Matching Transformer Design for UHF Band Using Particle Swarm Optimization

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1. Abstract:

In this paper the PSO technique is used for designing a matching transmission line for a 1:4 power splitter in UHF band. This problem has been solved using modified Genetic Algorithms (GAs) in [1]. Also, different boundary conditions in PSO are discussed for this problem.

2. Introduction

The Particle Swarm Optimization (PSO) is one of the successful evolutionary computation methods in a wide range of problems that is very easy to understand and needs for few lines of codes. PSO method has been used in many multidimensional problems in Electromagnetics[2].

In continue, a brief review of PSO is presented and then goal problem is describe and then translated to PSO language, and then simulation results are presented.

3. Particle Swarm Optimization:

Particle Swarm Optimization method developed in 1995 by Kennedy and Eberhart and is shown to be more successful than some othe optimization algorithms like Genetic Algorithm (GA). A swarm of particles is defined, where each particle is assigned a random position in the N-dimensional problem spaces so that each each particle's position corresponds to a candidate solution to the optimization problem[4]. Below equation determine the particle's velocity updating procedure:

$$v_n = w * v_n + c_1\, rand(\,) * (p_{best,n} - x_n) + c_2\, rand(\,) * (g_{best,n} - x_n)$$

c_1 and c_2 are constants that define the update velocity how much is affected by the particle's and swarm's best locations.

W is inertia weight. A large inertia weight facilitates a global search while a small inertia weight facilitates a local search [3]

4. Problem Description

The power splitter is used to match the line impedance with Z_0=50 Ω to 4 parallel loads, (load= 50/4 =12.5Ω).The power splitter consists of 10 coaxial lines in series with variable inner diameter, (the outer diameter is assumed to be 45mm) and variable lengths, the total length is 50 cm, so the problem has 19 dimensions. By calculating the input impedance of the power splitter the VSWR is obtained. The goal is to minimize the VSWR in the UHF frequency band. (470 MHz to 860 MHz)

Methodology

In PSO language every particle position is defined by 19 dimension vector, (10 radius and 9 independent lengths), with predetermined maximum and minimum in each dimension. The ideal condition is to obtain input impedance equal to 50Ω at all frequencies in UHF band, so for every solution the (Re[zin]-50)^2+(Im[zin])^2 is calculated at some frequencies in UHF band (15 frequencies equally spaced in 455MHz to 875 MHz) and by summing them the final fitness function is determined.

When a particle exceeds of allowed space of every one of dimension, several different boundary conditions can be selected,

Random Boundary Condition: in which the particle position for next iteration is selected randomly in the whole space.

Absorbing Boundary Condition: in which the particle will remain on the maximum or minimum in that dimension until it come back to the solution space again.

Invisible Boundary Condition: in which the particle passes from the solution space but its fitness value will not consider until it comes back to the solution space.

5. Simulation Results:

Three different boundary conditions are considered, and in each case the best solution obtained in that case is presented in the optimum parameters, global best movement of particles, mean of particles fitness function in every iteration and its variance.

1. Random Boundary Condition:

In this Boundary Condition, when a particle exceeds the boundary in each of dimensions, the value of that dimension for that particle will be random value in the allowed space solution of that dimension.
The chosen value for c_1 and c_2 and w are 2.1, 2.1 and 0.7 respectively. These numbers are obtained empirically for getting the best solution with random boundary condition.
Table 1 shows the parameters value of a solution obtained by PSO with Random Boundary Condition, in this run the fitness function is minimized to 1.905

Table.1: Solution obtain by PSO technique with random boundary condition

Number of Section	Length of Section (mm)	Diameter of Section (mm)
1	20.22	22.42
2	40.90	19.33
3	34.15	23.17
4	41.43	22.33
5	32.85	25.72
6	47.38	26.53
7	60.19	29.61
8	83.28	32.83
9	75.99	35.33
10	63.60	36.09

Table.2: Solution obtain by GA

Number of Section	Length of Section (mm)	Diameter of Section (mm)
1	74.18	18.79
2	24.96	18.50
3	4.99	15.66
4	48.50	17.91
5	14.98	21.72
6	69.19	19.18
7	41.73	22.70
8	85.95	26.99
9	57.06	32.27
10	78.46	34.61

Figure 1 shows the global best versus iteration in PSO solution:

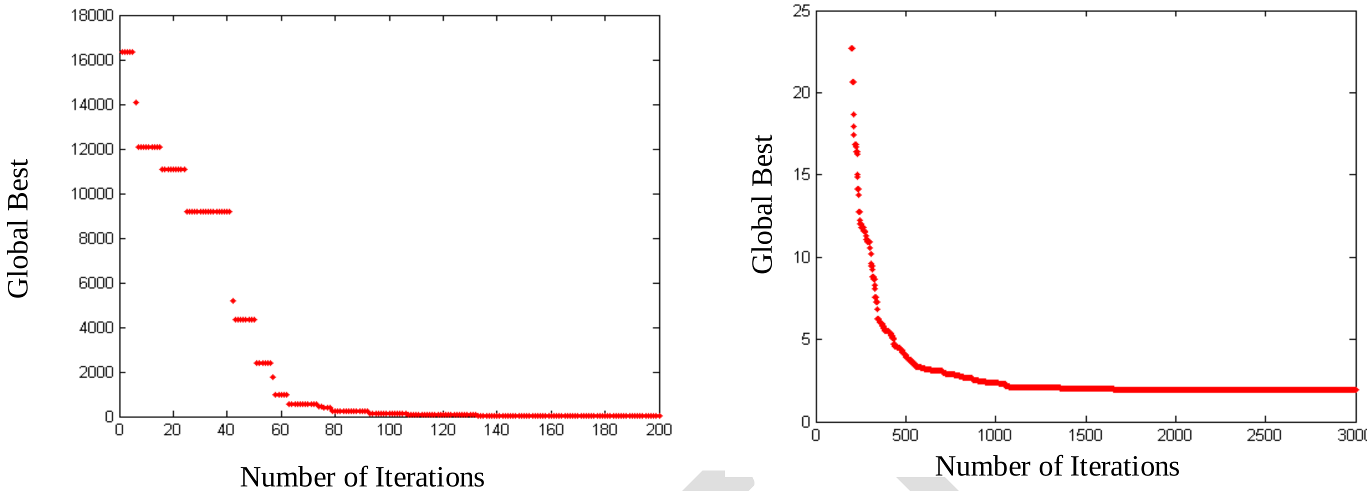

Figure.1 Global best versus iteration in Random Boundary Condition solution

Figure 2 shows the mean of particles fitness function versus iteration:

