

# QPSO FOR FAILURE CORRECTION OF LINEAR ARRAY ANTENNA INCLUDING WIDE NULL PLACEMENT

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## Abstract

In this paper, the authors have proposed a method based on Quantum Particle Swarm Optimization (QPSO) algorithm in the context of radiation pattern correction of a linear array of isotropic antennas corrupted with one or more faulty antenna elements. Care is taken to maintain the values of side lobe level and maximum Wide Null Placement of the corrected pattern to be identical to the values of non-defective radiation pattern. This correction is made possible by altering the beam weights of the remaining elements in the array. The advantage of this method is that the necessity of replacement of the faulty elements is eliminated. Simulation is done on the linear antenna array constructed of individual isotropic elements separated by identical inter-element spacing and the results obtained from the simulation depict the effectiveness of the proposed method. This method can also be extended to other array geometries.

## Keywords:

Antenna Array, Failure Correction, Quantum Particle Swarm Optimization, Side Lobe Level, Wide Null Placement

## 1. INTRODUCTION

Antenna arrays [1] are preferred over individual antennas in various applications for the advantages [1] that the former provides in terms of high directivity, diversity reception, maximum signal to interference ratio, beam steering etc., over the individual element (antenna). At the same time, it also suffers from high side lobe level (SLL), which further aggravates in case of failure of one or more individual elements in the arrays. The condition can be visualized from the corrupted radiation pattern in terms of not only SLL, but also other radiation pattern parameters like half power beam width, first null beam width, etc. The chances of replacing the faulty element is remote when the cost of replacement and time utilized in replacement is considered, especially in terms of long distance applications using satellite antenna.

This condition made the way for introducing the idea of failure correction [2]-[6] which refers to altering the beam weights of the remaining unfailed elements resulting in a new or corrected radiation pattern that matches closely with the unfailed radiation pattern in terms of radiation pattern parameters. This obviously results in saving cost of replacement.

Array failure correction with a digitally beamformed array is described in [2]. Generalization of an array failure correction method is presented in [3].

Literature survey in the past also revealed correction techniques devised using evolutionary algorithms like genetic algorithm [4]-[5], simulated annealing [6], and failure detection using genetic algorithm [7]. Standard particle swarm

optimization is first presented in the article [8]. Particle swarm optimization [9]-[10] has been applied for array antenna synthesis including null placement. Iterative fast fourier transform [11] has been applied to a scanned array with null placement at appropriate place.

In this paper, the authors have utilized quantum particle swarm optimization (QPSO) [12]-[13] in the context of correction of a radiation pattern of linear antenna array failed with three elements with the objective of obtaining expected side lobe level and wide null placement close to that of the original pattern values.

## 2. METHODOLOGY

The geometry of a linear array of isotropic antennas placed along Z-axis is shown in Fig.1. The array is made of  $M$  individual isotropic antennas [1] and the distance between the antenna elements is  $d$ .

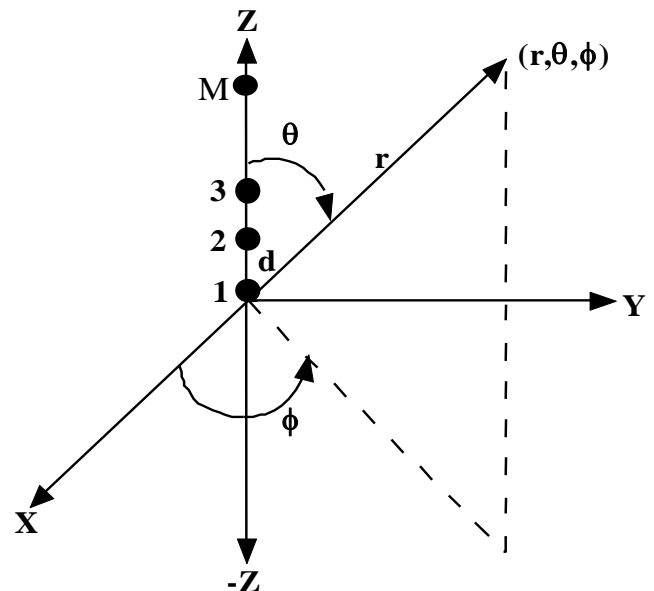


Fig.1. Linear array of isotropic antennas along Z-axis

The free space [1] far-field pattern  $F_{ar}(\theta)$  in the principal vertical plane is given by Eq.(1).

$$F_{ar}(\theta) = \sum_{n=1}^M I_n e^{i(n-1)kd \cos \theta} \quad (1)$$

where,  $n$  being element number,  $I_n$  being current amplitudes of the individual  $M$  elements,  $i$  is the imaginary unit,  $k = 2\pi/\lambda$  is the

wave number with  $\lambda$  being the wavelength and  $\theta$  is the angle of the far-field point measured from  $z$ -axis.

