Optimum Design of a Patch Antenna with Metamaterial

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This paper presents an optimization design for a circular patch antenna composed of metamaterial in its substrate. The genetic algorithm, particle swarm optimization and coordinate descent methods are compared in the resolution of the optimum design that aims to maximize the gain of the antenna. To accomplish this goal it was necessary several experiments with different antenna configurations. The optimization methods interacted with a finite integration technique software to compute the antenna gain. In this patch antenna design it was achieved a gain of three times greater than the original version of the antenna.

***Index Terms*— Patch antennas, metamaterials, design optimization, genetic algorithms, particle swarm optimization, coordinate descent.**

I. Introduction

PATCH ANTENNAS are commonly used in wireless communications because of their simplicity of structure, reduced weight, and low cost. These antennas can still be easily connected to an RF network via single or multi-layer substrate.

Patch antennas with metamaterials also called resonant electromagnetic circuits have great capability to have their own parameters varied, through the modification of the dimensions of their structures. With these resonant circuits, the possibilities of using optimization techniques in these antennas are further diversified, also minimizing the effects of cross polarization, which reduce their efficiency. The effective electrical permittivity and magnetic permeability values given by the dimension of the structures of its resonant circuits are determinant parameters of the electric field radiation pattern and its manipulation is the object of this work.

Due to the complexity of electromagnetic systems with metamaterials and the need for their efficient use, many methods of optimization in antennas with metamaterials have been used by the scientific community [1-4]. In [1] optimization is performed on tunable squared split ring resonators (SRR). In Johnson's work [2] there is the optimization of digital satellite transmission metamaterial antennas aiming at the suppression of sidelobes. For this, more than 10,000 tunable metamaterial cells were used for their optimization based on the cancellation of the sidelobe. In [3] Myers studied the optimization of metamaterial cells using genetic algorithms, making possible the miniaturization of metamaterial antennas. In [4], Patel has used squared SRR for implementation of a narrow bandpass antenna. Also it has been common to utilize evolutionary computing algorithms to find an optimal design for a device. As an example of these optimization algorithms, we have genetic inheritance and foraging behavior [5].

In this paper we present the use of genetic algorithm, particle swarm optimization (PSO) and coordinate descent methods to maximize the gain of a patch antenna with metamaterial substrate and complementary split ring resonators (CSRR). The objective function was constructed to obtain an optimum patch antenna gain. The antenna used as reference is reported in [6]. Among the relevant geometric parameters, we highlight the radius of the rings, aperture and distance of the rings, which determine their electrical characteristics.

II. Antenna Patch Optimum Design

The circular patch antenna with rectangular substrate has dimensions L x W, and is composed of a layer of metamaterial cells as a ground plane [6]. This antenna has a conductive patch on one side, a substrate layer of FR4, and on the ground side there are printed non-conducting rings (CSRR), as shown in Fig. 1. The design parameters are external radius of the internal ring of the CSRR (R), CSRR ring aperture (E), transmission line thickness (T), patch antenna radius (P), and dielectric thickness (D).

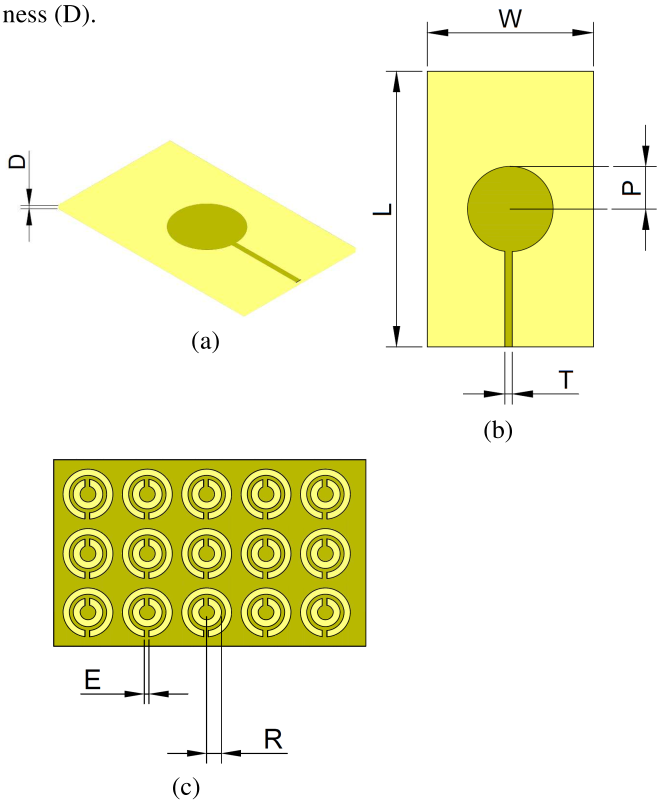

Fig. 1. Patch antenna with metamaterial cells: (a) side view, (b) circular patch (top view), and (c) ground plane with CSRR array.

