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OPTIMIZING INCLUDED ANGLE OF SYMMETRICAL V-DIPOLES FOR HIGHER DIRECTIVITY USING BACTERIA FORAGING OPTIMIZATION ALGORITHM

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Abstract—Recently the social foraging behavior of E. coli bacteria has been used to solve optimization problems. This paper presents an approach involving Bacterial Foraging (BF) to find appropriate included angle (ψ) and there by two other slant angles (θ_1, θ_2) for which the V-dipole provides higher directivity in comparison to straight dipole. Symmetrical V and Straight dipole is analyzed completely using Method of Moments (MoM). MoM codes in MATLAB environment have been developed both for straight dipole and V-dipole to obtain impedance, directivity, and radiation patterns in both E-plane and H-plane. Then MoM codes is coupled with well known Bacteria Foraging Algorithm (BFA) to get best included angle. Moreover, some modification of BFA is done for the faster convergence.

1. INTRODUCTION

In this paper, firstly Bacteria Foraging Algorithm (BFA) has been explained briefly which is our goal to apply in the antenna problem. Both straight and V dipoles antennas or antenna are considered as the test objects and for comparison purpose. The structural details for both are depicted in Figure 1 and Figure 2. Straight dipole is considered as a simple case while V-dipole as a complex structure for the application of BFA. Both dipoles are analyzed and equations are derived using Method of Moments [1–3] to get current distribution on the antenna surface. We have considered only symmetrical V-dipole antennas for the analysis that can be easily extended for asymmetrical antenna also.

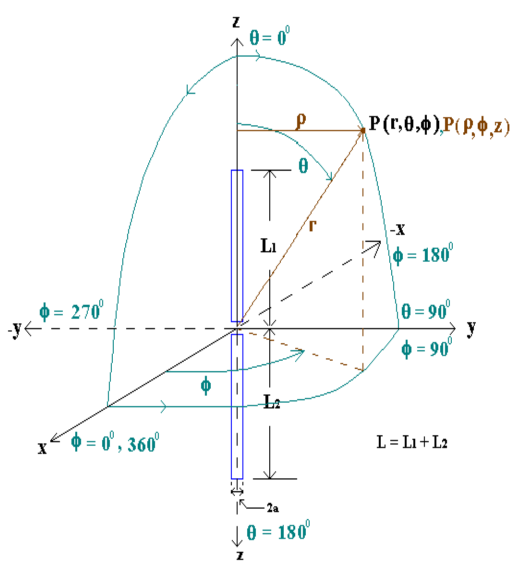


Figure 1. Straight dipole in rectangular, cylindrical & spherical co-ordinate system.

Numerical techniques (MoM) are used to solve unknown current density from integral equations where the unknown current density is a part of the integrand. The integral equations are known as Pocklington's and Hallen's integral equations, which can be derived from fundamentals of electromagnetism [1, 2]. The process of solution begins with several assumptions, which are valid for thin wires e.g., current is considered in center of the axis [12] and may take discrete values at discrete point.

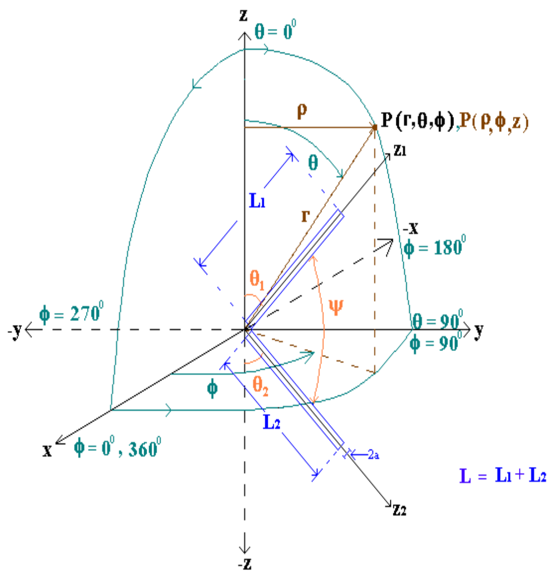


Figure 2. V-dipole in rectangular, cylindrical & spherical co-ordinate system.

During the last decades various optimization techniques like Genetic Algorithm (GA), Ant Colony Optimization, Particle Swarm Optimization, Tabu Search, Bees Algorithm, Differential Evolution, and Clonal selection [13–21] have been used for optimizing parameters in the antenna and antenna arrays problem. Each of these methods has own pros and cons. Besides that many hybrid optimization methods [22–26] are also be there which are best suited for application specific domains. An alternative method known as Bacteria Foraging Algorithm (BFA) recently becomes popular that is based on the foraging behavior of Escherichia Coli (E. Coli) bacteria present in the human intestine [27] and already been in use to many engineering problems including antenna arrays [28–31]. In paper [28], authors have shown the BFA is better than Particle Swarm Algorithm in terms of convergence, robustness and precision. In [29], proposed a hybrid approach involving GA and BFA to tune PID controller of an automatic voltage regulator and has shown the efficiency of this approach for global optimization problems. Paper [30] has illustrated the faster settling time and higher robustness with BFA-PID controller. The array antenna optimization technique is used in paper [31] using BFA. This paper also discusses the usefulness of BFA.

