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Synthesis of Linear Dipole Antenna Arrays with Mutual Coupling Effect Using Novel Particle Swarm Optimization Algorithm

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ABSTRACT
In this paper the synthesis of linear antenna array geometry with mutual coupling effect is considered to minimize Side-Lobe Level (SLL) using a new class of Particle Swarm Optimization technique i.e. Novel Particle Swarm Optimization (NPSO). The NPSO algorithm is a high-performance evolutionary algorithm capable of solving general N-dimensional, linear and nonlinear optimization problems. The array geometry synthesis is first formulated as an optimization problem with the goal of SLL suppression, and then solved by the NPSO algorithm for the optimum element locations and current excitations first without taking into the mutual coupling effect and in the second case without mutual coupling. The current excitations considering the mutual coupling effect can be calculated using simple mutual impedance matrix transformation. Design examples are presented that demonstrate the use of the NPSO algorithm in these two cases. Finally, it can be observed that due to the mutual coupling effect the pattern gets distorted but as far as the performance criteria of optimization is concerned, it does not changes.

KEYWORDS: First null beam-width, Linear antenna array, Mutual coupling, Novel particle swarm optimization, Side-lobe Level.

INTRODUCTION

The Antenna Array consists of an arrangement of radiating antenna elements in a specific configuration. Generally each of the antenna elements in the antenna arrays is identical to each other. The Total far field pattern of the array antennas can be found by vectorially summing the radiating fields of each of the antenna elements. There are usually five parameters in an antenna array which needs to be controlled to form the radiation pattern in an efficient way and, they are, the geometrical shape of the overall array (linear, rectangular, circular, planar etc.), relative separation between antenna elements, excitation amplitude of each of the antenna elements, excitation phase of each antenna elements, and radiation pattern of each of the antenna elements [1]. In various fields like communication engineering a highly directional antenna is needed [2]. Antenna arrays can fulfill these criteria and can provide us high gain and directivity [3]. A linear antenna array is one in which antenna elements are placed along a straight line and there is a fixed separation between antenna elements. The main aim in an antenna array design is to define the physical structure of the array that yields the radiation pattern that is very close to the desired radiation pattern. Here our design aim will be to reduce the SLL with respect to the main beam for a half wavelength linear dipole antenna array. This can be performed by designing the required separation between the antenna elements and also the non-uniform excitations over the antenna array aperture [4-6]. Our aim can be accomplished with an innovative kind of Particle Swarm Optimization i.e.

the Novel Particle Swarm Optimization algorithm [9]. It is also observed that the performance of NPSO does not get degraded when the antenna array is operating under the mutual coupling environment. The performance parameter i.e. the SLL and BWFN does not change due to the mutual coupling effect. Arrangement of the paper: in section II, the theory part is included which include the design equations for the arrays and the details about NPSO algorithm and the method to model the mutual coupling effect. In section III, simulation results are given. In section IV conclusion of whole work is described.

II. Theory:

2.1. Design equation for linear antenna array:

Linear antenna arrays are the one where the antenna elements are located along a straight line and which may have uniform or non-uniform separation. If all the antenna elements are considered to be half wavelength dipoles, then the total radiation pattern of this symmetric linear dipole antenna array can be written with the help of pattern multiplication theorem [1] as follows:

$$TAF(\theta, I) = 2\sum_{n=1}^{N} I_n \cos\left[\frac{(2n-1)}{2} \times kd\cos\theta\right] \frac{\cos(0.5\pi\cos\theta)}{\sin\theta} \tag{1}$$

where I_n symbolizes current excitation of the n[th] antenna element, $K = 2\pi/\lambda$ is the phase constant; d is the inter element spacing, λ is the wave-length of the signal, and θ is the angle from the positive z axis to the orthogonal projection on the point of observation.

