Design of Rectangular and Circular Microstrip Antennas Using the Taguchi Method for WLAN Applications

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***Resumo*— Este artigo é uma extensão de [1] combinando uma técnica de otimização com fórmulas aproximadas. Essa combinação visa a síntese de antenas para aplicativos WLAN. As fórmulas aproximadas fornecem equações para a determinação da frequência de ressonância. A partir dessas fórmulas, podemos obter as dimensões físicas de antenas. Para a otimização da resposta em frequência, o método Taguchi é usado. Resultados numéricos e experimentais são apresentados. Uma boa concordância entre os resultados é observada.**

Palavras-Chave*— *Antenas de microfita retangulares e circulares, método de otimização, Método Taguchi.

Abstract— **This paper is an extension of [1] combining an optimization technique with closed formulas. This combination aims synthesis of antennas for WLAN applications. The closed formulas provide equations for resonant frequency determination. From those formulas, we can obtain physical dimensions of antennas. For the optimization of resonant frequency response, the Taguchi Method is used. Numerical and experimental results are presented. A good agreement between numerical and experimental results is observed.**

Keywords*— *Rectangular and Circular microstrip antennas, optimization method, Taguchi Method.

I. INTRODUCTION

Wireless local area networks (WLAN) are becoming more and more predominant today. For WLAN applications, the antenna is an important part of the wireless communication system [2]. Microstrip antennas have advantages that made them a perfect candidate for WLAN systems. Though bound by certain disadvantages, microstrip patch antennas can be tailored so they can be used in WLAN systems and other applications, e.g. PCS, Bluetooth, RFID, etc [3], [4].

Design parameters of microstrip antenna need to be calculated in high accuracy to ensure proper operation. Design of rectangular or circular microstrip patch antenna requires high accuracy of calculations, and it is not so easy task. The known models (transmission line model or cavity model) give less accurate results. An alternative is use optimization techniques to design more precisely microstrip antennas [5] – [7].

Many problems of synthesis in electromagnetism present approaches based on trial and error. The class of optimization algorithms, known as "metaheuristics" [8] – [10], are no more than trial and error procedures performed in a more intelligent and systematic way [11].

The optimization methods can be divided into global and local techniques [12]. Global techniques have advantages over local techniques and, in electromagnetic applications, global techniques are favored in relation to local techniques, because the former produces a global optimum rather than a great location, finding useful solutions when local techniques fail.

In this context, the Taguchi method appears as an efficient and popular approach because it reduces the number of executions, satisfying a reasonable coverage percentage, of the problem. The Taguchi method is based on the concept of orthogonal arrays [12], [13].

In this study, we applied the Taguchi method, in the design of rectangular and circular microstrip antennas, presented in [1] to design of rectangular and circular microstrip antennas for WLAN applications.

II. DESIGN THEORY

Researches about microstrip antennas began in the 1950s [13]. The ease of manufacturing this type of antenna has attracted the attention of many researchers. Basically, the microstrip antenna consists of a metal strip on a dielectric layer (substrate) and a ground plane located below the substrate [14], as we can see in Fig. 1.. The antenna's resonant frequency is dependent on its physical and electrical parameters (substrate characteristics).

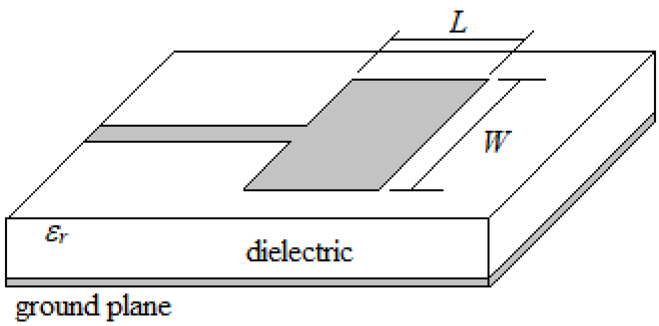

Fig. 1. Microstrip antenna conventional.

Microstrip antennas, also known as planar antennas, are simple structures that can be constructed in a wide variety of forms (geometries), but seeking the simplification in the analysis, when it comes to mathematical modeling, in antenna construction, is very the use of simple geometries such as rectangular and circular.

The chosen geometries in this paper were rectangular and circular patches, because there are simple formulas for they.

The rectangular geometry is widely used because it is easy to analyze and well known. For test of the Taguchi method, we use the approximate analysis presented in [1]. Formulas of design were also presented in [1], and we will not repeat here. The geometry of the geometry is illustrated in Fig. 2.