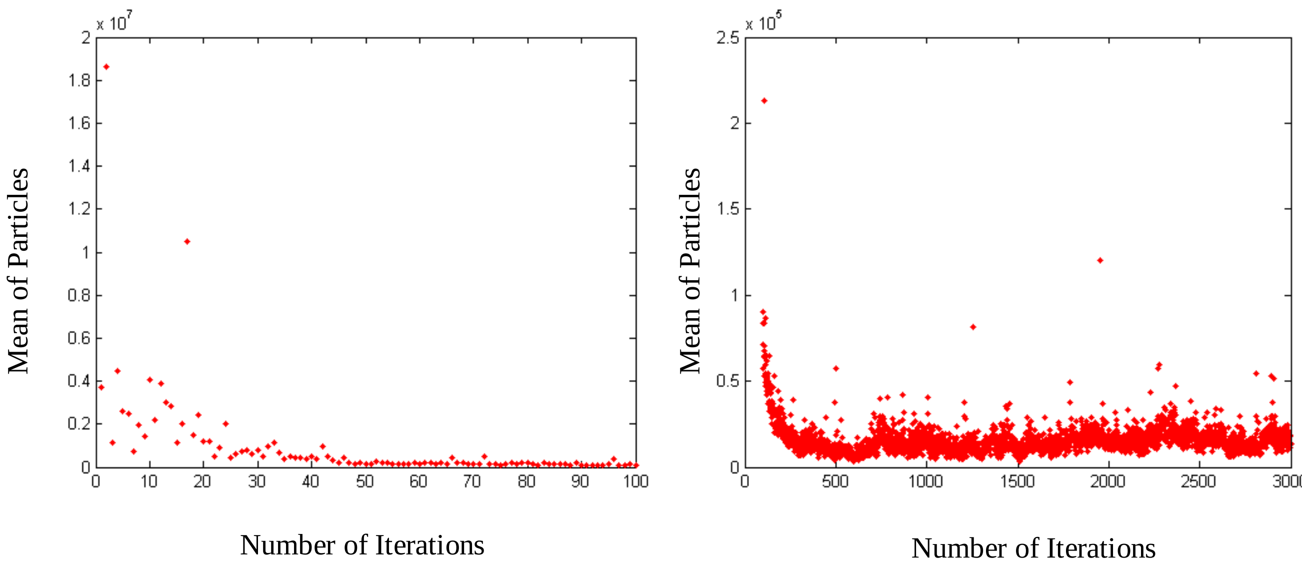

Figure 2 Mean of particles versus iteration in Random Boundary Condition solution

Figure 3 shows the variance of particles fitness function versus iteration:

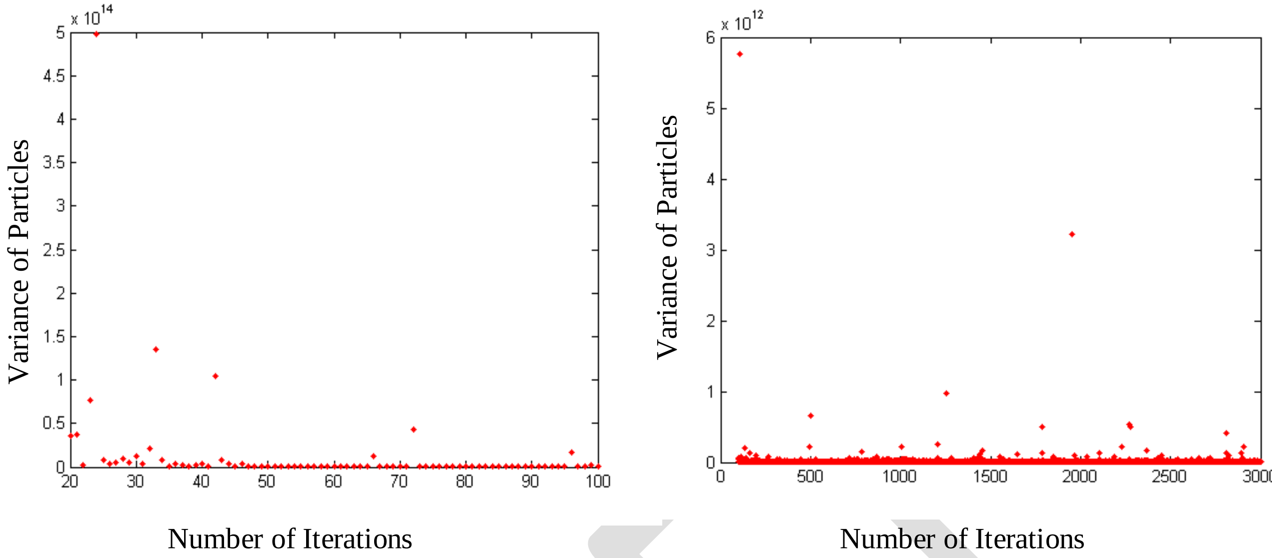

Figure 3 Variance of particles versus iteration in Random Boundary Condition solution

In Figure 4 the VSWR function of the power splitter for both PSO (with Random Boundary Condition) and GA solution are presented, in GA solution the maximum of VSWR in the UHF band is 1.063, and for PSO this maximum is below 1.01