Now as we have defined the total array factor, the next stage will be to formulate the objective function which is required to be minimized. The objective function Misfitness (MFT) will be:

$$MFT = \frac{|TAF(\theta_{nsl1}, I_m) + TAF(\theta_{nsl2}, I_n)|}{|TAF(\theta_0, I_n)|} + |BWFN_{desired} - BWFN(I_n = 1)| \tag{2}$$

BWFN stands for first null beamwidth or simply it can be stated as the angular separation between the first nulls of the main beam. θ_0 is the angle in $\theta \in [0, \pi]$ at which the maximum of central lobe is achieved. θ_{nsl1} and θ_{nsl2} are the angles where the maximum side-lobe are achieved in the lower and upper bands, respectively. $BWFN_{desired}$ refers to the calculated first null beam width (in radians) for the non-uniform excitation case and $BWFN(I_n = 1)$ refers to the calculated first null beamwidth (in radians) for uniform excitation. The minimization of MFT means that there should be maximum suppressions of SLL.

2.2. Novel particle swarm optimization algorithm:

The Particle Swarm Optimization (PSO), unlike customary optimization methods is a flexible and robust population-based optimization technique with implicit parallelism, which can comfortably handle non-differential objective functions. Eberhart and Shi as can be seen in [7] established the PSO concept which is said to be similar to the behavior of the swarm of birds.

Velocities of the particles are adjusted with the help of following equation:

$$V_i^{(n+1)} = w * V_i^n + c_1 * r_1 * (pbest_i - S_i^n) + c_2 * r_2 * (gbest - S_i^n) \tag{3}$$

where V_i^n is velocity of the i[th] particle at the n[th] iteration; c_j is the weighting factor; w is the weighting function; S_i^n is the current position of particle i at iteration n; r_i is a random number between 0 and 1; $pbest_i$ represents the personal best of the particle i; *gbest* represents the group best among all the *pbests* of the group. In the solution space, the searching point can be adjusted using the following equation:

$$S_i^{n+1} = S_i^n + V_i^{n+1} \tag{4}$$

1st term in (3) represents the previous velocity of the particle and the 2nd and 3rd terms are required in changing the velocity of the particle. If the 2nd and 3rd terms are not present, the particle will continue flying in the same direction until it collides with the boundary. To be precise, it resembles a sort of inertia and attempts to search for new areas. If we perform the following changes then the global search ability of traditional PSO is very much improved. This modified PSO can be termed as NPSO as observed in [9]:

a) 2 random parameters r_1 and r_2 of equation (3) are independent. When both become large, both the personal and social experiences is supposed to be over used and the particle will be driven too far away with respect to the local optimum. When both become small, both the personal and social experiences will not be used fully and also the convergence speed of this technique will be reduced. Hence, instead of taking r_1 and r_2 which are independent, we choose a single random number r_3 so that will correspond to the situation that when r_3 will be large, $(1-r_3)$ will be small and vice-versa. Furthermore, to regulate the balance of global and the local searches, a different random parameter r_4 is presented. There could be some rare cases for the birds flocking for food that after the location of the particle is changed in accordance with (3), a bird may not fly towards a region at which it thinks is most hopeful for food. Instead, it may lead to a region which is in reverse direction of what it should fly in order to reach the expected promising regions. Thus, the direction of the bird's velocity must be reversed so that it may fly back into the promising region. $sign(r_5)$ is presented for this purpose..

b) Now, a new variation in the velocity expression of (3) can be done by dividing the cognitive component into 2 different parts. The 1st part will be called- the good experience component which characterizes the particle's memory about its formerly visited best position. Next, the 2nd part is the bad experience component which aids the particle to remember its formerly visited worst position. Using the bad experience component, the particle can dodge its previous worst position and will try to dwell in a better position.

