# Real Coded GA (RCGA) for Control of Nulls and Sidelobes in a Concentric Circular Antenna Array (CCAA)

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***Abstract***— A Concentric Circular Antenna Array (CCAA) contains antenna elements positioned along different circular rings with common centre and different radii. CCAA has become very popular in cellular and wireless communications. The ever increasing demand for wireless communications and the rise of electromagnetic pollution is causing interference to the existing users. This paper illustrates the procedure for placing nulls in the interference direction while reducing sidelobe level (SLL) of a CCAA under the constraint of fixed FNBW (as in the case of uniform excitation). This is achieved by optimizing the excitation current amplitudes of the antenna elements in CCAA using Real-coded Genetic Algorithm (RCGA). Three design examples are presented that illustrate the effectiveness of the proposed method.

***Keywords***— *Concentric Circular Antenna Array (CCAA); Real-Coded Genetic Algorithm (RCGA); Nulls; Sidelobe level (SLL); First Null Beam Width (FNBW)*

## 1. INTRODUCTION

Antenna arrays are used in a wide range of applications including RADARs, satellite communications, terrestrial mobile communications, astronomy, and several others [1], [2]. Antenna arrays may be linear, planar (square, rectangular), circular or spherical in geometry. Linear arrays have the main drawback of symmetric array factor around the reference element i.e., radiation pattern in two opposite directions about the main lobe cannot be controlled independently. Both linear arrays and planar arrays have the disadvantage that their main lobe can be moved only in half of the space. Finally, for beam tilting mechanical means should be used or an extra control feature should be implemented [3].

A very popular type of antenna arrays is the circular array which has several advantages over other schemes such as all-azimuth scan capability (i.e., it can perform 360 scan around its centre) and the invariant beam pattern. Concentric circular antenna arrays (CCAA) that contain many concentric circular rings of different radii and a number of elements has several advantages including the flexibility to use both in narrowband and broadband beam-forming applications. The main lobe could be oriented in any desired direction. Moreover, beam tilting is naturally obtained through the same type of control used for the lobe orientation [3].

The increasing amount of electromagnetic pollution has encouraged the study of array pattern nulling techniques. These techniques are important in radar, mobile communication to minimize degradation of the signal to noise ratio due to undesired interference. Much current research on antenna arrays is focused on using robust and easily adapted optimization techniques to improve the nulling performance[4],[5].

The rest of the paper is arranged as follows: In Section 2, the general design equations for the non-uniformly excited CCAA and the cost function used in achieving the desired goal are stated. In Section 3, RCGA is introduced for solving the cost function obtained in Section 2. Numerical results are presented in Section 4 and finally the Section 5 concludes with a summary of the work.

## II. DESIGN EQUATIONS

### *A. Array Factor of CCAA*

A Concentric Circular Antenna Array (CCAA) consists of antenna elements arranged in different concentric rings which differ in their radii. A CCAA with M rings is shown in figure 1. The mth (m=1, 2…M) ring has a radius of $r_m$ and contains $N_m$ elements. Assuming the elements are isotropic, the array factor can be written as shown in equation 1 [6].

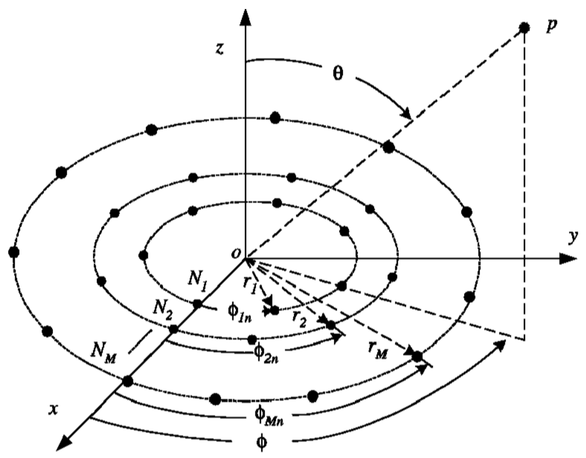


Fig.1: Concentric Circular Antenna Array (CCAA)

$$AF(\emptyset, I) = \sum_{m=1}^{M}\sum_{n=1}^{N_m} I_{mn} \exp\left[ j(Kr_m sin\theta \cos(\emptyset - \varphi_{mn}) + \alpha_{mn})\right] \quad (1)$$

Where, $I_{mn}$ denotes the excitation current amplitude of the $n^{th}$ element of the $m^{th}$ ring. $K=2\pi/\lambda$ is the wavenumber and $\lambda$ is the wavelength. Θ and Ø denote the elevation and azimuth angle measured from positive Z and X axes respectively. Assuming the elevation angle $\Theta=90^0$, the array factor can be written as a function of Ø.

