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# DESIGN OPTIMIZATION OF A BOW-TIE ANTENNA FOR 2.45 GHz RFID READERS USING A HYBRID BSO-NM ALGORITHM

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**Abstract**—Recently the Bacterial foraging optimization algorithm (BFA) has attracted a lot of attention as a high-performance optimizer. This paper presents a hybrid approach involving Bacterial Swarm Optimization (BSO) and Nelder-Mead (NM) algorithm. The proposed algorithm is used to design a bow-tie antenna for 2.45 GHz Radio Frequency Identification (RFID) readers. The antenna is analyzed completely using Method of Moments (MoM), then the MoM code is coupled with the BSO-NM algorithm to optimize the antenna. The simulated antenna and the optimization algorithm programs were implemented using MATLAB version 7.4. To verify the validity of numerical simulations, the results are compared with those obtained using Feko Software Suite 5.3.

## 1. INTRODUCTION

During the last decades various optimization techniques like Genetic Algorithm (GA), Ant Colony Optimization (ACO), Particle Swarm Optimization (PSO), and Bees Algorithm (BA) [1–7] in addition to many hybrid optimization methods [8–10] have been used for optimizing parameters in the antenna and antenna arrays problem. Each of these methods has its own pros and cons. An alternative method known as Bacteria Foraging Algorithm (BFA) that is based on the foraging behavior of Escherichia Coli (E. Coli) bacteria present in the human intestine [11] has already been in use to many engineering problems including antenna design and antenna arrays [12–17]. In [12],

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authors have shown that the BFA is better than the PSO in terms of convergence, robustness and precision. Paper [13] has illustrated the faster settling time and higher robustness with BFA-PID (proportional-integral-derivative) controller. The interference suppression of linear antenna arrays by amplitude-only control is introduced in [14] using BFA. In [15], the Bacterial Foraging Algorithm (BFA) is used to optimize the included angle of symmetrical V-dipole for higher directivity. An improved adaptive approach involving BFA is proposed in [16] to optimize both the amplitude and phase of the weights of a linear array of antennas for maximum array factor at any desired direction and nulls in specific directions. In [17], the BFA is used to calculate the resonant frequency and the feed point of a microstrip patch antenna.

Moreover, some modification of BFA is done for faster convergence. Firstly, the BFA is oriented by Particle Swarm Optimization (PSO) to combine both algorithms' advantages, which is called the BSO algorithm. This combination aims to make use of the PSO ability to exchange social information and the BFA ability in finding a new solution by elimination and dispersal [18–20]. The hybrid approach involving PSO and BFA algorithm is introduced in [18] for optimizing multi-modal and high dimensional functions. It is found that, the overall performance of the BSO algorithm is definitely better than the standalone BFA on the numerical benchmarks tested and at least comparable with PSO and its variants. In [19], the BF algorithm Oriented by PSO Strategy technique is applied to the PID parameter tuning for a set of test plants. Simulation results demonstrated that the proposed algorithm out performed both conventional PSO and BFA algorithms. Also, the performance of the BFA-PSO was investigated on 23 numerical benchmark functions in [20]. The simulation results show that the BFA oriented by PSO strategy greatly improved the optimization performance of the BFA.

In addition, a hybrid approach consisting of GA and BFA is presented in [21]. The performance is illustrated using various test functions and for tuning a PID controller of an automatic voltage regulator (AVR) system. It is found that, the hybrid system GA-BFA performed very well. In [22], a novel stochastic optimization approach to solve constrained economic load dispatch problem using hybrid bacterial foraging technique and Nelder-Mead algorithm is presented. The proposed approach has produced results comparable or better than those generated by other evolutionary algorithms and the solutions obtained have superior solution quality and good convergence characteristics.

