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Design of Broadband Log Periodic Dipole Antenna Using Swarm Optimization

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Abstract This paper presents an optimized design for Log Periodic Dipole Array (LPDA) for WiMAX, GSM, DCS, Wi-Fi, 3G mobile communication and Bluetooth bands. First of all, the LPDA is designed by evaluating length, diameter and spacing between dipole elements. Then, the design is optimized by using evolutionary techniques called swam optimization and it is observed that the optimized design has smaller size and better gain than the conventional LPDA design. Thus, the optimization technique provides a cost effective solution with improved characteristics for LPDA.

Keywords Log Periodic Dipole Array (LPDA), WiMAX, GSM, DCS, Wi-Fi, 3G Mobile Communication, Bluetooth, Swarm Optimization, Small Size

1. Introduction

To accommodate large number of communication channels, a frequency independent antenna design is preferred. One of the powerful methods to address a requirement is designing of Log Periodic Dipole Array (LPDA). The initial work of LPDA with its mathematical description was carried out by Isbell and Carrel[1-2]. An LPDA is a wideband antenna whose characteristics are not affected by changing the spectrum of frequencies. Therefore, it is known as frequency independent antenna[3]. It consists of N number of dipole elements having unequal length, spacing and diameter. The main task in the designing of LPDA is the evaluation of current behaviour across the dipole elements[1]. The initial work to determine the current across dipole elements is carried out by King in 1957[4].

The design of an LPDA can be optimized by employing an optimization technique. There are numerous optimization techniques such as swarm optimization, genetic algorithm, artificial neural networks, etc. are frequently applied in electromagnetic related problems. Out of those techniques, swarm optimization and its different variants are considered powerful optimization tools which offer almost guaranteed convergence for complex problems[5-6]. PSO was successfully applied in various applications such as array design[7], device modelling[8], communications[9], etc.

Previously, the design of an LPDA was presented with particle swarm optimization and genetic algorithm[10-11]. The purpose of the presented work was to increase the gain of an LPDA with the reduction in size. In this paper, the variant of swarm optimization which is Quantum Particle Swarm Optimization (QPSO) is used to optimize the physical variables of an LPDA for its potential applications in mobile communication. From the results, it is noted that the QPSO based design offers at least 12.69% improvement in gain and small size than the previously presented designs [10-11].

2. Swarm Optimization

In swarm optimization, a particle tries to get a best position which is called its personal best p_{best}. There is also a best position with respect to the entire swarm called global best g_{best}. The number of parameters to be optimized for a given problem is a dimension of a swarm. A swarm is initialized with a random positions and velocities. To avoid explosion[12], sometimes, a search space is also define to ensure the confinement of particles within the defined space. For this purpose, one can define v_{max} by using following equation

$$v_{\max} = \frac{x_{\max} - x_{\min}}{2} \tag{1}$$

Let us consider a j^{th}-dimensioanl problem with N number of particles for k^{th}-iteration. The position vector is represented by

$$x(k) = [x_1(k), x_2(k), x_3(k), \cdots, x_M(k)] \tag{2}$$

The associated velocity of these particles is represented as

$$v(k) = [v_1(k), v_2(k), v_3(k), \cdots, v_M(k)] \tag{3}$$

Optimization is achieved by updating position and

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velocity vectors by defining an appropriate objective function. The new position and velocity is referred as p_{best} and v_{pbest}. Optimization process compares the error associated with each particle and the lowest error is referred as g_{best}. The velocity of the particles is then updated by using equation which is given below[13-15].

$$v_{ij}(k+1) = \omega \times v_{ij}(k) + v_{pbest} + v_{gbest} \tag{4}$$

where

$$v_{pbest} = c_1 \times \phi_1 \times \left[p_{best_{ij}}(k) - v_{ij}(k)\right] \tag{5}$$

$$v_{gbest} = c_2 \times \phi_2 \times \left[g_{best_{ij}}(k) - v_{ij}(k)\right] \tag{6}$$