Ultimately, with all the modifications in hand, the modified velocity of jth component of ith particle can be expressed as follows:

$$V_i^{(n+1)} = r_4 * sign(r_5) * V_i^n + (1-r_4) * c_1 * r_3 * \{pbest_i^n - S_i^n\} + (1-r_4) * c_2 * (1-r_3) * \{gbest^n - S_i^n\} + (1-r_4) * c_1 * r_3 (S_i^n - pworst_i^n) \quad (5)$$

where $sign(r_5)$ represents a function defined by:

$sign(r_5) = -1$ where $r_5 \le 0.05$

$= 1$ where $r_5 > 0.05$

V_i^n represents the velocity of the ith particle at nth iteration; S_i^k symbolizes the present position of particle i at iteration n; r_3, r_4 and r_5 represents the random numbers in between 0 and 1; $gbest^n$ represents the group best amongst all the pbests for the group. $pbest_i^n$ and $pworst_i^n$ represents the personal best and the personal worst of particle *i* respectively. Searching point in the space is changed according to equation (4) only.

2.3. Analysis of mutual coupling:

The mutual coupling effect in an antenna array can be modelled just by knowing the mutual impedances between the elements in an antenna array as can be found in [11]. This can be observed with the help of following matrix equation:

$$\begin{bmatrix} I_1 \\ I_2 \\ \vdots \\ I_N \end{bmatrix} = \begin{bmatrix} 1 & \frac{z_{12}}{z_c} & \cdots & \frac{z_{1N}}{z_c} \\ \frac{z_{21}}{z_c} & 1 & \cdots & \vdots \\ \vdots & \vdots & \ddots & \vdots \\ \frac{z_{N1}}{z_c} & \cdots & \cdots & 1 \end{bmatrix} \begin{bmatrix} I_{m1} \\ I_{m2} \\ \vdots \\ I_{mN} \end{bmatrix} \quad (6)$$

Which can also be represented in short as $\boldsymbol{I} = \boldsymbol{Z} \times \boldsymbol{I_m}$ where $\boldsymbol{I}$ is the normal currents without considering the mutual coupling effect and $\boldsymbol{I_m}$ is the current vector for N-element array considering the mutual coupling effect. If $\boldsymbol{I}$ is known one can get $\boldsymbol{I_m}$ by just a matrix inverse operation as $\boldsymbol{I_m} = \boldsymbol{Z^{-1}} \times \boldsymbol{I}$.

Here $Z_c = Z + Z_g$ where Z_g is the generator impedance taken as 50 Ω here and $Z = Z_{11} = Z_{22} = \ldots\ldots = Z_{NN}$ are the self-impedances of antenna elements.

Calculation of mutual Impedances for wire antennas is done using induced EMF method [1].

III. Simulation and results:

This section provides the results for various sets of linear array designs acquired using NPSO methods both with and without mutual coupling effect. Table 1, 3, 5 & 7 shows the excitations and the performance parameters i.e. the SLL and BWFN for antenna arrays containing 12, 16, 20 and 24 elements respectively without considering the mutual coupling effect. Table 2, 4, 6 & 8 shows the excitations and the performance parameters i.e. the SLL and BWFN for antenna arrays containing 12, 16, 20 and 24 elements respectively but with considering the mutual coupling effect. These excitations for mutual coupling considerations are obtained using equation 6.The results that are acquired prove to be quite satisfactory. The NPSO technique has very quickly converged to correct optimal solutions. It can be seen that in each of the tables without considering the mutual coupling effect, the first row contains uniform excitation for λ/2 spacing, the second row contains non-uniform excitations with fixed separation of λ/2 and the third row represents the antenna array with both non-uniform optimal excitations and also optimal spacing for $\left(d \in \left[\frac{\lambda}{2}, \lambda\right]\right)$. The BWFN and SLL verify that there is really no effect of mutual coupling on performance parameters of NPSO algorithm although the pattern suffers from distortion. Fig. 1 and Fig. 3 depict the radiation patterns obtained for 12 and 16 element arrays without mutual coupling effect respectively. Fig. 2 and Fig. 4 depict the radiation patterns obtained for 12 and 16 element arrays respectively with mutual coupling effect. It is seen from figs. 1 and 3 that the SLL reduction is more for non-uniform excitation with optimal spacing than the one which has non-uniform excitation with spacing of λ/2. Also it is observed that the SLL suppression is also better for non-uniform current excitation than the uniform current spacing with separation of λ/2. For example from fig. 1 one can see that when non-uniform excitation is considered SLL reduces to -19.43 dB from -13.43 dB .It further reduces to -35.42 dB for non-uniform excitation with optimal separation. Similar scenario is observed for fig.2

