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Optimization of bow-tie patch antenna using various soft computation techniques

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Abstract: In this project we have proposed a technique to design and optimize a bow-tie patch antenna with the help of various soft computation techniques such as Adaptive Neuro Fuzzy Inference System (ANFIS), Genetic Algorithm (GA) and a hybrid technique consisting of both ANFIS and GA. The codes for the different soft computation techniquesare developed using the MATLAB software. All results of the antenna are tested on software platform. The software used is IE3D (Integral Equation in Three Dimension) software of Mentor Graphics. The aim of this work is to study and observe resonant frequency, directivity, gain and efficiency obtained by designing the bow-tie patch antenna with the help of the different optimization techniques and to determine which technique gives the most effective antenna. Optimum solutions of various antenna parameters such as length and width are obtained using the soft computation techniques and these are utilized to design the bow-tie antenna using the IE3D software. The design involves a bow-tie antenna being developed on a patch. The patch can take many configurations, the most popular being rectangular and circular configurations. Other configurations are much more complex in design and require heavy numerical computations. In this project a rectangular patch is used. Bow-tie antennas are miniaturized antennas i.e. they are physically small in size, low weight, low cost and they are highly reliable. Also, such a software controlled antenna presents an interesting option for next generation communication.

Keywords: ANFIS, genetic algorithm, resonant frequency; directivity; gain; efficiency; optimum solution, miniaturized antenna.

I. INTRODUCTION

An Antenna is usually a metallic device for radiating and receiving radio waves [5]. Antennas are employed in systems such as radio and television broadcasting, point-to-point radio.

Several critical parameters affecting an antenna's performance are resonant frequency, directivity, gain, radiation pattern and its efficiency.A bow-tie antenna is a wire approximation in two dimensions of a bi-conic dipole antenna [1]. It is an antenna that consists of two triangular flat metal plates, arranged in the configuration of a bow-tie,with the feed point at the gap between the apexes of the triangles.

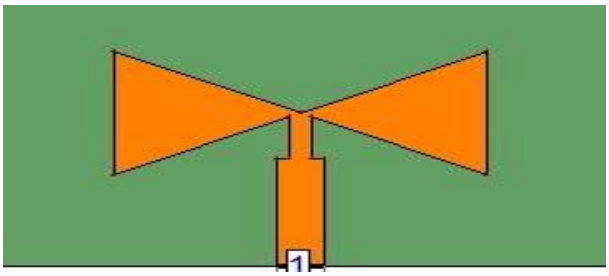

Fig. 1.1.A bow-tie antenna.

A bow-tie antenna is a form of bi-conical antenna which is a broad bandwidth antenna made of two roughly conical objects, nearly touching at their points [1]. It has a broad bandwidth because it is an example of travelling wave structure. It is generally used forUHF televisionreception [3]. Bow-tie antenna has aomni-directional radiation pattern. Bandwidth of this antenna is considerably higher than a dipole antenna. It gives a moderate gain of about 3.5-7 dB [2].

A bow-tie antenna is a miniaturized antenna [3]. In present day wireless communication systems, compactness is a must. Designing a miniaturized antenna and covering the lower spectrum of microwave frequency is a challenging task. TheFrench mathematician B.Mandelbrott introduced the termFractal and it was used for miniaturization of antenna and alsoprovide multiband operation which can perform over a singleantenna. The term fractal has mainly two importantcharacteristic which provide multiband coverage andcompactness of antenna – (1) self similarity, and (2) space filling.By using this functionality these fractal structures can beimplemented in any antenna for providing broad bandcoverage applications [1]. Here, the fractal structure isimplemented on a bow-tie antenna. The bow-tie antenna can, thus, be regarded as a compact antenna and it can providemulti-band operation [4]. In this project, we design the bow-tie antenna using several soft computation techniques.

This design involves designing a bow-tie antenna on a patch. A patch antenna is also known as a rectangular microstrip antenna. It is a type of radio antenna with a low profile, which can be mounted on a flat surface. It consists of a flat rectangular sheet or "patch" of metal, mounted over a larger sheet of metal called a ground plane [5].They

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are usually employed at UHF (Ultra-high frequencies) and higher frequencies because the size of the antenna is directly tied to the wavelength at the resonant frequency. A single patch antenna provides a maximum directive gain of around 6-9 dB. The ability to create high gain arrays in a low-profile antenna is one reason that patch arrays are common on airplanes and in other military applications.