The update position vector is represented by

$$x_{ij}(k+1) = v_{ij}(k) + x_{ij}(k) \tag{7}$$

In swarm optimization, convergence depends on controlling the parameters and changing them to appropriate values. But, this is sometimes difficult especially when multiple parameters are involved in an optimization process [16]. To resolve this problem, a quantum formula for swarm optimization is suggested, where the behaviour of particles follow the quantum mechanics principle[17-18]. In QPSO, particles update their positions by using following expression

$$x_{n+1} = P \pm \chi \left|m_{best} - x_n\right| \times \ln\left(\frac{1}{u}\right) \tag{8}$$

where

$$P = \frac{c_1 \times p_{best_i} + c_2 \times g_{best}}{\phi_1 + \phi_2} \tag{9}$$

$$m_{best} = \frac{\sum_{i=1}^{M} p_{best_i}}{M} \tag{10}$$

3. LPDA Fundamental

The successive dipole elements of an LPDA are connected alternatively with a balanced transmission line called feeder as shown in Figure 1. It is a self-complementary structure because of its periodicity[6]. The length of shortest and longest dipole element is determined by the upper and lower frequency. The ratio between length and diameter of two consecutive elements of an LPDA is given by[19]

$$\tau = \frac{L_n + 1}{L_n} = \frac{d_n + 1}{d_n} \tag{11}$$

The scaling factor and the geometry of an LPDA is given by[19]

$$\sigma = \frac{2d_n}{L_n} \tag{12}$$

$$\alpha = \tan^{-1}\left[\frac{1-\tau}{4\sigma}\right] \tag{13}$$

The scaling factor τ has a value in the range $0.76 \le \tau \le 1$. By choosing an appropriate value of τ and the length of first element, the length of rest of the elements can be determined which is also defined in Equation (11). In order to get an acceptable gain, there must be an appropriate distance of dipole elements from the source and it can be calculated as

$$X_n = h_n \times \tan(\alpha) \tag{14}$$

Thus, the total length of an LPDA is given by

$$S = 2\sigma L_1 \frac{1-\tau^{N-1}}{1-\tau} \tag{15}$$

To obtain proper radiation pattern, we need to know the behaviour of current across each dipole element which can be expressed as[20]

$$[I_E] = ([Y_F][Z_E] + [U])^{-1}[I] \tag{16}$$

where,$[Z_E]$ is the impedance of dipole elements and$[Y_F]$ is the admittance of feed line. The impedance matrix$[Z_E]$ of dipole elements can be calculated by adopting different methods. The self and mutual impedance method is a very warm subject for the researchers and is given by[4]

$$[Z_E] = \begin{bmatrix} Z_{11} & \cdots & Z_{1N} \\ \vdots & \ddots & \vdots \\ Z_{N1} & \cdots & Z_{NN} \end{bmatrix} \tag{17}$$

The admittance matrix[YF] of feed line is determined by the following method.

$$[Y_F] = \begin{bmatrix} Y_{11} & Y_{12} & \cdots & \cdots & \cdots & \cdots & 0 \\ Y_{21} & Y_{22} & Y_{23} & \cdots & \cdots & \cdots & 0 \\ 0 & Y_{32} & Y_{33} & Y_{34} & \cdots & \cdots & 0 \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\ 0 & \cdots & \cdots & \cdots & \cdots & Y_{NN-1} & Y_{NN} \end{bmatrix} \tag{18}$$

To determine accurate results, the method of moment and finite element method is used. The method of moment is well defined in[21]. For the case of parallel connected dipole elements with unequal lengths, spacing and diameter, the resistance and reactance is determined by using equations as defined in[19]. The impedance of each dipole element is determined by combining the resistive and reactive components of dipole elements. As we know the impedance of dipole elements and admittance of feed line, we can evaluate current by using Equation (16). After that, it is easy to determine far-field E-plane, H-plane radiation patterns and gain of an LPDA which is as follows[20]:

$$|E| = \left|\sum_{n=1}^{N} I_{E_n}\left(\frac{\sin\theta}{\sin\beta h_n}\right)\exp\left[-j\beta|x_n|\sin\theta\right] \times \cos(\beta h_n \cos\theta) - \cos\beta h_n\right| \tag{19}$$

$$|H| = \left|\sum_{n=1}^{N} I_{E_n}\left(\frac{1}{\sin\beta h_n}\right)\exp\left[-j\beta|x_n|\cos\varphi\right] \times \left[1 - \cos\beta h_n\right]\right| \tag{20}$$

and

$$Gain = 10\log\left\{\left(\frac{60}{P_{in}}\right)\times\left|\sum_{i=1}^{N} I_E \exp^{-j\beta|X_i|} \times \left(1-\cos(\beta h_i)\right)\left(1-\sin(\beta h_i)\right)\right|\right\} \quad (21)$$

where, $P_{in} = 0.5Re\ \{[V_E]\}, [V_E] = [Z_E][I_E]$ and $\beta = 2\pi/\lambda$. Figure 2 shows electric (E-plane) and magnetic (H-plane) field patterns which are drawn using Equation (19) and (20), respectively.