Normalized absolute far-field in dB can be expressed as follows:

$$F_n(\theta) = 20 \log_{10} \left[ \frac{|F_{ar}(\theta)|}{|F_{ar}(\theta)_{\max}|} \right] \quad (2)$$

The objective is to obtain new amplitudes (current excitations) of the remaining antenna array elements other than the faulty ones using QPSO which will minimize the following objective function (fitness) thus providing new radiation pattern with expected radiation pattern parameters matching closely to the ones of original pattern. The amplitudes of the faulty elements are made as zero in the objective function.

$$Fitness = \left[ wt_1 \times F_1^2 + wt_2 \times F_2^2 \right] \quad (3)$$

where,

$$F_1 = \begin{cases} SLL_{obt} - SLL_{des}, & \text{if } \rightarrow SLL_{obt} > SLL_{des} \\ 0, & \text{if } \rightarrow SLL_{obt} \leq SLL_{des} \end{cases} \quad (4)$$

$$F_2 = \begin{cases} WN_{\max}^o - WN_{\max}^d, & \text{if } \rightarrow WN_{\max}^o > WN_{\max}^d \\ 0, & \text{if } \rightarrow WN_{\max}^o \leq WN_{\max}^d \end{cases} \quad (5)$$

The terms  $wt_1$  and  $wt_2$  refers to the weight given to each term in Eq.(3).

Here the following values are chosen for the above-referred weights.  $wt_1 = 5$ ,  $wt_2 = 1$  for original pattern and  $wt_1 = 8$ ,  $wt_2 = 1$  for corrected pattern.  $SLL_{des}$  and  $SLL_{obt}$  are desired and obtained values of side lobe level, and  $WN_{\max}^o$  and  $WN_{\max}^d$  are obtained and desired values of maximum null depth respectively.

### 3. QUANTUM PARTICLE SWARM OPTIMIZATION ALGORITHM

The QPSO algorithm [12]-[13] a variant of Particle swarm optimization algorithm is based on the theoretical concepts of particle swarm and quantum mechanics principles [12].

The steps with which QPSO is modeled is as follows:

**Step 1:** The positions of the particle or the solutions in a population of a  $S$ -dimensional space is initialized in a random fashion.

**Step 2:** Based on the type of the objective function, the fitness of the particles is evaluated and if the current value is found to be better than the personal best values, then the personal best value is replaced by current fitness value as *popbest* and the current coordinates as *popbest* coordinates.

**Step 3:** The *meanbest* of  $P$  particles is determined using the following equation:

$$meanbest = \frac{1}{P} \sum_{n=1}^P popbest_n \quad (6)$$

**Step 4:** The fitness value check is done for all the particles in the population and its coordinates and overall current best fitness value is assigned as the *globalbest* and corresponding coordinates as *globalbest* coordinates.

**Step 5:** The vector local focus of the particle is obtained using the following equation:

$$f_{jd}^t = rand1_{jd}^t * (popbest_{jd}) + (1 - rand1_{jd}^t) * (globalbest) \quad (7)$$

**Step 6:** The next step is to update the position ( $A_{jd}$ ) of the  $d$ -th dimension of the  $j$ -th particle using the following equations:

$$A_{jd}^t = f_{jd}^t + (-1)^{ceil(0.5 + rand2_{jd}^t)} * m \quad (8)$$

where,

$$m = \alpha * |meanbest - A_{jd}^{t-1}| * \log(1 / rand3_{jd}^t)$$

The parameter  $\alpha = 0.75$  is the expansion-contraction coefficient that deals with convergence.