From fig. 2 it can be seen that the SLL and BWFN does not change with respect to fig. 1 which proves that the radiation pattern under mutual coupling effect just distorts the radiation pattern but does not affect the performance of optimization algorithm. Similar situation can be compared for fig.3 and 4.

Table 1: Current excitations, BWFN and SLL for 12 element linear array without mutual coupling

Spacing(d)	($I_1, I_2, \ldots\ldots I_6$); Current Excitations	BWFN (in deg.)	SLL (in dB)
λ/2	Uniform	19.44	-13.43
λ/2	0.8347, 0.7939, 0.7155, 0.6016, 0.4820, 0.6583	21.60	-19.43
0.8122*λ	0.7915, 0.7123, 0.5708, 0.4032, 0.2420, 0.1289	20.20	-35.42

Table 2: Current excitations, BWFN and SLL for 12 element linear arrays with mutual coupling effect

Spacing(d)	($I_{m1}, I_{m2}, \ldots\ldots I_{m6}$); Current excitations	BWFN (in deg.)	SLL (in dB)
λ/2	1.2035 + 0.3659i, 1.1959 + 0.3608i, 1.2129 + 0.3728i, 1.1820 + 0.3483i, 1.2393 + 0.4036i, 1.1043 + 0.2101i	19.44	-13.43
λ/2	1.0031 + 0.3026i, 0.9467 + 0.2835i, 0.8695 + 0.2660i, 0.7011 + 0.2015i, 0.6305 + 0.2343i, 0.7063 + 0.1131i	21.60	-19.43
0.8122*λ	1.0409 - 0.2160i, 0.9399 - 0.1938i, 0.7583 - 0.1545i, 0.5393 - 0.1058i, 0.3259 - 0.0584i, 0.1701 - 0.0136i	20.20	-35.42

Table 3: Current Excitations, BWFN and SLL for 16 element arrays without the mutual coupling effect.

Spacing(d)	($I_1, I_2, \ldots\ldots I_8$); Current Excitations	BWFN (in deg.)	SLL (in dB)
λ/2	Uniform	14.40	-13.36
λ/2	0.7025, 0.7566, 0.5995, 0.6597, 0.5381, 0.3959, 0.5166, 0.6005	15.48	-18.94
0.8311*λ	0.8090, 0.7575, 0.6674, 0.5529, 0.4274, 0.2977, 0.1805, 0.1222	14.76	-36.55

Table 4: Current Excitations, BWFN and SLL for 16 element arrays with mutual coupling effect.

Spacing(d)	($I_{m1}, I_{m2}, \ldots\ldots I_{m8}$); Current Excitations	BWFN (in deg.)	SLL (in dB)
λ/2	1.2027 + 0.3652i, 1.1987 + 0.3630i, 1.2071 + 0.3678i,1.1932 + 0.3594i, 1.2150 + 0.3738i, 1.1803 + 0.3474i, 1.2408 + 0.4044i, 1.1029 + 0.2091i	14.40	-13.36
λ/2	0.8514 + 0.2642i, 0.8874 + 0.2500i, 0.7460 + 0.2477i, 0.7708 + 0.2166i, 0.6546 + 0.2001i, 0.4790 + 0.1579i, 0.6395 + 0.2063i, 0.6584 + 0.1190i	15.48	-18.94
0.8311*λ	1.0434 - 0.2538i, 0.9808 - 0.2371i, 0.8683 - 0.2072i, 0.7214 - 0.1698i, 0.5576 - 0.1292i, 0.3898 - 0.0897i, 0.2389 - 0.0551i, 0.1531 - 0.0153i	14.76	-36.55

Table 5: Current Excitations, BWFN and SLL for 20 element arrays without the mutual coupling effect.