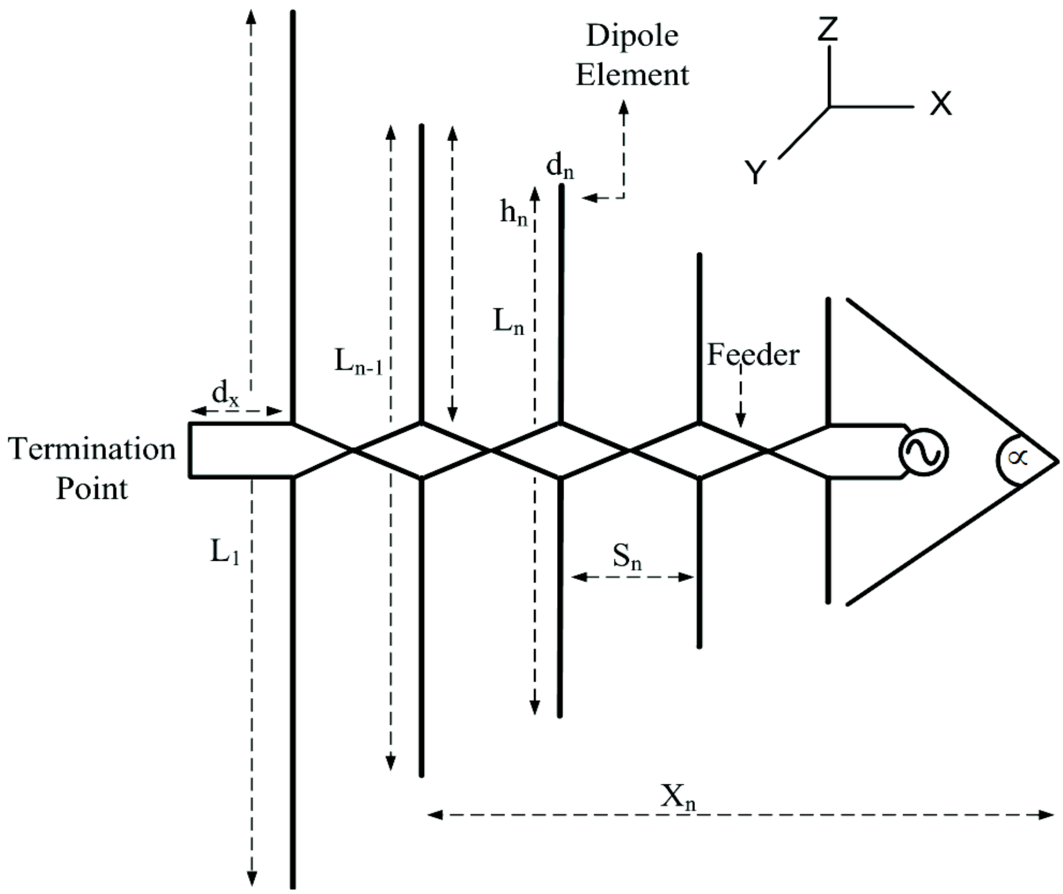


Figure 1. Design and geometry of Log-Periodic Dipole Array

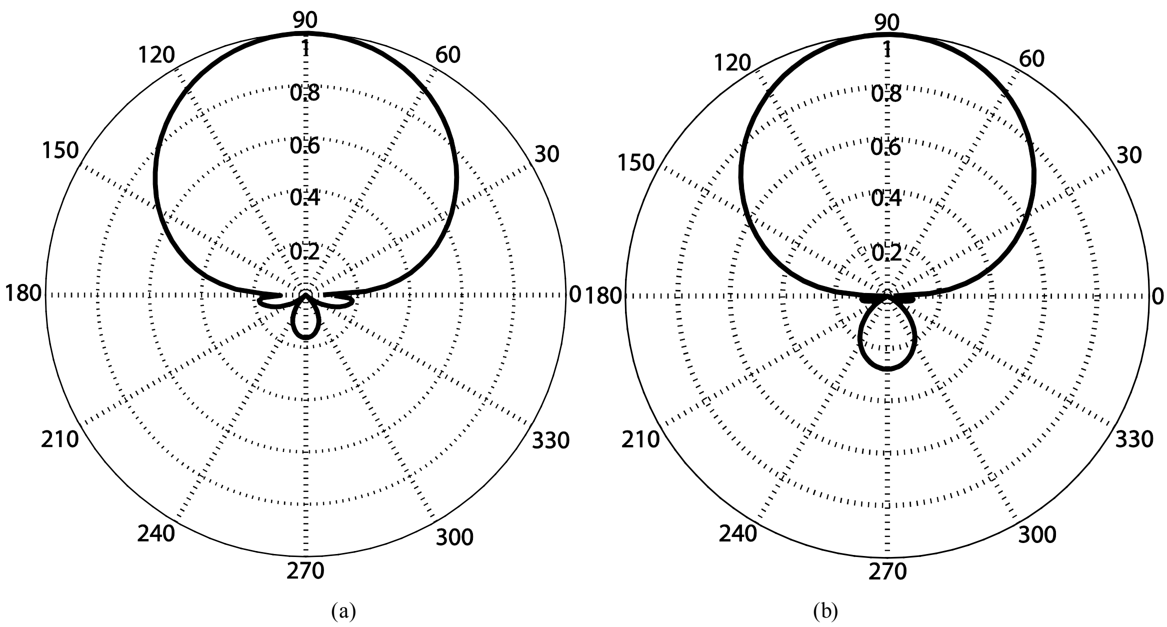


Figure 2. Radiation patterns of LPDA (a) E-plane and (b) H-plane

4. Log Periodic Dipole Array Design

Designing an LPDA for different wireless applications is a cumbersome process. The spectral band of interest in the proposed design is 400-2800 MHz. For the desired band, the conventional design parameters are listed in Table 1. The length, spacing and diameter of each dipole element are calculated by using Equations (11), (12) and (14). We choose 13 dipole elements for optimization and the initial/ conventional values of13diole elements are given in Table 2. After designing LPDA, we optimize it by using two optimization techniques which are PSO and QPSO. In order to optimize an LPDA, a fitness function is developed which based on the gain of an antenna and defined as

$$FitnessFunction = \{Gain_{opt} = Gain_{ev}; Gain_{ev} \succ Gain_{con} \quad (22)$$

where

$$Gain_{ev} = \frac{\sum_{i=1}^{K} Gain_i^{opt.} - Gain_i^{conv}}{K} \quad (23)$$

Table 1. Conventional design parameters

Serial No.	Parameters	Values
1	τ	0.9
2	σ	0.16
3	L_l	λref×0.5
4	N	13
5	L_n/a_n	125
6	Z_o	100

Table 2. Parameters used in LPDA design

Element #	L_n (m)	d_n (m)	D_n (m)	h_n (m)	X_n (m)
1	0.375	0.003	0.12	0.1875	0.0437
2	0.3375	0.0027	0.108	0.1688	0.0394