Bacteria Foraging technique [4–7] is gaining importance in the optimization problems. Because,

1. Philosophy say Biology provides highly automated, robust and effective organism
2. Search strategy of bacteria is salutatory (like common fish) in nature
3. Bacteria can sense, decide and act to adopt social foraging (foraging in groups).

Above all Search and optimal foraging decision-making of animals can be used for solving engineering problems. To perform social foraging an animal needs communication capabilities and it gains advantages that can exploit essentially the sensing capabilities of the group, so that the group can gang-up on larger prey, individuals can obtain protection from predators while in a group, and in a certain sense the group can forage a type of collective intelligence.

Taking straight and V-dipole antenna structure as test systems; the principle of operation and complete analysis has been described. In the analysis part the electric field, magnetic field, input impedance and directivity in dB have been derived for both type of dipoles. All these parameters are function of included angle in case of a V dipole. The directivity (DR) is the Cost function of the V dipole, which is to be maximized. As the directivity is a function of included angle, BFA is applied to search the best included angle to realize the maximum directivity. The BFA is usually used to minimize the Cost function of the system. To achieve this, a fitness function FT (ψ) has been formulated out of this Cost function of the dipole system in such a way that when fitness function is minimized, the Cost function gets maximized. This fitness function becomes the COST function for bacteria in BFA. Finally, optimization of included angle using BFA is shown after getting minimized COST function. In the result section a comparative statement for both dipoles are given.

2. BACTERIA FORAGING OPTIMIZATION: A BRIEF OVERVIEW

The idea of BFA is based on the fact that natural selection tends to eliminate animals with poor foraging strategies and favor those having successful foraging strategies. After many generations, poor foraging strategies are either eliminated or reshaped into good ones. The *E. coli* bacteria that are present in our intestines have a foraging strategy governed by four processes, namely, chemotaxis, swarming, reproduction, and elimination and dispersal [4].

1) Chemotaxis: This process is achieved through swimming and tumbling. Depending upon the rotation of the flagella in each bacterium, it decides whether it should move in a predefined direction (swimming) or an altogether different direction (tumbling), in the entire lifetime of the bacterium. To represent a tumble, a unit length random direction, $\phi(j)$ say, is generated; this will be used to define the direction of movement after a tumble. In particular

$$\theta^i(j+1,k,l) = \theta^i(j,k,l) + C(i)\phi(j) \tag{1}$$

where, $\theta^i(j,k,l)$ represents the ith bacterium at jth chemotactic kth reproductive, and lth elimination and dispersal step. $C(i)$ is the size of the step taken in the random direction specified by the tumble. "C" is termed as the "run length unit."

2) Swarming: It is always desired that the bacterium that has searched the optimum path of food should try to attract other bacteria so that they reach the desired place more rapidly. Swarming makes the bacteria congregate into groups and hence move as concentric patterns of groups with high bacterial density. Mathematically, swarming can be represented by

$$\begin{aligned} J_{cc}(\theta, P(j,k,l)) &= \sum_{i=1}^{S} J_{cc}^{i}\left(\theta, \theta^i(j,k,l)\right) \\ = &\sum_{i=1}^{S}\left[-d_{attract}\exp\left(-\omega_{attract}\sum_{m=1}^{p}\left(\theta_m - \theta_m^i\right)^2\right)\right] + \\ &\sum_{i=1}^{S}\left[h_{repelent}\exp\left(-\omega_{repelent}\sum_{m=1}^{p}\left(\theta_m - \theta_m^i\right)^2\right)\right] \end{aligned} \tag{2}$$

where $J_{cc}(\theta, P(j,k,l))$ is the cost function value to be added to the actual cost function to be minimized to present a time varying cost function. "S" is the total number of bacteria. "p" is the number of parameters to be optimized that are present in each bacterium. $d_{attract}$, $\omega_{attract}$, $h_{repelent}$, and $\omega_{repelent}$ are different coefficients that are to be chosen judiciously.

3) Reproduction: The least healthy bacteria die, and the other healthiest bacteria each split into two bacteria, which are placed in the same location. This makes the population of bacteria constant.

4) Elimination and Dispersal: It is possible that in the local environment, the life of a population of bacteria changes either

gradually by consumption of nutrients or suddenly due to some other influence. Events can kill or disperse all the bacteria in a region. They have the effect of possibly destroying the chemotactic progress, but in contrast, they also assist it, since dispersal may place bacteria near good food sources. Elimination and dispersal helps in reducing the behavior of *stagnation* (i.e., being trapped in a premature solution point or local optima). The detailed mathematical derivations as well as theoretical aspect of this new concept are presented in [5, 6].

3. PROBLEM STATEMENT

Problem: To increase the radiation characteristic, V-dipole has been considered and analyzed. The parameter directivity of the V-dipole is maximized by searching best included angle with the help of BFA. The result is also compared with similar length straight dipole. In literature many complicated structures have been analyzed to get higher directivity. In this paper, our attempt is to analyze a simple structure to get higher directivity by applying BFA.