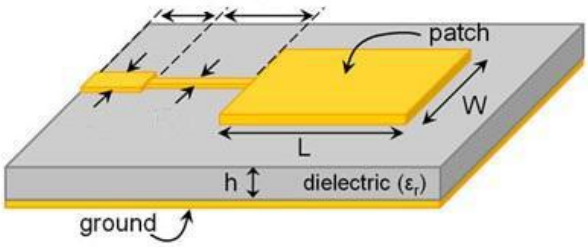

Fig. 1.2.Structure of a patch antenna.

The various soft computation techniques used to find out the dimensions of the bow-tie patch antenna are as follows –(1) Genetic algorithm (GA) – GA can be defined as a search heuristic and it mimics the process of natural selection. It is a global optimization algorithm derived from evolution and natural selection [8]. This heuristic or a meta-heuristic is used to generate useful solutions to optimization and search problems. Genetic algorithms belongs to the larger class of evolutionary algorithms, which generate solutions to optimization problems using techniques such as inheritance, mutation, selection, and crossover i.e. the techniques inspired by natural evolution. Genetic algorithm finds application inbioinformatics,computational science, engineering, economics, chemistry, manufacturing, mathematics, physics, and several other fields [8]. Genetic algorithms are inspired by Darwin's theory about evolution. Solution to any problem solved by genetic algorithm process is evolved. Although genetic algorithm cannot always provide optimal solution, it has its own advantages and is a powerful tool for solving complex problems [9].

In this antenna design, genetic algorithm is used to find out the various bow-tie antenna parameters such as its length and the width. Genetic algorithm technique is utilized to find out the fittest or the optimum solution of each of these parameters [6]. Using the values of the dimensions obtained from the technique, the antenna can be developed using IE3D software.

(2) Adaptive Neuro Fuzzy Inference System (ANFIS) – ANFIS is a kind of artificial 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 together in a single framework.

Using a given input/output data set, the toolbox function ANFIS constructs a fuzzy inference system (FIS) whose membership function parameters are adjusted or tuned using either a back propagation algorithm alone, or in combination with a least squares type of method. In the simulation, the ANFIS architecture is employed to model non-linear functions, identify non-linear components on-line in a control system, and predict a time series, all yielding results [10].

In this technique, a sequence of data is trained i.e. a training sequence is developed. Using this training sequence, optimized value of the output parameter corresponding to the respective input parameter can be obtained. Let us suppose that a sequence of resonant frequencies are trained corresponding to the length of the antenna.

The ANFIS technique gives us the optimized value of resonant frequency corresponding to any length within the limits of the training sequence. Then, the antenna can be designed using IE3D software and the resonant frequency corresponding to that particular length can be checked.

(3) A hybrid technique consisting both ANFIS and Genetic Algorithm (ANFIS-GA) – As the name suggests, this technique is a mixture of both the optimization techniques already used to design the bow-tie antenna. Genetic algorithm, here, is used to find out the dimension of the bow-tie patch antenna. It employs fitness function and various constraints to find out the optimum solution of the required dimension.

An ANFIS code is developed in which sequence of output parameter is trained corresponding to the dimension of the antenna. Then for a particular value of the dimension, the output parameter is obtained. The antenna is, then, designed using IE3D software and the validity of result obtained from the hybridization technique is checked.

II. MODELLING

The steps followed for carrying out this antenna design are as follows-

(1) Antenna design using Genetic Algorithm technique -
- A genetic algorithm code for finding out the length and width of the bow-tie antenna is developed using MATLAB software.
- After finding out the dimensions of the antenna, the required antenna is designed using IE3D software of MentorGraphics.

(2) Antenna design using ANFIS technique –
- Various antennas of different lengths are designed and resonant frequency is found out for each antenna. Thus, a training sequence is developed.
- Using the ANFIS code, resonant frequency for a particular length of antenna is found out using MATLAB software.
- The antenna is, then, designed using IE3D software and various antenna parameters are obtained.