3	0.3038	0.0024	0.0972	0.1519	0.0354
4	0.2734	0.0022	0.0875	0.1367	0.0319
5	0.246	0.002	0.0787	0.123	0.0287
6	0.2214	0.0018	0.0709	0.1107	0.0258
7	0.1993	0.0016	0.0638	0.0996	0.0232
8	0.1794	0.0014	0.0574	0.0897	0.0209
9	0.1614	0.0013	0.0517	0.0807	0.0188
10	0.1453	0.0012	0.0465	0.0726	0.0169
11	0.1308	0.001	0.0418	0.0654	0.0153
12	0.1177	0.0009	0.0377	0.0588	0.0137
13	0.1059	0.0008	0.0355	0.053	0.0124

The optimizing parameters of LPDA are length, spacing and diameter. The swarm particles are initialized randomly. The initial velocity of the particles is zero and the maximum velocity is calculated by using Equation (1). The next step is to update the position and velocity of swarm particles. The two constant parameters which define the movement dynamics of the particles are c_1 and c_2. The value of c1 and c2 is 1.4 for the proposed design. The required optimized design is achieved after 100 iterations and is given in Table 3. The optimum response of gain against these parameters is shown in Figure 3 and 4.

The quantum particle swarm optimization (QPSO) is applied is applied on conventional design to analyse the behaviour of LPDA. In case of QPSO, particle position is important instead of velocity as discussed in Equation (8). QPSO algorithm is followed to observe the impact of optimization on conventional design[16]. The gain comparison with conventional and QPSO based design is shown in Figure 3 and 4.

