Optimization of Hexa-band PIFA using Artificial Neuro-Fuzzy Inference System based CAD Model

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ABSTRACT
In this paper, optimization of hexa-band planar inverted f-antenna is carried out using artificial neuro-fuzzy inference system. The geometrical parameters of the antenna under consideration were given as input to the proposed CAD model while the return loss characteristics were obtained as output. A comparison of the output of the proposed CAD model and that of commercially available full wave solver was carried out. Based on the comparison, it was found that the results resembles closely. Results provided by the proposed CAD model were accurate and required less computation time and computational resources once trained properly.

General Terms
Antenna return-loss, optimization

Keywords
Artificial neuro-fuzzy inference system, hexa-band planar inverted-F antenna, membership function

1. INTRODUCTION
With the advancement in wireless communication, the need for smaller, lighter and multifunctional mobile handsets has arisen. In last decade, the mobile antennas have become internal from external and this subject itself has become a great area of research. This is because; mobile handset antennas should fulfill certain stringent requirements. This includes the constraints of size and weight. One of the best antennas fulfilling these constraints is a planar inverted-F antenna (PIFA) [1]. Structurally, PIFA consists of a ground plane, substrate, a metallic patch, a shorting pin/plate and a feed. PIFA operates at $\lambda/4$ length and is suitable for an application, where size and weight are constraints [2]. However, the narrow bandwidth of PIFA makes it difficult to be used as a multi-band antenna with single radiator. In order to overcome this limitation several researchers have tried and have come out with very innovative designs. These include a single-band PIFA [3-4], a dual-band PIFA [5], capacitive loading [6], capacitive feeding [7], use of parasitic elements [8], combinations of different loading techniques [9] and resonant slots [10]. In the present work, a compact hexa-band PIFA proposed for mobile hand-set application and discussed in [11] is used as a reference. Accurate analysis and modeling of PIFA is very crucial task as in PIFA, there are several geometrical parameters to be decided for optimum performance. Conventionally these types of antennas can be designed and analyzed using computational electromagnetic techniques. However, these techniques involve complex analytical models, lengthy calculations and need high computational resources. These all make the task of antenna designing and analyzing more complicated and time consuming. On the other hand, in past few years, many researchers have successfully used soft computing techniques for designing and analyzing complex antenna structures. Soft computing techniques, also known as machine learning techniques are very fast and also easy to implement. In the recent years, many such techniques, like Genetic Algorithm (GA), Artificial Neural Network (ANN), Ant Colony Optimization (ACO), Particle Swarm Optimization (PSO), Bacteria Foraging Optimization (BFO), Artificial Neuro Fuzzy Optimization (ANFIS), etc. have been explored. As reported in the open literature, many such techniques have been used to optimize PIFA [12-17]. Recently, researchers have employed ANFIS to optimize several different antenna structures [18-20]. Considering the great interest in ANFIS, in the present work, the same is used to optimize the hexa-band PIFA. To the best of the authors' knowledge, optimization of hexa-band PIFA has not been carried out using ANFIS.
The paper proposes an ANFIS based model to provide return-loss characteristics of a compact hexa-band PIFA for mobile handset application. The return-loss characteristics obtained through ANFIS model is then compared with that of a commercially available full wave solver and it was found that the resemblance is close. The paper is organized as follows: geometry of the hexa-band PIFA is discussed in section 2 while basics of ANFIS are discussed in section 3. The development of ANFIS based CAD tool are outlined in section 4. Results and analysis are summarized in section 5 while conclusions are drawn in section 6.

2. HEXA-BAND PIFA
Hexa-band PIFA consists of a long radiator and a short radiator and is designed to have triple-resonance characteristics. The first resonance frequency operates at GSM (880–960 MHz) band while the second and third resonance frequencies operate at DCS (1710–1880 MHz), PCS (1880–1990 MHz), UMTS (1920–2170 MHz), WiBro(2300–2390 MHz) and Bluetooth (2400–2480 MHz).The -6dB bandwidth as widely used for internal WWAN antenna in practical mobile phone applications is considered in the present work. The geometry of the antenna under consideration is shown in Fig.1.

The different parameters of the hexa-band PIFA shown in Fig. 1 are as follows:
l_1 = total length of the long radiator
l_2 = total length of the short radiator
a = length of the horizontal portion of the short radiator
d = distance separating long and short radiator
l_f = distance between the feed point and the shoring pin

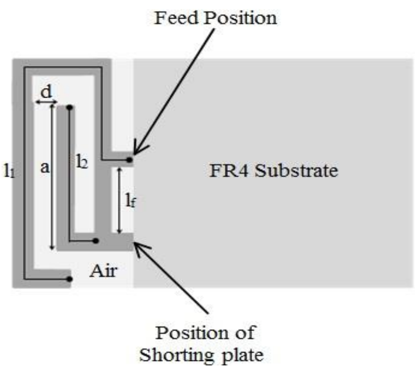

Fig 1: Schematic of hexa-band PIFA under consideration

As reported in [11], frequency f_1 is determined by the total length of the long radiator l_1 while frequency f_2 is determined by the total length of the short radiator l_2. Since f_3 is the first harmonic of the f_1 it is also controlled by the total length of the long radiator l_1.

3. ANFIS ARCHITECTURE

ANFIS is a kind of neural network that is based on Takagi–Sugeno fuzzy inference system. Since it integrates both neural networks and fuzzy logic principles, it has potential to capture the benefits of both in a single framework. Its inference system corresponds to a set of fuzzy IF–THEN rules that have learning capability to approximate nonlinear functions [21].

