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Synthesis of Thinned Planar Concentric Circular Antenna Array using Evolutionary Algorithms

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Abstract: *Optimizing the planar concentric circular antenna array is a very complex problem as it contains more number of variables. Metaheuristic algorithms find the best solution for this as these algorithms perform iterative process which explores efficiently the search space that contains both the global search space and local search space. Here different metaheuristic algorithms were applied for optimizing planar concentric circular antenna array and the results were compared with the results of uniform excitation and spacing.*

Keywords: *Planar Concentric Circular Antenna Array, Metaheuristic algorithms, Side lobe level, Narrow beams.*

I. Introduction

Study of mathematical problems using different tools is nothing but optimization. In general optimization algorithms can be classified in many ways. One of the major classifications is deterministic and stochastic. The algorithms which follow a specific path and procedure are known as deterministic algorithms. In these algorithms always same result is achieved. All the classic algorithms are considered to be deterministic algorithms. Stochastic algorithms start with random number and they land at random number as final result. Different results are obtained every time when this algorithm is executed. Metaheuristic algorithms are one of the classifications of stochastic algorithms. These algorithms efficiently explore the search space so as to produce the optimal solution. In the present paper five algorithms BAT, Firefly (FF), Flower Pollination (FP), Genetic Algorithm (GA) and Cuckoo Search (CS) are applied to Planar Concentric Circular Antenna Array (PCCAA) [1 – 5] to reduce the Side Lobe Level (SLL) and Beam Width (BW).An attempt is made here to compare results for all the algorithms.

Algorithms

BAT Algorithm:

BAT algorithm is bio inspired metaheuristic algorithm that is developed by Yang in the year 2010. It works on the echolation behaviour of micro bats. The main three rules that are used in BAT algorithm are

- To sense the distance the echolation principle is used by BATs. They know the exact difference between food, prey and all the different barriers that come across in their magical way.
- With initial velocity and frequency BATs will fly starting at a reference position they search for the food/ prey by varying the wave length and loudness of the pulse that is emitted by them. The emitted pulse wave length and loudness are adjusted with the pulse rate of emission.
- It is assumed that the loudness is varied from maximum to minimum.

Firefly Algorithm:

Firefly is metaheuristic algorithm developed by yang in 2007. This algorithm works on the flashing light characteristics of fire flies. The three main rules related to firefly algorithm are as given below

- The fireflies considered here are unisex so that one firefly is being attracted by others irrespective of their sex.
- The attractiveness is directly proportional to the brightness of the firefly. As their distance increases the attractiveness decreases. Firefly will move randomly until it finds brighter firefly.
- With the objective function the brightness of the firefly is affected.

Flower Pollination Algorithm:

Flower Pollination algorithm is based on the flower pollination principle developed by Yang in the year 2012. Flower Pollination is the concept of transferring pollen from male flower to female flower with the pollinating agents like insects which follow the levy flight movement. The main rules of the algorithm are

- The global pollination process is indicated by biotic and cross pollination. Here the pollen is carried by insects that follow levy flight movement.
- Local pollination process is indicated by abiotic or self pollination.

- Pollinators can develop flower constancy which is like reproduction probability and proportional to the similarity of two flowers involved.
- From local pollination to global pollination the values can be changed with probability rate.

Genetic Algorithm:

Genetic Algorithm is based on the mechanics of biological evaluation. Genetic Algorithm is developed by John Holland in 1970's. It is stochastic algorithm which does not use gradient information. Basically Genetic Algorithms are two types, one is Binary GA and second one is Real Coded GA. The main steps involved in GA are

- Initialize the population
- Evaluate the population
- Select the parents for reproduction
- With the cross over probability perform the cross over or copy parents.
- With the mutation probability mutate off spring at each position in chromosome.
- Accept the new generation and evaluate the population
- If the best results are not obtained then start with step 2 again.

Cuckoo Search Algorithm:

Cuckoo Search algorithm is latest metaheuristic nature inspired algorithm developed by Yang in 2009. It has been proved that CS algorithm works efficiently than the rest of the algorithms. Than with simple isotropic random walks this algorithm is enhance by levy flight movements.