If  $A_{jd}^t < A_{minimum}^t$ ,

Then,

$$A_{jd}^t = A_{minimum}^t + 0.25 * rand4_{jd}^t * (A_{maximum}^t - A_{minimum}^t) \quad (9)$$

If  $A_{jd}^t > A_{maximum}^t$ ,

Then,

$$A_{jd}^t = A_{maximum}^t - 0.25 * rand5_{jd}^t * (A_{maximum}^t - A_{minimum}^t) \quad (10)$$

In the Eqs.(7-10),  $t$  is used to refer the current generation, and all the *rand1*, *rand2*, *rand3*, *rand4* and *rand5* are uniform random numbers whose values ranges between 0 and 1. ( $A_{maximum}^t, A_{minimum}^t$ ) is the maximum and minimum value of variable.

**Step 7:** The above steps (2)-(6) are repeated till there is any more update in the fitness values. It is made to stop in this paper for 300 iterations when generating original pattern and 600 iterations, when the correction is done.

### 4. RESULTS

For simulation purposes, the authors utilized a linear antenna array of 26 isotropic antennas with equal spacing of 0.5 $\lambda$  between any two consecutive element (inter element spacing) has been considered along the  $z$ -axis with specified side lobe level of -25dB or less and specified maximum null depth of -50 dB or less to generate the free space [1] far-field pattern in the principal vertical plane. We have chosen the following elements to be faulty, namely, second element ( $I_2 = 0$ ), seventh element ( $I_7 = 0$ ) and twenty fifth element ( $I_{25} = 0$ ) and this is done in a random manner. The following three cases are discussed.

**Case 1:** Original pattern Generation is done using QPSO for 26 isotropic elements with a particle size of 60. Here no element is considered faulty. The current amplitudes of all the 26 elements are obtained after running QPSO for 300 iterations.

**Case 2:** Damaged pattern generation is done by letting the current amplitudes of the second, seventh and twenty fifth elements to be zero in the excitations obtained

using Case 1, i.e., currents  $I(2)$ ;  $I(7)$  &  $I(25)$  are equal to zero.

**Case 3:** Corrected pattern generation is done by running the QPSO for 600 iterations and the current amplitudes of the remaining twenty three elements (non-faulty elements) with a particle size of 60 are obtained.

Simulation is done using Matlab with a PC having Intel core2 duo processor with clock frequency of 2.93GHz and 4 GB of RAM. Processing time is also measured. Table.1 shows the desired and obtained comparative results among original (case 1), damaged (case 2) and corrected pattern (case 3). Fig.2 shows the normalized current amplitude distribution for original and corrected pattern. Fig.3 shows normalized original power pattern in dB, Fig.4 shows normalized damaged power pattern in dB and Fig.5 shows normalized corrected power pattern in dB.

Table.1. Desired and Obtained Results

Design Parameters	Desired Value	Obtained Value for Case 1	Obtained Value for Case 2	Obtained Value for Case 3
Side Lobe Level in dB	-25	-25.03	-19.40	-25.03
Wide Null in dB ( $\theta = 143^\circ$ to $150^\circ$ )	-50	-51.64	-19.63	-50.19
Computation time (Seconds)	.....	436.14	.....	916.81

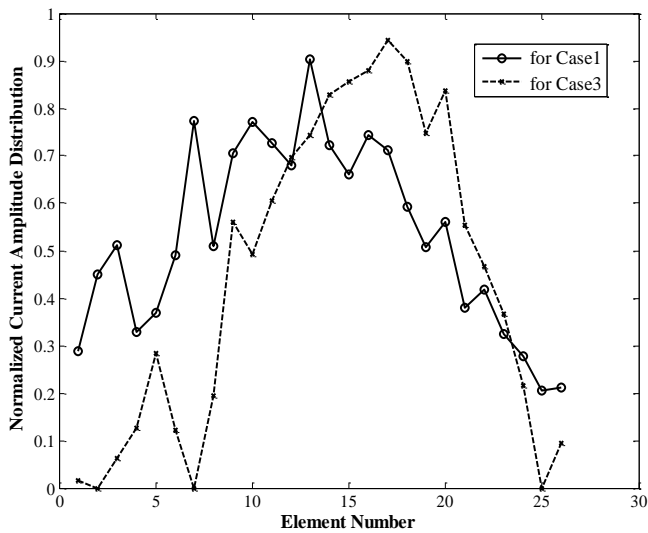


Fig.2. Normalized current amplitude distribution versus element number for original pattern (Case 1) and corrected pattern (Case 3)

