iJRASET
International Journal For Research in
Applied Science and Engineering Technology

INTERNATIONAL JOURNAL FOR RESEARCH

IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY

Volume: 6 **Issue:** IV **Month of publication:** April 2018

DOI: http://doi.org/10.22214/ijraset.2018.4704

International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 6.887
Volume 6 Issue IV, April 2018- Available at www.ijraset.com

Design of Printed Antennas Using Hybrid Soft Computing Methods

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Abstract: Artificial intelligence is being well equipped with learning and pattern recognition skills, optimization and decision making skills and techniques to implement logical reasoning. Various techniques of Artificial Intelligence have been very successfully implemented in the field of designing and development of antenna which is again an element with enormous importance in the field of wireless communication. These paper emphases on use of various techniques based on Soft Computation in designing of different types of antenna.

In the proposed work, ANN has been implemented to design different parameters of antennas. ANN was first implemented to design one or two parameters of printed monopole antenna. Gradually, as the work progressed, ANN was implemented to determine more design parameters of different types of monopole antennas. Two basic and conventional well known algorithms i.e. Backpropagation Algorithm and Radial Basis Networks are initially used to carry out the work which has led to successful design of ANN models for designing different monopole antennas. These two techniques were used for designing same type of antenna for comparing their performance. Moreover, ANN was even successfully implemented to design antenna based on bandwidth which was quite a new idea.

Successful implementation of ANN steered the work towards exploring other techniques of soft computation like Genetic Algorithm. The work now progressed from simple geometrical antenna structure to complex antenna structures like bow-tie structures and alphanumeric seven segment structures. GA was applied for optimization of design parameters of Bow-tie microstrip antenna and monopole antenna. Next the technique which has been applied for designing purpose is a hybrid method based on ANFIS. This hybrid technique has been implemented for designing different antenna structures including a new reconfigurable antenna. Finally a hybrid method including GA and ANFIS has been utilized to design antenna parameters.

Keywords: Antenna; Hybrid; Microstrip Patch Antenna; GA and ANFIS; Printed Antenna; ANN

I. INTRODUCTION

A. Background

Antenna plays a vital role in any wireless communication system. According to [Balanis, 2005], the very concept of wireless technology was first presented by Heinrich Herzand and its first practical application for radio was put forward by Guglielmo Marconi in the year 1901.

B. Printed Antenna

The new technologies of Printed Antennain 19th century has been the witness of adaptable growth and development in the field of wireless communication. Antenna which was once a simple long copper wire used for radio broadcast, communication, military applications, aircraft, radars, missiles, space applications has undergone manifold changes to emerge into a complex structure to meet the rising demand of Cellular mobile communication in different types as Code Division Multiple Accessing (CDMA), Digital Communication System (DCS), Global System for Mobile communications (GSM), Japanese Personal Digital Cellular (PDC) system, North American dual-mode cellular system Interim Standard (IS)-54 and North American IS-95 system etc. Simple voice based communication is replaced with high quality video by using technologies like Third Generation GSM (3G), Fourth Generation WiMax, Wireless Fidelity (WiFi), Wi Bro, Wide band-CDMA, Wire1ess-LAN etc. The printed antennas have become more important for its omni-directional radiation pattern. In this study, an attempt is made to design, simulate, analyze and fabricate printed antennas with patch of various shapes such as circular, rectangular, square and alphanumeric structures. Printed antennas are becoming more and more popular both as microstrip patch antenna as well as monopole antenna.

1) *Microstrip Patch Antenna:* The idea of microstrip radiator was first put forward by [Deschamps, 1953] though the first practical antenna of this type came to existence twenty years later.

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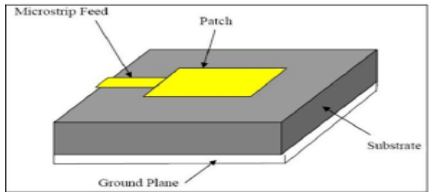

Fig. 1.1 Microstrip patch antenna

These antennas became popular for their low profile characteristics and their property of easy manufacturing process using printed circuit technologies as shown in Fig. 1.1. These antennas consist of a radiating patch of any geometrical shape above a conducting ground plane on a substrate. The radiating patch is usually made of copper and is separated from the ground plane using some dielectric material.

2) *Monopole Antenna:* These are radio antennas consisting of a straight conductor in shape of a rod, often placed perpendicularly over some type of conductive surface, called a ground plane. Construction wise monopole antennas are different from microstrip antenna due to the fact that the radiating path and ground plane are not above each other. One of the main limitations of these types of antennas is the presence of large ground plane. To overcome this limitation, truncated ground plane can be used. The rising demand for Ultra Wide Band communication requires antennas to have large frequency spectrum of ultra-short pulse used for communication. This requirement has increased the demand of low profile, cheap UWB antennas as they provide satisfactory performances in both frequency and time domain. Recently monopole antennas are presented with various designs as for example elliptical, square, bow-tie, diamond and trapezoidal.