Table 3. Optimized parameters of LPDA using PSO

Element #	L_n (m)	d_n (m)	D_n (m)	h_n (m)	X_n (m)
1	0.235	0.0027	0.108	0.1175	0.0274
2	0.2115	0.0024	0.0972	0.1058	0.0247
3	0.1903	0.0022	0.0875	0.0952	0.0222
4	0.1713	0.0020	0.0787	0.0857	0.02
5	0.1542	0.0018	0.0709	0.0771	0.0180
6	0.1388	0.0016	0.0638	0.0694	0.0162
7	0.1249	0.0014	0.0574	0.0624	0.0146
8	0.1124	0.0013	0.0517	0.0562	0.0131
9	0.1012	0.0012	0.0465	0.0506	0.0118
10	0.0910	0.0010	0.0418	0.0455	0.0106
11	0.0819	0.0009	0.0377	0.0410	0.0096
12	0.0737	0.0008	0.0300	0.0369	0.0086
13	0.00664	0.0008	0.0300	0.0332	0.0077

Table 4. Optimized parameters of LPDA using QPSO

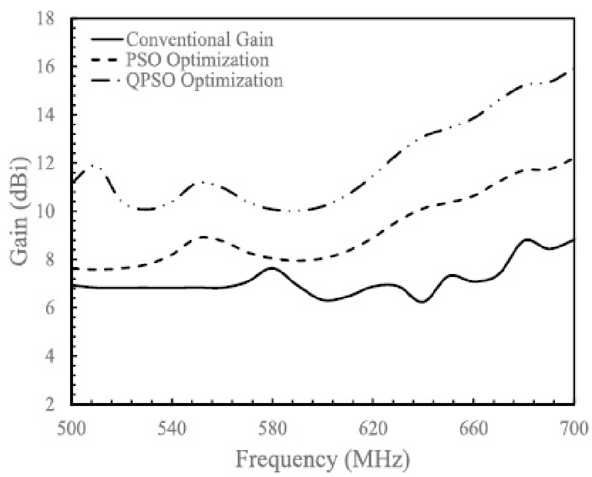
Element #	L_n (m)	d_n (m)	D_n (m)	h_n (m)	X_n (m)
1	0.24	0.0019	0.0786	0.12	0.028
2	0.216	0.0017	0.0691	0.108	0.0252
3	0.1944	0.0016	0.0622	0.0972	0.0227
4	0.175	0.0014	0.0560	0.0875	0.0204
5	0.1575	0.0013	0.0504	0.0787	0.0184
6	0.1417	0.0011	0.0453	0.0709	0.0165
7	0.1275	0.0010	0.0408	0.0638	0.0149
8	0.1148	0.0009	0.0367	0.0574	0.0134
9	0.1033	0.0008	0.0331	0.0517	0.0121
10	0.093	0.0007	0.0298	0.0465	0.0108
11	0.0837	0.0007	0.0268	0.0418	0.0098
12	0.0753	0.0006	0.0241	0.0377	0.0088
13	0.0678	0.0005	0.0235	0.0339	0.0079

It is clear from the figures that the gain is improved by using PSO and QPSO optimization techniques. The average gain values of the conventional design, PSO and QPSO based designs are given in Table 4 and the percentage improvement in gain is given in Table 5. One thing is noted from Figure 4(a) and (b) that at higher frequencies PSO optimized gain is better than the QPSO optimized gain.

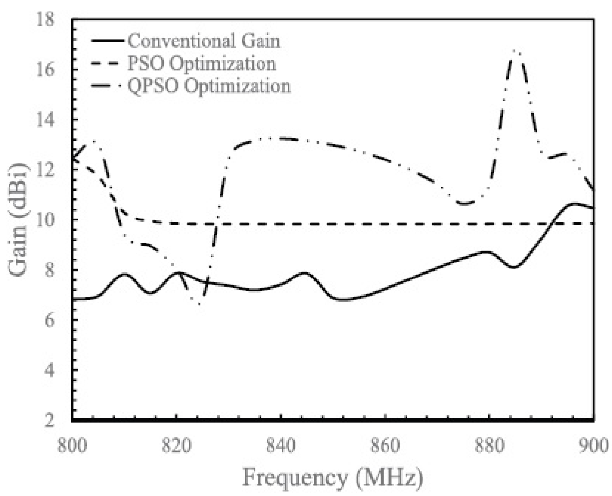
Another important factor considered the designing of LPDA is its physical size. It is observed that PSO and QPSO techniques reduced the physical size of LPDA and the optimized values are given in Table 3 and 4. The reduction in size tends to the ease of implementation and provides cost effective solution.

