An Investigation on Special Antennae using Artificial Neural Networks

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Abstract— This study aims to provide an overview and deployment of Artificial Neural Network(ANN) based microstrip antenna and arrays , with different configurations, feeding mechanisms, and performances. Their performance improvement methods, including bandwidth enhancement, size reduction, and gain improvement are also discussed based on available literature. This paper shows the designing of antennas by using Artificial Neural Networks with the help of different techniques. The techniques such as genetic algorithm, Levenberg-Marquardt algorithm, Neurospectral method, reflect array element modeling and pattern synthesis are discussed here .

Keywords—Levenberg - Marquardt; Artificial Neural Network; Neurospectral; reflect array element; pattern synthesis

I. INTRODUCTION

Artificial Neural Network (ANN) is a forecasting method. It is based on simple mathematical models of the brain. The complex non linear relationship between the response variable and its predictors were explained by ANN. ANN is based on a large collection of neural units (AKA artificial neurons), loosely modeling the way a biological brain solves problems with large clusters of biological neurons connected by axons. Each neural unit is connected with many others, and links can be enforcing or inhibitory in their effect on the activation state of connected neural units. Each individual neural unit may have a summation function which combines the values of all its inputs together. There may be a threshold function or limiting function on each connection and on the unit itself: such that the signal must surpass the limit before propagating to other neurons. These systems are self-learning and trained, rather than explicitly programmed, and excel in areas where the solution or feature detection is difficult to express in a traditional computer program.

II. BROADBAND ANTENNAS USING ANN

Input impedance of the broadband antenna can be predicted by using ANN [1]. It approximates the non-linear relationship between the antenna geometry and model parameters. It can be constructor by the Hilbert transform from the resistance. It is suitable for modeling high dimensional and highly non-linear problems. Antenna geometry parameters and frequency are given as input to the ANN. The output comes from the antenna is input impedance. This approach is also successful for narrowband antenna design. Number of hidden units increases drastically.

The broadband antenna contains multiple resonances in the input impedance. It led to a large number of hidden units. The changes in reactance at resonance is difficult for ANN. In order to overcome the problem suitable physical principles have been embedded. We select Gaussian model because it is very simple and insensitive to the parameters error. Resistance behavior leads to a reduced network size, improved training time, and better chance of successful training. Once the method is modeled, the reactance can be recovered via the Hilbert transform. A Gaussian model to approximate the frequency dependent resistance envelope of a symmetric resonator.

The nonlinear relationship between the antenna geometry and the model parameters was constructed by the ANN. Introducing the model simplified the construction and training of the ANN, resulting in robust performance. The neural network have been trained by using particle swarm optimization as a local search procedure seeded with an initial guess from the gradient descent learning. Hilbert transform can be used to construct to the reactance of the antenna.

In order to test the performance of the resulting ANN, a loop antenna with multiple tuning arms was optimized by a Gaussian Algorithm, whereby the developed ANN system have been used for the cost function evaluations.

Circularly-polarized Square Micro strip Antenna with truncated corners was designed using ANN synthesis model [2]. Using the empirical formulae, training data sets, the resonant frequency and Q-factor of micro strip antennas were calculated. The size of the truncated corners and operation frequency with the best axial ratio are obtained. The three hidden layered network is trained by Levenberg-Marquardt algorithm in order to achieve an accurate synthesis model. The result was compared with the electromagnetic simulation and measurement.

The dielectric substrate with thickness H, loss tangent tan δ, relative permittivity €r was etched by square patch with a dimension of L x L. The condition for the CP operation of the single-feed CPSMA with truncated corners.

$$Lt=L / (\sqrt{2Qn}) \quad (1)$$

Where Lt is the dimension of the truncation, Qn is the total quality factor of the square micro strip antenna. The algorithm is adopted to train the MLPs for obtaining high-precision synthesis models. The aim of this communication is to develop an accurate ANN based synthesis models for single-feed CPSMAs with truncated corners. The synthesis model can be used to calculate the physical dimensions of the single-feed CPSMA with truncated corners. To design the rectangular patch antenna in the computer aided design by using spectral domain formulation, green's function is constituted by the combination of the continuous function and delta function using ann[3].

Computer aided design for patch antenna based on the different analysis methods. Cavity model for patches of regular shapes on electrically thin substrates and it is simple and less accurate. Many microwave design optimization problems are using ANN technique. For antennas like direction finding, beam forming. The developed ANN to relate the patch length with patch width, substrate thickness, permittivity, permeability and its variability.

