Application of Monarch Butterfly Optimization for C2C Communication Systems Antenna Design

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***Abstract*—This paper describes an E-shaped patch antenna design which is suitable for Car-to-Car (C2C) communication. The antenna design is obtained by applying a simple and efficient optimization technique, called Monarch Butterfly Optimization. Simulation results demonstrate quite satisfactory values of the antenna's operational bandwidth, maximum gain, and 3 dB beamwidth.**

***Index Terms*—C2C communication, monarch butterfly optimization, E-shaped patch antenna, meta-heuristic algorithm**

I. Introduction

Cars are one of the main transportation vehicles in daily life. During the last years, several electronic devices and new features have been introduced in cars aiding driving safety [1]. Wireless access in vehicular environments is defined by IEEE 802.11p standard. It uses channels of 10 MHz bandwidth in the 5.9 GHz band $(5.850 - 5.925\ GHz)$. Nowadays, Car-to-Car (C2C) communication can advance driving safety using collision avoidance, adaptive cruise control, overtaking assistance, etc. [2].

Monarch butterfly optimization (MBO) is a recently introduced evolutionary algorithm by Wang et al [3]. It models the migration of monarch butterflies that live in North America to express a general-purpose metaheuristic technique. MBO has been successfully applied to several real-world engineering problems.

In this paper, we design an E-shaped patch antenna on a single layer suitable for C2C communication. The antenna is layered on a FR4 substrate that provides a competitive advantage of low-cost fabrication. The E-shaped patch antenna is fed through a microstrip line, that extends manufacturing simplicity. The proposed antenna is described by 10 different design parameters. It is apparent that such a design can be achieved by using an optimization technique.

II. Monarch Butterfly Optimization (MBO)

MBO concept is based on the migration behavior of the monarch butterflies in nature [3]. MBO divides the population into two sub-populations. Let us define as $pop_1 = ceil(pop_{ratio} \times pop_{tot})$ the number of monarch butterflies in subpopulation 1, and $pop_2 = pop_{tot} - pop_1$ the number in subpopulation 2, respectively. In the above definition, $ceil()$ function returns the smallest integer greater than or equal to a given number; pop_{tot} is the total number of butterflies; pop_{ratio} is the ratio of butterflies in subpopulation 1. The decision variables of the optimization problem are the positions of the monarch butterflies. To update these positions, MBO uses two different operators which are applied sequentially.

The first is the migration operator, that describes the migration process of the monarch butterflies from one subpopulation to another. During this process, the total population is remaining unchanged by replacing the parent with a newly generated child (offspring), if the latter has better fitness value compared to its parent. The migration process is described by the following:

$$
\begin{aligned}
b_{i,j}^{t+1} &= b_{r1,j}^{t}, \text{if } pop_{rand} <= pop_{ratio} \\
b_{i,j}^{t+1} &= b_{r2,j}^{t}, \text{otherwise}
\end{aligned} \tag{1}
$$

where:

- $b_{i,j}^{t+1}$ is the value of the i^{th} butterfly position at the j^{th} dimension of the next generation ($t+1$, t is the current generation),
- $b_{r1,j}^{t}$ is the value of newly generated position at the j^{th} dimension of a randomly selected butterfly $(r1)$ from subpopulation 1,
- $b_{r2,j}^{t}$ is the value of newly generated position at the j^{th} dimension of a randomly selected butterfly $(r2)$ from subpopulation 2, and
- pop_{rand} is a random number given by:

$$pop_{rand} = rand_{(0,1)} \times period \tag{2}$$

where $rand_{(0,1)}$ is a uniformly distributed number within the interval $(0, 1)$ and $period$ is the migration period.

From (1) and (2) we conclude that MBO method can settle the direction of migration operator by modifying the number pop_{ratio}.

The second operator is the butterfly adjusting operator, that also updates the positions of the monarch butterflies. This process is described by the following:

$$b_{i,j}^{t+1} = b_{best,j}^{t}, \text{if } rand_{(0,1)} <= pop_{ratio}$$
$$b_{i,j}^{t+1} = b_{r3,j}^{t}, \text{otherwise} \tag{3}$$

where:

- $b_{best,j}^{t}$ is the best so far individual value at the j^{th} dimension of the whole population and
- $b_{r3,j}^{t}$ is the value of the position at the j^{th} dimension of a randomly selected butterfly $(r3)$ from subpopulation 2.

More details about the MBO algorithm can be found in [3].

III. Design and Characterization of E-shaped Antenna

Fig. 1 illustrates the geometry of the proposed antenna. It consists of an E-shaped patch layered on FR4 substrate. The patch antenna and the ground plane are of copper material. The dimensions of the substrate are proportional to the dimensions of the patch antenna by a factor of 2.85. The dielectric constant of FR4 substrate is 4.4 and its thickness is $1.6\ mm$. The source is located at the edge of the substrate. The feed length is fixed, and it is given by the following formula:

$$Feed_L = \frac{Substrate_W}{2} - \frac{Patch_W}{2} \tag{4}$$

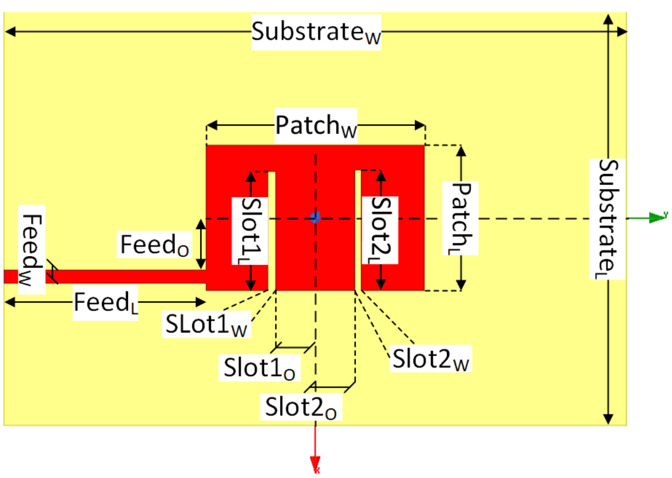

Fig. 1. Geometry of the proposed E-shaped patch antenna for C2C communication.

