Selection of Optimal Alphanumeric Pattern of Seven Segment Antenna Using Adaptive Neuro Fuzzy Inference System

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Abstract – **The paper proposes various antenna designs based on different shapes of alphanumeric characters. A seven segment structure is presented using seven patches and connecting those using thin metallic contacts to present various digits or alphabets. The antenna designs were simulated on IE3D software and data were collected. The paper also presents a model based on Adaptive Neuro Fuzzy Inference System (ANFIS) with the help of which user can determine the exact shape of antenna for a given resonant frequency. The main aim of this work is to have multiple antennas of various bandwidths and resonant frequencies within one structure and to select the required structure of the antenna using ANFIS.**

Keywords – **IE3D, Alphanumeric design, UWB, ANFIS, Resonant Frequency**

I. Introduction

One of the most propitious characteristics of ultra wideband communication is its ability to amplify the data rates for short range data transmission in a frequency ranging from 3.1-10.6 GHz, having a bandwidth of greater than 500 MHz [1, 2]. However, designing of antennas with ultra-wideband (UWB) characteristics are the main challenge, especially when the compactness of the structures and economy are the main concerns. For successful application of UWB communication system, antenna elements should be fabricated with the target to cover the bandwidth greater than 500MHz. The idea of combining various antenna elements within one structure such that most of the frequency range can be covered will give rise to a compact and self-complementary communication system. So a new idea of creating a compact antenna has been developed in which the dimensions of the ground plane and feed are kept constant varying only the patch of the antenna structure. However, instead of fabricating the patch of the antenna elements separately, they are linked by metallic links within a structure of eight. However each structure has its own frequency band and resonant frequency and each has its own application. Therefore the selection of the suitable antenna structure according to the requirement is an issue of concern. In this matter, soft computing technique has been introduced.

Using soft computing techniques to design and optimize antenna has proved to be very advantageous since the last decade. Soft computing technique has achieved a new standard by enhancing the designing process. It has not only overcome the limits of approximation, tedious calculations and human errors, but also proved to be a time saving method. The fundamental technique of some soft computing methods like ANFIS is complementary in nature rather than competitive. A problem can be solved much easily combining neural network and genetic algorithm (GA) rather than putting them in competition. ANFIS is an excellent example of the efficient combination of two techniques, i.e. neural network and fuzzy logic [3-6]. Therefore ANFIS has been utilized as a soft computing tool to select the exact antenna structure which can be used for a given resonant frequency and bandwidth depending on the requirement of the user.

In this paper, Section I gives a detailed idea of the antenna structure which is then followed by a description of the artificial model design in Section II. The results of the proposed antenna have been discussed in Section III. The complete analysis of the work has been briefly described in conclusion in Section IV.

II. Antenna Design

The basic idea behind the design was taken from seven segment display. Seven different patches are arranged together in the form of number eight [7]. The patches are linked with the help of metallic links to give various structures of the digits zero to nine and alphabets from A to Z. For

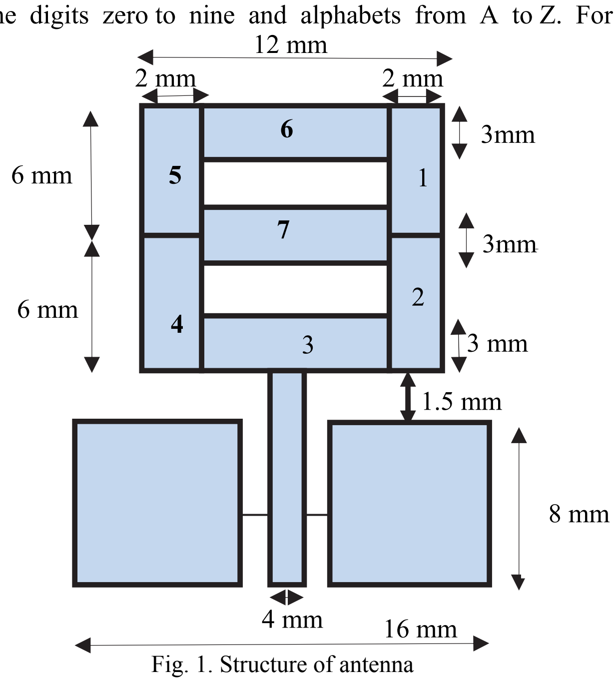

Fig. 1. Structure of antenna

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example, if we connect the patch numbers 6, 1, 7, 4 and 3 then we get a structure of 2. Fig. 1 shows the seven segment structure of the antenna.