Using Artificial neural network model the 1.2 meter, reflect array antenna was analyzed[4]. The analysis has been carried by using reflect array modeling and pattern synthesis. ANN is used to produce the amplitude and phase of complex reflection coefficient of the reflect array element. The 9 input parameters used are 6 geometrical parameters, incident angle in terms of azimuth and elevation angle, frequency. Next the artificial neural network is used instead of electromagnetic computation to find the electric field on planar structure and radiation pattern. A good agreement is obtained compared to an analogous analysis carried out by Method of Moments.

A. Reflect array antenna definition

The antenna used is an elliptical reflect array with axes 1248 mm x 1196 mm, containing 96 rows by 92 columns (6944 cells of 13 mm x 13 mm). It has been designed to comply with the requirements of a transmit and receive DBS antenna in the Ku band and it provides coverage to South America. Feed at the centre is located at coordinates of (-373, 0, 1482) infrared to the reflect array coordinate system. The three layers of elements present in the reflect array.

The hexagonal cells that produce the slight anisotropy of the quartz honeycomb used in this analysis. The sizes of every patch varied from one cell to the next cell in order to required phase-shift in the given frequency band in dual polarization. The designing parameters are a_i and b_i, for i=1, 2, 3 these are considered as the dimensions of the three patches in each
Cell of dimensions d_x x d_y = 13mm x 13mm. The output parameters used to characterize the reflect array elements.
The reflect array elements are the complex reflection coefficient of the electric field for two linear polarization.

B. Ultrasonic consolidation technique (UC):

It is a 3D printing or low temperature additive manufacturing technique for metals. The process can be done by scrubbing metal foils together with ultrasonic vibrations. The process done under the pressure in a continuous fashion. Metals are joined in the solid-state via disruption of surface oxide films between the metals. To introduce internal features and to add detail to the metal part contour milling is used interchangeably with the additive stage of the process. UC has the ability to join multiple metal types together, i.e., dissimilar metal joining, with no or minimal intermetalic formation and allows the embedment of temperature sensitive materials at relatively low temperature typically less than 50% of the metal matrix melting temperature.

A shielded parallel plate resonator-backed slot antenna was proposed[5]. Two challenges faced in implementing slot antenna. Firstly, slot antennas at resonance will direct half of the radiated power in the undesired direction into the platform. Secondly, the backward radiation increases the sensitivity of slot antenna to its environment. The input impedance, radiation pattern and gain of the slot antenna alter the function of the platform. As a result, conventional slot antennas are generally designed to function in conjunction with a predefined platform.

Profiled corrugated circular horns are differing from standard horns in having a nonlinear internal profile.The results are obtained by both for the analysis and for the synthesis problem and then compared with the many standard methods[6]. This unconventional solution gives a shorter processing times and good level of accuracy. They require very accurate procedures for their modeling, design and fabrication. Horn characterization is using full-wave software simulators, on combined field integral equation (CFIE) techniques and they permit to reduce the cost.

However, the computational times are very high in each frequency point. Conventional optimization techniques rely on very large number of analysis, so the horn design is demanding task in powerful computer. So, to overcome this problem to propose an unconventional approach use of artificial neural networks (ANNs).The flexible and powerful mathematical algorithms are used an innovative tool in the electromagnetic problem. Model based on the neural network is very simple and easily to implement in the software tool, providing the output in very less time and the computation resources are very less used.

A coherent wireless communication system is considered that support users, where each user transmits on the same angular carrier frequency of with a single transmit antenna. In order to achieve user separation in the angular domain the receiver is equipped with a linear antenna array consisting of uniformly spaced elements. Although a structure of uniformly spaced linear antenna array is assumed for beam forming, the results can be extended to other antenna array structures[7].

In the uplink scenario, the receiver has to detect all the users' data, and it has access to the training symbols of all the users. The most effective way of adaptive implementation of the SRBF network detector is to estimate the system's channel matrix first and then use it to calculate the state subset. In the downlink scenario, the task of receiver is to detect the data of the single desired user during training, the receiver has the training data of the reference user i, but the receiver does not have access to the interfering users' data. Thus, estimating the system's channel matrix is a challenging task.

