Design and Optimization of a Circularly Polarized Microstrip Antenna for GPS Applications Using ANFIS and GA

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Abstract

In this paper a method based on combining adaptive neuro fuzzy inference systems (ANFISs) and genetic algorithm (GA) is applied for design and optimization of a circularly polarized microstrip antenna for L_1 frequency band of GPS. In design process, trained ANFISs are used for estimating return loss and axial ratio. In optimization process, a proper objective function is defined and minimized with GA in order to obtain optimum physical parameters. The optimization method is much faster than conventional optimization methods. Both simulation and measurement results confirm the accuracy and efficiency of the method.

1. Introduction

Microstrip antennas have some attractive features such as low profile, light weight, low production cost and ease of fabrication. However, designing wideband circularly polarized microstrip antenna is a challenging area [1]. To overcome this limitation, researchers have introduced a number of schemes and some MSAs with the required properties have been fabricated previously [2-5]. These schemes are generally divided into two categories: parametric study and optimization methods. In parametric studies, researchers using powerful softwares such as HFSS, IE3D, etc. try to adjust antenna parameters such that desirable goals achieve. In optimization methods, on the other hand, microwave softwares which perform full wave analysis are usually used for evaluating fitness function in an optimization loop which is usually done in another environment like MATLAB.

Since parametric study is intrinsically based on trial and error, there is no warranty to achieve a desirable goal even after numerous tests. On the other hand, optimization methods is often time consuming because of the large number of runs of full wave software which are needed for termination of an optimization process. In [6] we successfully used ANFISs trained by hybrid learning algorithm in order to approximate a proper objective function. The data required for training these ANFISs was extracted from HFSS through a few runs. Then GA was applied to this objective function and optimum physical antenna parameters which maximize antenna bandwidth were obtained. In this paper using the same approach, a circularly polarized microstrip antenna for L_1 band of GPS applications was designed and optimized. This method is much faster than other well-known optimization techniques in which microwave software must be run repeatedly. Indeed, in this method HFSS is run a few times, just for generating training data, and other optimization process is done in MATLAB.

In the next section, we introduce a microstrip antenna whose parameters can be adjusted so that required bandwidth and circular polarization in L_1 frequency of GPS can be achieved. Characteristics of ANFISs, which were used to estimate antenna return loss and axial ratio, and also comparison between exact and estimated values will appear in section 3. Then, in section 4, simulated and measured results of optimized antenna are compared which show good agreement. Finally conclusions are presented in sections 5.

2. Antenna Structure

One of the most applicable approaches to produce circular polarization in a square patch microstrip antenna is to add or cut some segments known as perturbation [1]. The antenna which is investigated in this paper is a two layered square-shaped microstrip antenna with two perturbations in its corners. Figure 1 illustrates this antenna from two perspectives. As it can be seen from this figure, the coaxial feed is located orthogonal to patch and in the center of the patch in the x-direction, in order to produce two orthogonally degenerate modes for circular polarization. The

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position of the feed in the y-direction should be adjusted for the antenna input impedance matching. First layer of the antenna is in fact an air gap between antenna substrate and ground plane whose thickness (h_1) is very essential for increasing the antenna bandwidth. Second layer, on the other hand, is a Rogers RT/duroid 5870 microwave substrate with relative permittivity of 2.33 and dielectric thickness of 0.787 mm.

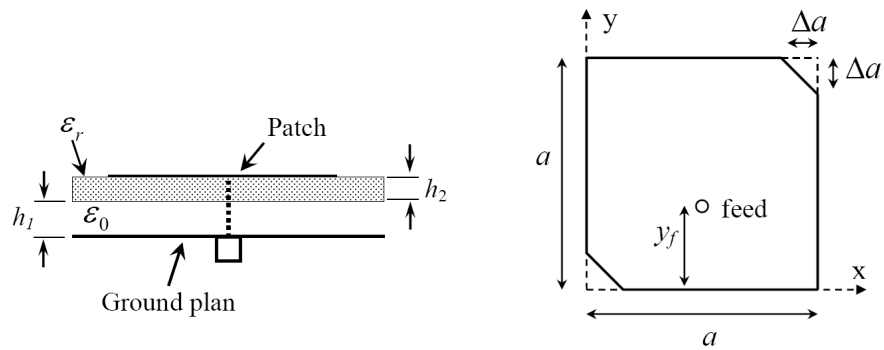

Figure 1. Antenna geometry from two perspectives.