A simple ANFIS structure is shown in Fig 2. It consists of five layers excluding input and output layer. The inputs are given to fuzzy layer which converts them to fuzzy value. "AND" operation is performed on these fuzzy values in the product layer to determine the weight factor of each rule. The weights are then normalized in the normalized layer. After normalization, output rules are constructed in de-fuzzy layer. Lastly all ruled outputs are summed in summation layer and final output is provided.

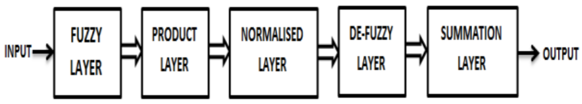

Fig 2: Block diagram of ANFIS Architecture

4. DEVELOPMENT OF ANFIS BASED CAD MODEL

The geometrical parameters of the hexa-band PIFA i.e. a, d and l_f are taken as inputs while the return loss is considered as the output as shown in Fig. 3. The choice of the input parameters is based on a study of change in return-loss with different parameters of the hexa-band PIFA. As it is difficult to cover all the bands using single network, 51 such networks were developed. Each of the networks will provide the value of return-loss at single frequency starting from 0.5 to 3 GHz with a step size of 0.05 GHz.

The necessary data for training and testing the network was generated by using full wave solver (FWS). All the networks were trained after a series of iterations and it was ensured that the error is minimum for each individual network. Finally, the output obtained from each individual network was used to prepare a complete return-loss characteristic of a hexa-band PIFA. This characteristic was then compared with the results obtained from the FWS. Table 1 shows the details of the proposed ANFIS structure while Table 2 shows the range over which the geometrical parameters are varied:

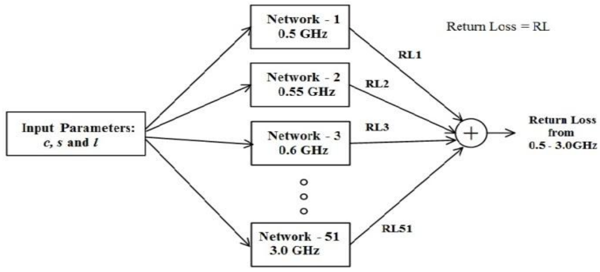

Fig 3: Proposed ANFIS architecture

Table 1.Description of the proposed ANFIS based CAD model

Parameters	Value
Number of training datasets	1300
Number of testing datasets	288
Number of membership function	5
Number of epochs	20
Type of membership function	*gbell*

Table 2.Range variation of different parameters for the Development of ANFIS based CAD model

Parameter	Range (unit: mm)	Step Size
a	1 – 38	3
d	1 – 5	1
l_f	1 – 37	2

5. RESULTS AND ANALYSIS

This section presents the comparison of the results obtained from the full wave solver and proposed ANFIS based CAD model. The results show return-loss for various combinations of geometrical parameters of a hexa-band PIFA. Considering the space constraints, only three combinations of results are shown in the paper. However, accurate results were obtained for all the 288 combinations of test data sets. Also, it may be noted that not all input combinations produces the hexa-band characteristics. Only unique combinations of geometrical parameters produce a hexa-band performance. Fig. 4 shows the comparison between the full wave solver (FWS) and ANFIS model for a= 1.5mm, l_f= 1.5mm and d= 1.5mm. Similarly, Fig. 5 and 6 show the comparison for a= 11.5mm, l_f= 21.5mm and d= 4.5mm and a= 33mm, l_f= 15mm and d= 4mm, respectively. It can be easily seen that the results from the proposed ANFIS based CAD model resembles that of the FWS. This in a way ensures the effectiveness of ANFIS for designing and analyzing PIFA.

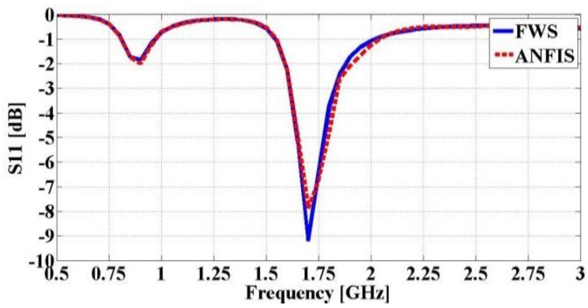

Fig 5: Comparison of return loss for*a*= 1.5mm, l_f= 1.5mm and *d*= 1.5mm

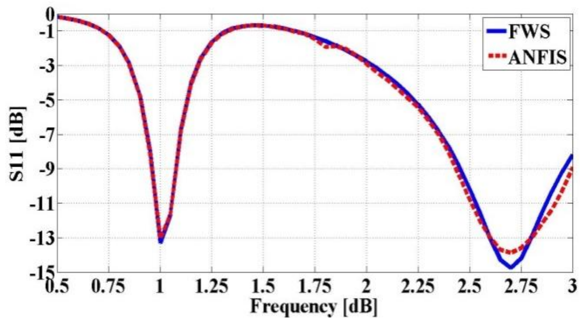

Fig 6: Comparison of return loss for *a*= 33mm, l_f= 15mm and *d*= 4mm

6. CONCLUSION

In the present work, an ANFIS based CAD model was proposed to analyze the return-loss characteristics of a compact hexa-band PIFA. It was observed that the return-loss obtained from the ANFIS based model resembles closely to that obtained by the full wave solver. Moreover, it was also seen that change in the parameters of the antenna caused changes in the number of resonant frequency of the antenna. The proposed model takes very less time to give accurate return-loss characteristics of the antenna given its geometrical parameters. However, care should be taken in generation of datasets as well as training and testing of the ANFIS model. In a nutshell, it can be said that ANFIS not only provides accurate result, but also reduces computation time once trained correctly.

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