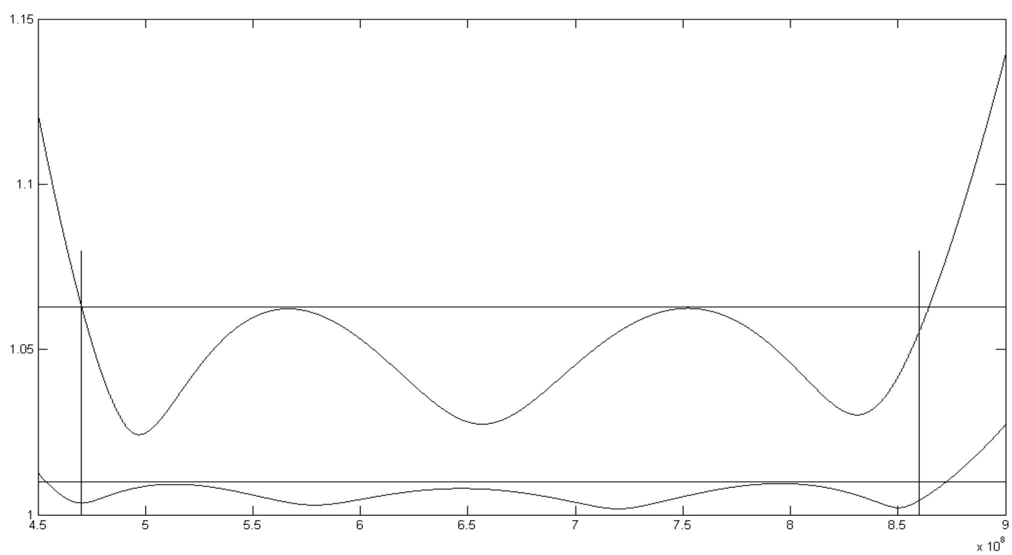

Figure4. Comparison between GA solution and PSO solution, two vertical lines show the limits of UHF frequency band, the upper horizontal line shows the maximum of VSWR of GA solution in this band (1.063) and the other horizontal line shows this maximum for PSO solution (1.01).

2. Absorbing Boundary Condition:

In this boundary Condition, when a particle exceeds the boundary in each one of dimensions, it will remain at the boundary for next iteration.

The chosen value for both c_1 and c_2 is 2.1, same the Random Boundary Condition,

But many runs of program show that the optimum value for inertial weight is 0.5, small value of inertia weight decreases the exploration and the probability of reaching the boundary is reduced.

Table 3 shows the parameter values for the best solution by Absorbing Boundary Condition. In this run the fitness function is minimized to 2.869

Table.3: Solution obtain by PSO technique with Absorbing Boundary Condition

Number of Section	Length of Section (mm)	Diameter of Section (mm)
1	87.72	20.77
2	10.00	25.35
3	10.00	16.59
4	90.00	25.38
5	28.56	27.82
6	90.00	31.32
7	73.72	34.62
8	90.00	35.84
9	10.00	39.18
10	10.00	33.83

The allowed range for Length is 10.00mm to 90.00mm and as we see from the above table length of 7 sections from 10 sections are selected at the boundary of this parameter and this may not be optimum and is a result from bad boundary condition.

Figure 5 shows the Global best movement of particles with Absorbing Boundary Condition

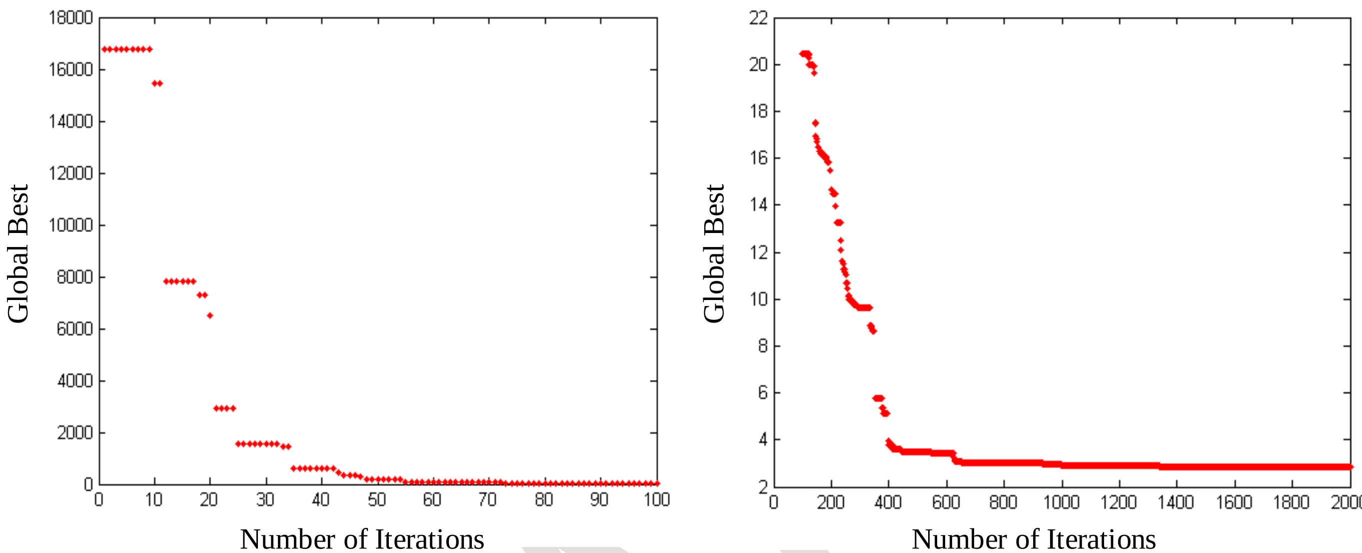

Figure5. Global Best versus iteration in Absorbing Boundary Condition solution

Figure 6 show the mean of particle's fitness function versus iteration for Absorbing Boundary Condition:

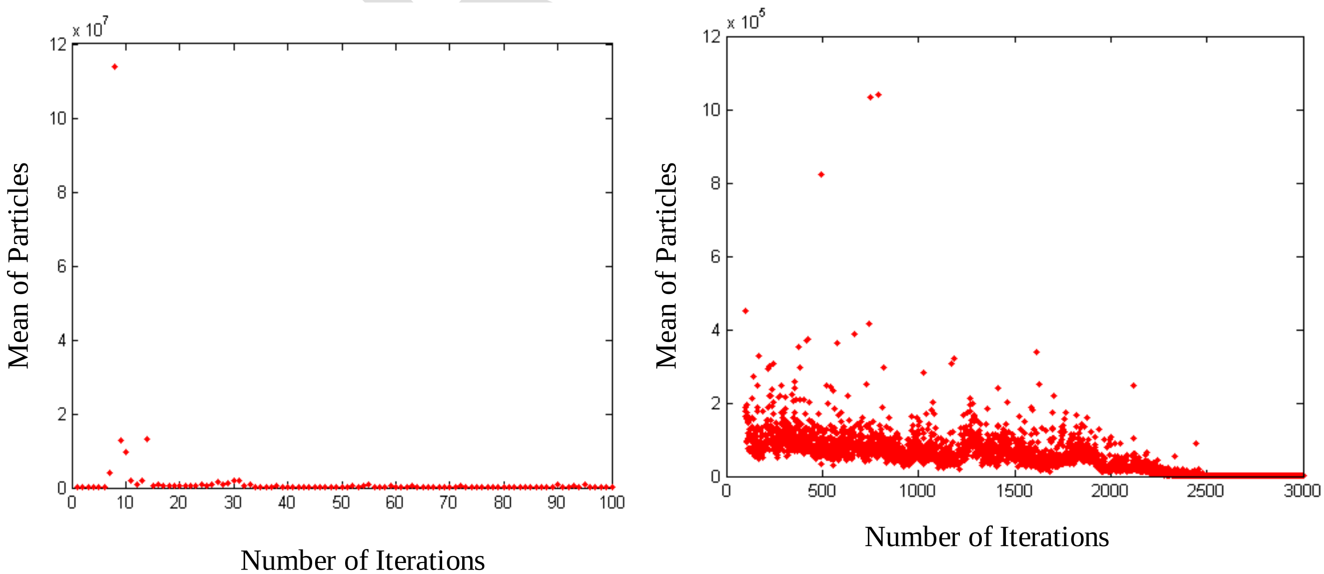

Figure 6 Mean of particles versus iteration in Absorbing Boundary Condition solution

Figure 7 shows the variance of particles versus iteration in for Absorbing Boundary Condition Solution:

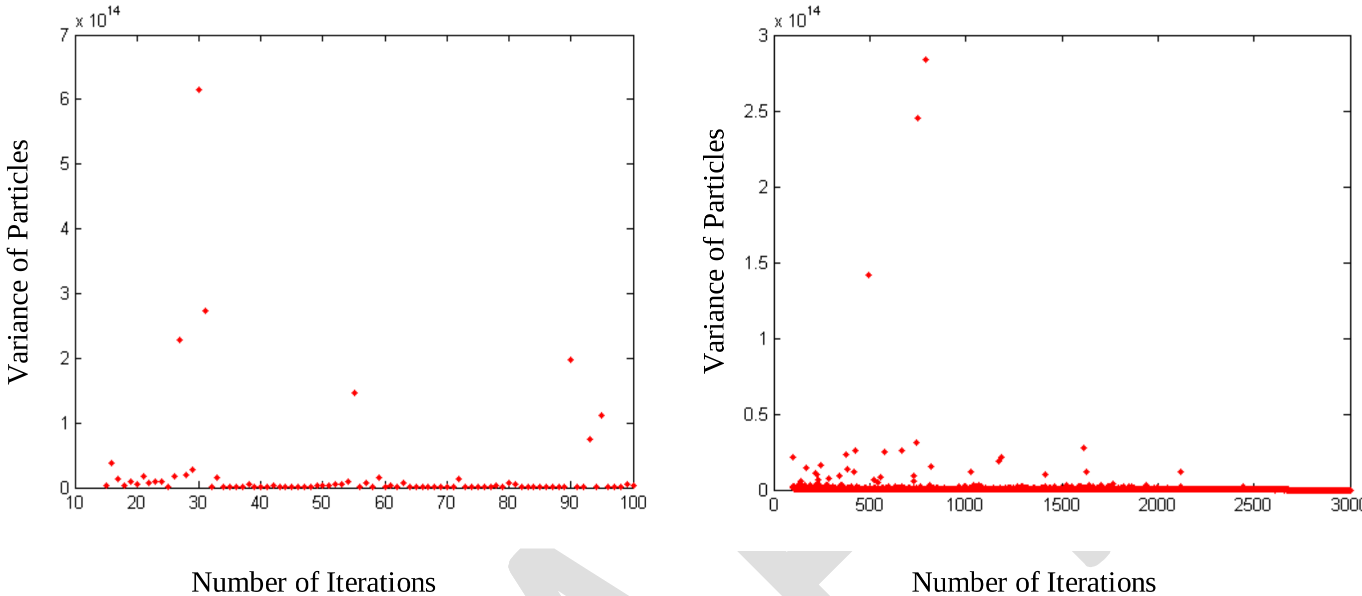

Figure 7 Variance of particles versus iteration in Absorbing Boundary Condition solution

In Figure 8 the VSWR function of the power splitter for both PSO (with Absorbing Boundary Condition) and GA solution are presented, in GA solution the maximum of VSWR in the UHF band is 1.063, and for PSO this maximum is 1.012

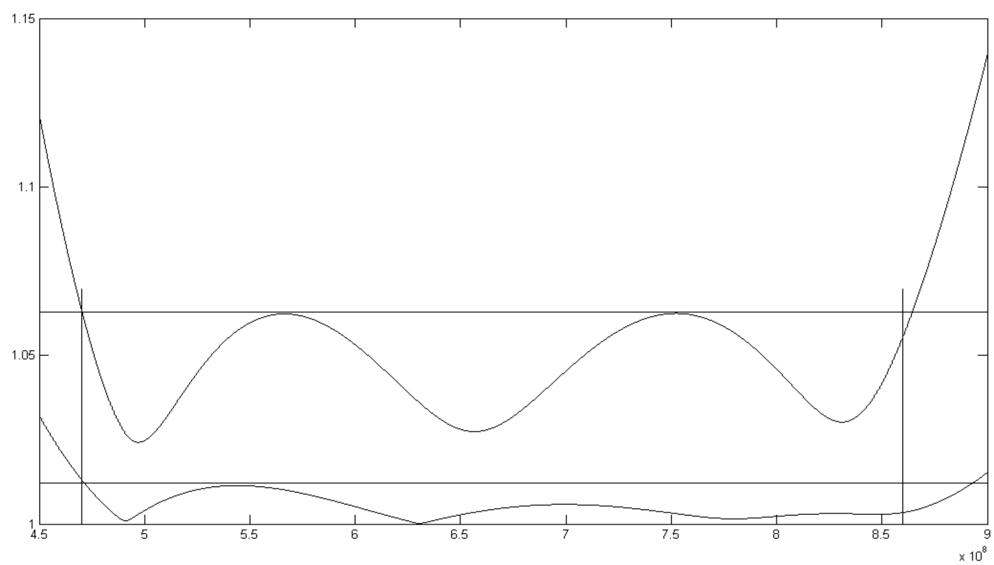

Figure8. Comparison between GA solution and PSO solution with Absorbing Boundary Condition, two vertical lines show the limits of UHF frequency band, the upper horizontal line shows the maximum of VSWR of GA solution in this band (1.063) and the other horizontal line shows this maximum for PSO solution (1.012).