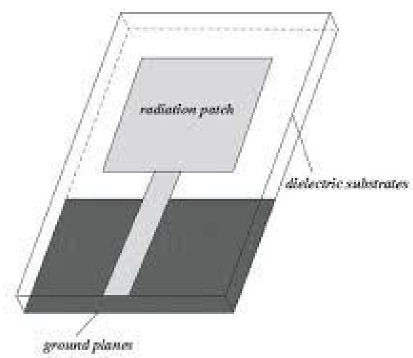

Fig. 1.2 Monopole Antenna

II. LITERATURE REVIEW

A. Introduction

Microstrip patch antennas can be marked as the initiating point in the domain of printed antennas. But the main drawback of these antennas is its size of the groundplane and low gain which made it quite difficult to incorporate it in printed form in portable devices and in high end communication system. Therefore various attempts were taken to miniaturize these antennas to make them compatible with integrated circuits.

Authors in [Lo et al. 1997] present an aperture coupled microstrip antenna using dielectric constant of high permittivity. The neural network approach is based on neurobiological studies which actual begun a century ago but became popular from 1940s and still the researchers are searching for new approaches to make artificial neural network (ANN) a more efficient tool. During this time only, authors of [McCulloch and Pitts, 1943] invented the first artificial model using the concept of biological neurons.

Hence, the advancement of neural network approach in this field has inspired to develop some ANN models for the design of antennas.

In [Mishra et al., 1997], the authors proposed ANN model based on BP algorithm for the determination of length of patch for a given resonant frequency, dielectric constant and feedgap. A new concept of combining ANN with finite difference time domain (FDTD) named as NFDTD i.e. neural-finite time difference time domain put forward by the same authors in 1999 to design printed antennas for wide band and UWB applications is worth mentioning. The same authors in 2005 reported a multiband reconfigurable planar antenna designed using back propagation method to train a multi-layer perceptron for locating the operational frequency bands of the antenna at different reconfigured conditions. Moreover, SOM neural network is also developed to locate the switches to be turned on at a desired frequency.

Some of the recent research work related to this field is being discussed below:

The authors in [Sagiroglu et al., 1998] have proposed three layers MLP used as the ANN structure which is trained with BP technique. The formulae considered here for determining resonant frequency $\mathbf{F_{nm}}$is given by:

$$\mathbf{F_{nm} = \alpha_{nm}\, c / 2\pi a \sqrt{\xi_r}}$$

where'$\boldsymbol{\alpha_{nm}}$' is the mth zero of the derivative of the Bessel's function of order n, **'c'** is the velocity of electromagnetic waves in free space, '$\boldsymbol{\xi_r}$' is the relative dielectric constant of the substrate and **'a'** is the radius of circular patch. Based on this formula, the proposed model can be used to determine the value of $\mathbf{F_{nm}}$for a given value of **'a'**, '$\boldsymbol{\xi_r}$' and **'h'** where **'h'** is the thickness of the dielectric substrate. The proposed model is in good agreement with the measured values.

B. Genetic Algorithm

GA is a of the most popular optimization techniques which is yet another artificial technique influenced by human biological system. This is an optimization technique which is inspired by "natural selection" and is the backbone of genetics. GA is a search method which can be used to handle the common characteristics of electromagnetism much better than any other optimization techniques. The fundamental block of genetic algorithm is gene which consists of binary encoding of various parameters.

An array of genes is known as chromosomes. GA generally initiate with a population of randomly selected solutions. Each solution has a set of properties which can be altered or mutated for a best solution. Generally these solutions are represented in binary as strings of zeros and ones. The process of evolution undergoes numerous iterations with the population known as generation. The objective function or the cost function of each and every individual in the given population is evaluated in each iteration to calculate the fitness function. The individuals with more fitness value are selected from the population and the genome of each individual is mutated to form a next generation. Basically there are two requirements for applying GA:

a. An exact genetic representation of the solution.

b. A fitness function to evaluate the solution domain.

Each solution of a given population is represented in form of array of bits. These arrays are generally of fixed length so that crossover becomes simple and easy. Crossover can be made possible between chromosomes of variable length but the entire process becomes very much complicated. Various advanced technique like genetic, evolutionary and gene expression programming utilizes tree like, graph form representation of chromosomes of variable length. After proper genetic representation and fitness functions are defined, a GA initializes a population of solutions and then improves it through repetitive application of the mutation, crossover, inversion and selection process.