The idea of Radio Frequency Identification (RFID) of objects and remote control of devices was first introduced in 1948 by H. Stockman [23]. In recent years, RFID has been widely used in service industries as an automatic identification tool [24]. A basic RFID system comprises a radio-scanner unit, called reader, and a set of remote transponders, denoted as tags, which include an antenna and a microchip transmitter with internal read/write memory. Several frequency bands have been standardized for this technology, low frequency (LF, 125–134 kHz), high frequency (HF, 13.56 MHz), ultra-high frequency (UHF, 860–960 MHz) and microwave (2.4 GHz and 5.8 GHz). The systems using the UHF band and 2.45 GHz band are believed suitable for long-distance communication utilizing a passive type RFID [25, 26]. However, because the UHF band overlaps with the frequency of a cellular phone, the UHF band is not preferable. Therefore, the 2.45 GHz band is preferred [25]. Several papers have been published on designing RFID antennas [27–29]. In [27], a miniaturized printed dipole antenna with the V-shaped ground is proposed for RFID readers operating at the frequency of 2.45 GHz. A compact folded printed dipole antenna for UHF RFID reader is presented in [28]. In [29] the GA is used to design a UHF RFID bow-tie tag antenna. Bow-tie antennas have many advantages such as low profile, high radiation efficiency, ease of manufacturing and low fabrication cost. Therefore, the bow-tie antennas are suitable to be used as RFID antennas for various applications.

In this paper, a simple algorithm called Nelder-Mead, which is a local optimization technique, is used along with the BSO algorithm, which is a global optimization technique, in order to explore the search space for finding the local minima of the location obtained by global minima. The hybrid BSO-NM algorithm is used to adjust the dimensions of the bow-tie antenna to be resonant at 2.45 GHz for a matched input impedance ($Z_{in}$) of 50 Ω. The performance of the designed antenna is assessed using a full EM analysis based on the method of moments (MoMs) [30]. The BSO-NM algorithm and the simulated antenna was implemented using MATLAB-Software version 7.4. To verify the validity of numerical simulations, the results are compared with those obtained using Feko Software Suite 5.3 [31].

The organization of the present paper is as follows. Section 2, provides a brief literature overview of the proposed hybrid approach based on Bacterial Swarm Optimization (BSO) and Nelder-Mead (NM) algorithms. In Section 3, the antenna design is explained. Numerical results are discussed in Section 4. Finally, Section 5 presents the conclusions.

## 2. A HYBRID BACTERIAL SWARM OPTIMIZATION AND NELDER-MEAD (BSO-NM) ALGORITHM

### 2.1. Nelder-Mead (NM) Algorithm

A simplex method for finding a local minimum of a function of several variables has been devised by Nelder and Mead [32]. It is the most popular direct search method since it does not require the calculation of derivatives. The Nelder-Mead method is described for the minimization of a function of $n$ variables, which depends on the comparison of function values at the $(n + 1)$ vertices of a general simplex. The function values are found at each of these points. The points with the low $(P_L)$, high $(P_1)$, and second high $(P_2)$ function values are determined. Next, the centroid of the points except $P_1$, $\bar{P}$, is determined to replace the vertex with the highest value by another point. The simplex method essentially has four steps possible during each iteration: Reflection, contraction in one dimension, contraction around the low vertex, and expansion. The basis for each step is provided here:

**Reflection:** A reflected point, $P_R$, is found by reflecting $P_1$ through $\bar{P}$ with the equation

$$P_R = (1 + \alpha)\bar{P} - \alpha P_1$$

where $\alpha$ is the reflection factor ($\alpha = 1$). $P_R$ replaces $P_1$ if $f(P_L) < f(P_R) < f(P_1)$.

**Expansion:** if $f(P_R) < f(P_L)$ then the simplex grows along the centroid direction with the hope that the expansion point, $P_E$, is better than $P_L$. The expansion is determined with the equation

$$P_E = (1 - \gamma)\bar{P} - \gamma P_R$$

where $\gamma$ is the expansion factor ($\gamma = 2$). $P_E$ replaces $P_1$ if $f(P_E) < f(P_L)$.