In order to have a resonance in the frequency of 1575 MHz, the length of the patch edges must be fixed at a=80.93 mm while other parameters such as air gap thickness (h_1), the length of perturbation segments (Δa) and feed position (y_f) can be changed to obtain low axial ratio and wide bandwidth (more than 40 MHz around center frequency).

3. Estimating Antenna Properties Using ANFISs

In most previous researches (such as [7-10]), artificial neural networks (ANNs) and ANFISs were merely used for antenna analysis, and GA was used to optimize antenna parameters. In this paper these two techniques are combined, and optimum antenna parameters which lead to low axial ratio and large bandwidth are obtained. As mentioned in previous section, h_1, Δa and y_f are optimization parameters and the objective function should be depended to them. Indeed, in this research the objective function is defined according to antenna return loss and its axial ratio which are expressed in terms of frequency (f), h_1, Δa and y_f.

At first, return loss and axial ratio of the antenna is estimated using ANFISs. For both return loss and axial ratio, we consider 4, 1, 2 and 2 Gaussian membership functions respectively for f, y_f, h_1 and Δa in initial fuzzy inference systems. The inputs of these networks are randomly selected between two distinct values for each parameter and their outputs are extracted from HFSS. Using these input output pairs, ANFISs can be trained and approximate exact values with good accuracy. In figures 2 and 3, approximative and exact values (obtained by ANFISs and HFSS respectively) of return loss and axial ratio are compared with each other. In both figures, good agreement can be seen between exact and approximative values.

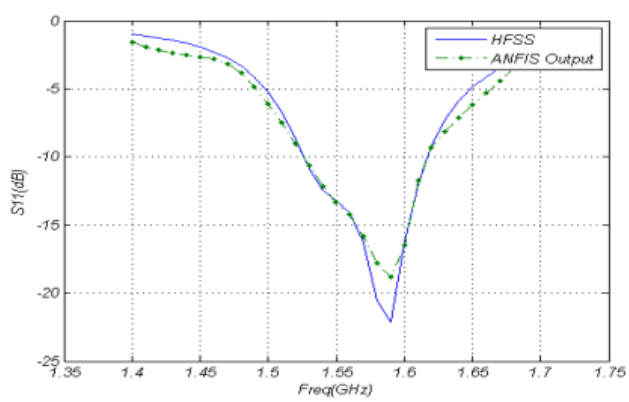

Figure 2. Return loss comparison between ANFIS output and exact data obtained by HFSS for an antenna with random parameters (Δa=*9.9705*mm, h_1=*2.1275*mm, y_f= *17.6972*mm).

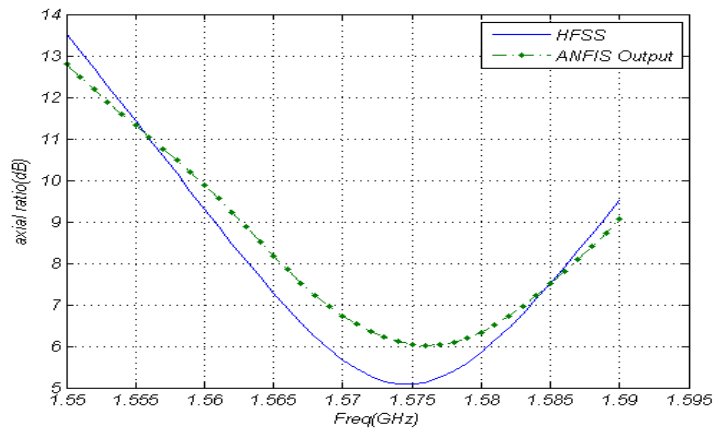

Figure 3. Axial ratio comparison between ANFIS output and exact data obtained by HFSS for an antenna with random parameters (Δa=7.7449mm, h_1=2.5938mm, y_f= *17.5121*mm).

4. Simulation and measurement results

Since it is desired to design a circularly polarized microstrip antenna with at least 40 MHz bandwidth around center frequency (1575 MHz), the objective function is defined as:

$$obj.func = \int_{1555}^{1595} \left[\left[\frac{1+sgn(|S_{11}|+12)}{2} \right] \times (|S_{11}| + 12) + \left[\frac{1+sgn(|ax|-3)}{2} \right] \times (|ax| - 3) \right] df, \quad (1)$$

where sgn is the abbreviation of sign function and $|S_{11}|$ and $|ax|$ are absolute values of return loss and axial ratio in dB respectively. It is necessary to note that the relationships between these two properties and optimization parameters, have been found using ANFISs described in the previous section.