C. Bow Tie Antenna

A bow tie antenna as shown in Fig. 2.1 is a type of antenna which is made of two conical conductive radiating surfaces connected at one point. It can be defined as two dimensions bi-conic dipole antenna. These antennas have wide bandwidth and are used for UHF reception of television.

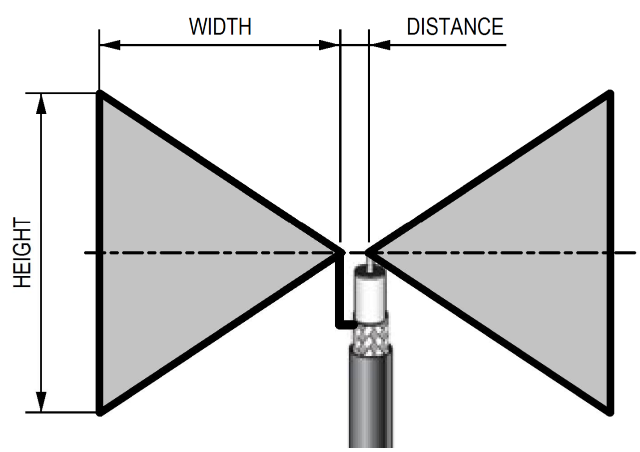

Fig. 2.1 Bow – tie antenna

In this chapter GA is implemented to optimize two parameters of bow tie antenna i.e. length and width of bow tie such that the various properties of antenna i.e. directivity, gain and bandwidth can be improved while keeping the other parameters i.e. dimensions of the ground plane and feedgap as constant. The feed which is on the same side of substrate is kept constant as 3 x 1.6 mm. The substrate has the thickness of 1.6 mm and relative permittivity of 4.4 and tan of 0.001.The dimensions of the ground plane is taken as 13.6 mm x 21.79 mm. Using the optimized values of length and width, a bow tie antenna is designed on IE3D software. Another simple rectangular microstrip patch antenna is designed using the same length and width. The results obtained from the IE3D software in case of bow tie antenna and microstrip patch antenna are then compared to validate the performance of proposed GA optimization technique.

The codes for length and width of the bow-tie antenna is developed using MATLAB software

The various steps followed are as stated below:

Step 1: A proper fitness function is selected. Fitness function considered is the resonating frequency. Length and width of the bow tie antenna are to be optimized such that resonant frequency should be 12 GHz. Resonant frequency are related to length and width as shown in equations 5.1 to 5.5. Moreover the values of length and width should not be zero and bounded by boundary limits.

Step 2: MATLAB codes are written for length and width of the bow-tie antenna.

Step 3: Using GA tool (genetic algorithm tool), the optimized values for the desired antenna design parameters have been obtained.

Table 5.1 Antenna design parameters using Genetic Algorithm method

Si.No.	Antenna design parameters	Values using genetic algorithm method
1	Length	15.799103155924198mm
2	Width	7.607257743127308 mm

Optimized values of the antenna design parameters are obtained using the genetic algorithm. The values of length and width obtained using GA are shown in Table 5.1, which when developed resonates at 12 GHz. The other parameters i.e. dimensions of the groundplane and feedgap as constant. The substrate is FR4 sheet having thickness of 1.6 mm, permittivity of 4.4 and tan 0.001.

III. METHODOLOGY

A. ANN and ANFIS

A detailed study of the literature has been done to take stock of the existing works done so far in this field. The literature survey will include two parallel surveys. In one hand, study of the various structures of different types of printed antenna are to be done and their performance are to be analyzed whereas on the other hand, the survey will include the study on various processes of artificial intelligence including) artificial neural network (ANN) ii) various optimization techniques iii) Adaptive Neuro Fuzzy Inference System (ANFIS).

In the proposed work, various sets of data for different printed antenna structure will be collected by using IE3D software which is a 3-dimensional integral equation simulator based on method of moments (MOM) simulation. As performance or operating band of frequency of antennas depend on the design parameters like dimensions of ground plane, dimensions of radiating element, type of materials used, dielectric constant of the substrate, substrate thickness etc., hence, different frequency bands can be obtained by varying one or more design parameters. Taking different combinations of design parameters, sets of data are to be collected. The process will be repeated for different types of antenna.

Of all the data collected, 90% of it will be used to train the models based on artificial intelligence and 10% of the data will be used to test the model. Different models will be developed by using hybridization of different artificial intelligence methods. Using one set of simulated data, a prototype model will be fabricated and then testing of the model can be done using some of the simulated data and error percentage can be calculated for validation of the proposed models. The schema of the proposed methodology is presented as a flowchart in the next section.