**1D Contraction:** if $f(P_R) > f(P_2)$ then the simplex contracts along the centroid direction with the hope that the contracted point, $P_C$, is better than $P_2$. The 1D contraction is determined with the equation

$$P_C = (1 - \beta_1)\bar{P} + \beta_1 P_0$$

where $\beta_1$ is the 1D contraction factor ($\beta_1 = 0.5$) and $P_0$ is the selection of $P_1$ or $P_R$ which has the lowest function value. $P_C$ replaces $P_1$ if $f(P_C) < f(P_0)$.

**Full contraction:** if $f(P_C) > f(P_0)$ then 1D contraction does not suffice, and the whole simplex is contracted around $P_L$. The full contraction is determined with the equation

$$P_i = (1 - \beta_2)P_L + \beta_2 P_i$$

where $\beta_2$ is the full contraction factor ($\beta_2 = 0.5$) and $P_i$ represents all the points except $P_L$. Typically, when a point replaces $P_1$ the current iteration is completed. Next the termination condition is checked. If the tolerance is not met then the next iteration is started.

## 2.2. Bacterial Swarm Optimization (BSO) Algorithm

The idea of BFA is based on the fact that natural selection tends to favor animals having successful foraging strategies and eliminate animals with poor foraging strategies or reshape into good ones after many generations. This activity of foraging inspired the researchers to utilize it as a novel optimization tool. The Escherichia coli bacteria present in human intestines also practice a foraging strategy. The control system of the E. coli bacteria governing their foraging process can be subdivided into four sections, which are chemotaxis, swarming, reproduction and elimination and dispersal [11–16]. The BSO algorithm combines PSO [33] and BF techniques in order to make use of PSO ability to exchange social information and BF ability in finding a new solution by elimination and dispersal. Where, after undergoing a chemotactic step, each bacterium also gets mutated by a PSO operator. In BFA, a unit length direction of tumble behavior is randomly generated; random direction may lead to delay in reaching the global solution. However, in the BSO, the unit length random direction of tumble behavior is decided by the global best position and the best position of each bacterium. During the chemotaxis loop, the update of the tumble direction is determined by:

$$\varphi(j+1) = \omega * \varphi(j) + C_1 * R_1 * (P_{lbest} - P_{current}) + C_2 * R_2 * (P_{gbest} - P_{current})$$

where $P_{lbest}$ is the best position of each bacterial and $P_{gbest}$ is the global best bacterial. $C_1$, and $C_2$ are the acceleration constants, which represent the weighting of stochastic acceleration terms that pull each particle towards personal and global positions. $R_1$, and $R_2$ are two random numbers in the range $[0, 1]$, $\omega$ is the inertia weight introduced to balance between the global and local search abilities. The brief pseudo-code of the hybrid BSO-NM algorithm has been provided below:

**[Step 1] Initialization**: Parameters Setting.

- $p$: Dimension of the search space.
- $S$: The number of bacteria in the population.
- $N_c$: Chemotactic steps.
- $N_s$: Swimming length.
- $N_{re}$: The number of reproduction steps.

- $N_{ed}$: The number of elimination-dispersal events.
- $S_r$: The number of bacteria reproductions (splits) per generation $(S/2)$
- $P_{ed}$: The probability that each bacteria will be eliminated-dispersed.
- $C(i)$ $(i = 1, 2, \ldots, S)$: The size of the step taken in the random direction specified by the tumble.
- $P(j, k, l) : P(j, k, l) = \{\theta^i(j, k, l)\ i = 1, 2, \ldots, S\ \}$.
- Generate a random vector $\varphi(j)$ which elements lie in $[-1, 1]$.
- $C_1$, $C_2$, $R_1$, $R_2$, $\omega$: PSO parameters.

[**Step 2**] **Elimination Dispersal loop:** $l = l + 1$.
[**Step 3**] **Reproduction loop:** $k = k + 1$.
[**Step 4**] **Chemotaxis loop:** $j = j + 1$.

[**substep a**] For $i = 1, 2, \ldots, S$, take a chemotactic step for every bacterium $(i)$.

[**substep b**] Compute fitness function: $J(i, j, k, l)$, then let $J_{last} = J(i, j, k, l)$.