In the structure, the ground plane and feed line is kept same for all the structure. The ground plane has the dimension of 16 mm of width and 8 mm of length, whereas the feed line has a length of 9.5 mm and breadth of 4 mm. The antenna is simulated using flame retardant (FR4) substrate which is a grade assigned to a composite material made of epoxy laminate sheets, rods, tubes and printed circuit board of dielectric constant 4.4 on IE3D platform. IE3D from Mentor Graphics prior known as Zealand, USA is an integral equation based on the method of moment and is used as electromagnetic simulator [8].

The patches as for example 1 and 2 or 3 and 4 are connected to each other with thin strips of copper. But these thin copper strips can be replaced with micro-electromechanical system (MEMS) implemented to move the micro millimetre sized parts. MEMS refers to a collection of micro-sensors and actuators, which can react to environmental change under micro- circuit control. MEMS is based on both mechanical and electronic devices on a monolithic microchip which gives superior performance over solid-state components. RF-MEMS can be used as inductors, tunable capacitors, switches, in VCOs, and resonators. In this work, MEMS switches can be used to achieve multi-frequency, reconfigurable antennas for very high frequency applications [9].

The area of the radiating patch varies according to the structure selected, for example in Fig. 2, where all the seven patches are used and in Fig. 4, where only four patches are used. As the surface area of the radiating patch varies the antenna characteristics change as shown in the S_{11} parameter of Fig. 3 and Fig. 5.

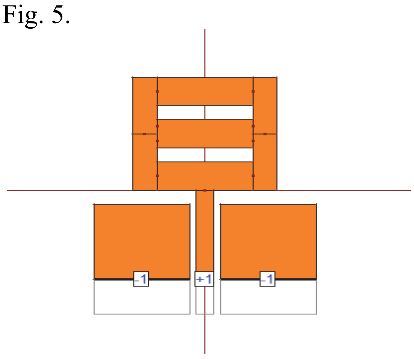

Fig. 2. Simulated structure of antenna in the shape of number 8

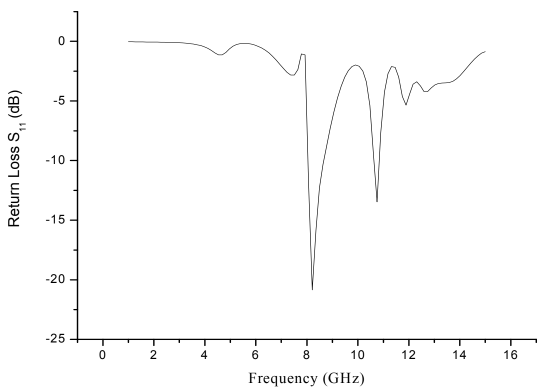

Fig. 3. S_{11} parameter response of number 8

III. Development of ANFIS Model

In this paper, ANFIS is used to determine which shape of the antenna will be appropriate for a specific resonant frequency and correspondingly which patches will be selected to represent that shape of the antenna. ANFIS is an optimized technique which combines the learning property of artificial neural network and decision making property of fuzzy logic. In this case, ANFIS uses learning characteristics of the backpropagation algorithm of artificial neural network to train the model with the given data and uses decision making characteristics of fuzzy logic to select the best structure matching the input requirement.