International Journal for Research in Applied Science & Engineering Technology (IJRASET)
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B. Flowchart for ANN and ANFIS

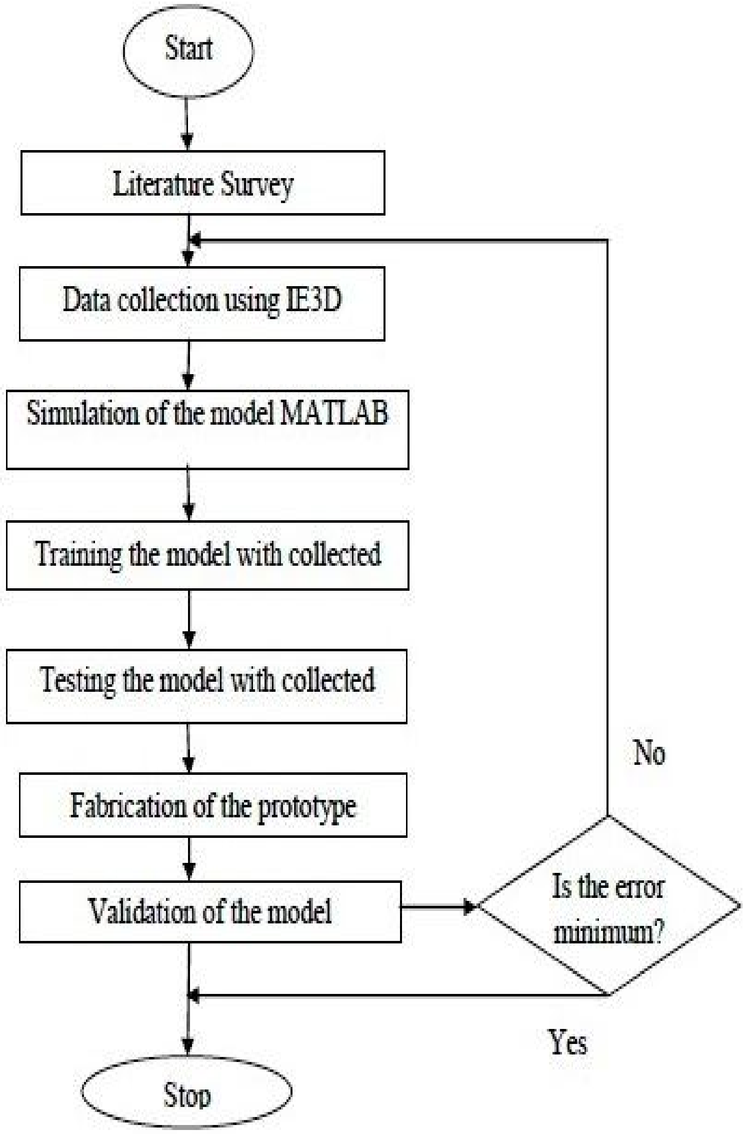

Fig. 3.1 Flowchart for ANN and ANFIS

C. Genetic Algorithm

1) Random population of n chromosomes is selected.
2) The fitness function of each chromosome in the population is evaluated.
3) New population is created by following steps:
4) Two chromosomes are selected as parent from a population on the basis of their fitness.
5) Crossover takes place between the parents to form a new offspring.
6) Mutation is done at each locus to mutate new offspring.
7) A new population is set using the off springs and the entire process is repeated.
8) If the optimization condition is satisfied the process will stop and return the value else the process will repeat population.

D. Hybrid Method

1) Section 3.2 is repeated to optimize a particular characteristic of antenna.
2) The value of the optimized parameter is then given to the ANFIS model for determining the design parameters.

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E. Flowchart of Genetic Algorithm

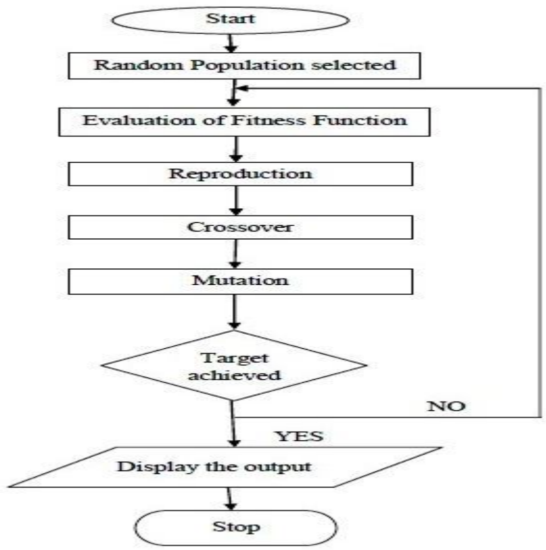

Fig. 3.2 Flowchart for GA

F. Flowchart of Hybrid Method

To apply the ANN technique to evaluate the performance of design parameters of an antenna, the following steps are followed:

1) *Data collection:* Data is collected using IE3D software by simulating various antenna models varying one design parameter at a time keeping the other design parameters constant. The values of the simulated results for example resonant frequency, higher and lower cutoff frequency, bandwidth etc. are collected.