Table 5. Comparison between PSO and QPSO based designs

Frequency Bands	Frequency (MHz)	Percentage Improvement PSO	Percentage Improvement QPSO
WiMAX	500-700	20.93	39.45
GSM	800-900	21.44	32.85
DCS	1800-1900	15.85	14.26
3G, Wi-Fi and Bluetooth	2200-2600	12.69	11.11

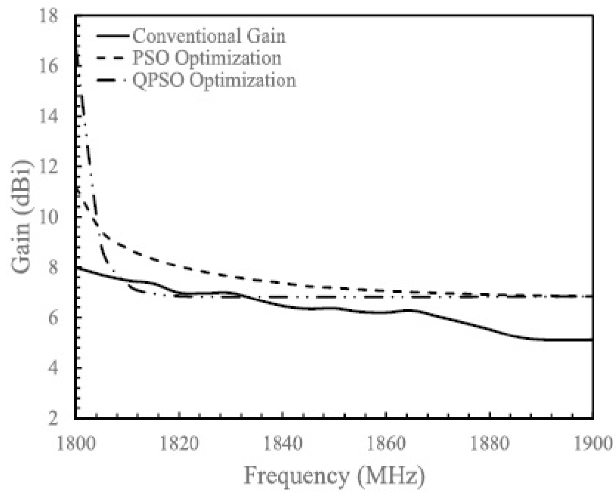


(a)

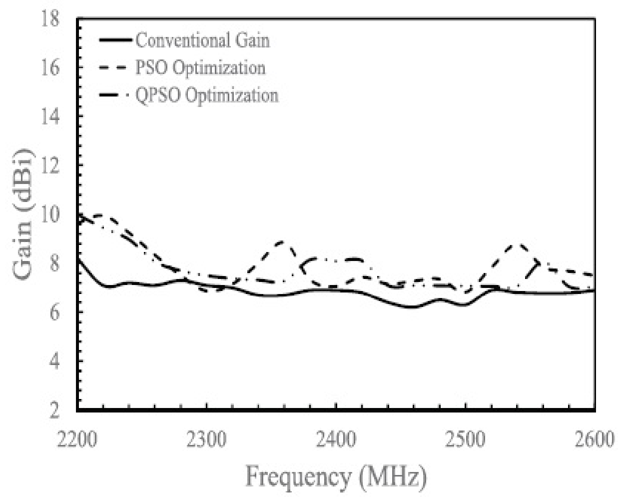


(b)

Figure 3. Conventional and optimized gain for (a) WiMAX and (b) GSM frequency bands



(a)



(b)

Figure 4. Conventional and optimized gain for (a) DCS and (b) Wi-Fi,, 3G mobile and Bluetooth frequency bands

5. Conclusions

A Log Periodic Dipole Antenna (LPDA) is designed by using conventional technique for microwave communication bands. The response as a gain is observed against the spectral band. After that the design is optimized by using stochastic techniques called PSO and QPSO. It is observed from the comparative optimized results that optimized design improved the gain for each frequency band compared to the conventional design. It is also noted that the optimized design is much smaller as compared to the conventional design.

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Nomenclature

x_i	i^{th} Particle position
v_i	i^{th} Particle velocity
x_{max}	Maximum position
x_{min}	Minimum position
v_{max}	Maximum velocity
c_1	Cognitive component
c_2	Social component
ϕ_1, ϕ_2	Random numbers
χ	Random selected spacing factor
ω	Inertia weight
k	Number of iterations
M	Number of particles in swarm
v_{pbest}	Personal best velocity
v_{gbest}	Global best velocity
j	dimension of problem
τ	Scaling factor
σ	Spacing factor
α	Geometry of LPDA
N	Number of dipole elements
L_n	Length of n^{th} dipole element
X_n	Distance from source to nth dipole element
h_n	Half-length of n^{th} dipole element
D_n	Spacing between elements
d_n	Diameter of n^{th} dipole element
I_E	Current across dipole elements
Z_E	Impedance of dipole element
Y_F	Admittance of feeder line

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