Spacing(d)	($I_1, I_2, \ldots\ldots I_{10}$); Current Excitations	BWFN (in deg.)	SLL (in dB)
λ/2	Uniform	10.80	-13.34
λ/2	0.8486 , 0.7795, 0.6880, 0.6148, 0.6683, 0.6432, 0.5263, 0.4628, 0.3148, 0.6404	13.68	-20.84
0.8990*λ	0.8795, 0.8478, 0.7735, 0.6776, 0.5792, 0.4606, 0.3378, 0.2424, 0.1478, 0.1046	11.52	-37.91

Table 6: Current Excitations, BWFN and SLL for 20 element arrays with the mutual coupling effect.

Spacing(d)	($I_{m1}, I_{m2}, \ldots\ldots I_{m10}$);Current Excitations	BWFN (in deg.)	SLL (in dB)

λ/2	1.2023 + 0.3649i, 1.2000 + 0.3638i, 1.2048 + 0.3662i, 1.1970 + 0.3622i, 1.2085 + 0.3685i, 1.1919 + 0.3588i, 1.2160 + 0.3743i, 1.1794 + 0.3470i, 1.2427 + 0.4051i, 1.1033 + 0.2088i	10.80	-13.34
λ/2	1.0170 + 0.3044i, 0.9347 + 0.2826i, 0.8290 + 0.2519i, 0.7425 + 0.2343i, 0.8057 + 0.2399i,0.7554 + 0.2203i, 0.6568 + 0.2103i, 0.5180 + 0.1362i, 0.4519 + 0.1965i, 0.6674 + 0.0874i	13.68	-20.84
0.8990*λ	0.9884 - 0.4117i, 0.9534 - 0.3935i, 0.8732 - 0.3615i, 0.7674 - 0.3166i, 0.6575 - 0.2614i, 0.5265 - 0.2046i, 0.3916 - 0.1498i, 0.2838 - 0.0969i, 0.1776 - 0.0565i, 0.1250 - 0.0160i	11.52	-37.91

Table 7: Current Excitations, BWFN and SLL for 24 element arrays without the mutual coupling effect.

Spacing(d)	(I_1, I_2, ……I_{24}); Current Excitations	BWFN (in deg.)	SLL (in dB)
λ/2	Uniform	10.08	-13.31
λ/2	0.8293, 0.7469, 0.7575, 0.8936, 0.5784, 0.6285, 0.6711, 0.5199, 0.4227, 0.4819, 0.4029, 0.6935	10.80	-21.17
0.9074*λ	0.8279, 0.8203, 0.7479, 0.6887, 0.5802, 0.4801, 0.3998, 0.2927, 0.2107, 0.1392, 0.0834, 0.0259	10.44	-40.85

Table 8: Current Excitations, BWFN and SLL for 24 element arrays with the mutual coupling effect.

Spacing(d)	(I_{m1}, I_{m2}, ……I_{m6}); Current Excitations	BWFN (in deg.)	SLL (in dB)
λ/2	1.2021 + 0.3648i, 1.2006 + 0.3641i, 1.2037 + 0.3655i, 1.1988 + 0.3633i, 1.2058 + 0.3667i, 1.1962 + 0.3619i, 1.2103 + 0.3690i, 1.1925 + 0.3589i, 1.2177 + 0.3750i, 1.1800 + 0.3477i, 1.2438 + 0.4064i, 1.1035 + 0.2093i	10.08	-13.31
λ/2	0.9938 + 0.2963i, 0.8958 + 0.2762i, 0.9325 + 0.2974i, 1.0280 + 0.2731i, 0.7365 + 0.2559i, 0.7383 + 0.2194i, 0.8100 + 0.2341i, 0.6122 + 0.1869i, 0.5407 + 0.1815i, 0.5359 + 0.1382i, 0.5550 + 0.2222i, 0.7292 + 0.1035i	10.80	-21.17
0.9074*λ	0.9087 - 0.4052i, 0.8987 - 0.3881i, 0.8230 - 0.3658i, 0.7592 - 0.3246i, 0.6453 - 0.2826i, 0.5381 - 0.2341i, 0.4493 - 0.1819i, 0.3341 - 0.1378i, 0.2444 - 0.0948i, 0.1656 - 0.0596i, 0.1038 - 0.0307i, 0.0417 - 0.0123i	10.44	-40.85