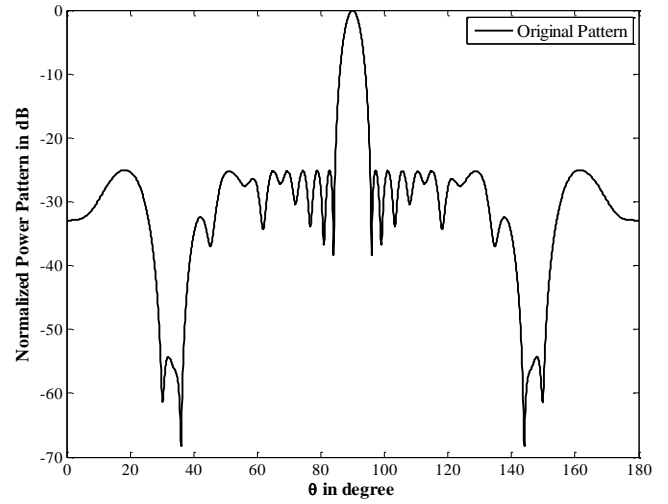


Fig.3. Normalized original power pattern in dB for 26 elements linear array with a single wide null of prescribed maximum depth -50dB from  $\theta = 143^\circ$  to  $150^\circ$

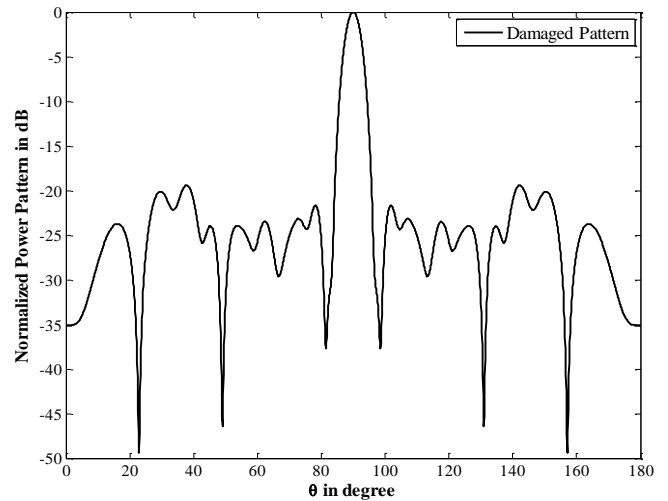


Fig.4. Normalized damaged Power Pattern in dB for 26 elements linear array with second, seventh, twenty fifth element to be faulty obtained from original pattern

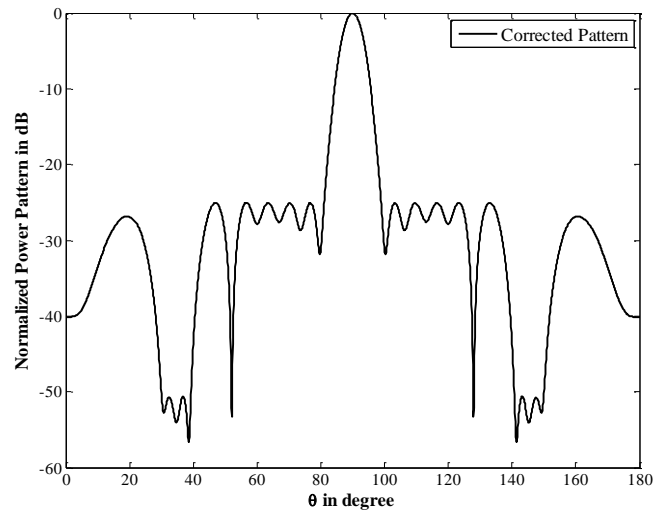


Fig.5. Normalized corrected power Pattern in dB for 26 elements linear array with second, seventh, twenty fifth element to be faulty with a single wide null of prescribed maximum depth -50dB from  $\theta = 143^\circ$  to  $150^\circ$

## 5. CONCLUSION

This paper presents a method based on quantum particle swarm optimization for failure correction of a linear array of isotropic antennas with fixed side lobe level and maximum null depth. Results clearly depict a good amount of agreement between the desired and obtained results in terms of side lobe level and wide null placement. There would be a large scope of work by doing extensive study on the parameter dependency i.e., number of elements, element spacing, length of antenna and considering mutual coupling effects on the radiation pattern.

Results for an array failure correction of isotropic antennas with wide null placement have illustrated the performance of this proposed technique.

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