A. Test System

In this paper, two structures, one straight dipole and one V-dipole of equal length, each of radius $= 0.001\lambda$ have been considered as shown in Figure 1 and Figure 2, λ is the wavelength of the signal applied at feed point. If spherical co-ordinate system is considered then the straight dipole is along the z-axis and feed point is at the center of the co-ordinate system. The feed system along with the signal source is symmetrical to the plane ($\theta = 0°$ and $\phi = 90°$). The V-dipole has been considered in the same way but one half makes an angle θ_1 with positive z-axis and other half makes an angle θ_2 with negative z-axis. This means V-dipole has an included angle (ψ), where $\psi + \theta_1 + \theta_2 = 180°$. Since symmetrical dipole system has been emphasized, so for V-dipole $\theta_1 = \theta_2$ and $\psi = \pi - 2\theta_1 = \pi - 2\theta_2$.

B. Operating Principle of the Intended Structure

The straight dipole is supposed to radiate in a particular plane when a RF signal is applied at its feed point with the help of RF feeder and matching unit. In the similar condition the radiation from the V-dipole is much higher than straight dipole for the length in the range of 0.6λ to 1.5λ. The higher directivity purely depends on a particular included angle. So far design is considered the length of the dipole seems very high but at high radio frequency the size will be small and can be designed easily.

C. Optimal Directivity or Directive Gain (ODG): Problem Formulation

The ODG problem is a nonlinear optimization problem, the solution of which determines the optimal settings of included angle. Hence, the problem is to solve a set of nonlinear equations describing the optimal solution of dipole radiating system.

Hallen's integral equation has been formulated for a center-fed cylindrical straight dipole and V-dipole by considering unknown current distribution and applied RF signal. To find the current distribution and input impedance Hallen's equation is solved using Method of Moments [7]. Here each arm of the structures is treated separately and finally their responses are added vectorially to get the desired expression. The current distribution is an unknown quantity and is to be found out such that the resultant tangential electric field cancels the applied field over the feed-gap and equals zero along the rest of the surface of the perfectly conducting structure. When the currents and boundary conditions of the electromagnetic problem to be solved are known, both the electric and magnetic fields can be found. This is usually done with the help of vector potential. The current density and vector potential are related as follows.

$$A(r) = \mu \int_v J(r') \frac{\exp\left(-jk|r-r'|\right)}{4\pi|r-r'|} dv' \tag{3}$$

$$H(r) = \frac{1}{\mu} \nabla \times A(r') \tag{4}$$

$$E(r) = -j\omega A(r') - j\frac{\nabla\nabla.A(r')}{\omega\mu\varepsilon} \tag{5}$$

Considering thin wire approximation, the vector potential for upper arm length in cylindrical co-ordinate system can be written as

$$A_{z_1} = \mu \int_0^{2\pi}\int_0^{L_1} \hat{z}\frac{I(z_1')}{2\pi a}\frac{\exp(-jkR)}{4\pi R} dz_1' a d\varphi' \tag{6}$$

where $R = |r - r'| = [(z_1 - z_1') + a^2]^{1/2}$.

Solving the boundary condition for electric field and considering feed gap negligibly small, the Hallen's integral equation for upper arm length is expressed as given below.

$$\left(k^2 + \frac{\partial^2}{\partial z_1^2}\right) A(z_1) = -j\omega\varepsilon_0 v_g \delta(z)\cos\theta_1 \tag{7}$$

Solving the above differential Equation (7) and finding unknown constants of the solution by considering various approximations for vector potential, the solved equation is given as

$$\int_0^{L_1} I(z_1')G(z_1, z_1')dz_1' = -\frac{j}{2\eta}\sin k|z_1| + A_1 \cos kz_1 \tag{8}$$

where both z_1 and z_1' are constrained to $(0,\ L_1)$ and where

$$G(z_1, z_1') = \frac{\exp\left(-jk\left[a^2 + (z_1 - z_1')^2\right]^{1/2}\right)}{4\pi\left[a^2 + (z_1 - z_1')^2\right]^{1/2}} \tag{9}$$

Using Method of Moments the Equation (8) can be written as

$$\sum_{n=1}^{N} I(n) \int_{(n-1)\Delta}^{n\Delta} G\left[(m-0.5)\Delta, z_1'\right] dz_1' - A_1 \cos k[(m-0.5)\Delta]$$
$$= -\frac{j}{2\eta}\cos\theta_1 \sin k[(m-0.5)\Delta] \tag{10}$$