In this algorithm egg in a nest represent one solution. Hence for good results the cuckoos are made to replace the eggs in the nest. Main rules of this algorithm are

- One egg will be laid by cuckoo at a time and it will be dumped in the randomly chosen nest.
- Very good quality and best eggs will be carried out for the next generations.
- The number of host nests is defined and the egg laid by a cuckoo is discovered by the host bird with probability rate. In this case the host bird can either get rid off egg or simply abandon the nest and build a completely new nest.

The PCCAA Geometry

The normalised power pattern of the PCCAA is calculated as follows

$$P(\theta,\phi) = 20log_{10}\left[\frac{|E(\theta,\phi)|}{|E(\theta,\phi)|_{max}}\right] \quad (1)$$

Where E (θ, ϕ) is radiation pattern of the PCCAA given by the following equations

$$E(\theta,\phi) = \sum_{m=1}^{M}\sum_{n=1}^{N} I_{mn} e^{jkr_m[sin\theta\cos(\phi-\phi_{mn})-sin\theta_0\cos(\phi_0-\phi_{mn})]} \quad (2)$$

$$\mathrm{rm} = \frac{Nd_m}{2\pi} \quad (3)$$

ϕ_{mn} is given by

$$\phi_{\mathrm{mn}} = \frac{2n\pi}{N} \quad (4)$$

Where

I_{mn} is excitation currents
r_m is radius of m^{th} ring
d_m is inter element spacing,
k is the wave number, $k=2\pi/\lambda$
θ is elevation angle,
M is no of rings,
N is no of elements in each ring
θ_0, ϕ_0 = direction at which main beam achieves its maximum

For the designing problems presented here $\theta_0 = 0°$ and $\phi_0 = 0°$are considered.
ϕ is the azimuth angle between the positive x-axis and the projection of the far field point in the x–y plane as shown in Fig 1.

Fig1 shows PCCAA with fully populated antenna elements where as Fig.2 shows Thinned PCCAA

II. Results And Discussion

The work was carried out in three stages first power patterns for concentric circular antenna array were numerically evaluated using equations 1- 4 with uniform excitation equal to 1 and uniform spacing equal to 0.5λ. In the second stage the different algorithms [6 – 10] that are mentioned above are applied to optimize the excitation currents of the elements. Further thinning [11- 13] is applied on the PCCAA using uniform as well as non uniform excitation currents which resulted in very much enhanced results.