3. Invisible Boundary Condition:

In this boundary condition, the particles are allowed to passes from the boundary of every dimension, but the value of such a particle will not be considered until it comes back to the solution space.

The chosen value for both c_1 and c_2 is 2.1, same the previous boundary conditions, Many runs of program show that the optimum value for inertial weight is close to 0.7

Table 4 shows the parameter values for the best solution by Invisible Boundary Condition. In this run the fitness function is minimized to 0.955.

Table.4: Solution obtain by PSO technique with Invisible Boundary Condition

Number of Section	Length of Section (mm)	Diameter of Section (mm)
1	90.02	20.70
2	63.72	22.38
3	10.03	32.96
4	69.18	23.93
5	30.18	33.53
6	79.28	29.43
7	33.98	37.78
8	44.79	30.83
9	36.24	38.04
10	42.58	34.96

Figure 11 shows the Global best movement of particles with Invisible Boundary Condition

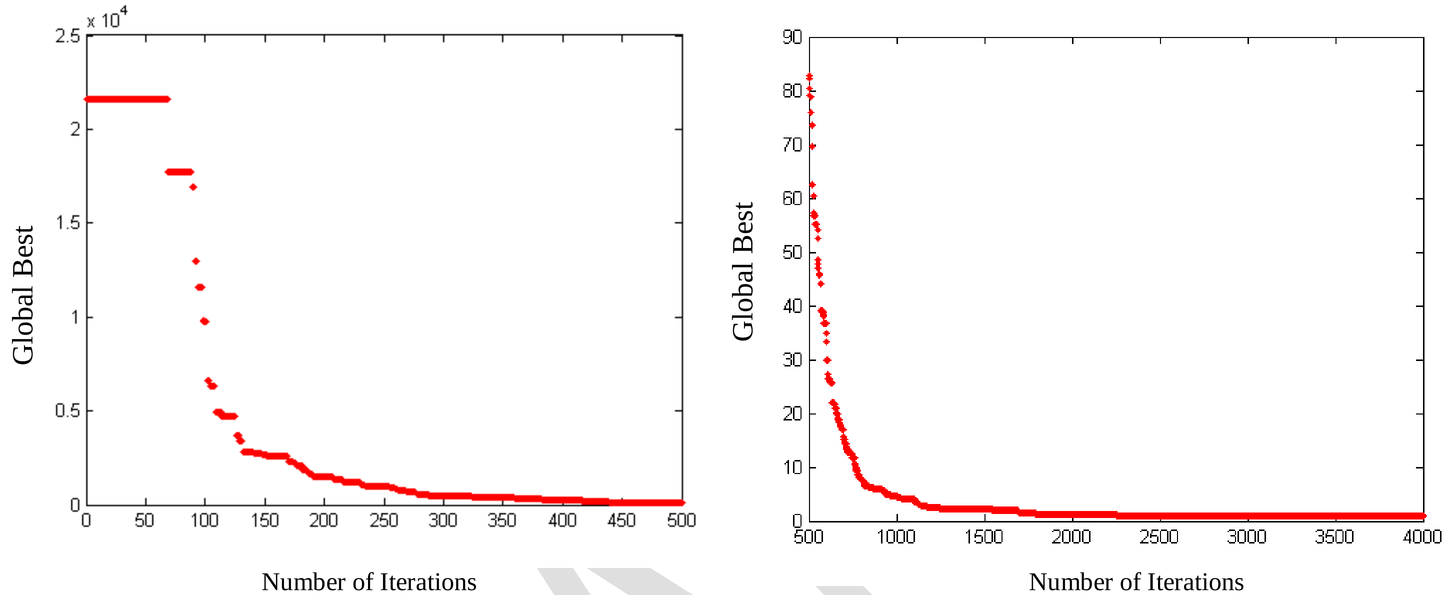

Figure11. Global Best versus iteration in Invisible Boundary Condition solution

Figure 12 show the mean of particle's fitness function versus iteration for Invisible Boundary Condition:

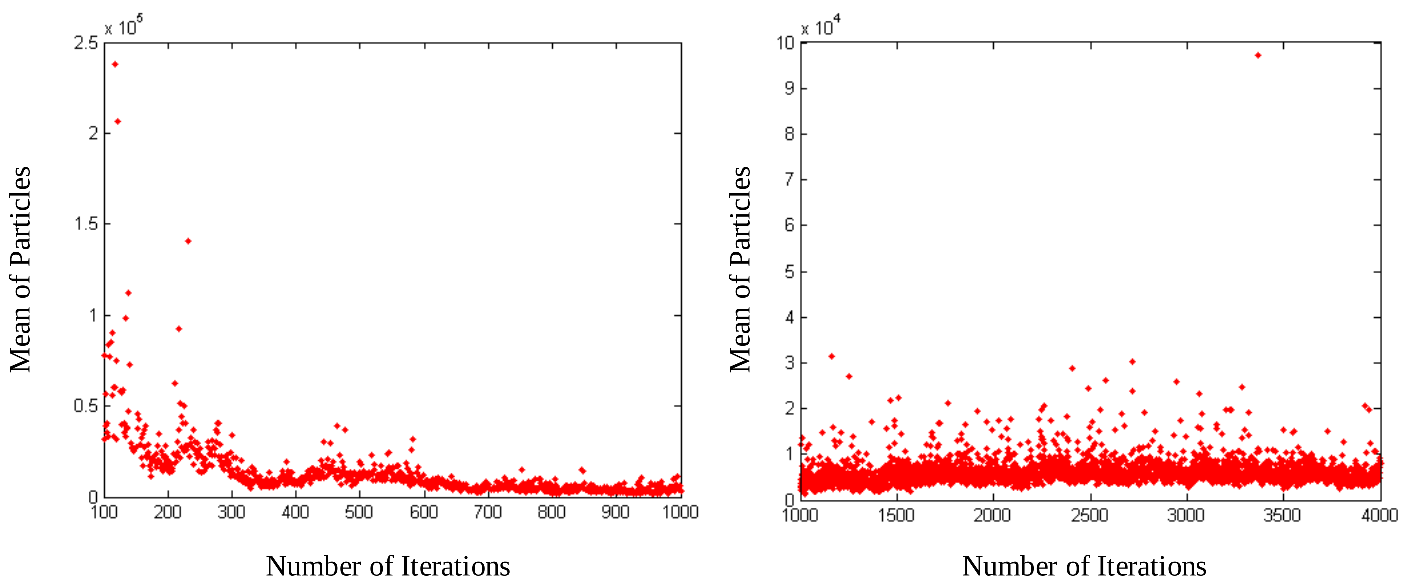

Figure 12 Mean of particles versus iteration in Invisible Boundary Condition solution

Figure 13 shows the variance of particles versus iteration in for Invisible Boundary Condition Solution:

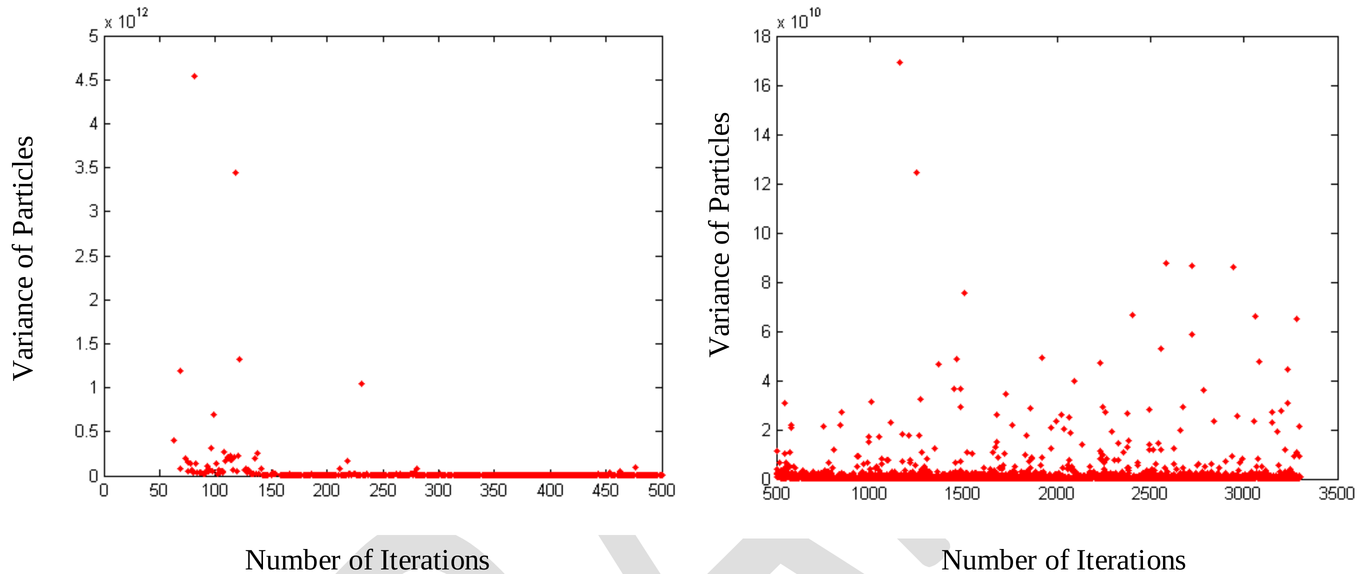

Figure 13 Variance of particles versus iteration in Invisible Boundary Condition solution

In Figure 14 the VSWR function of the power splitter for both PSO (with Invisible Boundary Condition) and GA solution are presented, in GA solution the maximum of VSWR in the UHF band is 1.063, and for PSO this maximum is 1.009

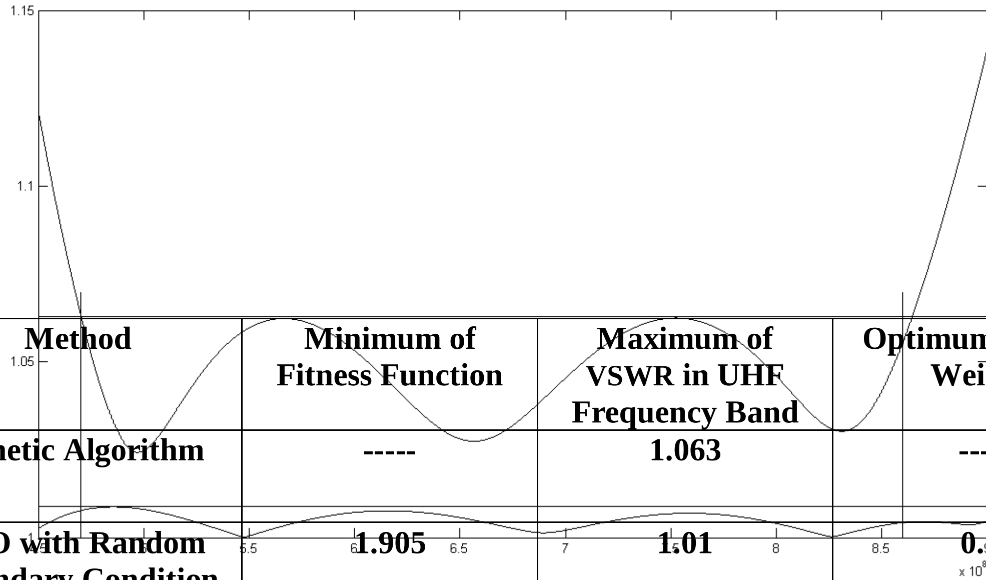

Figure14. Comparison between GA solution and PSO solution with Invisible Boundary Condition, two vertical lines show the limits of UHF frequency band, the upper horizontal line shows the maximum of VSWR of GA solution in this band (1.063) and the other horizontal line shows this maximum for PSO solution (1.009).

Table 5 compares the GA solution and PSO solution with different boundary conditions.