[**substep c**] **Tumble:** Let

$$\begin{aligned}\varphi(j+1) \ = \ & \omega * \varphi(j) + C_1 * R_1 * (P_{lbest} - P_{current}) \\ & + C_2 * R_2 * (P_{gbest} - P_{current})\end{aligned}$$

[**substep d**] **Move:** Let $\theta^i(j + 1, k, l) = \theta^i(j, k, l) + C(i)\varphi(j)$ Compute fitness function: $J(i, j, k, l)$.

[**substep e**] **Swim:** Let $m = 0$; while $(m < N_s)$

- let $m = m + 1$;
- if $J(i, j + 1, k, l) < J_{last}$
  Let $J_{last} = J(i, j + 1, k, l)$,
  Let $\theta^i(j + 1, k, l) = \theta^i(j, k, l) + C(i)\varphi(j)$,
  Compute fitness function: $J(i, j + 1, k, l)$,
- Else let $m = N_s$:

[**substep f**] Go to next bacterium $(i+1)$.

[**Step 5**] If $(j < N_c)$, go to **Step 4**.
[**Step 6**] **Reproduction:**

[**substep a**] For the given $k$ and $l$, and for each $i = 1, 2, \ldots, S$, let

$$J^i_{health} = \sum_{j=1}^{N_c+1} J(i, j, k, l)$$

be the health of the bacteria. Then sort bacteria in order of ascending values $(J_{health})$.

[**substep b**] The $S_r$ bacteria with the highest $J_{health}$ values die and the other $S_r$ bacteria with the best values split and the copies that are made are placed at the same location as their parent.

[**Step 7**] If $(k < N_{re})$, go to **Step 3**.
[**Step 8**] **Elimination-dispersal:** Eliminate and disperse bacteria with probability $P_{ed}$.
[**Step 9**] If $(l < N_{ed})$, go to **Step 2**.
[**Step 10**] **Call Nelder-Mead Algorithm**.
[**Step 11**] **End**.

It should be noted that the number of steps allowed for swimming $N_s$, in a chemotactic loop with $N_c$ iterations, is not allowed to be large to avoid trap in local minima. Therefore the parameter setting of the BFA and BSO algorithm is summarized as follows. The number of chemotactic steps $N_c = 2$; swimming length $N_s = 2$; the number of reproduction steps $N_{re} = 1$; the number of elimination-dispersal events $N_{ed} = 1$; the probability of elimination-dispersal $P_{ed}$ which used to disperse to a new location is assumed to be 0.25 as standard value; the length of steps during runs $C(i) = 0.1$. In case of the BSO algorithm the best-suitable set of parameters after a series of hand tuning experiments have been chosen [18] (the acceleration factors $C_1$ and $C_2$ were both 1.494, and a decaying inertia weight $\omega$ is 0.8). The population size $S = 100$; however, when the hybrid BFA-NM and BSO-NM algorithms are used the bacteria size is decreased to $(S = 50)$ to keep the same evaluation values. To make the comparison fair, the populations for all the considered algorithms were initialized using the same random seeds.

## 3. ANTENNA DESIGN

The bow-tie antenna is made from a bi-triangular sheet of metal with the feed at its vertex. Figure 1 shows the geometry of the bow-tie antenna with a half-height $(h)$, feeding neck width $(d)$, and flare angle $(\alpha)$. To test our basic program, the Feko Software Suite 5.3 is used to implement a bow-tie antenna with a half-height $(h = 10\,\text{cm})$, feeding neck width $(d = 1\,\text{cm})$, and flare angle $(\alpha = 90^\circ)$. Figure 2 illustrates the reflection coefficient $|S_{11}|$ in dB for the bow-tie antenna using our basic program and the Feko Software. It is clear that the results obtained from our program match those obtained via the Feko Software.