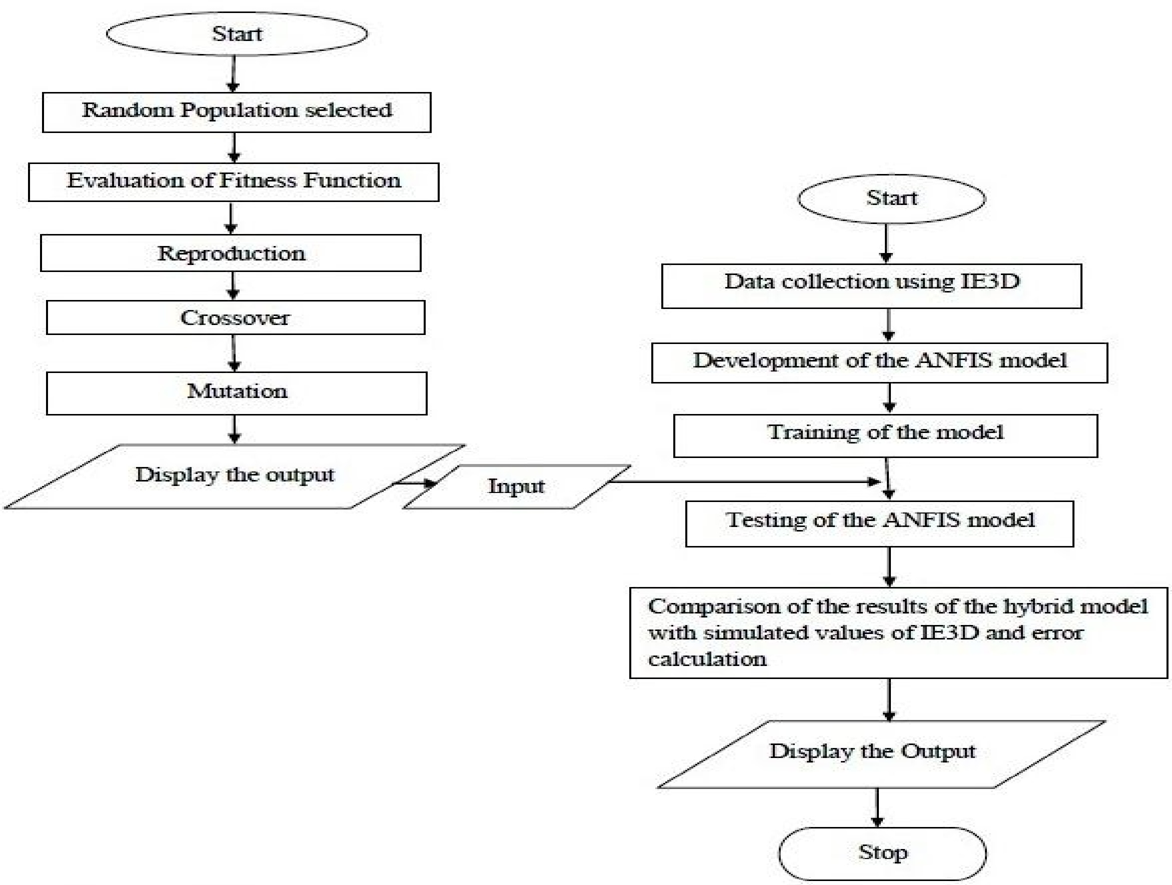

Fig. 3.3 Flowchart for Hybrid Method

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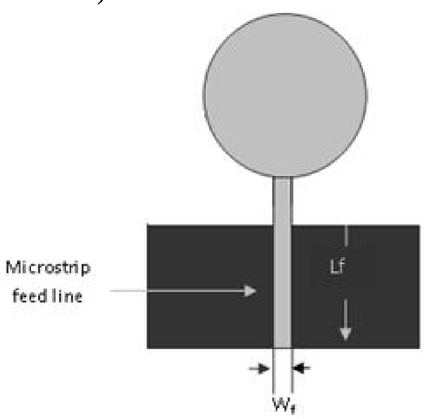
2) *Formation of the neural network model:* The ANN network is based on three layers. The three layers are input layer, output layer and the hidden layer. The input layer and the output layer consist of one or more dataset in form of matrix. The hidden layer depends on these two layers and the weights that link these layers. The number of hidden layers has to be estimated. Initial synaptic weight and biases are set randomly.
3) *Training of the ANN model:* The input dataset is matched with the output dataset and the synaptic weights between the two layers get adjusted with completion of each layer. The training gets completed when the network reacts to all input patterns and provides the output parameters correctly.
4) *Testing of the developed ANN model:* The developed model is tested by providing some random values of the input parameters other than the training data and the corresponding output values given by the ANN structure are collected.
5) *Validation of the ANN model:* Using the output design parameters antenna models are simulated on the IE3D software and the simulated results are compared with the inputs given to the user to calculate the error percentage.