Monochromatic isotropic sources with inter element distance equal to q compose a ULA. It receives a desired signal from angle of arrival (Ao Aa) and N interference signals from respective angles of arrival (Ao Aa) θn (n=1, . . . , N). Every Ao Aa is defined by the direction of arrival(DoA) of the respective incoming signal and the normal to the array axis direction. The ULA receives Gaussian noise signals of zero-mean value and variance σ2 The values of θn (n = 0, 1, . . . , N) and the signal to noise ratio (SNR) are considered as input data by all the beam formers[8]. Each beamformer aims at calculating the array excitation weights wm (m = 1, . . . , M) that satisfy two different requirements, i.e., maximize the SINR and minimize the SLL.

In the MADIWO algorithm, the adaptive seed dispersion mechanism described. The modification concerns the σ −f dependence, which is expressed by as:

$$\sigma = r1f\ 2 + r2f + r3 \qquad (2)$$

Selection of Neural Network Structure Due to neural network efficiency and instant response, NNs have been successfully applied. The feed-forward back-propagation architecture is selected for all the NN. Each NN consists of an input layer of N + 1 nodes, which is fed by any angle vector two hidden layers that use Hyperbolic Tangent Sigmoid (HTS) transfer function

In a microstrip antenna, some parts of the radiating surface can be removed without any significant changes in the antenna's performance. multi-slot microstrip antenna have been designed to implementing and achieve a wide bandwidth. Four slots are incorporates into this patch, and are positioned on both sides of the feed. The structure of the slots resembles the geometrical shape[9]. A multilayer 2 x 80 x I structures used for training the network. The network architecture, showing the angle and frequency as inputs and the gain as output. Experimental measurements are carried out to see the radiation patterns at 10.5 GHz and at 12 GHz. The back-propagation algorithm - the gradient descent method was modified using the tunneling technique. tunneling technique is based on violation of the Lipschitz condition at the equilibrium position.

The ratio of radiation intensity in a given direction from the antenna to its radiation intensity averaged over all direction is known as directivity.

Based on the heuristic data of input-output pairs, the ANN can operate and its function does not depend on complexity of method used for generating training data set. Prediction of output after training ANN has been the basis for the operation of this model. This process will be continued until the performance goal in terms of pre-defined mean square error(MSE) value has been achieved. The input and output layers activation functions are linear and the hidden layer activation functions were based on radial basis. RBF-NNs trained with LM algorithm used to estimating directivity. The simulation had been performed for collinear and parallel short dipole uniform linear array and for 4X4 planar (square)array[10].

A varactor-loaded H-shaped antenna with radiation pattern control is described [11]. A cylindrical wire model with four varactors is analyzed with the help of method of moments. "FEKO"simulator used to show the figure-of-eight radiation pattern is rotated by 360 in the plane of the antenna with variation of capacitances of the four varactors. The antenna exhibits rotation of a figure-of-eight radiation pattern with a VSWR less than 2.7, and the maximum gain from 2 9 dB to 1.4 dB at 750 MHz.

ANN is becoming powerful technique for obtaining solutions to the problems that are cross-disciplinary in nature. The neural networks are extremely distributed to the analogous processors that has usual tendency for storing the empirical knowledge during training and making it available for use during testing.ANN models resembling the brain since knowledge was acquired by the neural networks through a training process, and interneuron connection strengths were used to store that knowledge. Known examples of a problem are used to acquire the knowledge during training of the ANN model. The trained model was then set to use in this acquired knowledge effectively in solving" unknown" or "untrained" problems .

Multilayered preceptor (MLP) neural networks contain an input layer, a hidden layer (or a number of hidden layers), and an output layer. Each layer in the model have an entirely different role. Three common steps has to be used to train the MLP neural net-works. First, the training samples were generated, the structural configuration of the hidden layer was selected in the second step, and third step, the weights and biases are optimized using the training algorithm. For this realization, all the initial weights and biases are replaced by the corresponding optimization values. Then trained model predicting the "slot-size" introduced on the radiating patch and the inserted "air-gap" between the ground plane and the substrate sheet, simultaneously within a fraction of a second for any arbitrary set of resonance frequencies, gains, directivities, antenna efficiencies, and radiation efficiencies for dual resonance within their specified ranges [12].

GA's are probabilistic optimization methods that use an iterative search technique based on ideas from evolutionary principles[13]. The algorithm is based on a number of ad hoc steps including: 1) discretization of the parameter space; 2) development of an arbitrary encoding algorithm to establish a one-to-one relationship between each code and the discrete points of the parameter space; 3) random generation of a trial set known as initial population; 4) selection of high performance parameters according to the objective function known as natural selection; 5) reached. mating and mutation; and 6) recursion until a convergence is Consider an N -dimensional optimization problem. The optimization procedure starts with initialization of the population.