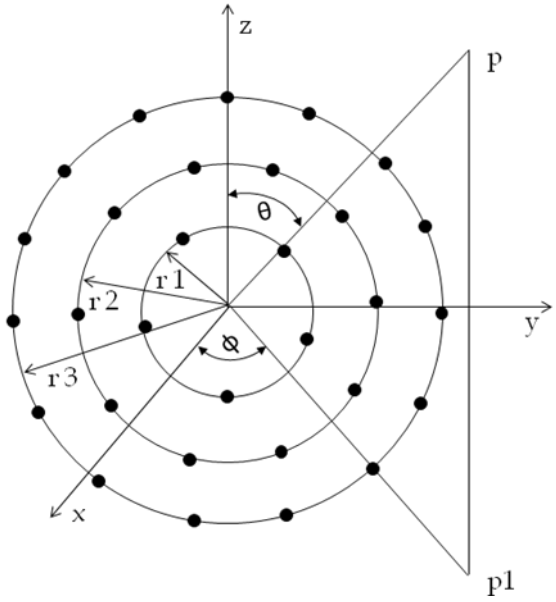

Fig.1 Fully excited PCCAA

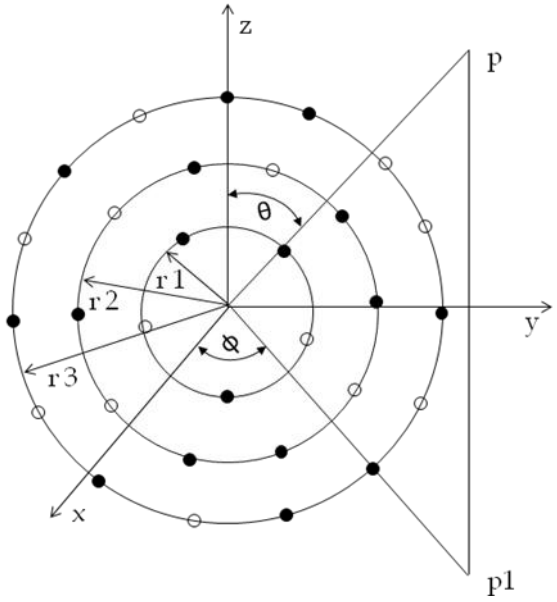

Fig.2 Thinned PCCAA

Number of elements in the rings are considered to be multiples of 5. For three rings PCCAA the power pattern with all the metaheuristic algorithm coefficients are numerically evaluated and is presented in the Fig.3. The Optimized spacing between the elements considered is 0.862λ. From the figure it is observed that the SLL is -21.5 dB and the beam width is 13.6^o for BAT algorithm, the SLL is -22.5 dB and the beam width is 13.2^o for FF algorithm, the SLL is -22.6 dB and the beam width is 14^o for FP algorithm, the SLL is -21.9 dB and the beam width is 13.7^o for GA algorithm, the SLL is -23.3dB and the beam width is 13.2^o for CS algorithm.

On observing the results it is evident that the CS algorithm performs well. As compared with the uniform excitation and uniform spacing (SLL= -15.82 dB and Beam Width = 21.4^o) the SLL and beam width are reduced to appreciable values. The convergence characteristics of the different algorithms are presented in the Fig.4.

Fig.5 presents the power pattern for thinned three rings PCCAA. Here thinning is applied in two ways that is with uniform excited coefficients referred as uniform thinning and considering different algorithm coefficients referred as non uniform thinning.

From the figure it is observed that the SLL is -21.4 dB and the beam width is 13.4^o for uniform thinning with 30% of thinning, SLL is -20.25 dB and the beam width is 15^o for BAT algorithm with 33.3% of thinning, the SLL is -22.8 dB and the beam width is 14^o for FF algorithm with 16.7% of thinning, the SLL is -22.6 dB and the beam width is 14^o for FP algorithm with 20% of thinning, the SLL is -21.3 dB and the beam

width is 14.4^o for GA algorithm with 13% of thinning, the SLL is -22.5dB and the beam width is 13.3^o for CS algorithm with 30% of thinning. On observing the results it is evident that the CS algorithm performs well which yields reduced SLL and less beam width.

Convergence characteristics are presented in Fig.6. It is evident from the convergence characteristics that the cuckoo search algorithm shows better performance results compared to the rest of the algorithms with normal array or thinned array.

Excitation Co-efficients, SLL and Beam Width Comparison values for three rings PCCAA for different algorithms are presented in Table1. Excitation Co-efficients, SLL and Beam Width Comparison values for three rings PCCAA for different algorithms for thinning are presented in Table2.

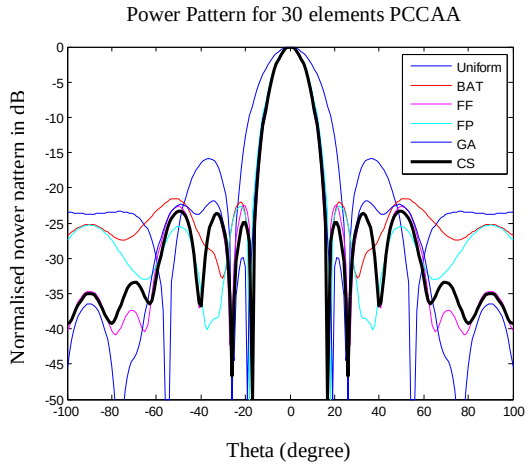

Fig 3. Power pattern for three rings PCCAA for different algorithms.

