Applications of ANN and ANFIS to Predict the Resonant Frequency of L-Shaped Compact Microstrip Antennas

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Abstract **─** Since the Compact Microstrip Antennas (CMAs) with various shapes are crucial for mobile communication, they take much attention in present days and studies related to analysis and design on them have been increasing day by day. In this work, simple approaches based on Artificial Neural Network (ANN) and Adaptive Neuro-Fuzzy Inference System (ANFIS) for computing the resonant frequency of L-shaped CMAs operating at UHF band have been presented. In order to train and test the ANN and ANFIS models, 192 LCMAs having different physical dimensions and relative dielectric constants were simulated by electromagnetic simulation software named IE3D™, which is based on Method of Moment (MoM). 172 of LCMAs were employed for training, while the remainders were utilized for testing the models. Average Percentage Errors (APEs) for training were obtained as 0.345% and 0.090% for ANN and ANFIS models, respectively. The constructed models were then tested over the test data and APEs values were achieved as 0.537% for ANN and 0.454% for ANFIS. Afterwards, the accuracy and validity of ANN and ANFIS models proposed in this work were verified on measurement data of the fabricated LCMAs. The results indicate that ANN and ANFIS can be successfully used to predict the resonant frequency of LCMAs without necessitating any other sophisticated calculations.

Index Terms **─** Adaptive Neuro-Fuzzy Inference System (ANFIS), Artificial Neural Network (ANN), compact microstrip antenna, L-shaped compact microstrip antenna, resonant frequency.

I. INTRODUCTION

The Microstrip Antennas (MAs) [1-3], thanks to their attractive features, such as low profile, light weight, easy fabrication and conformability to mounting hosts have been rapidly increasing for applications of wireless communication systems; for instance, 2G/3G mobile services, marine or land vehicle navigations (GPS), wireless LANs access and

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remote sensor with monitoring systems. These applications usually require small antennas in order to meet the miniaturization of mobile units. The size of conventional MAs having rectangular, triangular and circular patch shapes, has become large for mobile terminals. Thus, size reduction is becoming major design considerations. Compact MAs (CMAs) are called for a miniaturized version of MAs. For constructing CMAs, various approaches such as method of loading slots on the patch or ground plane, shorting pins and using high permittivity substrate layer have been employed [2]. Several CMA configurations obtained by using the method of slots loading on the patch, such as C shape by [4], E shape by [5], H shape by [6] and L shape by [7] have been proposed in recent years.

In analysis of the conventional MA, the techniques such as cavity model [8] and transmission line model [9] can be used. These techniques may not be used for CMAs because of their irregular shapes. In general, simulation and experimental studies are successfully carried out for the analysis and design of CMAs. Electromagnetic simulation tools employing the computational electromagnetics, such as Finite Difference Time Domain (FDTD) method [10] and Method of Moment (MoM) [11] to solve the complicated Maxwell equations are utilized. However, designing procedure may be complicated and highly time consuming by using these tools.

The latest advancements in wireless communication technology have led to an increase in the usage of CMAs with various shapes; therefore, simple approaches should be utilized to analyze their performances. The resonant frequency is of crucial importance in the CMA design, since these antennas inherently suffer from narrow bandwidth. In the literature, several approaches based on approximate formulas have been proposed for determining the resonant frequency of CMAs with arrow, C, E, H, L and rectangular ring shapes [12-16]. In these formulas, the resonant frequency is calculated by using the resonant length equations together with the edge extension dimension and effective relative dielectric constant expressions derived for the rectangular MA. In general, the formulation methods lead to confusion because of many successive calculations.

This paper attempt to predict the resonant frequency of L shaped CMAs (LCMAs) by using Artificial Neural Network (ANN) [17] and Adaptive Neuro-Fuzzy Inference System (ANFIS) [18], to take the advantage of the fast computation of the ANN and ANFIS with a simple manner. For achieving this goal, 192 of LCMAs having various parameters, such as antenna dimensions and dielectric constants were simulated by the packaged software named IE3D™ (version 14), depended on the MoM. 172 of LCMAs were used for the training phase and the remainders were utilized for the testing phase of the models. The accuracy and validity of the models were also tested and verified on two experimental data.