Writing Equation (10) in matrix form

$$\begin{bmatrix} G_{1,1} & G_{1,2} & \cdot\ \cdot & G_{1,N-1} & -\cos kz_{1,1} \\ G_{2,1} & G_{2,2} & \cdot\ \cdot & G_{1,N-1} & -\cos kz_{1,2} \\ \cdot & \cdot & \cdot\ \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot\ \cdot & \cdot & \cdot \\ G_{N,1} & \cdot & \cdot\ \cdot & G_{N,N-1} & -\cos kz_{1,m} \end{bmatrix} \begin{bmatrix} I_1 \\ I_2 \\ \cdot \\ I_{N-1} \\ A_2 \end{bmatrix} = \begin{bmatrix} -\frac{j}{2\eta}\cos\theta_1 \sin k\,|z_{1,1}| \\ -\frac{j}{2\eta}\cos\theta_1 \sin k\,|z_{1,2}| \\ \cdot \\ \cdot \\ -\frac{j}{2\eta}\cos\theta_1 \sin k\,|z_{1,m}| \end{bmatrix} \tag{11}$$

Similarly, for the lower half arm one can find out another matrix as given below.

$$\begin{bmatrix} G_{1,1} & G_{1,2} & \cdot\ \cdot & G_{1,N-1} & -\cos kz_{2,1} \\ G_{2,1} & G_{2,2} & \cdot\ \cdot & G_{2,N-1} & -\cos kz_{2,2} \\ \cdot & \cdot & \cdot\ \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot\ \cdot & \cdot & \cdot \\ G_{N,1} & \cdot & \cdot\ \cdot & G_{N,N-1} & -\cos kz_{2,m} \end{bmatrix} \begin{bmatrix} I_1 \\ I_2 \\ \cdot \\ I_{N-1} \\ A_2 \end{bmatrix} = \begin{bmatrix} \frac{j}{2\eta}\cos(\psi+\theta_1) \sin k\,|z_{2,1}| \\ \frac{j}{2\eta}\cos(\psi+\theta_1) \sin k\,|z_{2,2}| \\ \cdot \\ \cdot \\ \frac{j}{2\eta}\cos(\psi+\theta_1) \sin k\,|z_{2,m}| \end{bmatrix} \tag{12}$$

For symmetrical dipole constant A_1 and A_2 are same in magnitude and phase. Adding both the matrix equation will generate Equation (13).

$$\begin{bmatrix} G_{1,1} & G_{1,2} & \cdot & \cdot & G_{1,N-1} & -\cos kz_{2,1} \\ G_{2,1} & G_{2,2} & \cdot & \cdot & G_{2,N-1} & -\cos kz_{2,2} \\ \cdot & \cdot & \cdot & \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot & \cdot & \cdot & \cdot \\ G_{N,1} & \cdot & \cdot & \cdot & G_{N,N-1} & -\cos kz_{2,m} \end{bmatrix} \begin{bmatrix} I_1 \\ I_2 \\ \cdot \\ I_{N-1} \\ A_1 \end{bmatrix} = \begin{bmatrix} \frac{j}{4\eta}\{\cos(\psi+\theta_1)\sin k\,|z_{2,1}| - \cos\theta_1 \sin|z_{1,1}|\} \\ \frac{j}{4\eta}\{\cos(\psi+\theta_1)\sin k\,|z_{2,2}| - \cos\theta_1 \sin|z_{1,2}|\} \\ \cdot \\ \cdot \\ \frac{j}{4\eta}\{\cos(\psi+\theta_1)\sin k\,|z_{2,m}| - \cos\theta_1 \sin|z_{1,m}|\} \end{bmatrix} \tag{13}$$

Manipulating above matrix equation, unknown current distribution can be found out.

Once the current distribution is known then input impedance, E and H field and Directivity can be found out as given below.

$$Z_{in} = \frac{1}{I_1(l)} \tag{14}$$

In case of the straight dipole the far field electric component can be written as [4],

$$E_\theta = j\eta \frac{kI_m e^{-jkr}}{4\pi r} \sin\theta \left\{ \int_{-L_2}^{0} \sin\left[k\left(L_2 + z'\right)\right] e^{+jkz'\cos\theta} dz' + \int_{0}^{+L_1} \sin\left[k\left(L_1 - z'\right)\right] e^{+jkz'\cos\theta} dz' \right\} \tag{15}$$

But in case of V-dipole, there will be two electric components, due to the included angle between the arms. Upper arm has been considered in the direction of z_1 and lower arm has been considered in the direction of z_2.

The far field electric component for the V-dipole can be written as

$$E_\theta = jk\frac{\eta}{4\pi}\sin\theta \left[\int_0^{L_1} \frac{I_m \sin\{k(L_1 - z_1')\}}{r_1} e^{-jkr_1}\cos\theta_1 dz_1' + \int_0^{L_2} \frac{I_m \sin\{k(L_2 - z_2')\}}{r_2} e^{-jkr_2}\cos\theta_2 dz_2' \right] \tag{16}$$

$$E_\phi = jk\frac{\eta}{4\pi}\cos\phi\left[\int_0^{L_1}\frac{I_m\sin\{k(L_1-z_1')\}}{r_1}e^{-jkr_1}\sin\theta_1 dz_1' - \int_0^{L_2}\frac{I_m\sin\{k(L_2-z_2')\}}{r_2}e^{-jkr_2}\sin\theta_2 dz_2'\right] \tag{17}$$

