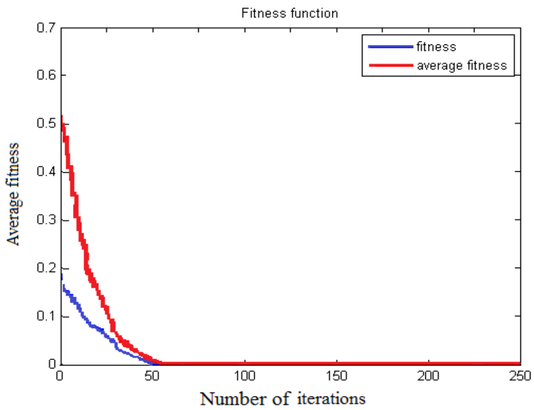

Fig. 6. The average fitness of the global best value for each iteration using PSO

It can be seen that both PSO and IPSO achieve the desired SLL, the nulls are also located at the desired angles with deep nulls for both algorithms, in term of HPBW, IPSO outperform PSO where the HPBW of IPSO is 13.2° which is less than desired, where PSO HPBW is 14.8° which is higher than desired, FNBW for both PSO and IPSO is almost identical.

For PSO and IPSO it can be seen from Figure 5and Figure 6 respectively that IPSO algorithm converges faster than PSO with a good value of 31 iterations, where PSO algorithm reaches its steady state and converges after about 52 iterations.

From Table 2 it can be seen that the current magnitude of the opposite elements about the center of the array are close for both algorithms, but it can be seen that IPSO achieves the desired requirement with current magnitude very close to Chebyshev, PSO also has a good current magnitude but its higher than Chebyshev.

B. Antenna Array Design in HFSS

The array structure is constructed using a High Frequency Structure Simulator software HFSS [11], it is an electromagnetic simulator based on the Finite Element Method (FEM) [17], which is based on adaptive meshing, HFSS is used to analyze various characteristic of the 3D electromagnetic structures. HFSS is going to be used here to verify IPSO results, and analyze the array structure and observe the effect of the single inset feed element on the total array factor.

1) Single Element Design and Simulation Results

In this work a rectangular inset feed microstrip patch antenna similar to that proposed one in [18] is used, the designed antenna is shown in Figure 7 its suitable for Wifi and WiMAX applications, it consists of a rectangular patch printed on Rogers RT/duroid 5880(tm) substrate and 0.0009 loss tangent, the design parameters are listed in Table 3.

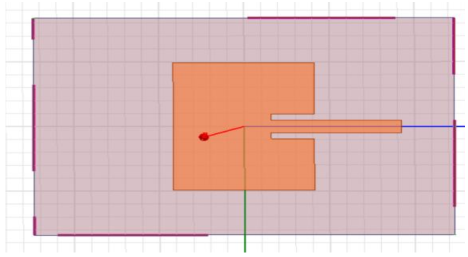

Fig 7. Structure of the proposed microstrip inset feed rectangular patch antenna.

TABLE 3 MEASUREMENT FOR THE INSET FEED RECTANGULAR PATCH ANTENNA

Parameters	*Units*
Operating Frequency	2.4835 GHz
Ground plane length (L × W)	11.92 cm
Patch Length	3.99 cm
Inset Distance	1.22 cm

Feed Length	3.68 cm
Dielectric Substrate height	62 mil
Ground plane width	8.1 cm
Patch Width	4.77 cm
Inset gap	0.243 cm
Feed width	0.486 cm

The simulated 3D gain, the 2D radiation pattern and reflection coefficient of the proposed antenna are shown in Figure 8, and Figure 9 and Figure 10 respectively, the gain is about 7.8dB and the reflection coefficient at resonant is about -25dB which is better than the original design in [18].

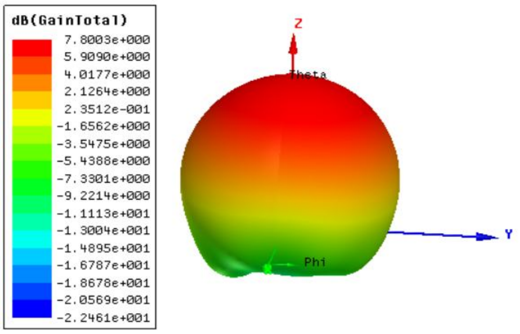

Fig 8. 3D gain of the radiation pattern.