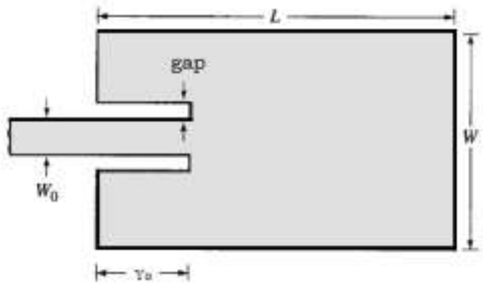

Fig. 2. Use of inset fed for feeding by microstrip line in a rectangular patch antenna.

Equally to the rectangular geometry, the circular geometry is also much used and has relatively simple analysis, being also well known. Again, an approximate analysis presented in [1] will be adopted. The circular patch antenna and its parameters are illustrated in Fig. 3.

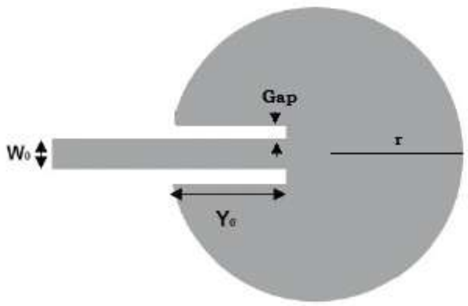

Fig. 3. Use of inset fed for feeding by microstrip line.

III. TAGUCHI METHOD

The Taguchi method has as its main objective to improve the characteristics of a process or a product by identifying and adjusting its essential parameters. We can cite as main advantages of the method [13], [15], [16]:

- Fast convergence;
- Easy implementation;
- Effective reduction in number of experiments;
- It doesn't depend on the initial values of the parameters.

The method was developed based on the concept of Orthogonal Arrays, an effective form of choosing the parameters of the project in an optimization process, which reduces the number of experiments necessary to solve the problem, quickly reaching the convergence to the desired structure [17] – [19].

The initialization in the process of the Taguchi Method is given by the selection of the Orthogonal Array, which will be used for the composition of the experiments, and the fitness function (function responsible for the adjustment of the parameters). The fitness function is defined according to the application. For the application of this work the fitness function is defined as:

$$FF = |f_{r\_desired} - f_{r\_achieved}| \quad (1)$$

The entire procedure was presented in [1] and we will not repeat here.

IV. RESULTS

We consider as input parameters the f_r desired, the permittivity of the dielectric (ε_r) and the thickness thereof (h). For rectangular geometry, the problem reduces to a 2-dimensional problem in which the two parameters of the patch (i.e. L and W) are determined. For this geometry, 3 problems are selected from literature and all of them are solved by means of the Taguchi method. In [14], the authors do not define the optimization range, that is, the **maximum** and **minimum** values, that output parameters can assume, for solved problems. This directly influences the convergence values of these parameters.

To show the efficiency of the technique, we will analyze the numerical convergence of the method, considering: convergence of the output values, convergence of the resonance frequency and percent error, as a function of the number of iterations. For this, we consider as range of values of output parameters **Maximum = 45 mm** and **Minimum = 10 mm**.

In the initial iteration, each parameter assumes three levels and is defined according to the optimization range, that is, the **maximum** and **minimum** values that **the parameter can reach**. Level 1 assumes the maximum, level 3 assumes the minimum and level 2 (optimal level) **initially** assumes the **mean value**. In the following iterations, Level 2 is always defined as **the best response** between the three levels of the anterior iteration (Level 1, Level 2 or Level 3 anterior) and the other levels defined from Level 2 (optimal level) of each iteration.

The initial idea was to design two microstrip patch antennas, one rectangular and another circular, to resonate at 2.45 GHz frequency, which is the central frequency for WLAN applications. The dielectric was FR-4 with 0.8 mm of thickness.

As we can see in Fig. 1, the rectangular microstrip antenna design consists of obtaining W and L parameters. For this, the Taguchi method was used. Fig. 4 shows the convergence of the value of W, as a function of the number of iterations, for rectangular antenna. From 24 iterations we have a satisfactory convergence for the three levels.

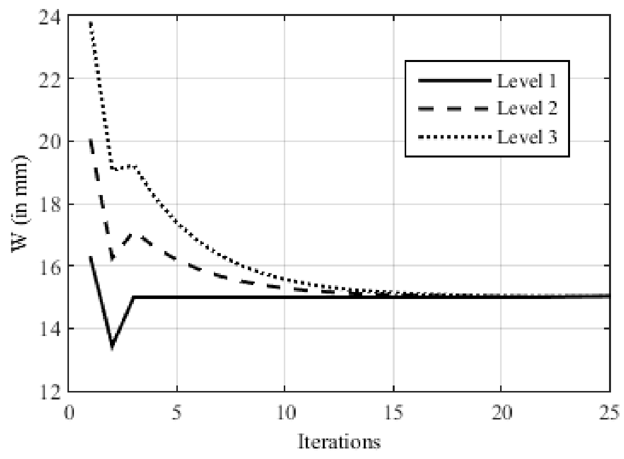

Fig. 4. Convergence curve for parameter W.