This paper deals with a bow-tie antenna design with performant algorithms (BFA and BSO) then a hybrid BFA-NM and BSO-NM algorithms are applied to illustrate the capability of the proposed BSO-NM algorithm as an optimization technique in antenna design. In this

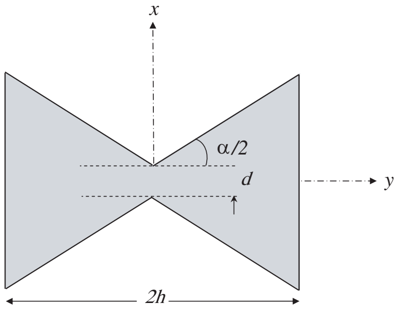


**Figure 1.** Geometry of bow-tie antenna.

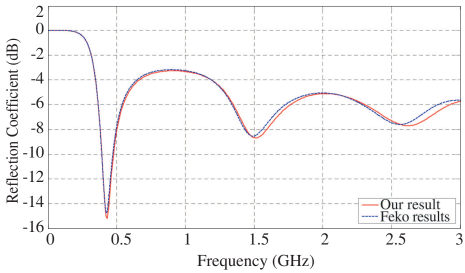


**Figure 2.** Reflection coefficient comparison between our result and Feko result for a bow-tie antenna ($h = 10\,\text{cm}$, $d = 1\,\text{cm}$, and $\alpha = 90°$).

paper the dimensions of a bow-tie antenna ($h$, $d$, and $\alpha$) are optimized to make it resonant at a center frequency of 2.45 GHz. The half-height ($h$) is changed from 1 mm to 25 mm, the feeding neck width ($d$) will change from 0.1 mm to 5 mm, and the flare angle ($\alpha$) from 45° to 90°. It should be noted that, as the boundaries for each variable increase, the algorithm requires more time for convergence.

For bow-tie antenna design problem, the $p$-dimensional position vector is mapped to 3 parameters ($h$, $d$, and $\alpha$). In the beginning, a population of $S$ bacterial is generated with random positions (values) in the range of the solution space. Then a random run length is assigned to each bacterium. As in all evolutionary computation techniques, there must be some function or method to evaluate the goodness of a position. The fitness function must take the position and return a single number representing the value of that position. In this paper the required cost function is to minimize the reflection coefficient at 2.45 GHz for matched input impedance ($Z_{in}$) of 50 Ω.

$$\text{objective function} = |S_{11}| \tag{1}$$

By obtaining the fitness values, it will be simple to move each bacterium to its next location. After this process is carried out for each bacterium, the process is repeated until the number of iteration is finished. In case of using a hybrid algorithm, the Nelder-Mead will start with ($h$, $d$, and $\alpha$) values which gave a minimum cost function either in BFA or BSO algorithm.

## 4. NUMERICAL RESULTS

Table 1 illustrates a comparison between the resulting values of $|S_{11}|$ obtained using BFA, BSO, BFA-NM, and BSO-NM algorithms at 2.45 GHz. Also, the table illustrates the optimized antenna dimensions for each algorithm. Figure 3 shows a comparison between the resulting values of $|S_{11}|$ employing the different evolutionary algorithm techniques. It can be seen from Table 1 and Figure 3 that the BSO-NM technique provided better results compared with other reported evolutionary algorithm techniques. It required about 20 min for both BFA-NM and BSO-NM on a Dell Latitude D530 (Core 2 Due Intel Processor 2 GHz, 2 GHz RAM) to get the result.

The input impedance frequency response for the optimized bowtie antenna using BSO-NM ($h = 21.078$, $d = 3.4818$, and $\alpha = 48.555°$) at 2.45 GHz is shown in Figure 4. It is clear that the obtained input resistance is 50 Ω with an input reactance of 0 Ω. Figure 5(a) shows a

**Table 1.** A comparison between the resulting values of $|S_{11}|$ and Gain obtained using different optimization techniques at 2.45 GHz.

| | Optimization Technique | | | |
|---|---|---|---|---|
| | BFA | BSO | BFA-NM | BSO-NM |
| $h$ (mm) | 20.989 | 21.029 | 21.089 | 21.078 |
| $d$ (mm) | 2.8358 | 2.2538 | 3.356 | 3.4818 |
| $\alpha$ (deg) | 46.8 | 45.05 | 48.025 | 48.555 |
| $S_{11}$ (dB) | −39.24 | −44.49 | −106.17 | −111.96 |