In order to find the optimum design there is a need to find out the best set of constructive parameters of the resonant rings. The optimization problem of the patch antenna could be modeled in different ways. In this work, it was decided to treat the problem as mono-objective, focusing on maximizing the antenna gain as a function G(x). The vector **x** represents the geometric parameters D, E, P, R and T. The increase of the gain has as consequence the reduction of the reflection, the increase of the efficiency of radiation and increase of the directivity of the antenna. Thus, the optimization problem can be defined as:

$$\max_{\mathbf{x} \in \mathbf{X}} G(\mathbf{x}) \qquad (1)$$

where: $\underline{x_i} \leq xi \leq \overline{x_i}, \quad i = 1, \ldots, 5.$

To solve (1) evolutionary optimization algorithms and analytical optimization algorithms were implemented.

The evolutionary algorithms are of biological heuristics which provides a greater possibility of reaching an optimal global value [7].

III. Experiments

The modeling of the gain of the patch antenna shown in Fig. 1 can be a complex task. Therefore, the gain in each configuration is obtained using the CST® software, which is based on a finite integration technique. The optimization algorithms that will interact with the CST were developed in Matlab® software with the search space shown in Table I. The antenna dimensions were fixed as L = 100 mm and W = 60 mm.

TABLE I
Search Space

	E	R	T	P	D
Min (mm)	0.5	4.5	2.0	8.0	1.0
Max (mm)	2.5	5.5	5.0	18.0	3.0

For the genetic algorithms, we used population with binary coding (12 bits), 30 individuals, 30 iterations, crossing probability 0.4, mutation probability 0.01. For the PSO it was used 30 particles, 30 iterations, reliability weight between 0.2 to 1.1 and cost weight between 0.1 to 0.4. In the coordinate descent, steps of 0.01 mm were applied to the most sensitive variable.

The optimization algorithms were executed a total of 1920 times, being 900 times for each evolutionary algorithm and 120 times for the coordinate descent algorithm. Each execution took 3 minutes, which were mainly spent on the CST gain simulation. We used the Intel (R) Core (TM) i3 CPU.

IV. Results

Significant results were obtained for the patch antenna gain, where a small variation in the antenna parameters yielded a gain more than 3 times greater than the initial one. The optimum result was found with the use of genetic algorithm, which proved to be more efficient for optimization of systems with metamaterials. To achieve this gain it was necessary to apply the different optimization routines in search for an antenna configuration with the optimum gain. The optimization results are presented in Table II, as well as the adjusted variables. The antenna optimized in this work has an initial gain of 1.97 dB at 2 GHz [6]; after the application of the optimization routines it was achieved a gain of 6.34 dB. The most expressive gain was reached with the genetic algorithm. In Fig. 2 it is presented the radiation diagram for the frequency of 2 GHz, with greater gain of the main lobe of 6.42 dB, at 173º.

TABLE II
Results of Optimization (180º)

	Initial	AG	PSO	Coordinate Descent
Gain (dB)	1.97	6.3440	6.1310	3.8570
E (mm)	2.00	1.7877	0.7028	1.0101
R (mm)	5.00	4.6360	4.5006	5.0301
T (mm)	4.00	4.5410	3.6716	3.9401
P (mm)	16.00	17.6967	16.7819	16.0801
D (mm)	1.60	1.4304	1.0001	1.6101

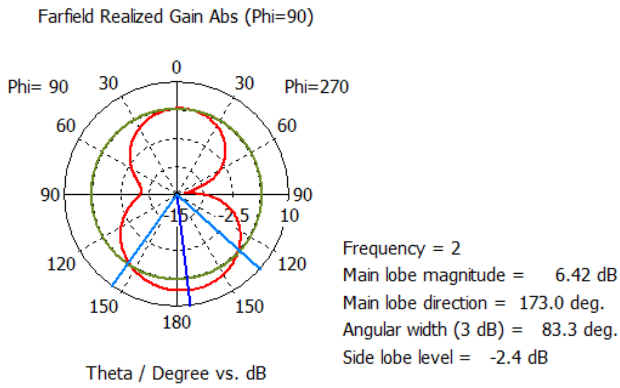

Fig. 2. Radiation diagram of the optimized antenna.

With the optimized dimensions obtained, the antenna was manufactured. Measurements of the antenna prototype were performed and will be presented in the full version of the paper. The measured gain is in accordance with the simulated results.

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