The angle $\emptyset_{mn}$ is the angular position of the nth element of the $m^{th}$ ring measured from positive X-axis. Assuming uniform spacing between the elements, we can write

$$\emptyset_{mn} = 2\pi\left(\frac{n-1}{N_m}\right); m = 1,\dots,M, n = 1,\dots,N \quad (2)$$

The term $\alpha_{mn}$ is the residual phase which is a function of angular position $\emptyset_{mn}$ and ring radius $r_m$.

$$\alpha_{mn} = -Kr_m\cos(\emptyset_0 - \emptyset_{mn}); m = 1,\dots,M, n = 1,\dots,N \quad (3)$$

Where $\emptyset_0$ is the desired value of Ø at which main lobe peak is needed.

### B. *Cost Function*

The Cost function in Real Coded GA is the objective function which will help in achieving the desired goal of introducing nulls and reducing sidelobe level while maintaining fixed FNBW. The Cost Function CF is

$$CF = C_1 \times \frac{\left|\prod_{i=1}^{m} AF(null_i)\right|}{|AF_{max}|} + C_2 \times (SLL_{cur} - SLL_{des}) + C_3 \times \left|\left(FNBW_{computed} - FNBW_{(Imn=1)}\right)\right| \quad (4)$$

In first term, m is the maximum number of positions where the null can be imposed. In this paper, the value of 'm' is considered to be two. AF ($null_i$) is the value of array factor at the particular null position and $AF_{max}$ is the maximum value of array factor. The second term is used to reduce SLL. $SLL_{cur}$ is the main sidelobe level in dB for the current iteration and $SLL_{des}$ is the desired sidelobe level in dB. The third term is used to keep FNBW constant. $FNBW_{computed}$ is the FNBW for current iteration and FNBW ($I_{mn}$=1) is the First Null beam width for the uniform excitation case.

$C_1$, $C_2$, $C_3$ are the weighting coefficients used to control the significance of each term. Since main aim is to introduce nulls, C1 must be greater than $C_2$ and $C_3$. In this paper they are taken as 18, 2 and 1 respectively.

## III. REAL CODED GENETIC ALGORITHM

Genetic-algorithm optimizers are robust, stochastic search methods, modeled on the principles and concepts of natural selection and evolution. Genetic Algorithms usually involves coding of parameters for performing optimization. The RCGA codes the variables as real numbers as opposed to binary numbers as in the case of BCGA [7-8].

1. The RCGA starts with a random set of variables called 'chromosomes' within the constrained limits. A set of such chromosomes is called a 'population'. Size of each chromosome depends on number of elements of CCAA.
2. Each chromosome in the set is then associated with a value called 'Cost Function' or 'fitness function' value
3. New population is created from the present one by selection, crossover and mutation. Selection of chromosomes for mating pool is done based on their fitness values (Better the fitness, better the chance of selection)
4. Perform crossover and mutation on the selected chromosomes to generate new population
5. Update the genetic cycle.

The iteration stops when the maximum number of cycles is reached or a certain maximum or minimum fitness value is obtained. The best chromosome satisfying the desired requirement is finally obtained.

