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Using Genetic Algorithms Reduction of Rectangular Microstrip Patches

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Abstract—This paper presents a new procedure for the miniaturization of rectangular microstrip patches based on genetic algorithms. The shape of a typical rectangular patch is modified in order to reduce its resonance frequency keeping the physical volume of the antenna constant. As an example, the resonance frequency of a square microstrip patch is reduced from 3 to 1.8 GHz. The patch is divided in 9 X 9 square cells. The genetic algorithm optimization procedure is subsequently used to remove some of the metallic cells. Good agreement is obtained in theoretical results.

Index Terms—Genetic algorithm, microstrip antennas, miniaturization.

I. INTRODUCTION

In recent years, the miniaturization of antennas became more and more important, especially due to the increasing demand for small antennas for cellular mobile communication system applications. Compact antennas are required to be integrated into very small mass-produced handsets. Lightweight and low cost are other important specifications. Many configurations have been proposed in the literature. Most of them suggest modifications of common well-known geometries leading to the reduction of the antenna physical size [1]–[4]. Other strategy is to increase the effective dielectric constant of the structure by the use of high permittivity substrates [5]. Another possibility is to load the antenna either with resistive or capacitive loads or even with shorting pins [6]–[8]. Recently, compact patch antennas integrated with active devices have been proposed [9], [10]. However, so far all the proposed structures are based on *intuitive designs* and their behavior can be predicted in terms of well-known radiation mechanisms.

The new computer-aided design (CAD) approach proposed in this paper is trying to obtain better results, by *overcoming the basic limitations of intuition*. The method is based on a full automatic iterative procedure leading to printed antennas with irregular (nonintuitive) shapes [11]. The algorithm proposed combines a genetic algorithm (GA) with the method of moments (MoM). A similar approach has already been used in [12] to improve the *Q* factor of a resonator, in [13] to optimize single-feed microstrip patches with circular polarization and in [14], [15] to obtain wideband patch antennas. A short overview of the GA optimization procedure is presented in Section II. The design methodology of the patch antenna element, chosen as the application example, is described in Section III. contains the discussion of theoretical results of the antenna prototype. Finally some conclusions are drawn in Section V.

II. OPTIMIZATION PROCEDURE

The optimization procedure in based on GAs. GA optimizers are robust global stochastic search methods based on the Darwinian concepts of natural selection and evolution. The parameters of each individual of the population are usually encoded as a string of bits (chromosomes). The first group of individuals (generation) is created randomly. Mating these individuals forms a new generation. The more fit individuals are selected and given greater chance of reproducing. Crossover and mutation are used to allow global exploration of the cost function. The best individual may be passed unchanged to the next generation (elitism). This iterative process creates successive generations until a stop criterion is reached. It is expected that individuals of successive generations converge to the global maximum [16], [17].

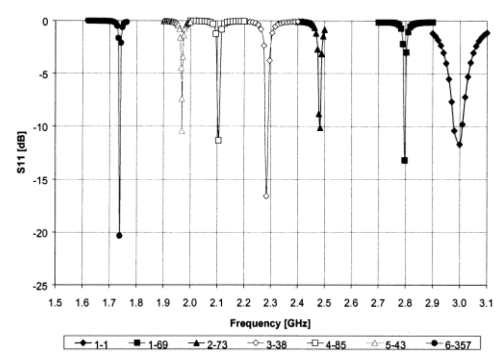

Fig. 1. Evolution of the patch input reflection coefficient.

In this case, the variables are the number of metal cells and their location (patch shape) and all the other antenna parameters remain constant during the optimization process. The initial common rectangular microstrip patch is divided into N X M equal rectangular cells. A public domain GA driver [18] has been used. It is a complete and versatile GA code with advanced options like niching, uniform or simple crossover, jump and creep mutation, elitism, or the possibility of choosing one or two children per couple of parents. The coding is straightforward as a "1" represents a cell with metal and a "0" represents a cell with no metal. All the cells are allowed to be metallic or nonmetallic except the cell where the coaxial probe is connected that must be necessarily metallic. Each chromosome is, therefore, coded as a string of N X M bits (genes). The initial population is generated randomly. For each cycle of the optimization procedure a start frequency (start freq), stop frequency (stop freq) and number of frequency points (n freq) are chosen. At each frequency point and for each individual the input reflection coefficient is evaluated using a MoM analysis engine (PATCH). If the return loss is less or equal to 10 dB the cost function is set to zero. If it is greater than 10 dB, the resonance frequency of the individual is set as the frequency where the input reflection coefficient is minimum. The cost function is then calculated as the difference between the resonance frequency and a higher reference frequency. The greater the difference between these two frequencies, the higher the fitness of the individual. A new generation is obtained from the previous one using tournament selection with elitism, single-point crossover, and mutation [16], [17]. The cycle goes on until the predefined number of generations limit is reached. Since there is no information about an "absolute" or "unique" solution, a new cycle can be started. In this case, new start freq and stop freq are defined to guarantee the optimization procedure efficiency.