The ANN attempted to model poorly understood problems by employing a mathematical model based on brain's structure. The brain consists of billions of densely interconnected neurons. The premise behind ANN models is that mimicking the brain's structure of many highly connected processing elements will enable computers to tackle tasks they have not as of yet performed well [17]. The ANFIS is a very powerful approach for constructing complex and nonlinear relationship between a set of input and output data sets and it combines the advantages of the expert knowledge of the Fuzzy Inference Systems (FISs) and the learning capability of ANNs [19]. Optimization of these linguistically expressions in FIS are made by a network and this provides the learning ability with addition to data processing ability of the ANFIS. The ANN and ANFIS have ability to learn, generalization, the smaller information requirement, fast real-time operation and ease of implementation without needing any expert knowledge [20]. Even if training phase takes a few minutes, the test phase takes only a few microseconds. A distinct advantage of both ANN and ANFIS, is that they bypass the repeated use of complex formulations or processes for a new case given to it after proper training. Because of these attractive features, the ANN and ANFIS have often been used to solve problems related to electromagnetics, microwave and different engineering areas [21-33].

II. MODELING OF THE ANN AND ANFIS FOR LCMAs

A. LCMA

As shown in Fig. 1, a LCMA has a slot having *d* dimensions on one corner of a rectangular patch ($L \times W$) on the substrate of height *h* having relative dielectric constant ε_r overall on the ground plane. Slot loading on the rectangular MA results in a decrease of resonant frequency; thus, size reduction for the antenna has been achieved effectively.

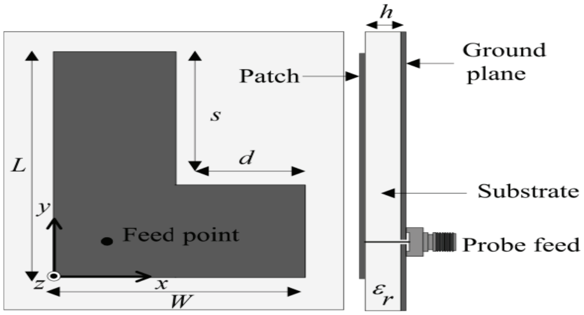


Fig. 1. Geometry of LCMA.

B. Simulations

In order to determine the resonant frequencies of 192 LCMAs having different dimensions and various substrate dielectric constants, which are tabulated in Table 1, simulations have been performed with the use of IE3D™. The antennas operate over the frequency range 0.78-3.23 GHz corresponding to UHF band.

In the simulations, maximum frequency and cell/wavelength rate were assumed as 4 GHz and 40, respectively. A 50 ohm probe feed was applied. Optimization module in IE3D™ based on genetic algorithm [34] was utilized to define the feed point for |S11| < – 10 dB objective function, resulting in the best return loss value.

Table 1: Physical and electrical parameters of simulated LCMAs

	Patch Dimensions (mm)					
Number of Simulations	*L*	*W*	*s*	*d*	*h*	ε_r
64	30	25	10, 15, 20, 25	4, 8, 12, 16	1.57	2.33, 4.5, 6.15, 9.8
64	40	30	20, 25, 30, 35	5, 10, 15, 20	2.50	2.33, 4.5, 6.15, 9.8
64	50	35	30, 35, 40, 45	6, 12, 18, 24	3.17	2.33, 4.5, 6.15, 9.8

C. Training of the ANN and ANFIS

The ANN and ANFIS have been individually applied to predict the resonant frequency values of LCMAs. 172 of LCMAs are employed for training, while 20 of LCMAs are used for testing the ANN and ANFIS models. As shown in Fig. 2, the physical and electrical parameters (*L*, *W*, *d*, *s*, *h* and ε_r) of the simulated antennas were given as inputs and their respective resonant frequency values of IE3D™ were given as outputs, for training the ANN and ANFIS models.

As shown in Fig. 3, the ANN model based on Multilayer Perceptron (MLP) [17] consisting of 1 hidden layer with 3 neurons, was constructed in this work. "Tangent sigmoid" function was used for input and hidden layers, while "purelin" function was utilized for output layers. The Levenberg–Marquardt (LM) algorithm [35] was used in the ANN model as training algorithm, since it is capable of fast learning and good convergence. The number of epochs, minimum gradient descent, momentum parameter (μ), μ increment, μ decrement, maximum μ and seed value were used for training as 250, 10^{-10}, 0.0001, 4, 0.1, 1010, 1446455104, respectively.