Fig. 5 illustrates the convergence of *L* parameter, as a function of the number of iterations, for rectangular antenna. From 24 iterations we also have a satisfactory convergence for the three levels.

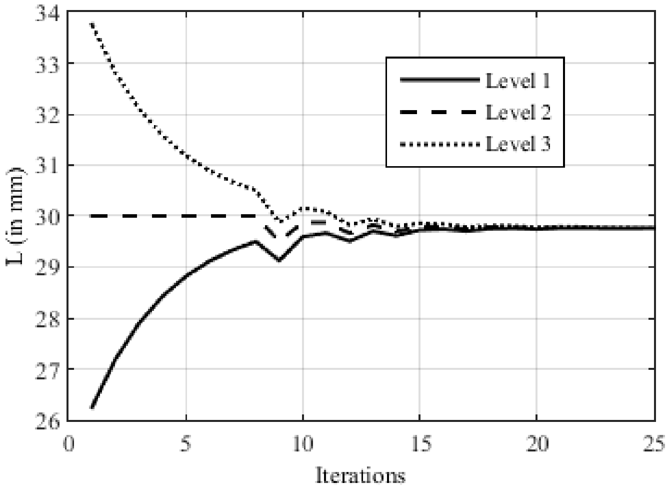

Fig. 5. Convergence curve for parameter *L*.

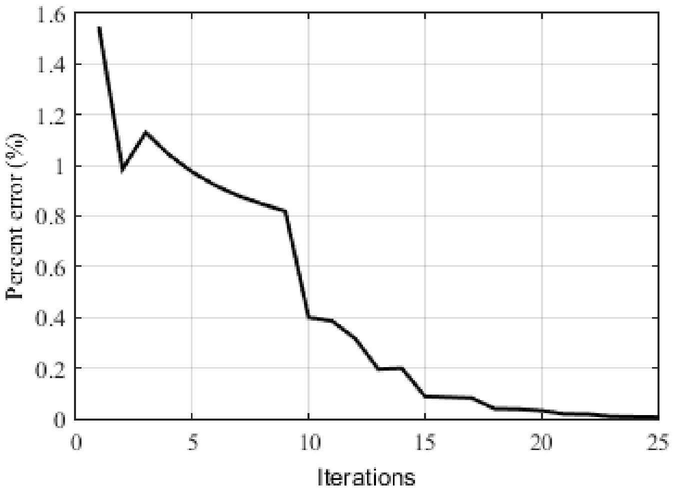

Fig. 6. Convergence curve for percent error for rectangular antenna.

After this, we simulated for a circular antenna. As we can see in Fig. 3, the circular microstrip antenna design consists of obtaining *r* parameter. For this, the Taguchi method was used. Fig. 7 shows the convergence of the value of *W*, as a function of the number of iterations, for rectangular antenna. From 24 iterations we have a satisfactory convergence for the three levels.

Through the convergence of the parameters it is possible to analyze the performance of the optimization method again. Fig. 8 shows that the percentage error related to the desired frequency is less than 5% already in the nine iteration, which shows the speed of convergence of the method.

Fig. 9 illustrates built prototypes of two optimized antennas. The rectangular antenna was built with parameters: gap value = 1 mm, Y_0 = 10 mm, W_0 = 1.8 mm, W = 15 mm and L = 30 mm. For circular antenna physical parameters were: gap = 1 mm, Y_0 = 10 mm, W_0 = 1.8 mm and r = 18 mm. the inset fed was designed to match the impedance for 50 Ω.

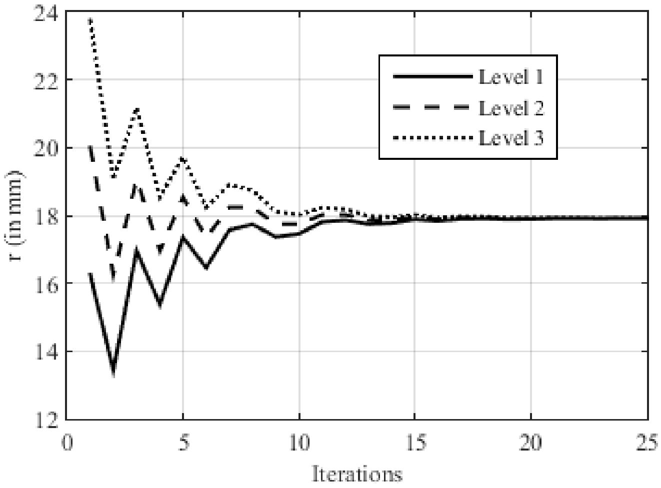

Fig. 7. Convergence curve for parameter, *r*.