(3) Antenna design using the hybrid model consisting of both ANFIS and genetic algorithm –
- By using genetic algoritm code, a proper length of the antenna is obtained.
- Using the ANFIS code, resonant frequency for that particular length of the antenna is obtained.

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- The antenna is designed using IE3D software and the resonant frequency is checked. The other antenna parameters are also found out.

The bow-tie antenna is designed using the following soft computation techniques. A detailed description of each technique is given below –

(1) Using genetic algorithm technique –

A genetic algorithm code is developed using MATLAB software for finding out values of dimensions of the antenna.

A. Equations

Bow-tie antenna dimensions can be found out by the use of following simple formulas –

- Width of the antenna can be calculated by –

$$W=\frac{c}{2f\sqrt{(\varepsilon r+1)/2}} \text{-----(1)}$$

- The effective dielectric constant is given by –

$$\varepsilon eff=\frac{\varepsilon r+1}{2}+\frac{\varepsilon r-1}{2}\sqrt{\frac{1}{1+12\frac{h}{w}}} \quad \text{-----(2)}$$

- For TM10 mode, length of patch must be less than λ/2. This difference in length is given by

$$\Delta L=0.412h\frac{(\varepsilon eff+0.3)(\frac{W}{h}+0.264)}{(\varepsilon eff-0.258)(\frac{W}{h}+0.8)} \text{-----(3)}$$

- The effective length of the antenna is given by –

$$Leff=\frac{c}{2\sqrt{\varepsilon eff}} \text{-----(4)}$$

- The length of the bow-tie antenna can be calculated by –

$$L=Leff-2\Delta L \quad \text{-----(5)}$$

B. Flowchart for Genetic Algorithm

The basic thought of Genetic algorithmis:-

- Randomly producing a original population whose number of individuals is a constant N.
- Producing next generation by crossing over and mutation among individuals.
- Forming the new population of N individuals from the generation of step 2).
- Producing the next population by repeating the step2) and 3) until obtaining the individual which satisfies conditions.

A typical genetic algorithm requires:-

- A genetic representation of the solution domain.
- A fitness function to evaluate the solution domain.

The flowchart can be given by:-

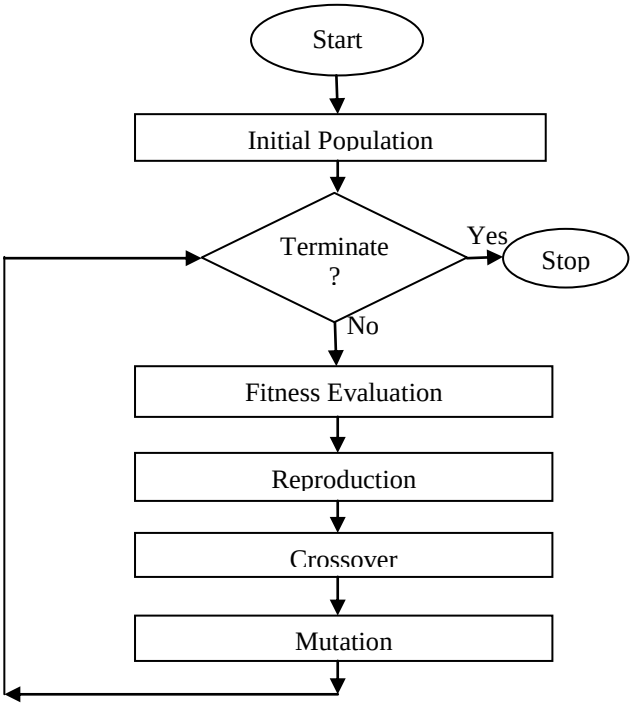

Fig. 2.1.Flowchart for Genetic Algorithm.

Frequency over which the various antenna parameters operate is considered as the fitness function [9].

C. Antenna Design

After obtaining the optimized values for the dimensions of the bow-tie antenna using the genetic algorithm technique, the antenna is designed using the IE3D software of MentorGraphics.

Table (1) shows the values of the input parameters for design of both the antennas:-

Sl. No.	**Input Parameters**	**Values using genetic algorithm method**
1	Length of the antenna	15.799103155924198 mm
2	Width of the antenna	7.607257743127308 mm

Table No. 1: Values of antenna input parameters using genetic algorithm technique.