We apply the Monarch Butterfly Optimization method to find the optimum solution, by updating the 10 different parameters of the antenna design. The objective of the optimization problem is to minimize the return loss $(S11)$ of the antenna (subsequently minimizing the VSWR parameter) in the $5.9\ GHz$ frequency band. Therefore, we select the lower $(5.850\ GHz)$ and upper $(5.925\ GHz)$ frequency limit of the C2C communication band. As a result, the objective function can be written as:

$$F(\bar{y}) = S_{11}^{5.850GHz}(\bar{y}) + \Psi \times ||S_{11}^{5.850GHz}(\bar{y})| - |L_{dB}|| + S_{11}^{5.925GHz}(\bar{y}) + \Psi \times ||S_{11}^{5.925GHz}(\bar{y})| - |L_{dB}|| \tag{5}$$

where:

- $\bar{y}$ is the vector of the antenna design parameters,
- $S_{11}^{5.850GHz}(\bar{y})$ and $S_{11}^{5.925GHz}(\bar{y})$ are the return loss values of the corresponding lower and upper frequency limit in the $5.9\ GHz$ frequency band,
- L_{dB} is the S_{11} limit in dB $(L_{dB} = -10\ dB)$, and
- Ψ is a very large number.

The size of the population in the MBO algorithm is set to 50, whereas the maximum number of iterations is 1000. The algorithm is executed 20 times and the best obtained result is reported in Table I. The E-shaped patch antenna is designed with ANSYS HFSS [4]. The integration of MBO source with HFSS software is applied with HFSS MATLAB API library toolbox [5].

TABLE I
Best Solution of the Antenna Geometry Obtained by MBO Algorithm

Parameter	Value (mm)	Parameter	Value (mm)
$Patch_W$	16.65	$Patch_L$	11.1
$Slot1_W$	0.6	$Slot1_L$	9.1
$Slot2_W$	0.5	$Slot2_L$	9.2
$Feed_W$	1.0	$Slot1_O$	3.0
$Feed_O$	4.0	$Slot2_O$	3.0

Fig. 2 illustrates the return loss vs frequency of the patch antenna at the feeding point. The proposed antenna design has a resonance of $-47.34\ dB$ at $5.899\ GHz$. Its operational bandwidth $(S11 < 10\ dB)$ is 4.58% or $270\ MHz$ and extends beyond the whole $5.9\ GHz$ frequency band of C2C communication systems.

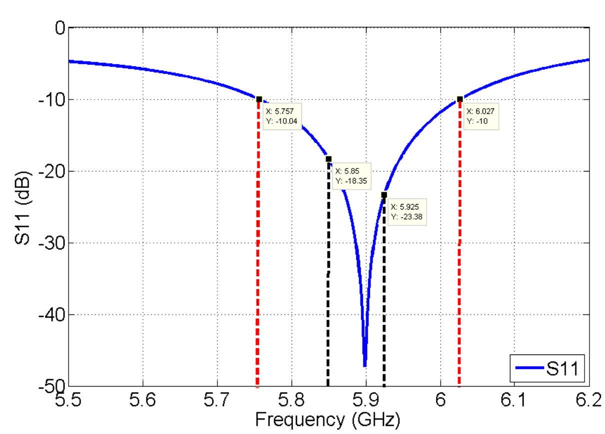

Fig. 2. Return loss $(S11)$ vs frequency of the proposed antenna (black dash lines: $5.9\ GHz$ frequncy band, red dash lines: operational bandwidth $(S11 < -10\ dB)$).

Fig. 3 illustrates the 3D pattern of the antenna gain (realized gain) obtained by the application of MBO algorithm. The maximum gain value of the proposed antenna at the broadside direction is $6.02\ dB$. From the presented results it is derived that the $3\ dB$ beamwidth is $82°$.

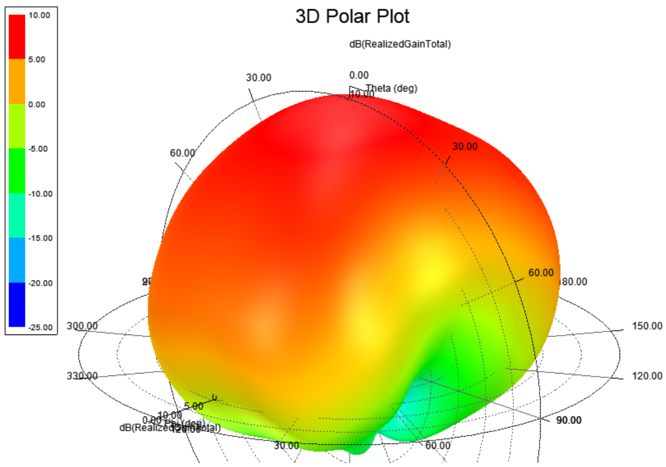

Fig. 3. $3D$ pattern of the antenna gain (realized gain) obtained by the MBO algorithm (color scale in dB).

IV. Conclusion

In this paper, we present an E-shaped patch antenna operating in the $5.9\ GHz$ frequency band, suitable for C2C communication. For the design approach, we apply a recently proposed algorithm, the MBO. From the obtained results, it is apparent that the patch antenna covers sufficiently the whole $5.9\ GHz$ band and has satisfactory values of realized gain and $3\ dB$ beamwidth.

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