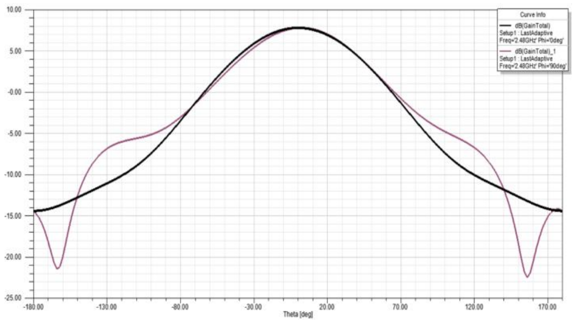

Fig 9. 2D Radiation Pattern.

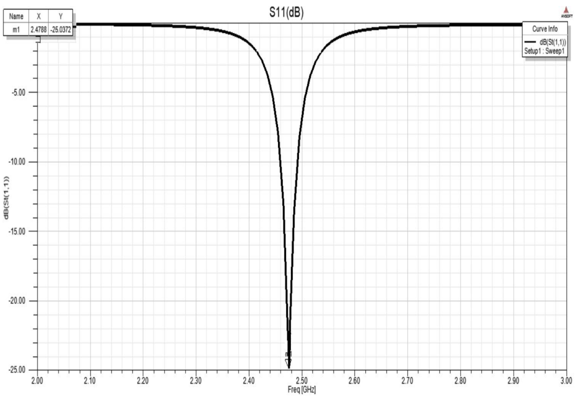

Fig 10. Variation of Reflection coefficient (S_{11}) in dB with frequency

2) Linear Array Design and Simulation Results

First a 10×1 linear array uniformly spaced with d=0.5λ is constructed as shown in Figure 11, where λ is the wavelength in free space. The current values returned by IPSO will be used since the resulting radiation pattern from the optimized current using IPSO achieves the desired requirements, and the magnitude of IPSO optimized current has lower magnitude which is more desirable.

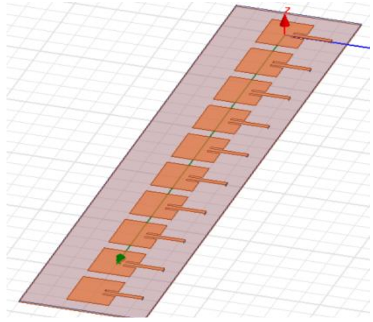

Fig. 11. Structure of 10×1 rectangular microstrip linear array antenna.

Example 1: a 10×1 linear array with asymmetric optimized complex current excitation using IPSO is considered, the current values are in Table 2 and the result array factor is shown in Figure 3, the spacing is uniform with d=0.5λ, the requirements for this antenna are a SLL of -40dB with a HPBW of 14.4° and two nulls at $-30^{\circ}, 30^{\circ}$.

Figure 12 and Figure 13 shows the resulting 3D and 2D radiation pattern in HFSS, reflection coefficient for the 10 elements and the scattering parameter between each two adjacent elements are illustrated in Figure 14 and Figure 15. The scattering parameter between each two adjacent elements is considered since it is known that the mutual coupling is maximum between the adjacent elements.

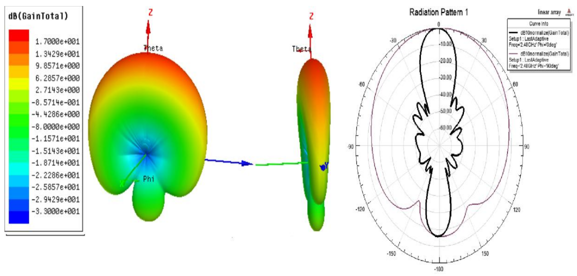

Fig 12. 3D gain and polar plot of the radiation pattern for the optimized 10×1 linear array using asymmetric complex current excitation with d=0.5λ.