The antenna is, thus, designed and required antenna output parameters are obtained.

(2) Using Adaptive Neuro Fuzzy Inference System (ANFIS) technique –

A. Flowchart for ANFIS technique

The basic thought behind the ANFIS technique is as follows –

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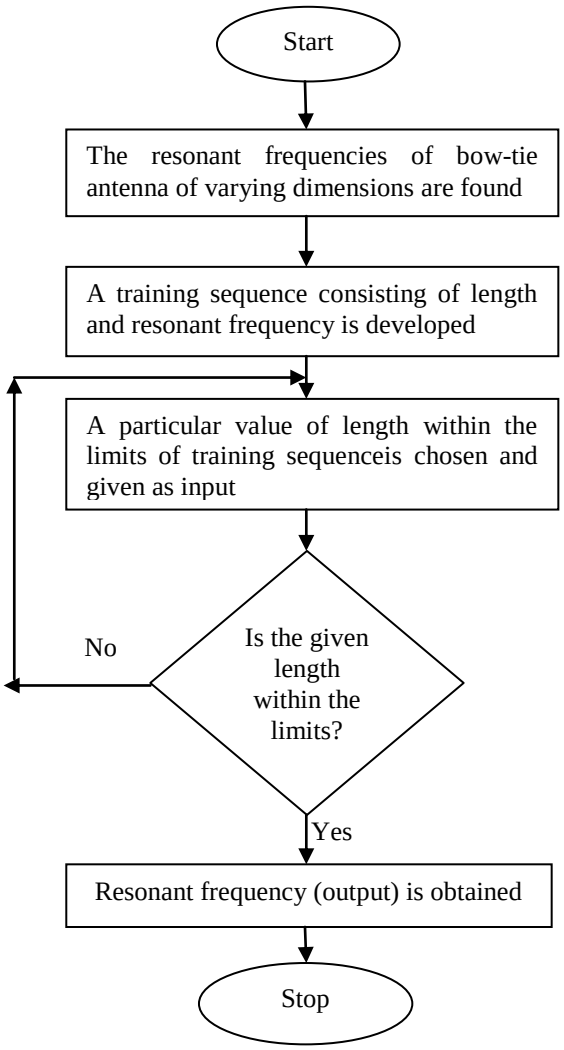

Fig. 2.2. Flowchart for ANFIS technique.

B. Antenna Design

The limit for length of bow-tie antenna was considered to be from 5 mm-25 mm.

The corresponding resonant frequencies were obtained for each value of length.

We considered the input length to be 15.799 mm and the resonant frequency obtained was 12.3239 GHz using the ANFIS code in MATLAB software.

The antenna is thus, designed using the IE3D software.

(3) Using the hybrid technique consisting of both ANFIS and GA –

In the hybrid model, codes for both genetic algorithm and ANFIS are developed using MATLAB and it eventually gives the resonant frequency.

A. Flowchart

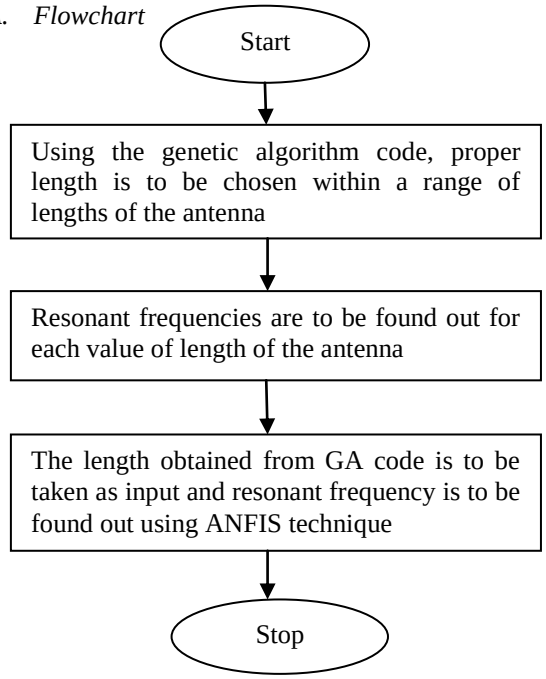

Fig. 2.3. Flowchart for GA-ANFIS hybrid technique.