Method	**Minimum of Fitness Function**	**Maximum of VSWR in UHF Frequency Band**	**Optimum Inertia Weight**
Genetic Algorithm	**-----**	**1.063**	**----**
PSO with Random Boundary Condition	**1.905**	**1.01**	**0.7**
PSO with Absorbing Boundary Condition	**2.869**	**1.012**	**0.5**
PSO with Invisible Boundary Condition	**0.955**	**1.009**	**0.7**

Table5. Comparison between GA and PSO with different boundary condition

The Invisible Boundary Condition makes the best result, as it was suggested in [2], because there is no constraint for swarms and so the exploration increases.

In PSO with Absorbing Boundary Condition the optimum inertia weight is less than the others because small value of inertia weight decreases the exploration and the probability of reaching the boundary is reduced.

Average of minimum fitness function value for 5 independent simultaneous runs with Random Boundary Condition:

In the Random Boundary Condition, 5 independent swarms are searching simultaneously, the average of global best for these 5 swarms is plotted in Figure 15versus the number of iterations.

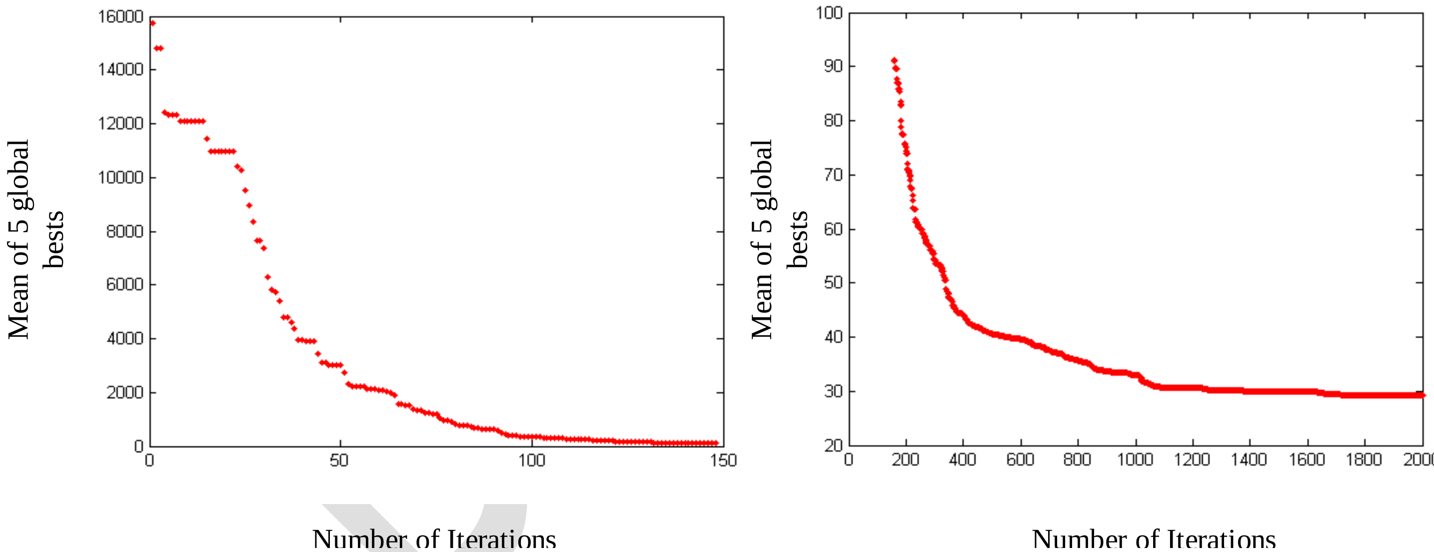

Figure15 Mean of global bests of 5 swarms

Figures 16 to 20 shows the 5 VSWR obtained by PSO and also the VSWR of GA solution.

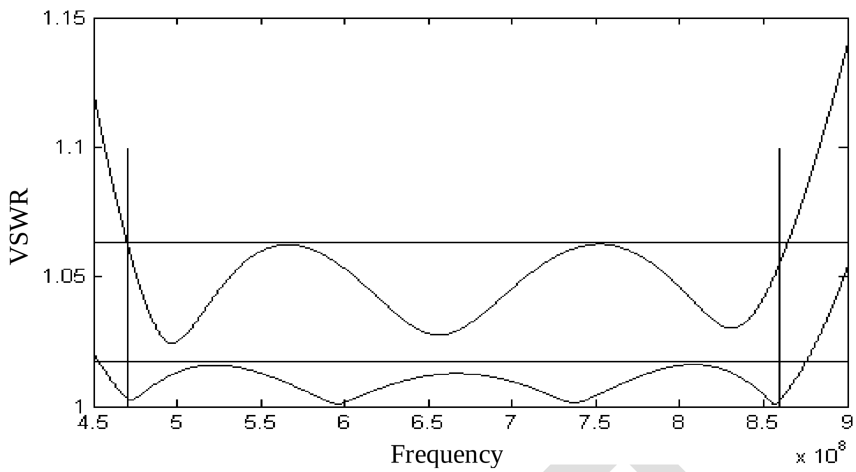

Figure16.Two horizontal lines show that maximum of VSWR for PSO solution is 1.017 and for GA is 1.063.

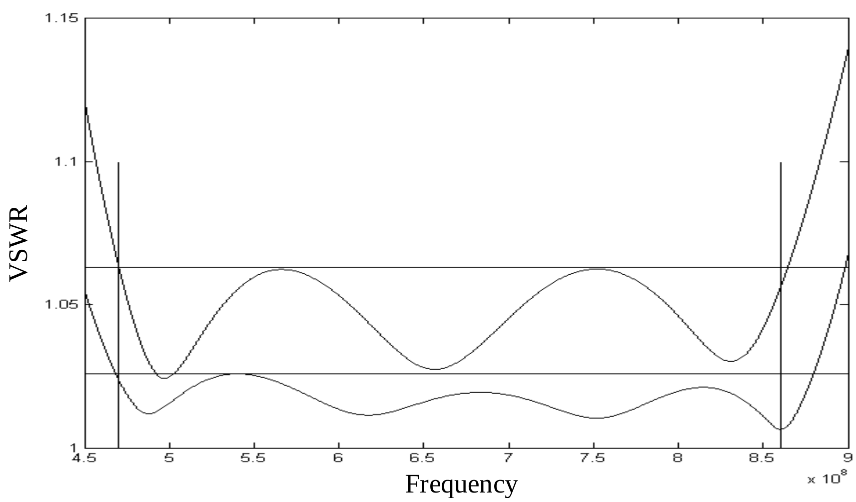

Figure17.Two horizontal lines show that maximum of VSWR for PSO solution is 1.026 and for GA is 1.063.