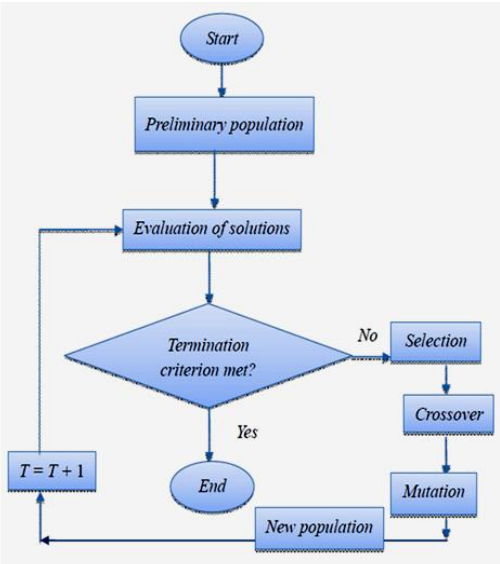


Fig.2: Flowchart of Genetic algorithm

## IV. EXPERIMENTAL RESULTS

The RCGA algorithm proposed in the previous section is implemented and simulated using Matlab 2013b for a CCAA having 3 circular rings with radii of 0.5917 λ, 0.6944 λ, 0.8463 λ respectively. The number of elements of the inner most circle ($N_1$) is taken as 8, for outermost circle ($N_3$) as 12, whereas for the middle circle ($N_2$) as 10. The excitation amplitudes are allowed to vary in between 0 and 1. Further, $\emptyset_0$= 0° is assumed so that the radiation patterns of the CCAA of main lobe starts from $\emptyset_0$ = 0°. In this experiment the algorithm parameters are set as follows:

Maximum number of generation = 700

Population size = 100

Selection strategy = Roulette wheel selection

Crossover = Uniform crossover with a probability of 0.7

Mutation = Gaussian mutation with a probability of 0.05

Fig.3 shows the radiation pattern for a uniformly excited CCAA ($I_{mn}$=1), it has a radiation pattern with –9.26 dB side lobe level and a BWFN of 62°.

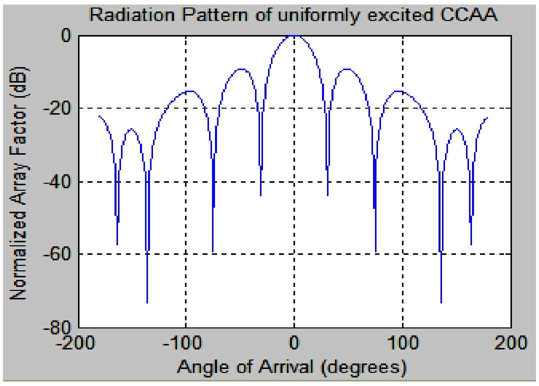


Fig.3**:** Radiation pattern of uniformly excited CCAA

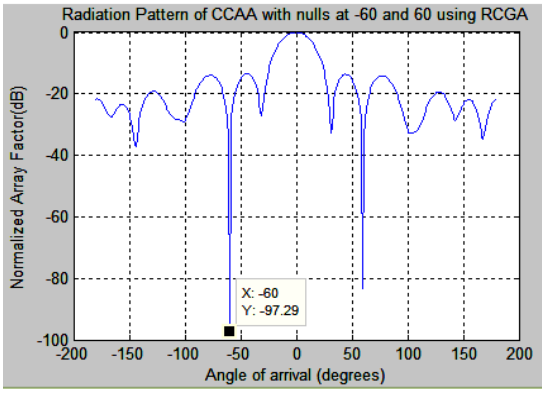


Fig.4: Radiation pattern of non-uniformly excited CCAA with nulls imposed at -60 and 60 degrees

Fig.4 shows radiation pattern of CCAA with nulls imposed at -60 and 60 degrees. It can be seen that nulls with depth of -97.29& -83.33 respectively were imposed at -60 and 60 degrees while SLL reduced to -13.32 with FNBW unaltered.

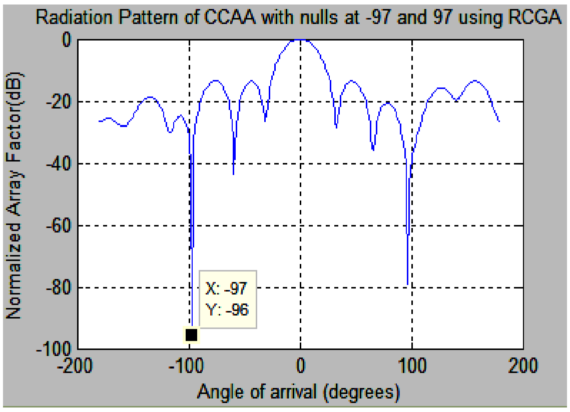


Fig.5: Radiation pattern of non-uniformly excited CCAA with nulls imposed at -97 and 97 degrees

Fig.5 shows radiation pattern of CCAA with nulls imposed at -97 and 97 degrees where there are second side lobe peaks in the reference pattern (uniform excitation case). It can be seen that nulls with depth of -96 & -79.8 respectively were introduced while SLL reduced to -13.52 with FNBW unaltered.