For validation purpose we measured and simulated the built prototypes in ANSYS HFSS. The measurements were performed with a HP vector network analyzer from 1 GH to 4 GHz. Figs 10 and 11 illustrates comparisons for measured and simulated results. A very good agreement is observed. For rectangular antenna the measured resonant frequency was 2.53 GHz, error of 3.2 %. For circular antenna the measured resonant frequency was 2.41 GHz, error of 1.6 %.

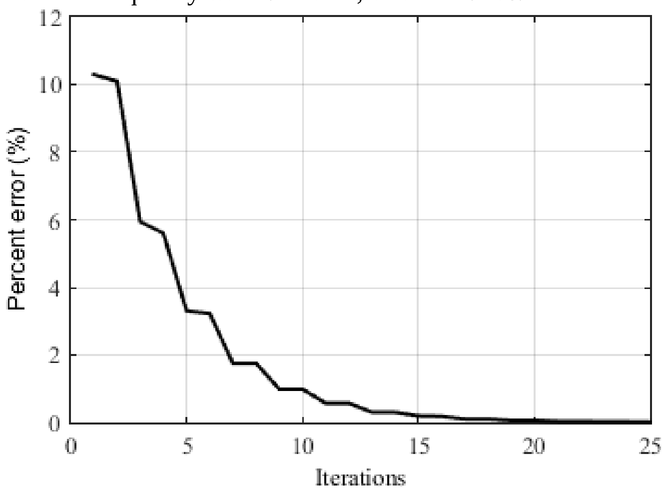

Fig. 8. Convergence curve for percent error for circular antenna.

Fig. 9. Built prototypes.

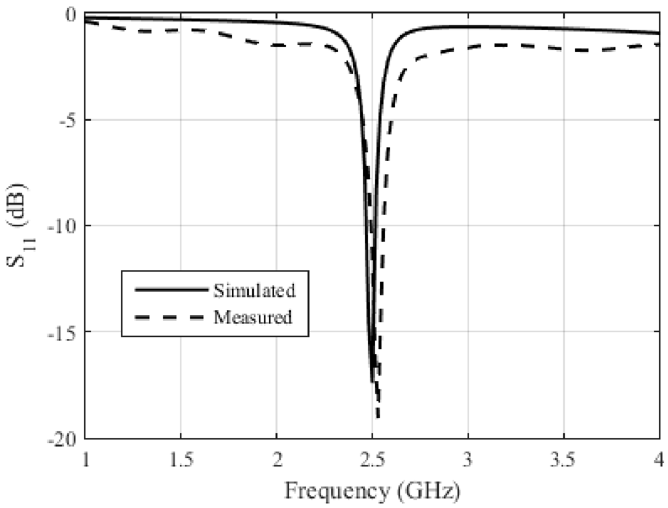

Fig. 10. Comparison between measured and simulated results for rectangular antenna.

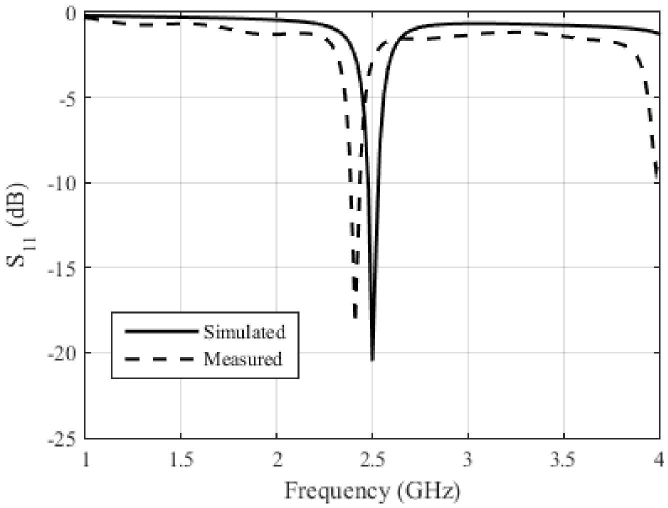

Fig. 11. Comparison between measured and simulated results for circular antenna..

V. CONCLUSIONS

Previously, similar approach to the rectangular microstrip patch antenna design problem was presented in [1], in which the solution is carried out by means of Taguchi method but without treat the limits and only for rectangular geometry. In this paper, we present the optimization of the problem for rectangular and circular geometries. In addition, a convergence study was presented and the percent error was analysed. As can be seen, the Taguchi's method is a great tool for optimizing planar antenna designs. A good agreement between measured and simulated results is obtained.

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