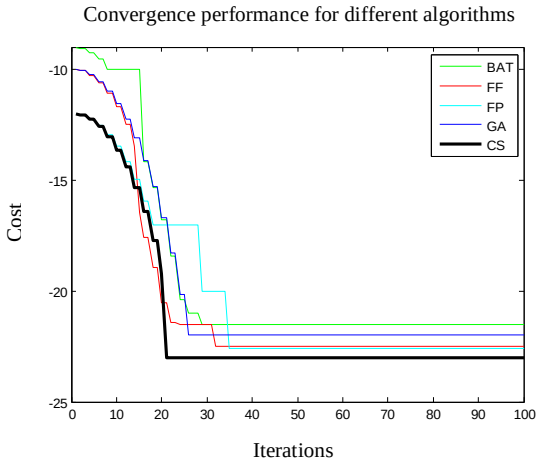

Fig 4. Convergence characteristics for different algorithms.

Table1. Excitation Co-efficients, SLL and Beam Width Comparison values for three rings PCCAA for different algorithms.

Algorithm	Current Excitations	Parameters
Uniform	1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,1	Max SLL = -15.8dB 3 dB B.W =21.4^0
BAT	0.4101 0.5933 0.9257 0.8619 0.3770 0.6040 0.7051 0.8776 0.6125 0.4402 0.4923 0.5185 0.9652 0.9721 0.6432 0.2923 0.4979 0.5904 0.5512 0.7344 0.5363 0.4050 0.3318 0.2045 0.3842 0.5089 0.2014 0.6752 0.0934 0.6994	Max SLL = -21.5dB 3 dB B.W =13.6^0
CS	0.9313 0.5200 0.8187 0.7328 0.3957 0.8970 0.7453 0.9007 0.6602 0.8803 0.3733 0.3370 0.9463 0.9469 0.2417 0.2363 0.7357 0.4001 0.2650 0.6438 0.7880 0.4219 0.8363 0.6690 0.8040 0.7582 0.5847 0.7269 0.2257 0.3774	Max SLL = -23.3dB 3 dB B.W =13.2^0
FF	0.9387 0.5795 0.8404 0.7653 0.4709 0.9088 0.7763 0.9120 0.7019 0.8942 0.4513 0.4197 0.9518 0.9523 0.3364 0.3317 0.7679 0.4747 0.3568 0.6876 0.8136 0.4939 0.8558 0.7097 0.8275 0.7875 0.6360 0.7602 0.3225 0.4550	Max SLL = -22.5dB 3 dB B.W =13.2^0
FP	0.6749 0.2515 0.0768 0.2525 0.9315 0.8009 0.5682 0.7195 0.5745 0.0443 0.4068 0.8897 0.9098 0.5985 0.4760 0.0045 0.4025 0.1003 0.7057 0.6587 0.9816 0.0351 0.1913 0.1980 0.6056 0.4444 0.7927 0.1953 0.0118 0.8478	Max SLL = -22.6dB 3 dB B.W =14^0
GA	0.8969 0.5088 0.7066 0.6526 0.5586 0.6343 0.8088 0.9183 0.3636 0.5309 0.2801 0.2636 0.3598 0.9459 0.6466 0.5479 0.5519 0.3544 0.2976 0.4611 0.9324 0.6085 0.2255 0.3815 0.5071 0.7947 0.2845 0.4691 0.9704 0.2196	Max SLL = -21.9dB 3 dB B.W =13.7^0

III. Conclusions

It is evident from the above results that CS algorithm outperforms the remaining algorithms. This algorithm is easy and simple to implement. As this CS algorithm converges in very few iterations this can be

considered as more useful and favourable algorithm. The SLL and beam width are reduced effectively. The produced beams by PCCAA can be used in wide applications.

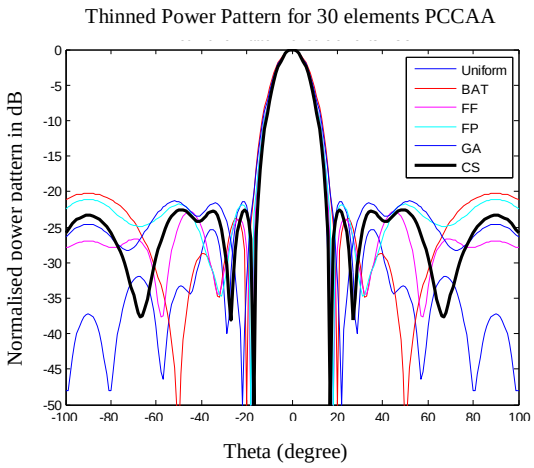

Fig 5. Power pattern for three rings PCCAA for Thinning.