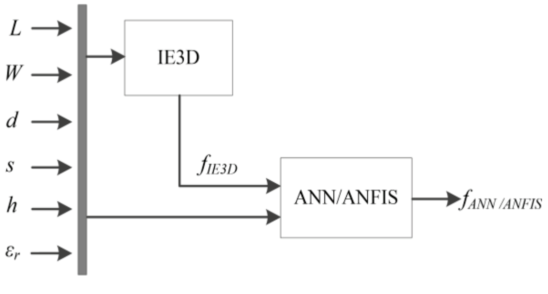


Fig. 2. Training of the ANN and ANFIS.

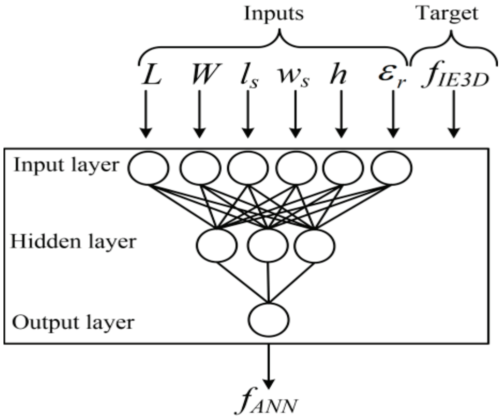


Fig. 3. ANN model.

For the ANFIS network, the hybrid-learning algorithm [18] combining the Least-Squares Method (LSM) and the Backpropagation (BP) [36] algorithm was used. This algorithm converges faster, since it reduces the dimension of the search space of the BP algorithm [37]. The ANFIS network designed in this work was shown in Fig. 4. The number of Membership Functions (MFs) for the input values and output value was selected 22. The number of epochs, range of influence, squash factor, accept ratio and reject ratio used for training were selected as: 100, 0.5, 1.25 0.5 and 0.15, respectively. The MFs used for input values were selected as Gaussian and for the output values was selected as linear functions. The numbers of nodes, linear parameters, nonlinear parameters, total parameters, training data pairs and fuzzy rules are: 317, 154, 264, 418, 172 and 22, respectively.

The training results of the ANN and ANFIS models together with the results of IE3D™ were given in Fig. 5. The method illustrated in Fig. 6 was used for calculating Average Percentage Errors (APEs) and APE values were obtained as 0.345% and 0.090% for the ANN and ANFIS, respectively.

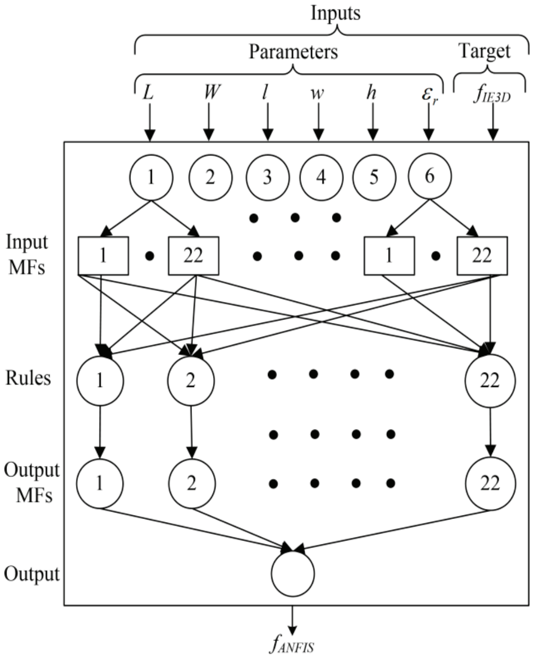


Fig. 4. ANFIS network.