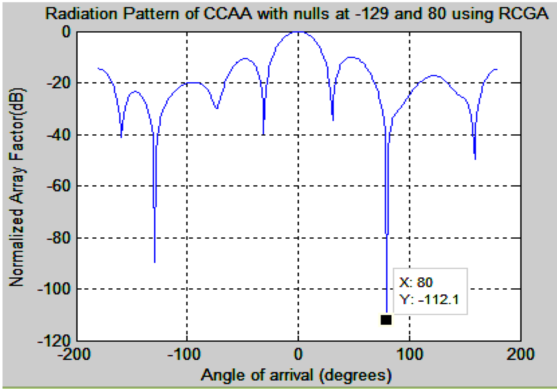


**Fig-6:** Radiation pattern of non-uniformly excited CCAA with nulls imposed at -129 and 80 degrees

Fig.6 shows radiation pattern of CCAA with nulls introduced at directions non-symmetric about the main lobe peak. It can be seen that nulls with depth of -89.87,-112.1 respectively were imposed at -129 and 80 degrees respectively while SLL reduced to -10.01 with FNBW unaltered.

Table-1 lists the SLL, FNBW, Null depths for different cases and compares them with the uniform excitation case.

Table-2 lists the excitation amplitudes for Uniform and non-uniformly excited cases.

Table-1: SLL, Null Depths and FNBW of Uniform and Non-Uniform (Optimized) Cases of CCAA

| **Case** | **Sidelobe Level (SLL) (dB)** | **FNBW (degrees)** | **Null depths at intended position** |
|---|---|---|---|
| Uniform | -9.266 | 62 | NA |
| Nulls at -60 and 60 | -13.32 | 62 | -97.29& -83.33 |
| Nulls at -97 and 97 | -13.52 | 62 | -96 & -79.8 |
| Nulls at -129 and 80 | -10.01 | 62 | -89.87 & -112.1 |

Table-2: Excitation Amplitudes of Uniform and Non-Uniform (Optimized) Cases of CCAA

| **Case** | **Excitation Amplitudes** |
|---|---|
| Uniform | $I_{mn}$=1 |
| Nulls at -60 and 60 | 0.9480 0.1090 0.0014 0.0609 0.9540<br>0.1159 0.0052 0.0911<br><br>0.5679 0.6793 0.0577 0.0050 0.5012<br>0.4406 0.3443 0.0007 0.0356 0.4958<br><br>0.0354 0.9680 0.8168 0.7117 0.9161<br>0.9725 0.0442 0.9725 0.7619 0.8347<br>0.5890 0.9976 |
| Nulls at -97 and 97 | 0.9033 0.2799 0.0842 0.0205 0.9632<br>0.1576 0.0312 0.0366<br><br>0.4551 0.0163 0.0972 0.2367 0.1551<br>0.4069 0.4991 0.0933 0.0154 0.4785<br><br>0.0638 0.8034 0.7927 0.8997 0.1134<br>0.8476 0.0681 0.9581 0.6605 0.7048<br>0.2334 0.9989 |
| Nulls at -129 and 80 | 0.9979 0.0076 0.8344 0.2683 0.9592<br>0.3520 0.9328 0.4456<br><br>0.4383 0.6262 0.1410 0.1215 0.6930<br>0.7485 0.5163 0.2216 0.3866 0.4096<br><br>0.2792 0.9849 0.9118 0.5003 0.9513<br>0.6964 0.2573 0.4467 0.7419 0.7746<br>0.4828 0.6777 |

## V. CONCLUSION

The simulation results show that the proposed method introduces nulls at desired interference directions and reduces sidelobe level (SLL) while keeping the FNBW unchanged. The results stand as a testimony to GA's capability in solving optimization problems related to antennas.

Although the method is proposed for CCAA, it can be applied to any type of array (linear, spherical, square etc.) and arrays with any type of antenna elements (dipoles, patch, etc.).

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