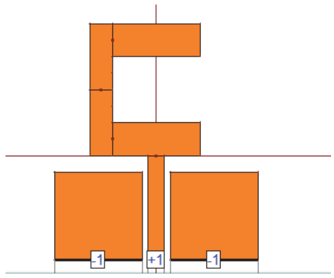

Fig. 4. Simulated structure of antenna in the shape of letter C

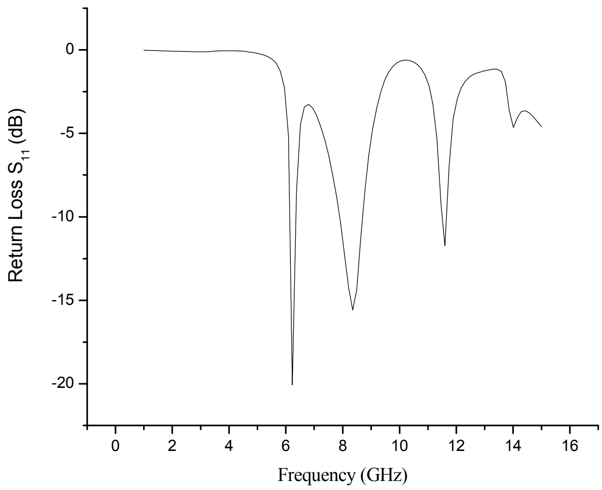

Fig. 5. S_{11} parameter response of letter C

ANFIS model comprises of five layers as seen in Fig. 6. The five layers comprise of fuzzy layer where the input (X) is assigned fuzzy membership value (A_1 to A_N), the product layer (π), normalized layer (N), de-fuzzy layer whose output is ($W'f_1$), and summation layer ($\sum$) respectively along with the input and output layer. The layer 1 which is fuzzy layer consists of nodes which are adaptive in nature and assigned a node function. Product layer, i.e. layer 2 consists of fixed nodes, which multiplies the input signal and outputs the product as the weight (W). Then layer 3 i.e. normalized layer again consists of fixed nodes, it presents the ratio of the i^{th} rule's firing strength to the sum of all rules' firing strengths which adjusts the weight (W').

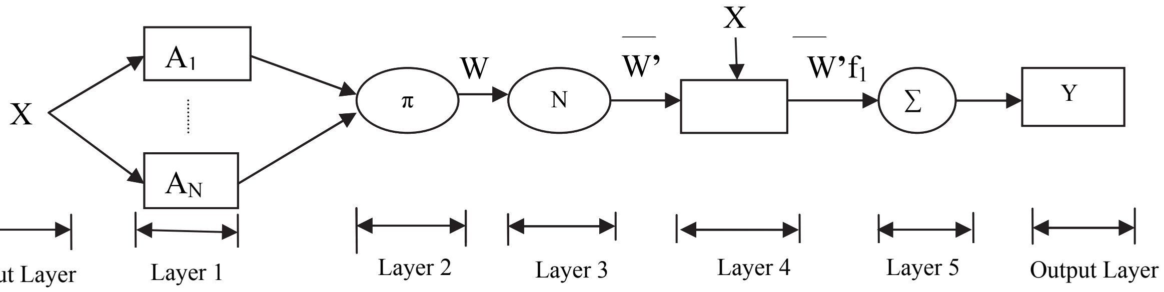

Fig. 6. Structure of ANFIS

Layer 4 is used for de-fuzzification depending on input and its membership function according to Sugeno fuzzy model. The single node in the last layer is a fixed node labeled, which computes the overall output (Y) as the summation of all incoming signals. ANFIS model generally computes single output. In the present structure, the output is in the form of a matrix where each row represents a specific parameter. ANFIS is based on Sugeno model and uses backpropagation learning algorithm [10, 11].

To design ANFIS, training data are required. They are collected from IE3D software by simulating antenna of various shapes of alphanumeric characters starting from 0 to 9 and A to Z. There are few alphabets which cannot be simulated using seven segment patches whereas there are few structures whose resonant frequency is not below -10 dB and thus not useful while there are yet few structures which provide multiband. There are 20 structures whose responses have been used as training data including multiband cases. The training data consist of one set comprising of 25 samples of resonant frequencies as input and corresponding values of lower cut-off frequencies, higher cut-off frequencies and structure of the antenna as output. The structure of each antenna is represented by the number of connected patches. Each patch is assigned a number as seen in Fig. 1. Antenna structures are represented by marking connected patch numbers as 1 while the rest as 0. Table 1 provides two examples to show how the structures are represented with the help of patch numbers. To represent the structure “b” patch numbers connected are 2, 3, 4, 5 and 7 which are marked as 1 while patch numbers 1and 6 are marked as 0.

TABLE 1
OUTPUT GIVEN BY ANFIS FOR ANTENNA STRUCTURES

Structure	Patch numbers connected	ANFIS Output
8	1, 2 , 3, 4, 5, 6, 7	1 1 1 1 1 1 1
b	2, 3, 4, 5, 7	0 1 1 1 1 0 1

The input and output parameters are collected by simulating antenna model from IE3D. The ANFIS model is trained by hybrid learning technique based on the back-propagation algorithm of neural network and Sugeno model of fuzzy logic.