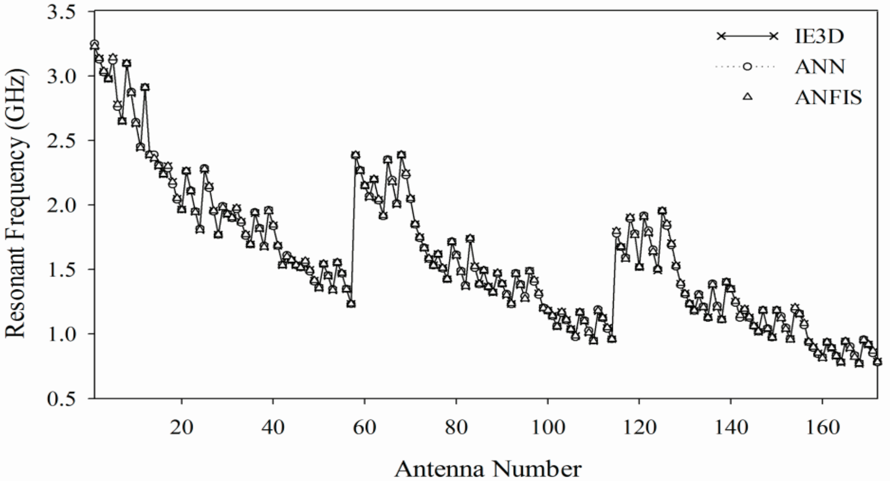


Fig. 5. Comparative results of the simulation, ANN and ANFIS models for training phase.

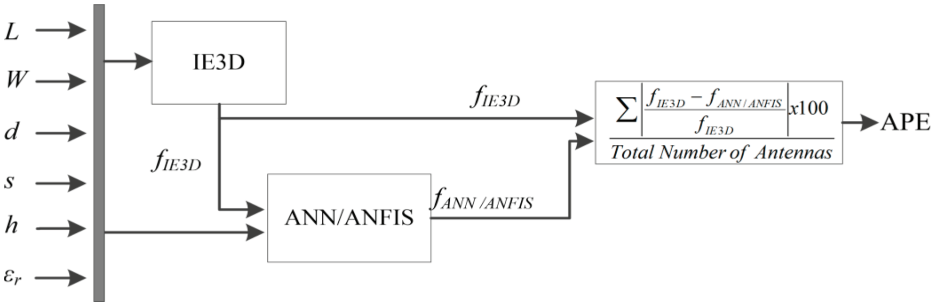


Fig. 6. APE calculation of the ANN and ANFIS.

D. Testing of the ANN and ANFIS

20 of simulated LCMAs representing the whole solution space were utilized to test the performance of the trained ANN and ANFIS models. The simulated and predicted resonant frequency values and calculated APEs with the instruction of Fig. 6, are given in Table 2. APEs were obtained respectively, as 0.537% and 0.454% for the ANN and ANFIS over 20 LCMAs.

Table 2: Resonant frequencies determined by the ANN and ANFIS for test phase

Patch Dimensions (mm)						Resonant Frequencies (GHz)			Percentage Errors (%)	
L	W	s	d	h	ε_r	Simulated	ANN	ANFIS	ANN	ANFIS
30	25	15	8	1.57	2.33	2.969	2.959	2.959	0.337	0.337
30	25	25	4	1.57	2.33	3.128	3.125	3.137	0.096	0.288
30	25	25	12	1.57	2.33	2.640	2.650	2.640	0.379	0.000
30	25	10	16	1.57	4.50	2.200	2.216	2.204	0.727	0.182
30	25	10	4	1.57	6.15	2.013	2.031	2.020	0.894	0.348
30	25	20	16	1.57	6.15	1.563	1.556	1.564	0.448	0.064
30	25	20	16	1.57	9.80	1.244	1.246	1.261	0.161	1.367
40	30	25	5	2.50	2.33	2.359	2.345	2.361	0.593	0.085
40	30	30	20	2.50	2.33	1.844	1.837	1.816	0.380	1.518
40	30	25	5	2.50	4.50	1.713	1.716	1.725	0.175	0.701
40	30	35	10	2.50	4.50	1.650	1.647	1.648	0.182	0.121
40	30	20	10	2.50	6.15	1.432	1.423	1.429	0.628	0.209
40	30	30	20	2.50	6.15	1.183	1.189	1.190	0.507	0.592
40	30	20	15	2.50	9.80	1.090	1.093	1.101	0.275	1.009
50	35	30	6	3.17	2.33	1.904	1.944	1.925	2.101	1.103
50	35	35	18	3.17	2.33	1.635	1.618	1.634	1.040	0.061
50	35	35	6	3.17	4.50	1.380	1.376	1.378	0.290	0.145
50	35	40	12	3.17	4.50	1.303	1.305	1.303	0.153	0.000
50	35	35	12	3.17	6.15	1.114	1.110	1.119	0.359	0.449
50	35	45	24	3.17	6.15	0.983	0.993	0.978	1.017	0.509
APE									0.537	0.454