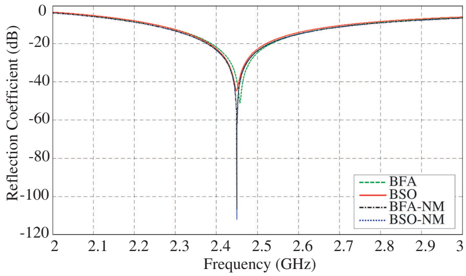


**Figure 3.** Reflection coefficient comparison for optimized bow-tie antenna using BFA, BSO, BFA-NM, BSO-NM algorithms.

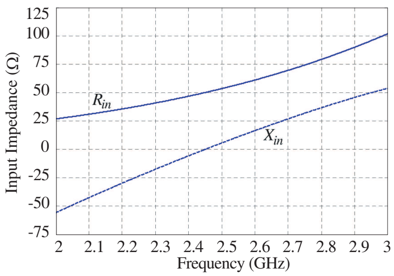


**Figure 4.** Input impedance versus frequency for an optimized bowtie antenna using BSO-NM ($h = 21.078$, $d = 3.4818$, and $\alpha = 48.555°$).

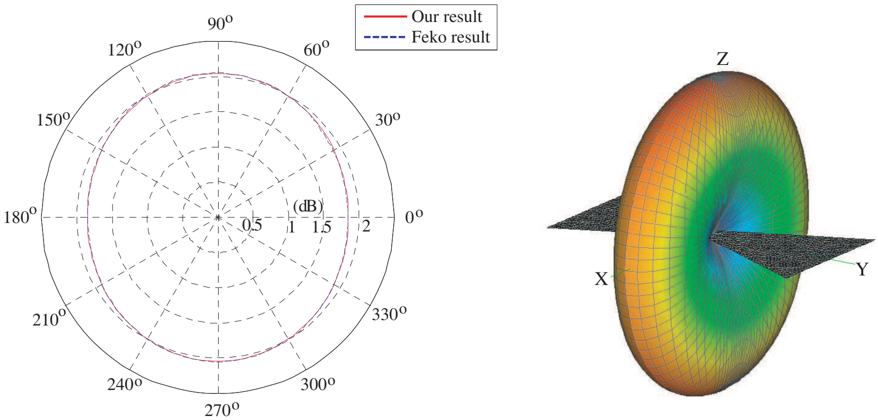


**Figure 5.** (a) A comparison between the resulting gain radiation pattern in $x$-$z$ plane employing the MoM-based Feko technique and the results obtained via our program for optimized bow-tie antenna using BSO-NM ($h = 21.078$, $d = 3.4818$, and $\alpha = 48.555°$) at 2.45 GHz. (b) 3D Radiation pattern for an optimized bowtie antenna using BSO-NM ($h = 21.078$, $d = 3.4818$, and $\alpha = 48.555°$) at 2.45 GHz.

comparison between the resulting gain radiation pattern in $x$-$z$ plane employing the MoM-based Feko technique and the results obtained via our program at 2.45 GHz for the bow-tie antenna optimized using BSO-NM. It can be seen that, our numerical simulation results are in good agreement with the Feko simulated results. The 3D radiation pattern is shown in Figure 5(b). It is clear that the antenna has good omnidirectional-radiation characteristics.

## 5. CONCLUSION

In this paper, a hybrid approach consisting of a Bacterial Swarm Optimization (BSO) and Nelder-Mead (NM) algorithm is illustrated. The hybrid BSO-NM technique is integrated with the method of moments (MoM) to optimize a bow-tie antenna for 2.45 GHz RFID reader. The BSO-NM algorithm has produced results better than those generated by standalone BFA and BSO. The performance also appears to be slightly better than the BFA-NM algorithm. Finally, it is anticipated that the introduced hybrid approach is very efficient and can be applied to other types of antennas and for adaptive arrays.

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