Now, GA can be applied to minimize this objective function in order to obtain optimum parameters which leads to low axial ratio and return loss in desired band. Optimum values determined by this strategy are: h_1*=2.182mm,* Δa*=10.576mm* and y_f*=16.933*.

To verify the accuracy of the method, the antenna with these parameters was simulated in Ansoft HFSS software and also fabricated on a Rogers RT/duroid 5870 microwave substrate. Simulated and measured return loss of the antenna depicted in figure 4 and shows its proper bandwidth around 1575 MHz. A photo of the fabricated antenna and its measured polarization pattern is shown in figure 5.

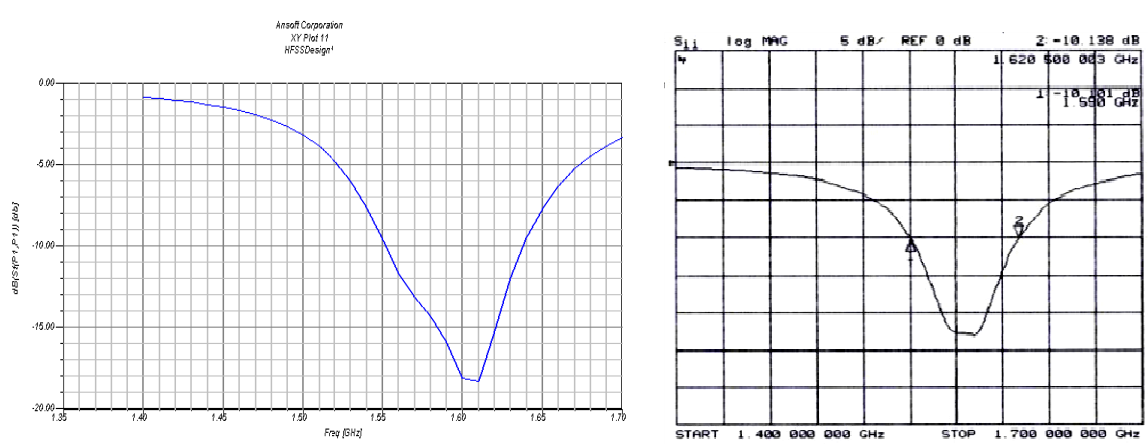

Figure 4. Simulated (left) and measured (right) return loss of the antenna.

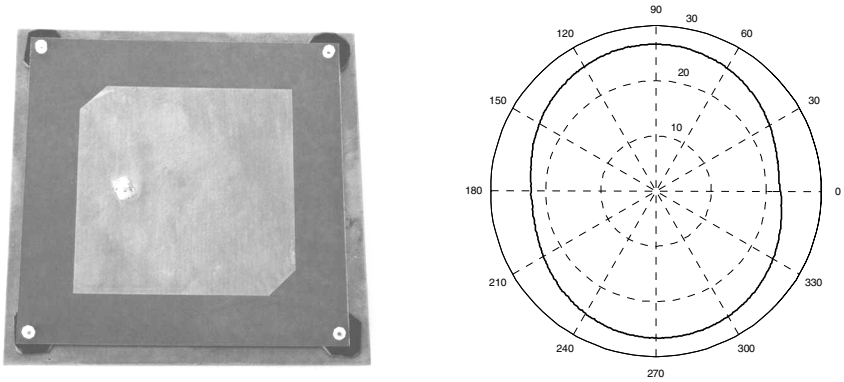

Figure 5. A photo of the fabricated antenna (left) and measured polarization pattern in 1575 MHz (right).

5. Conclusion

In this paper, using a hybrid method, based on estimating the properties of the microstrip antenna through ANFISs and optimizing its parameters with GA, we accurately designed a microstrip antenna which is suitable for GPS application because of its circular polarization and required bandwidth. Both simulation and measurement results confirm the accuracy of the method. Furthermore, this scheme is much faster than other well-known optimization techniques in which a microwave software must be run repeatedly and optimization process lasts a long time. Indeed, in this method we ran HFSS a few times, just for generating training data, and other optimization process is done in MATLAB which takes only a few minutes.

6. References

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