Further to investigate the robustness of the proposed ANN and ANFIS models over measurement data rather than simulation data, a LCMA was also fabricated by using material of Rogers™ RT/duroid 5870. The resonant frequency value of the antenna was measured by Agilent E5071B ENA series RF network analyzer. Figure 7 illustrates the simulated and measured return loss curves of the LCMA. Notice that the measurement result may include discrepancies because of material production, geometry etching and feed connector misalignment in the fabrication process. The measured, simulated and calculated resonant frequency results of the antennas are tabulated in Table 3. Table 3 also contains the measurement results reported by Chen (2000).

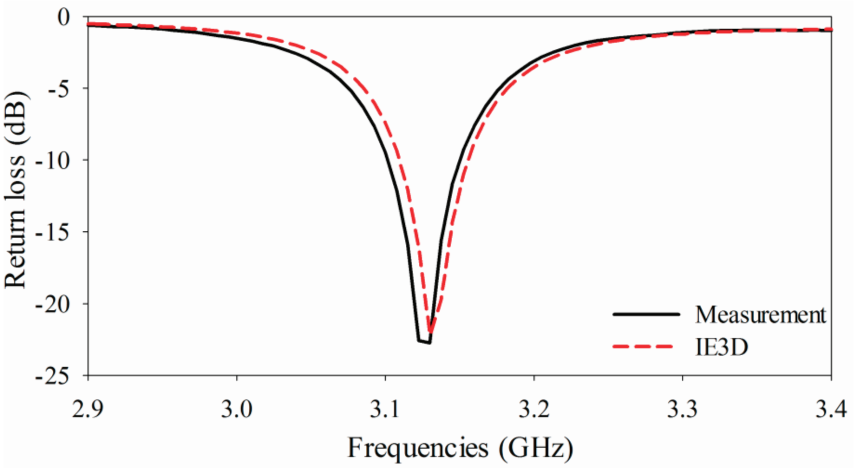


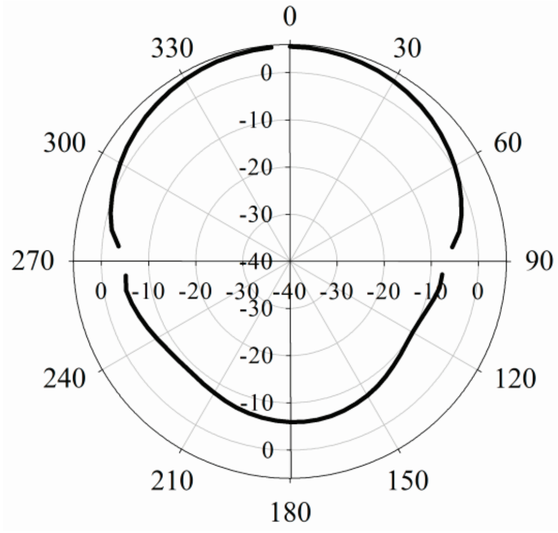
Fig. 7. Return loss (s_{11}) graph of the fabricated LCMA.

Table 3: Results of the simulation, measurement, ANN and ANFIS models

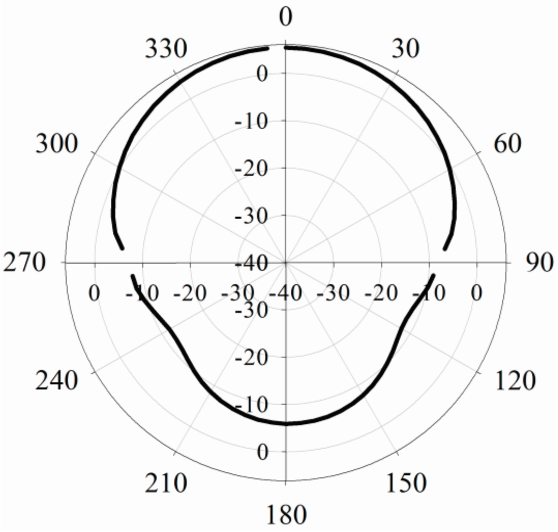
	Patch Dimensions (mm)						Resonant Frequencies (GHz)			Percentage Errors (%)	
	L	*W*	*s*	*d*	*h*	ε_r	Measured	ANN	ANFIS	ANN	ANFIS
LCMA *	30	25	10	8	1.57	2.33	3.130	3.121	3.135	0.542	0.096
LCMA [7]	50	45	22	20	8	1.07	2.680	2.738	2.765	0.436	0.545