III. PATCH DESIGN

The starting configuration is a typical rectangular patch fed by a perpendicular coaxial probe. The substrate has a thickness of 62 mils, a relative dielectric constant of 2.20, and a loss tangent of 0.0007. The dimensions of the patch are W = L = 32.94mm, and have been chosen to provide a resonance frequency around 3 GHz. The patch is fed symmetrically at 11.3 mm from the edge. The 50-Ω feeding coaxial probe has inner and outer diameters of 0.92 and 2.95 mm, respectively.

The GA optimization procedure is subsequently used to find the configuration with the lowest resonance frequency. N = M = 9 and populations of ten individuals are used. Uniform crossover with probability 0.1 and jump mutation with probability 0.6 has also been used. A reference frequency of 4 GHz has been chosen. The evolution of the patch input reflection coefficient during the optimization procedure is shown in Fig. 1.

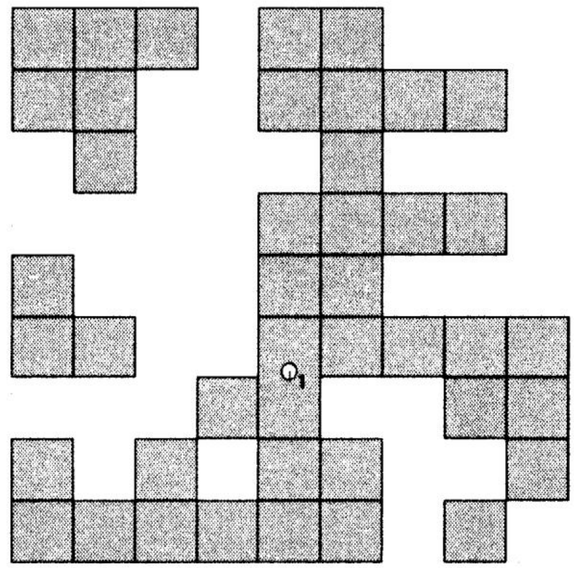

Fig. 2. Geometry of the optimized patch.

For each curve, the first number represents the order of the cycle and the second one represents the number of generations. The initial patch has a resonance frequency of 3 GHz. For the optimized patch (shown in Fig. 2) a resonance frequency of 1.738 GHz has been obtained with PATCH software tool. Therefore, a reduction of 42% has been achieved in the patch resonance frequency. The optimization procedure is computationally time consuming. In this case, a CPU time of around 20 h was needed in a 400-MHz PC.

Two commercially available software tools have been used to confirm the input reflection coefficient results of the optimized patch. ENSEMBLE [19] and IE3D [20] have predicted a resonance frequency of 1.795 GHz and 1.847 GHz, respectively.

IV. RESULTS

In the design procedure, a prototype of the optimized patch has been made. The corresponding experimental results are compared in Fig. 3.

On the contrary PATCH and ENSEMBLE simulations show a resonance frequency discrepancy of 6.8% and 3.9%, respectively. The corresponding E and H – plane results are shown in Figs. 4 and 5, respectively. A broad radiation pattern with maximum gain of about 1 dBi is obtained.

Half-power beam widths in and -plane are 75° and 78°, respectively. As expected, the cross-polarization level is quite high.

This is not surprising, as in the case presented only size reduction has been imposed in the cost function. However,

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the optimization procedure can be modified to impose any other constrains.

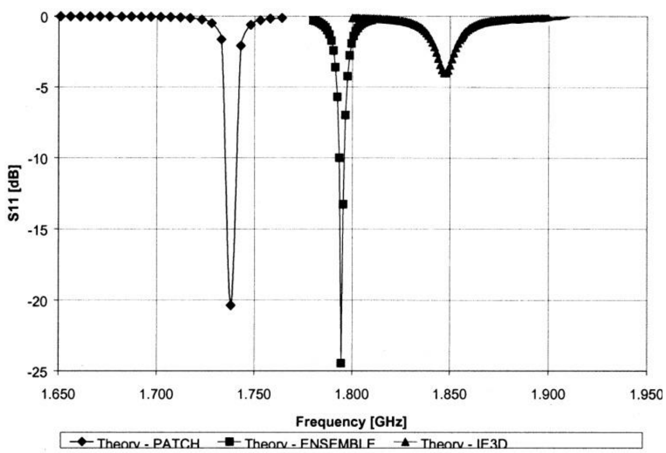

Fig. 3. Theoretical input reflection coefficient.

Fig. 4. Experimental E-plane gain.

V. CONCLUSION

A technique for the miniaturization of microstrip patch antennas has been presented. It is based on an optimization procedure using genetic algorithms and the method of moments with analytical Green's functions in spectral domain. The procedure starts with a typical rectangular patch, which is divided into an adequate number of rectangular cells. Some cells are then removed to provide reduction in the patch resonance frequency. As an application the resonance frequency of a rectangular patch, divided in 9 X 9 cells, has been decreased 42%.

The main benefit of the antenna proposed over the other proposed previously in the literature consists of its high efficiency. The same reduction in size can be obtained using a higher dielectric substrate and a typical rectangular patch. However, the efficiency of such a antenna would be significantly lower.

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