IV. RESULTS

A. *Design of Circular Monopole Antenna*

A simple monopole structure has been proposed in this research work with a circular radiating plate as shown in Fig 4.8The radiating patch of radius R and the feed line of length Lf, and width of W_f and a feedgap of h, are printed on the same side while on the other side the ground plane of length L and width W, is printed opposite to the radiating patch. The dielectric substrate chosen is FR4 (Flame Resistant 4) of thickness 1.6 mm.



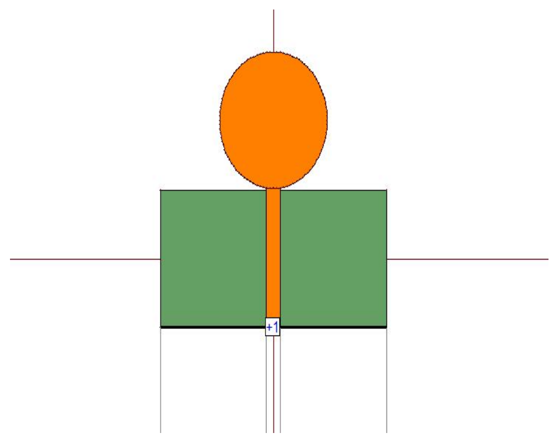


Fig. 4.7 (a) Geometry of circular monopole antenna   Fig. 4.7(b) Simulation of circular monopole antenna

In this proposed work, an antenna model is simulated on IE3D platform as shown in Fig 4.8 . During simulation, one dimension is changed at a time keeping the rest of the parameter values constant to determine the values of corresponding resonant frequencies (f_r).

After simulation is complete, various characteristics of CMA are analyzed and results are observed and noted down as training data for ANN. As an example the results of CMA with radius 10 mm, dimensions of groundplane as 42.88 mm of width and 20 mm of length and thickness of feed as 1.6 mm is presented. Fig.4.8 shows the S11 characteristics which clearly shows the bandwidth of 5.3 GHz where lower cut-off frequency is 4 GHz and higher cutoff frequency is 9.3 GHz with two resonant frequencies as 7.727 GHz and 8.4 GHz. 8.4 GHz is considered for analysis as it provides better gain and directivity as compared to the 7.727 GHz.

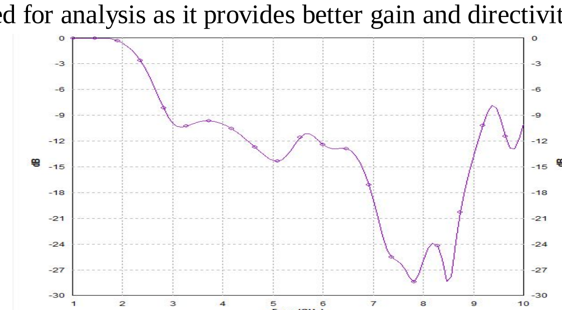


Fig. 4.8 S11 Characteristics of simulated circular monopole antenna

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The current distribution of the circular monopole antenna at 7.727 GHz is shown in Fig 4.9. The radiation pattern is represented in 3 dimensional co-ordinates system in Fig 4.10(a) whereas the two dimensional radiation patterns are represented in azimuthal plane in Fig 4.10(b).