*Fabricated in this work by using Rogers™ RT/duroid 5870 with tanδ=0.0012

The simulated radiation patterns for the fabricated LCMA operating at 3.138 GHz are given in Fig. 8 (a) for *x*-*z* plane ($\phi = 0^\circ$) and in Fig. 8 (b) for *y*-*z* plane ($\phi = 90^\circ$). It is seen that the radiation patterns have good performance and approach omni-directional radiation characteristic.



(a)



(b)

Fig. 8. The simulated radiation pattern of fabricated antenna at 3.138 GHz: (a) for *x*-*z* plane and (b) for *y*-*z* plane.

The simulated gain plot of the proposed antenna is given in Fig. 9. The peak gain occurs over the resonant frequency of 3.16 GHz with the radiation efficiency exceeding 80%. The gain varies over the 3 dBi for the 3.07-3.24 GHz band. This good radiation efficiency is due to the use of the dielectric material with low tangent loss.

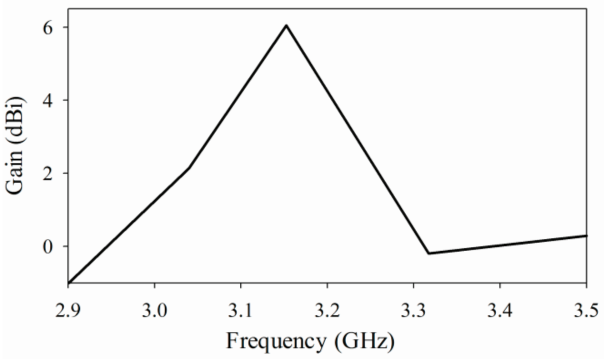


Fig. 9. The simulated gain graph of the fabricated antenna.

From Fig. 5 given for the training phase, the computation results of the ANN and ANFIS well fit to the simulation results of the IE3D™. Test phase results for 20 LCMAs given in Table 2, show that there is a well conformity between the simulated and computed resonant frequencies, in general. In fact, these results are enough to verify the proposed models. However, the experimental data given in Table 3 was also employed to investigate the validity of the models. The very good agreement between the measured values and our computed resonant frequency values supports the validity of the models. These all comparatively results point out that proposed ANN and ANFIS models can be successfully employed to estimate the resonant frequency of the LCMAs operating at UHF band. It is worth noting, that better results may be obtained from the ANN and ANFIS either by choosing different training and test data sets from the ones used in this work, or by supplying more input data set values for training.

III. CONCLUSION

In this study, the ANN and the ANFIS models have been proposed to predict the resonant frequencies of LCMAs. The resonant frequency values were obtained by simulating 192 LCMAs with various antenna dimensions and dielectric constant. It was shown that the computed results by the ANN and ANFIS models trained by means of simulation data are in very good agreement with simulated ones. Accuracy and validity of the proposed ANN and ANFIS models was further tested and verified on two experimental results, of which one was fabricated in this work and the other was reported elsewhere. Thus, the proposed models of ANN and ANFIS can successfully compute the resonant frequency of LCMA operating at UHF band. A major advantage of the ANN and ANFIS computation is that after once accomplished training, no need again any training for each new needs of calculation, since the ANN and ANFIS completely pass the repeated use of complex iterative processes for new cases. The proposed method is not limited to the resonant frequency computation of LCMAs. This method can easily be applied to other antenna and microwave circuit problems. Accurate, fast, and reliable models can be developed from measured/simulated antenna data. Once developed, these models can be used in place of computationally intensive numerical models to speed up antenna design.

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