B. Antenna Design

Using the genetic algorithm technique, the length of the antenna is found out to be 24.0031 mm. This length is taken as input to the ANFIS program. The limits of the length was considered to be from 5-25 mm. The resonant frequency corresponding to the input length is found out to be 12.2663 GHz.

III. RESULTS AND DISCUSSION

After the design of antenna using the soft computation techniques, the output parameters were compared. The output parameters which were taken into consideration were – resonant frequency, directivity, gain and antenna efficiency. Table (2) gives the comparison between the antenna designs using the various soft computation techniques :-

Sl. No.	**Output Parameters**	**Antenna designed using genetic algorithm technique**	**Antenna designed using ANFIS technique**	**Antenna designed using hybrid technique**
1	Resonant Frequency (GHz)	12.32	12.32	12.288
2	Directivity	5.30	5.37	4.92
3	Gain	4.25	4.23	4.19
4	Antenna Efficiency	80.18%	78.77%	85.16%

Table No. 2: Comparison between output parameters of the bow-tie antenna using all the soft computation techniques.

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From the above table, it can be clearly seen that all the soft computation techniques are of equal importance in designing a bow-tie antenna. There is no clear domination of one technique over the other in terms of the output parameters. The input frequency for design of antenna using genetic algorithm was considered to be 12 GHz. As the table shows, the obtained output resonant frequency for this antenna design was 12.32 GHz. The design using ANFIS technique yielded a resonant frequency of 12.32 GHz. The input frequency for the same was considered to be 12.3239 GHz. And if the hybrid technique is considered, the resonant frequency in that case is 12.288 GHz, which is closer to the input frequency considered in that case – 12.2663 GHz. Bow-tie antenna is a miniaturized antenna and multiple bandwidths were obtained in designing of the antenna. In terms of directivity, using ANFIS technique gives the more directive antenna (5.37). The directivity of the antenna using GA and the hybrid techniques are 5.30 and 4.92 respectively. However, if gain is the prime concern of the designer, using the genetic algorithm technique gives the most gain – 4.25. Designing the antenna using ANFIS and the hybrid technique gives 4.23 and 4.19 gain respectively. In terms of efficiency though, the antenna designed using the hybrid technique gives the most efficient antenna. The efficiency obtained is 85.16%. The antenna designed using GA and ANFIS technique gives efficiency of 80.18% and 78.77% respectively.

The obtained outputs show that all soft computation techniques are quite useful designing a bow-tie antenna and getting suitable results. It is the choice of the designer to choose one of the soft computation techniques according to his preference of directivity, gain or efficiency.

IV. CONCLUSION

In general, bow-tie antenna is a miniaturized antenna and it is for Ultra-High Frequency (UHF) television reception. It was observed that using various soft computation techniques, bow-tie antennas gives good directivity, gain and antenna efficiency as evident from this discussion. Use of global optimization methods decreases the complexity of typical mathematical formulas. It gives the optimized values of the required parameters as chosen. It has also been observed that all the soft computation techniques give good results in terms of the output parameters. While the ANFIS technique gives the most directive antenna, more gain is obtained using the genetic algorithm technique. However, the hybrid model consisting of both genetic algorithm and ANFIS gives the most efficient antenna. So, the soft computation techniques can be chosen by the designer according to his need.

As we know, the crowding of wireless band has necessitated the development of multiband and wideband wireless antennas. Bow-tie antenna is a form of bi-conical antenna which is a multiband antenna. Because of their broadband characteristics, the bow-tie antenna can be employed in the Very High Frequency (VHF) and Ultra High Frequency (UHF) frequency ranges [7]. Bow-tie antenna is thus a very useful antenna as it can be used in higher frequency ranges, it is a multiband antenna, it is small in size and easy to design and it gives good directivity, gain and efficiency. As the demand for communication has increased, the use of band has gone from narrowband to wideband and broadband within a very short time. To meet with these increasing demands, more efficient antennas such as bow-tie patch antennas are required.

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