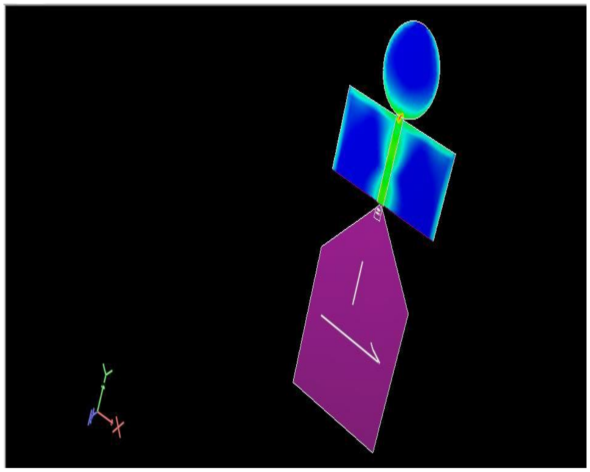

Fig. 4.9 Current Distribution of antenna

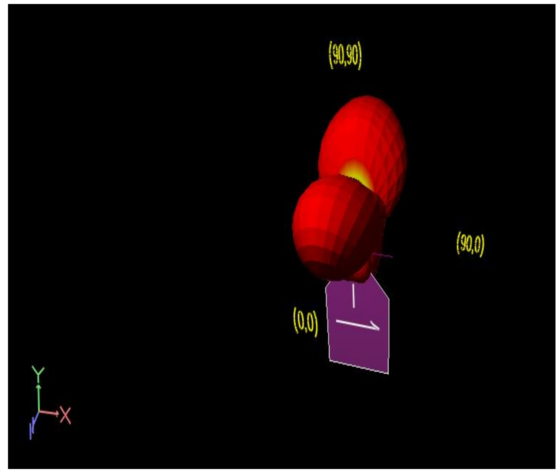

Fig. 4.10(a) 3D Radiation of simulated Cir. monopole antenna

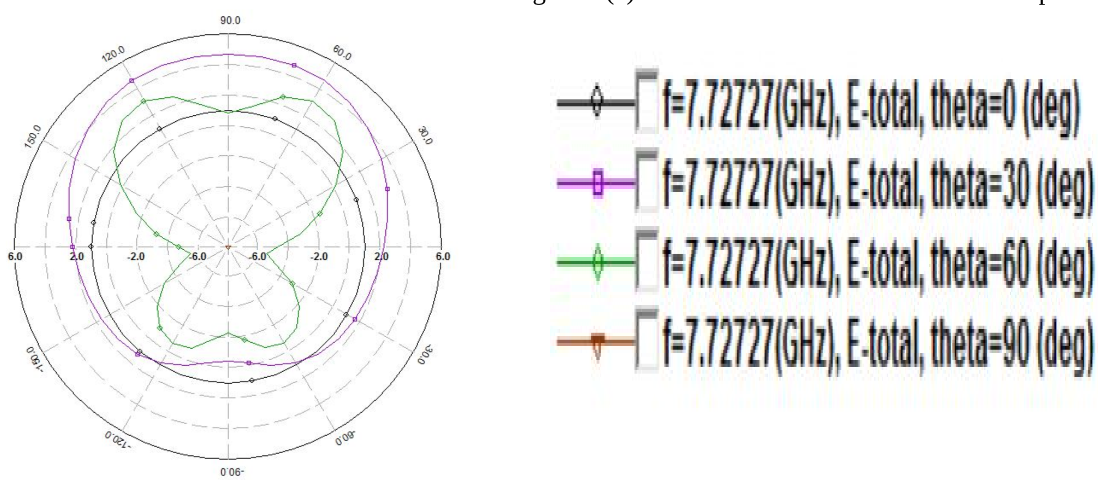

Fig. 4.10 (b) 2D Radiation Pattern (Azimuth Plane) of simulated circular monopole antenna

V. CONCLUSION AND FUTURE SCOPE

A. Conclusion

In this paper, different soft computing techniques were implemented for designing various types of printed antenna models.

Few structures like circular, square and rectangular patch antenna based on regular shapes were simple to design whereas few structures were complicated like bow tie antenna and alphanumeric seven segment antenna. All the designed antenna models were printed monopole antenna except the bow-tie antenna which is a microstrip antenna. Monopole antennas were preferred over microstrip antenna because monopole antenna generally provides ultrawideband characteristics compared to the microstrip antenna which suffers from the major drawback of narrowband characteristics. But still one structure is selected which is based on microstrip antenna because it has many advantages over the conventional microstrip antenna.Various soft-computing techniques have been successfully implemented for designing different antennas. Starting with a simple approach using ANN, the research work had gradually advanced to more complicated approaches like ANFIS, GA and finally hybridization of ANFIS and GA. Each artificial model using the above techniques were utilized to design more than one type of antenna and consecutively the operation of each of these artificial models were validated. It was seen that each of these techniques had few advantages and disadvantages, such as in the case of ANN, the advantage was its simplicity which saved considerable computational time making the artificial model faster. But as the work progressed with more complex techniques such as ANFIS, GA and their hybrid model, the efficiency of the artificial models improved in terms of accuracy at the cost of computational time. Hence a comparative study of all the above artificial models is given below in tabular forms in terms of their error percentage.

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ANFIS and ANN are both applied to determine the dimensions and feed position of rectangular patch antenna for a given resonant frequency keeping other parameters as constant. The dimensions of the groundplane and the feed are kept constant as 10 x 20 mm and 10 x 1.6 mm respectively. The substrate is FR4 sheet having thickness of 1.6 mm and relative permittivity of 4.4 and tan δ 0.001. Then using the dimensions of patch and feed position as determined by ANN and ANFIS antenna models are simulated in IE3D software and corresponding values of resonant frequencies are obtained. The frequencies obtained from simulated results are compared with the input frequencies to calculate the error percentage.