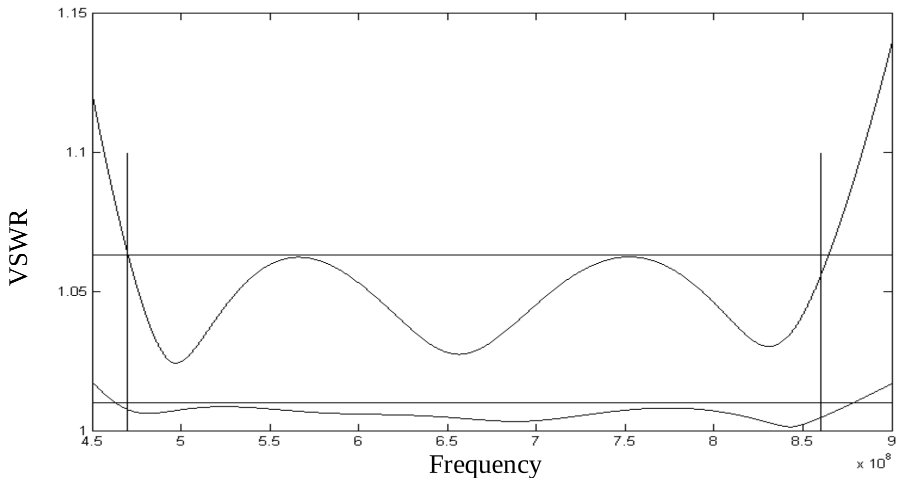

Figure18.Two horizontal lines show that maximum of VSWR for PSO solution is 1.01 and for GA is 1.063.

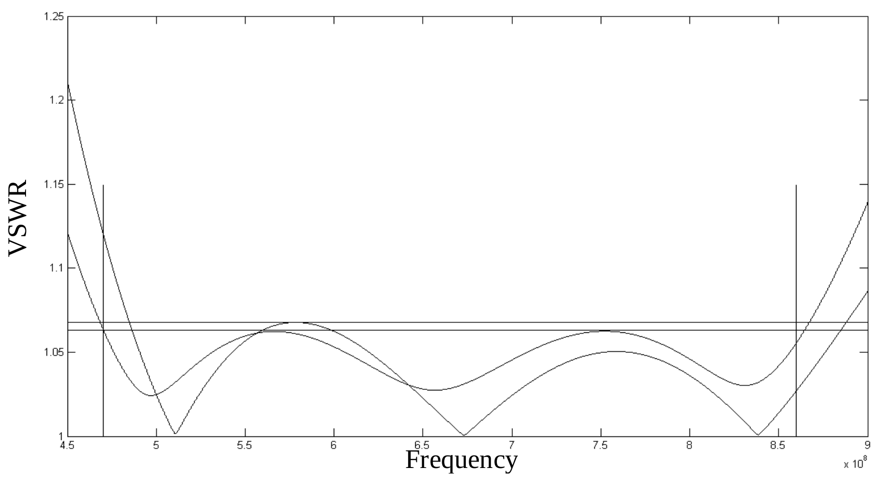

Figure19.Two horizontal lines show that maximum of VSWR for PSO solution is 1.068 and for GA is 1.063.

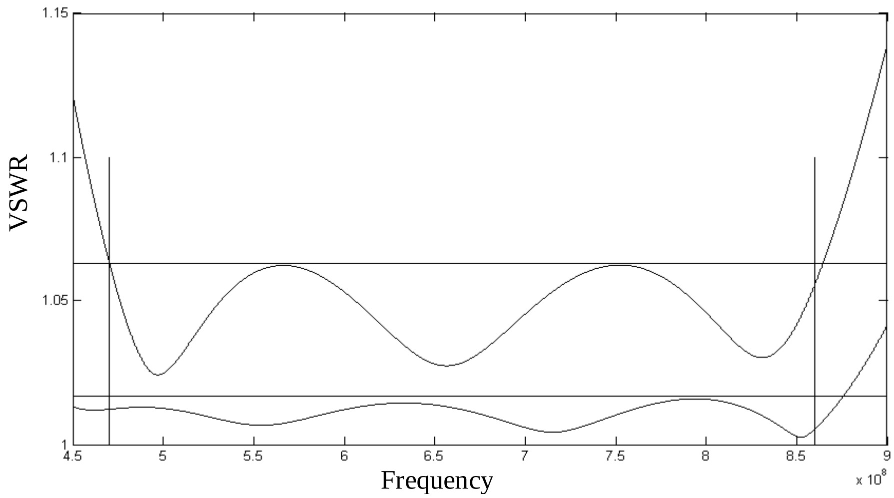

Figure20.Two horizontal lines show that maximum of VSWR for PSO solution is 1.017 and for GA is 1.063.

In the 5 solutions that obtained simultaneously, only one of them (Figure 19) is a like to GA solution, other 4 solution are better than GA.

References:

[1] A. Varahram and Jalil Rashed-Mohassel and Khalil Mafinezhad, "Design of Matching Transformers for UHF Band Power Splitter Using Modified Genetic Algorithms" 0-7803-7846-6/03/$17.00, 2003 IEEE

[2]J. Robinson and Y. Rahmat-Samii, "Particle Swarm Optimization in Electromagnetics" *IEEE Transactions on Antenna and Propagation*, Vol. 52, No.2, February 2004.

[3] Y.Shi and R. C. Eberhart, ' Emprical Study of Particle Swarm Optimization" 0-7803-5536-9/99/$10.00, 1999 IEEE

[4]. D. W. Boeringer and D. H. Werner, "Particle Swarm Optimization Versus Genetic Algorithms for Phased Array Synthesis" IEEE *Transactions on Antenna and Propagation*, Vol. 52, No. 3, March 2004