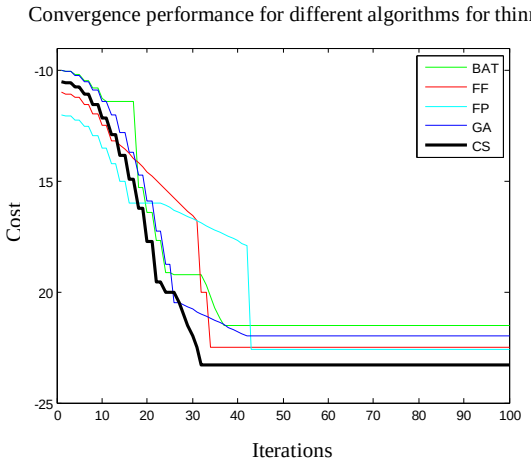

Fig 6. Convergence characteristics for different algorithms for Thinning.

Table2. Excitation Co-efficients, SLL and Beam Width Comparison values for three rings PCCAA for different algorithms for thinning.

Algorithm	Current Excitations	Parameters
Uniform	1,1,0,1,1,1,1,1,1,1,0,1,1,1,1,0,0,1,1,1,1,0,0,1,1,0,0,0,1,1	Max SLL = -21.4dB 3 dB B.W =13.4^0 %Thinning= 30%
BAT	0.4101 0.5933 0.0000 0.8619 0.3770 0.6040 0.7051 0.8776 0.0000 0.0000 0.4923 0.5185 0.9652 0.9721 0.6432 0.2923 0.0000 0.0000 0.5512 0.7344 0.5363 0.0000 0.3318 0.2045 0.3842 0.0000 0.0000 0.0000 0.0934 0.0000	Max SLL = -21.5dB 3 dB B.W =13.6^0 %Thinning= 33.3%
CS	0.9313 0.5200 0.8187 0.7328 0.0000 0.8970 0.7453 0.9007 0.6602 0.8803 0.3733 0.3370 0.9463 0.9469 0.0000 0.2363 0.7357 0.0000 0.2650 0.6438 0.0000 0.4219 0.8363 0.6690 0.8040 0.0000 0.0000 0.0000 0.0000 0.0000	Max SLL = -23.3dB 3 dB B.W =13.2^0 %Thinning= 30%
FF	0.9387 0.5795 0.8404 0.7653 0.4709 0.9088 0.7763 0.9120 0.7019 0.8942 0.4513 0.4197 0.9518 0.9523 0.3364 0.0000 0.7679 0.0000 0.0000 0.6876 0.8136 0.4939 0.8558 0.7097 0.8275 0.0000 0.6360 0.7602 0.3225 0.0000	Max SLL = -22.5dB 3 dB B.W =13.2^0 %Thinning= 16.7%
FP	0.6749 0.2515 0.0000 0.2525 0.9315 0.8009 0.0000 0.7195 0.5745 0.0000 0.0000 0.8897 0.9098 0.0000 0.4760 0.0000 0.4025 0.1003 0.7057 0.6587 0.9816 0.0351 0.1913 0.1980 0.6056 0.4444 0.7927 0.1953 0.0118 0.8478	Max SLL = -22.6dB 3 dB B.W =14^0 %Thinning= 20%
GA	0.8969 0.5088 0.7066 0.6526 0.5586 0.6343 0.8088 0.9183 0.3636 0.5309 0.2801 0.2636 0.3598 0.9459 0.6466 0.5479 0.5519 0.0000 0.0000 0.0000 0.9324 0.6085 0.2255 0.3815 0.5071 0.7947 0.0000 0.4691 0.9704 0.2196	Max SLL = -21.9dB 3 dB B.W =13.7^0 %Thinning= 13%

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