Once the training is complete, which hardly takes 2 sec, the ANFIS model is ready to determine which antenna is appropriate for a given resonant frequency. After training gets completed, the ANFIS model is tested with resonant frequencies which do not belong to the training parameters.

IV. RESULTS AND DISCUSSION

The basic idea behind having this structure was to implement it on devices which work on the variable frequency band. In such devices, this kind of model will not only make the device compact but also automatic and free from user’s intervention. The main challenge of the work was to create a model which can be trained with a limited number of data. However ANFIS served the purpose well as it uses a hybrid learning technique which also uses the concept of decision making. The switching of frequency bands according to the requirement can be decided by the developed model of ANFIS. In the present design, the frequency bandwidth varies from 6-14 GHz. The same design can be implemented with different frequencies by altering the dimensions of the patch of the seven segments. In this paper there are two sections of work done. The first part of the work done included the simulation of various antenna structures using IE3D platform and the second phase of the work consisted of development of a model which will select the suitable structure of the antenna based on the requirement of the user within a given frequency band. Another advantage of using ANFIS was that the training time required was just 2 seconds.

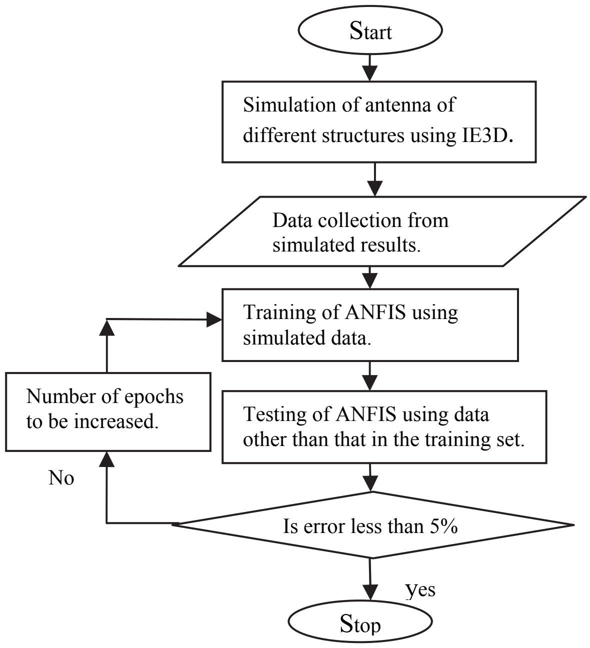

Fig. 7. Flowchart of the work done

TABLE 2
INPUT AND OUTPUT PARAMETERS GIVEN BY ANFIS

Serial number	INPUT (Resonant freq. in GHz)	Output given by ANFIS			
		Lower cut-off frequency (f_l in GHz)	Higher cut-off frequency (f_h in GHz)	Structure of Antenna	Patches connected
1	13.55	12.7982	14.6893	H - 1101101	5, 7, 1, 4, 2
2	6.24	6.1440	12	C - 0011110	6, 5, 4, 3
3	8.3	7.8757	18.8509	O - 1111110	6, 5, 4, 3, 2, 1
4	11.05	10.8937	14.31	F - 0001111	6, 5, 7, 4
5	8.36	7.9874	8.5962	b - 0111101	2, 3, 4, 5, 7
6	11.04	10.88	11.2960	E - 0011111	6, 5, 7, 4, 3
7	7.77	7.4406	8.1623	t - 0011101	5, 7, 4, 3
8	13.7	13.312	13.952	H – 1101101	5, 7, 1, 4, 2

After proper training, testing was done to check the viability of the developed model. The ANFIS model was tested using any resonant frequency as input which does not belong the training set. The output parameters given by the model was the structure of the antenna which can be used for the given resonant frequency and it also provides the lower cut-off and higher cut-off frequencies to provide an idea of the bandwidth associated with that particular structure of the antenna. The model also gives the number of patches of the seven segments to be connected to get that particular structure of antenna.

Table 2 gives the input and output parameters of the ANFIS whereas Table 3 compares the result given by ANFIS with that of the data collected from IE3D and the error percentage was calculated.

Precisely error percentage is calculated by comparing the input resonant frequency given by the user with the actual resonant frequency of the structure which is given by the model as output [12, 13]. At the same time, the lower cut-off frequency and the upper cut-off frequency given by the model as output is also compared with the corresponding actual values of the structure.