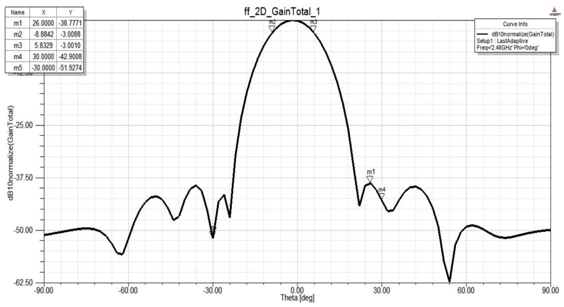

Fig 13. 2D Radiation Pattern of 10×1 optimized linear array with d=0.5λ.

The new gain is 15.16dB so the gain has increased by 7.4 dB, when comparing the HFSS radiation pattern in

Figure 13 to the one obtained in Figure 3 it can be seen that the maximum SLL is -38.7dB so it does not match the one obtained in Table 2, the HPBW in Table 2 is 13.2° which is better than desired but the one obtained in HFSS is 14.6° so the HPBW increased by 1.4° from the designed one, the nulls are placed at the desired angles with -43dB at $\theta_n = 30^{\circ}$ and a -52 dB null depth at $\theta_n = -30^{\circ}$, but still the depth of the nulls is shallower than the one obtained in Table 2, but the overall result is satisfying.

The reflection coefficients have been reduced for all elements by almost 6dB when compared to the single element, which is very close to the reflection coefficient of the same array when the current is uniform [2]. However, it is shown that when using real current excitation the reflection coefficient has been reduced for all elements by almost 11dB when compared to the single element [2], therefore when using complex current excitation (magnitude and phase) the mutual coupling caused by the current excitation is significantly reduced.

The new values of the reflection coefficients at resonance varies between -18.9 dB ($S_{1,1}$) to -21.6 dB ($S_{8,8}$), while the scattering parameter for every two adjacent elements is maximum at resonance which is about -12.35 dB.

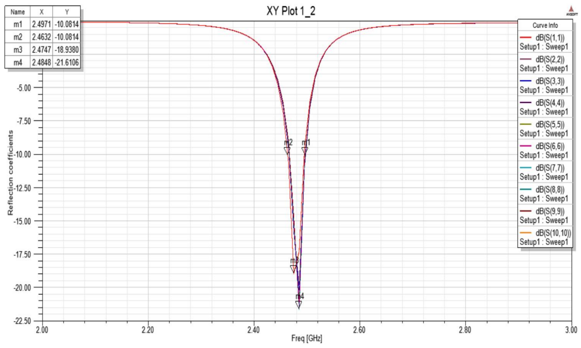

Fig 14. Variation of reflection coefficients of the 10 elements optimized linear array with frequency

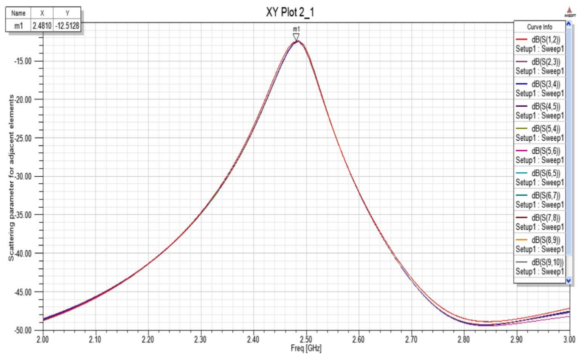

Fig 15. Variation of the scattering parameter for adjacent elements of the 10 elements optimized linear array with frequency

CONCLUSIONS

In this work, IPSO has been used to optimize linear array antenna, it has proven its efficiency in multi-objective optimization to find the optimum value for the desired properties, and this is done by adjusting the complex current excitation. A linear microstrip line antenna array is constructed in HFSS, the current excitations fed to the array elements are changed to the optimized value, the mutual coupling between elements is observed, and it has been found that using complex current excitation considerably reduce the mutual coupling caused by current interaction between array elements.

The resulting radiation pattern in HFSS agree well with the one found by IPSO algorithms, this is due to the fact that the shape of the radiation pattern of the single element of the inset feed microstrip patch is almost isotropic near the main beam and decrease gradually as we move toward the edges of the radiation pattern, therefore even if the array factor has higher SLL at the edges the total radiation pattern will not be affected and these higher SLL will be suppressed.

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