where $r_1 = [r_2 + z_{1'2} - 2r.z_{1'}(\cos\theta.\cos\theta_1 + \sin\theta.\sin\theta_1.\sin\phi)]^{1/2}$, $r_2 = [r_2 + z_{2'2} - 2r.z_{2'}(\sin\theta.\sin\theta_2.\sin\phi - \cos\theta.\cos\theta_2)]^{1/2}$,

$$P_r = \frac{1}{2}\left||E_\theta|^2 + |E_\varphi|^2\right| \tag{18}$$

Hence the radiated power

$$W = \int_{\theta=0}^{\pi}\int_{\varphi=0}^{2\pi} P_r r^2 \sin\theta d\varphi d\theta \tag{19}$$

and the directivity in dB

$$DR = 10\log_{10}\left[(r^2P_r)_{\max}\times 4\pi/W\right] \tag{20}$$

Fitness function for directivity of the radiating system described as

$$FT(\psi) = \frac{1}{1+DR(\psi)} \tag{21}$$

where $DR(\psi)$ is the Cost function for directivity, which is to be maximized.

In case of bacteria foraging technique the bacteria maintain good health or find sufficient food for its reproduction when fitness function is minimized. As per our explanation this fitness function is the COST function for all bacteria, which is to be minimized. That is why the fitness function has been considered like this i.e., reciprocal of Cost function for directivity.

4. BACTERIAL FORAGING: THE ALGORITHM USED

The BF algorithm suggested in [5, 6] is modified so as to expedite the convergence as described below.

1) In [6], the author has taken the average value of all the chemotactic cost functions, to decide the health of particular bacteria

in that generation, before sorting is carried out for reproduction. In this paper, instead of the average value, the minimum value of all the chemotactic cost functions is retained for deciding the bacterium's health. This speeds up the convergence, because in the average scheme [6], it may not retain the fittest bacterium for the subsequent generation. On the contrary, in this paper, the global minimum bacteria among all chemotactic stages pass on to the subsequent stage. 2) For swarming, the distances of all the bacteria in a new chemotactic stage is evaluated from the global optimum bacterium until that point and not the distances of each bacterium from the rest of the others, as suggested in [5, 6]. The convergence of normalized fitness function with respect to number of iteration available from four loops is shown in Figure 3. It is to be mentioned that for the analysis of V-dipoles, time taken for 10 bacteria case in 1.7 GHz Celeron processor is only 5–6 minutes which is much faster than when average value was taken (about 1 hour).

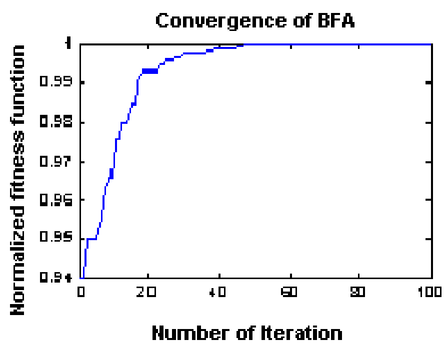


Figure 3. Convergence rate of modified BFA.

The algorithmic steps are described below:

Step 1—Initialization

The following variables are initialized.

1) Number of bacteria (S) to be used in the search.
2) Number of parameters (p) to be optimized.
3) Swimming length N_s
4) N_c the number of iterations in a chemotactic loop ($N_c > N_s$).
5) $N_{re}$the number of reproduction.
6) N_{ed} the number of elimination and dispersal events.
7) P_{ed} the probability of elimination and dispersal.

8) Location of each bacterium $P(p, S, 1)$, i.e., random numbers on [0–1].
9) $d_{attract}$, $\omega_{attract}$, $h_{repelent}$, and $\omega_{repelent}$ are given of fixed values

Step 2—Iterative algorithm for optimization

This section models the bacterial population chemotaxis, swarming, reproduction, and elimination and dispersal (initially, $j = k = l = 0$). For the algorithm updating, θ^i automatically results in updating of "P".

1) Elimination-dispersal loop: $l = l + 1$
2) Reproduction loop: $k = k + 1$
3) Chemotaxis loop: $j = j + 1$

These steps have been applied as given in [6].

a) For $i = 1, 2, \ldots, S$, calculate cost function value for each bacterium i as follows.
   - Compute value of cost function $J(i, j, k, l)$.
     Let $J_{sw}(i, j, k, l) = J(i, j, k, l) + J_{cc}(\theta^i(j, k, l), P(j, k, l))$
     $P(j, k, l)$ is the location of bacterium corresponding to the global minimum cost function out of all the generations and chemotactic loops until that point (i.e., add on the cell-to-cell attractant effect for swarming behavior).
   - Let $J_{last} = J_{sw}(i, j, k, l)$ to save this value since we may find a better cost via a run.
   - End of For loop

b) For $i = 1, 2, \ldots, S$, take the tumbling/swimming decision
   - Tumble: Generate a random vector $\Delta(i) \in R^P$ with each element number
     $\Delta_m(i)$ [where $m = 1, 2, \ldots, p$,] a random number on [0, 1].
   - Move: let

$$\theta^i(j+1, k, l) = \theta^i(j, k, l) + C(i)\frac{\Delta(i)}{\sqrt{\Delta^T(i)\Delta(i)}}$$