In few cases, the resonant frequency of two structures may be same or resonant frequency of one may lie within the active region of the bandwidth of another structure. For example in Fig. 8, if the input resonant frequency is 7.9 GHz, then the model may give either structure C or 8. In such cases, there is no error. As seen from the Table 3, the error percentage is very small in spite of having a very small number of training data, thus proving that ANFIS is a very good selection for this particular work [14].

Fig. 3 shows that structure 8 has two bands and two resonant frequencies which are 8.192 GHz and 10.72 GHz. Therefore the ANFIS model provides the same structure 8 as output as seen from Table 3 (Serial number 4 and 9) where the input resonant frequencies provided to the ANFIS model were 8.17 GHz and 10.7 GHz.

V. CONCLUSION

This work was an attempt to make a compact multipurpose antenna which can serve various requirements. In this work, antenna of various structures and different purposes can be made just by connecting the patches using metallic links.

Implementation of such links will avoid the time and effort of fabricating different antenna separately. Moreover the use of ANFIS can make the structure self operating with the help of MEMS switches and thus minimizes human intervention to switch from a particular structure to a different one for a given user defined resonant frequency. This idea can be further extended to design antenna of different range of bandwidth by changing the dimensions of ground plane and feed-line. Out of various soft computing techniques, ANFIS was selected on the basis of the fact that the number of training data were too less in number. However, if the testing data is varied by 5% from the training data, then the error percentage is increasing. If the number of training data is increased, then the error percentage can be reduced even if the tested data varies entirely from the training data.

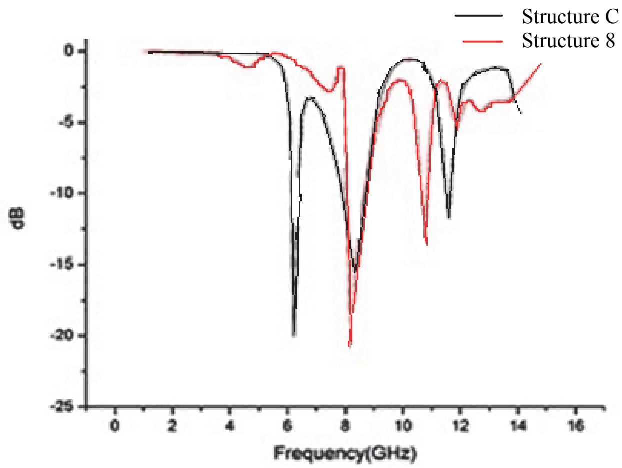

Fig. 8. S_{11} parameter response of number 8 and alphabet C

TABLE 3
COMPARISON OF THE DATA GIVEN BY ANFIS WITH THE SIMULATED DATA

Serial number	Input	Values given by ANFIS			Values given by IE3D for the given structure			Error Percentage%		
	Resonant freq. (f_r in GHz)	Lower cut-off freq. (f_l in GHz)	Higher cut-off freq. (f_h in GHz)	Structure of antenna	Resonant freq. (f_r in GHz)	Lower cut-off freq. (f_l in GHz)	Higher cut-off freq. (f_h in GHz)	Resonant freq.	Lower cut-off freq.	Higher cut-off freq.
1	7.65	7.3574	7.8449	4	7.648	7.424	7.84	0.026	0.89	0.06
2	6.23	6.2356	6.439	C	6.24	6.144	6.336	0.16	1.490	1.63
3	8.3	7.8757	8.7109	O	8.352	8.05	8.6	0.62	2.2	1.28
4	8.17	8.1082	8.6503	8	8.192	8.064	8.64	0.26	0.54	0.12
5	8.36	7.9874	8.5962	b	8.064	7.84	8.704	3.67	1.88	1.23
6	11.04	10.88	11.296	F	11.168	11.104	11.296	1.14	2.01	0
7	7.77	7.4406	8.1623	t	7.776	7.488	8.192	0.07	0.63	0.36255
8	13.7	13.312	13.952	H	13.6	13.3	13.952	0.73	0.090	0
9	10.7	10.5	10.9	8	10.72	10.656	10.816	0.18	1.46	0.77
10	9.3	8.2	9.8	s	9.5	8.53	9.641	2.11	3.86	1.64
11	8	7.81	8.512	b	8.064	7.84	8.704	0.793	0.382	2.205
12	11	10.93	11.214	F	11.168	11.104	11.296	1.504	1.567	0.725

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