B. Future Scope

This is applicable in the field of electro-magnetic as already mentioned in the literature. But there are various other optimization techniques like Fuzzy-logic, Ant colony algorithm etc. which needs to be explored in the field of optimal designing of antenna. In this research work various hybridization techniques as for example ANFIS and Hybrid method of GA and ANFIS have been implemented. There are a huge number of combinations of different soft-computational techniques possible to develop various other hybrid methods for generating optimal artificial models to design antenna parameters. Alphanumeric seven segment antenna is a new reconfigurable antenna which has been designed in this research work using ANFIS. Many other such reconfigurable antennas could be designed in the future. Bow-tie antenna is an example of first stage of fractal design. Other fractal designs needs to be explored in the future.

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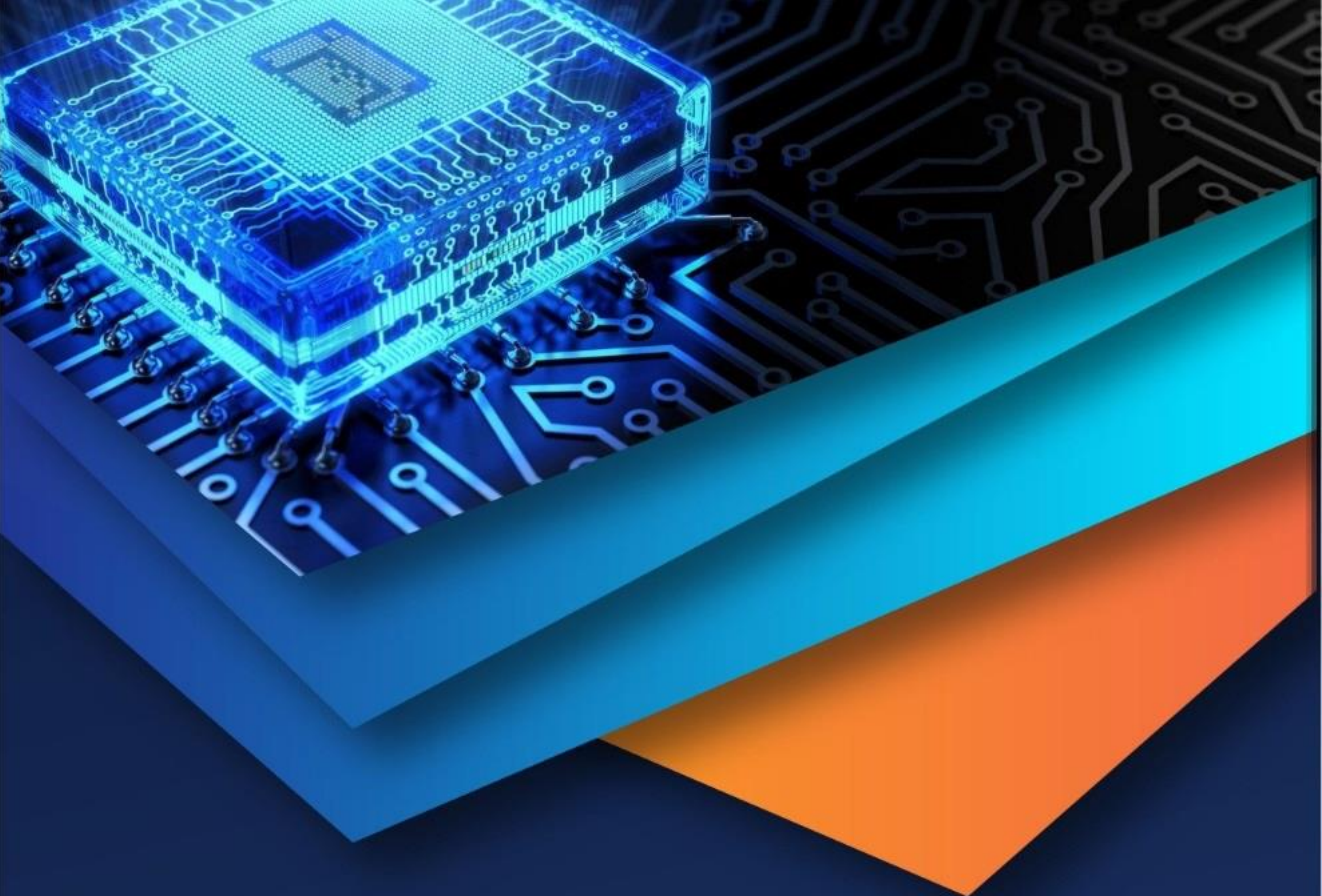

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