     Fixed step size in the direction of tumble for bacterium i is considered.
   - Compute $J(i, j+1, k, l)$ and then let

$$J_{sw}(i, j+1, k, l) = J(i, j+1, k, l) + J_{cc}(\theta^i(j+1, k, l), P(j+1, k, l))$$

   - Swim:
     (i) let $m = 0$; (counter for swim length)
     (ii) While $m < N_s$ (have not climbed down too long)

- let $m = m + 1$
- if $J_{sw}(i, j+1, k, l) < J_{last}$ (if doing better) then let $J_{last} = J_{sw}(i, j+1, k, l)$ and

$$\theta^i(j+1, k, l) = \theta^i(j, k, l) + C(i)\frac{\Delta(i)}{\sqrt{\Delta^T(i)\Delta(i)}}$$

use this $\theta^i(j+1, k, l)$ to compute new $J(i, j+1, k, l)$
- else, let $m = N_s$. This is the end of while statement.

c) Go to next bacterium $(i+1)$ if $i \neq S$ (i.e., go to "b") to process the next bacterium.

4) If $j > N_c$, go to step 3. In this case, continue chemotaxis since the life of the bacteria is not over.
5) Reproduction

a) For the given k and l, and for each $i = 1, 2, \ldots, S$, let $J^i_{health} = \min_{j \in \{1 \ldots N_c\}} \{J_{sw}(i, j, k, l)\}$ be the health of the bacterium i. Sort bacteria in order of ascending cost J_{health} (higher cost means lower health).
b) The $S_r = S/2$ bacteria with highest J_{health} values die and other S_r bacteria with best value split (and the copies that are made are placed at the same location as their parent)

6) If $k < N_{re}$, go to 2; in this case, we have not reached the number of specified reproduction steps, so we start the next generation in the chemotactic loop.
7) Elimination-dispersal: For $i = 1, 2, \ldots, S$, with probability P_{ed}, eliminates and disperses each bacterium (this keeps the number of bacteria in the population constant). To do this, if one eliminates a bacterium, simply disperse it to a random location on the optimization domain.

The flow chart of the improved algorithm is shown in Figure 4.

5. SIMULATION

The minimum value of DR is 1.76 dB for elementary dipole and maximum value may be infinite for any ideal directive structure.

So range of directivity is kept as

$$1.76 \leq DR(\psi) \leq \infty \tag{22}$$

In such a situation the minimum value may be considered for fitness function as 0 and maximum value as 1.

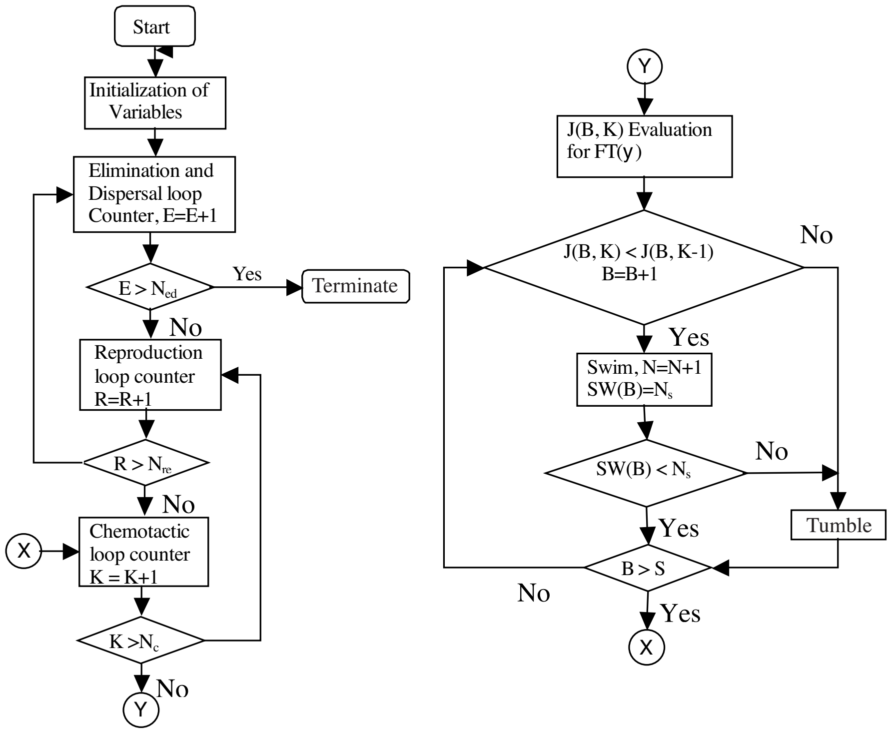


Figure 4. Flowchart of the bacteria foraging algorithm.