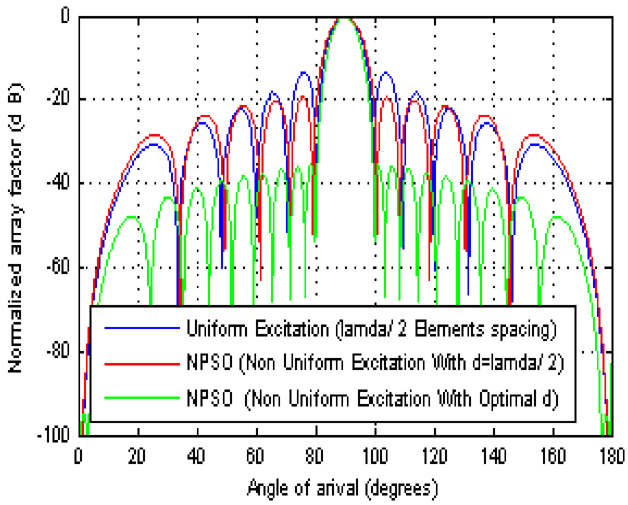

Fig. 1: Radiation Pattern of 12 element half wavelength dipole antenna arrays without mutual coupling effect.

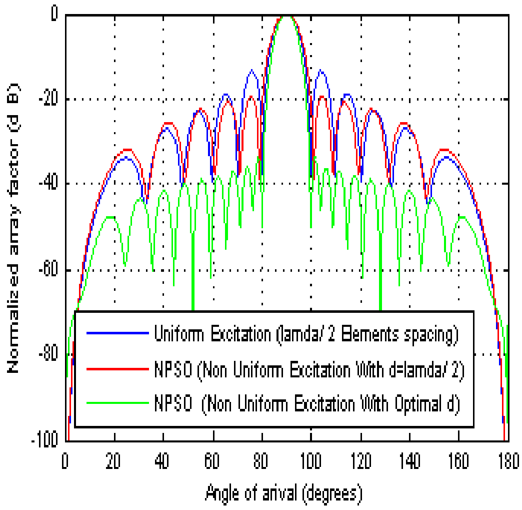

Fig. 2: Radiation pattern of 12 element half wavelength dipole antenna arrays with mutual coupling effect.

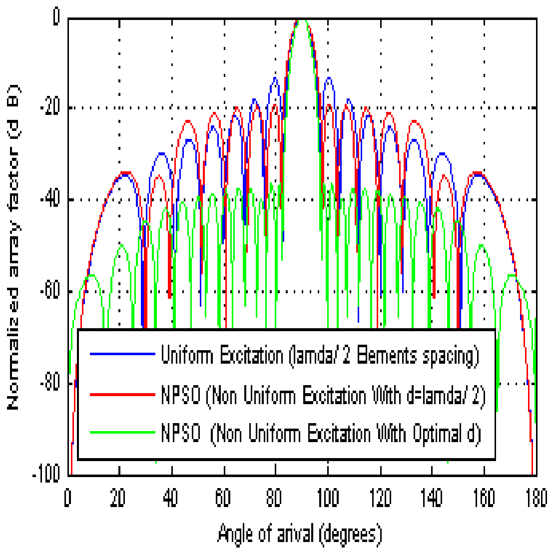

Fig. 3: Radiation Pattern of 16 element half wavelength dipole antenna arrays without including mutual coupling effect.