So range of Fitness function is defined as

$$1 > FT(\psi) \geq 0 \tag{23}$$

So, the intention of our program is to find the minimum value for the fitness function (near to zero) i.e., the place where maximum number of bacteria is found.

Considering Bacteria Foraging Algorithm a MATLAB program has been formulated for V and dipole antennae structure. The foragers find a best included angle i.e., ψ, which ultimately provides the highest directivity for a particular length of V-dipole depending on our fitness function.

For all the different lengths of V-dipole the parameters for simulations are as follow:

Sb = Number of bacteria = 10
Nk = Number of chemotactic steps = 30
Ns = Number of swim = 4
NG = Number of generation = 4

Nrd = Number of dispersal and elimination = 2
Ped = elimination-dispersal with probability = 0.25
$C(i)$ = the size of the step(variable for all bacteria) taken in the random direction specified by the tumble.

Table 1. Comparative chart for straight and V-dipole antennas.

Straight Dipole parameters				V – Dipole parameters				
L_1 in λ	L_2 in λ	Z_{in} in Ω	DR in dB	L_1 in λ	L_2 in λ	Optimized ψ from BF	Z_{in} in Ω	DR in dB
0.005	0.005	0.013–j9403	1.7611	0.005	0.005	110	0.0025 – j1524	1.7611
0.05	0.05	1.8–j2184	1.7753	0.05	0.05	175	1.9 –j2475	1.7753
0.10	0.10	8.11 – j1696	1.8187	0.10	0.10	175	8.13 – j1698	1.8188
0.25	0.25	73.447+ j14.252	2.1492	0.25	0.25	175	73.559+ j14.284	2.1495
0.50	0.50	92044 +j36167	3.7923	0.50	0.50	175	92123+ j36229	3.7960
0.55	0.55	2030 – j16594	4.3720	0.55	0.55	175	2032 – j 16611	4.3762
0.60	0.60	402.84 – j7929	4.9466	0.60	0.60	175	402.98 – j7937	4.9505
0.65	0.65	153.77 – j4511.4	5.1307	0.65	0.65	160	154.2 – j4581.5	5.1403
0.70	0.70	96.52 – j2226	4.0120	0.70	0.70	118	98.42 – j2593	4.8323
0.75	0.75	103.1 – j178.53	3.4076	0.75	0.75	101	117.7 – j207.42	4.5024
0.80	0.80	156.1+ j2072.1	3.8006	0.80	0.80	93	209.78+ j2914.2	4.2909
0.85	0.85	281.81+ j5026	3.7710	0.85	0.85	90	422.49+ j7209.3	4.2109
0.90	0.90	605.87+ j9804.2	3.7206	0.90	0.90	88	968.53+ j14279	4.2450
1.00	1.00	40505+ j101030	3.9498	1.00	1.00	88	63059+ j140470	4.5867
1.20	1.20	126.2 – j 4058.9	3.9697	1.20	1.20	77	179.3 – j6600.3	4.9856
1.50	1.50	18970+ j101050	4.6688	1.50	1.50	66.5	37150+ j185200	4.8686

6. RESULTS

Table 1 provides a comparative results between straight dipole and V-dipole for the same length. Various values like input impedance and directivity for symmetrical straight dipole and V-dipole obtained are provided in Table 1. Only the included angle for V-dipole is

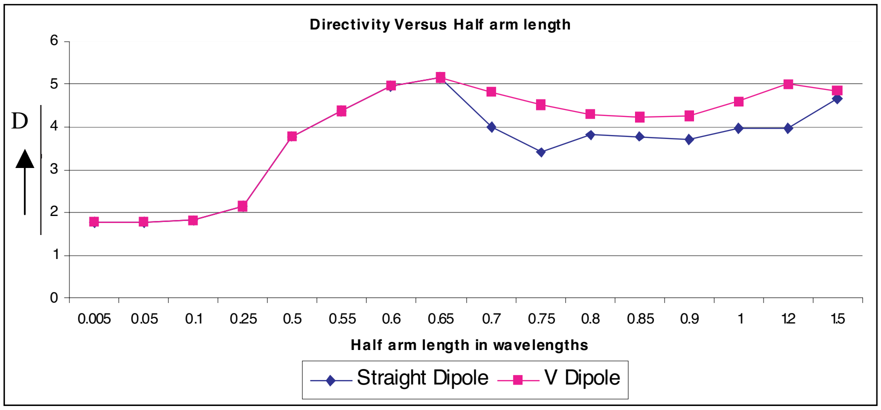
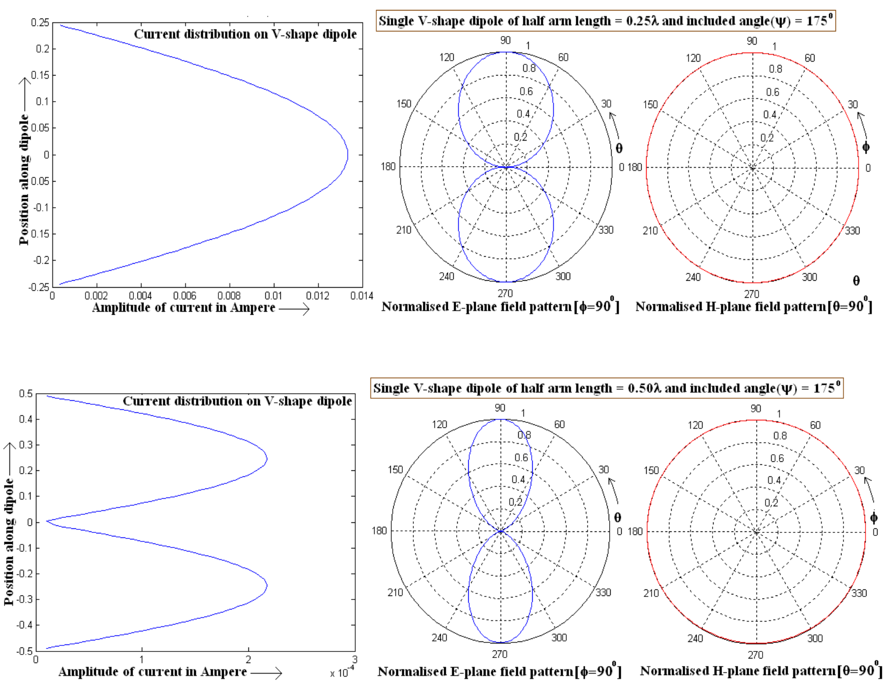


Figure 5. Comparison of directivity (D) vs. arm length.



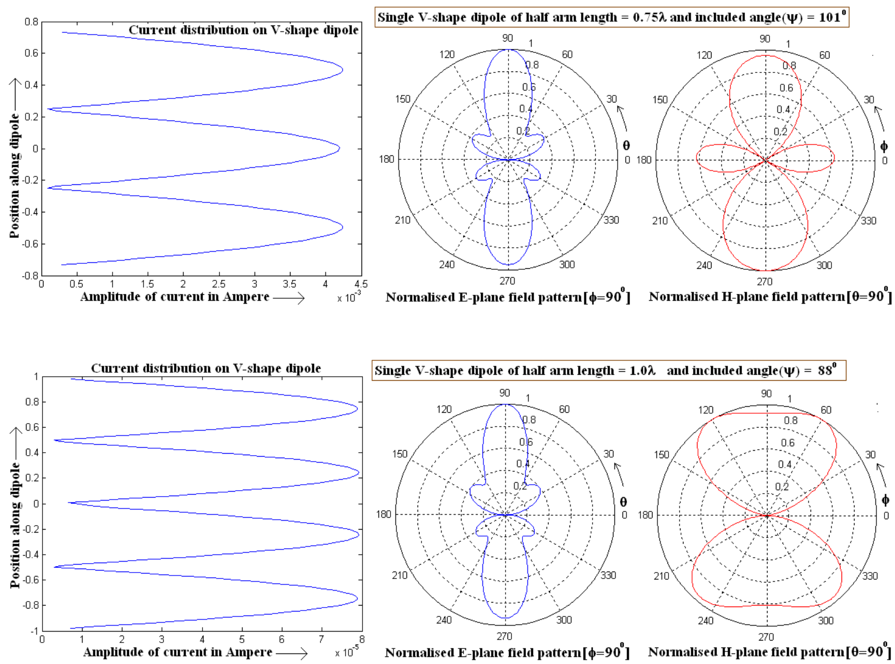


Figure 6. Radiation field patterns for V-antenna for different arm length.

Table 2. % of increase in directivity of V dipole in comparison to similar length straight dipole.

Length in λ	0.005	0.05	0.1	0.25	0.5	0.55	0.6	0.65	0.7	0.75	0.8	0.85	0.9	1	1.2	1.5
Increase in DR in %	0.00	0.00	0.01	0.01	0.10	0.10	0.08	0.19	20.45	32.13	12.90	11.67	14.09	16.12	25.59	4.28

optimized using BFA for maximum directivity. It is observed that increase in directivity starts from the half arm length of value 0.1λ. But increment is very little up to 0.65λ thereafter increases prominently for the half arm length value of 0.7λ to 1.2λ. Figure 5 is the plot for directivity in terms of length of the antenna. Some specific cases are plotted for radiation characteristics along with the current distribution in Figures 6. Finally, Table 2 represents the percentage of increase in directivity (in dB) for V dipoles with comparison to similar length straight dipole.

7. CONCLUSION

The focus of this paper is to describe the application of the BFA in antenna problem. It is clear from the result that to get good directivity, the length must be selected judiciously. The Method of Moments analysis of this paper would be very helpful to the researcher. Using BFA, this paper establishes a very old concept of providing higher directivity of long-V antenna compared to simple straight dipole. Moreover, some comparative results between symmetrical straight dipole and symmetrical V-dipole with some optimized ψ have been provided using bacteria foraging optimization technique. Similar attempt can also be made for asymmetrical cases using the same programs. Again, the modification made for the BFA can show the faster convergence. This may be applied to any complicated antenna structure including array antenna where time complexity would be of major concern.

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