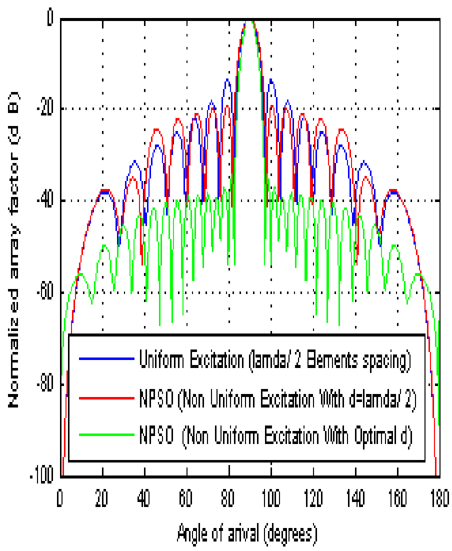

Fig. 4: Radiation Pattern of 16 element half wavelength dipole antenna arrays including mutual coupling effect.

Conclusions:

This paper investigates the design of a non-uniformly excited half wavelength symmetric linear dipole antenna array with and without mutual coupling effect using NPSO. This has shown that we are successful in suppressing the side-lobe levels first using optimized uniform excitation with fixed separation of λ/2 and after that the SLL is suppressed even more if the separation is also optimized in addition to the optimal excitations. This has been shown for both the cases considering with and without mutual coupling. Although the pattern gets distorted when we consider the mutual coupling environment but the performance criteria for the optimization is met quite nicely.

REFERENCES

1. Balanis, C.A., 2016. Antenna Theory: Analysis And Design. John Wiley & Sons.
2. Haupt, R.L. and D.H. Werner, 2007. Genetic Algorithms In Electromagnetics. John Wiley & Sons.
3. Murthy, P.K. and A. Kumar, 1976. Synthesis Of Linear Antenna Arrays.Antennas And Propagation, IEEE Transactions On, 24(6): 865-870.
4. Hodjat, F. and S.A. Hovanessian, 1978. Nonuniformly Spaced Linear And Planar Array Antennas For Sidelobe Reduction. Antennas And Propagation, IEEE Transactions On, 26(2): 198-204.
5. Ng, B.P., M.H. Er and C. Kot, 1994. Linear Array Geometry Synthesis With Minimum Sidelobe Level And Null Control. In Microwaves, Antennas And Propagation, IEE Proceedings, 141(3): 162-166.
6. Yan, K.K. and Y. Lu, 1997. Sidelobe Reduction In Array-Pattern Synthesis Using Genetic Algorithm. Antennas And Propagation, IEEE Transactions On, 45(7): 1117-1122.
7. Eberhart, R.C. and Y. Shi, 2001. Particle Swarm Optimization: Developments, Applications And Resources. In Evolutionary Computation, 2001. Proceedings Of The 2001 Congress On, 1: 81-86.
8. Roy, R. and S.P. Ghoshal, 2008. A Novel Crazy Swarm Optimized Economic Load Dispatch For Various Types Of Cost Functions. International Journal Of Electrical Power & Energy Systems, 30(4): 242-253.
9. Mandal, D., A.K. Bhattacharjee and S.P. Ghoshal, 2009. A Novel Particle Swarm Optimization Based Optimal Design Of Three-Ring Concentric Circular Antenna Array. In 2009 International Conference On Advances In Computing, Control, And Telecommunication Technologies, pp: 385-389.
10. Mandal, D., S.P. Ghoshal and A.K. Bhattacharjee, 2009. Determination Of The Optimal Design Of Three-Ring Concentric Circular Antenna Array Using Evolutionary Optimization Techniques. International Journal Of Recent Trends In Engineering, 2(5): 110-115.
11. Gupta, I.J. and A.A. Ksienski, 1983. Effect Of Mutual Coupling On The Performance Of Adaptive Arrays. Antennas And Propagation, IEEE Transactions On, 31(5): 785-791.