A frequency selective surface design by integrating optimization algorithms with fast full wave numerical methods is proposed [12]. The analysis was discussed with two methods :

C. FSS design using genetic algorithms:

The two ways to optimize FSS are

- Optimize the dimensions and dielectric layers of given element shape and gradient based technique.
- Elementary building blocks of predefined element shapes and dielectric layers has been cascaded.

Here GA used for optimization and the optimization is considered for shape and topology [14]. GA is an robust stochastic-based search method. Here O(N) hybrid finite element/boundary integral simulator has been employed. The integration of optimization algorithm with a rigorous full-wave 3D electromagnetic solver was the major goal which leads to practical design in minutes of computation time using a desktop computer. Initially binary setting 1,0 to determine whether metallization is present or not. By small altering in coding mutation is allowed.

FSS have been designed in the stopband range of <3GHZ and then no transmission above 3-5GHZ.

The 50 iteration can be used for the design process. Each takes about 10 minutes in desktop SUN Ultra-30 workstation.FSS has been designed to achieve phase response within the band range from 50 .The phase response achieved is 1.6-3.2GHZ.Th deviation range from 0.8-16GHZ.The phase have zigzagged in entire band by using metallic elements.

The microstrip patch is printed on the dielectric-air interface of a grounded dielectric slab, which have a thickness and a relative dielectric constant [15]. Every patch was assumed to be a probe-fed with an ideal current source, has a length , width , and is uniformly spaced from its neighbors by distances and in the and directions, respectively.

A conventional hybrid mom/green's function method solution for phased arrays was proposed, here electric field integral equation (EFIE) is formed by the enforcing the boundary condition that this total tangential electric field should vanish on the microstrip patch surfaces. conventional hybrid MoM/Green's function method solution starts with an expansion of the unknown induced array surface current and there related, in terms of a finite set of sub sectional basis functions. The GFBM/Green's function-DFT method has a finite arrays of microstrip patches DFT based acceleration algorithm is starts with the dividing these elements into strong and weak interaction groups. for a generic finite array of probe-fed microstrip patches with three basis functions per a single patch (each basis function is represented with a different color).

To achieve Broadband radiation suitable for applications in the Wireless LAN, Mobile communication and Bluetooth, the coaxial feeding technique is used to connect source with antenna. An E- shaped patch with substrate height of 2mm, relative permittivity of dielectric substrate is 2.33 and it resonates at resonance frequency of 2.4 GHz for ISM band applications is designed and simulated successfully[16]. The design and simulation of antenna has done by IE3D (Method of Moment) based full wave electromagnetic simulator. Now after that, the same antenna is modeled and analyzed using Artificial Neural Network (ANN) can be used to model and analyze this same antenna. ANN used for analysis is firstly trained using data collected from electromagnetic simulator of antennas using IE3D software. This input to the model consists two input parameters: x-coordinate and y- coordinate of probe feed point. The output to this ANN model consists four output parameters: Resonant Frequency, VSWR (dB) Return Loss and Input Impedance (in ohm).Levenberg-Marquardt back propagation algorithm is used for training. Thus a Slit loaded E-shaped EMPA has been designed and simulated in IE3D software, in which the return loss sharply enhances up to -34dB with VSWR of 0.82 with coaxial/probe feeding at 2.4 GHz WPAN (Bluetooth, Zig Bee and Wi-Fi) applications. The benefits of this antenna design are simplicity, accurate and easy determination of the characteristic parameters of Coaxial feed E-Shaped microstrip patch antenna. In IE3D, the time for calculating various antenna design parameters (antenna dimensions, exact feed point at which impedance matches to 50 ohm) taking lot of time .Hence Artificial Neural Network method was used as because ANN is more accurate, simplicity and take less time for computation.

In reconfigurable antennas to find optimum design parameters the engineering design processing requires modeling and optimization. While direct optimization only exploits time consuming but accurate fine model, surrogate based optimization exploits less accurate but fast coarse model to reduce the overall computational effort. space mapping with inverse difference technique is applied to antenna design problem together with efficient 3-step modeling has been presented in this paper. The combination of two techniques provides less computational effort and better convergence through the accuracy improvement based on the new inverse 3-step modeling strategy. By inverse 3-step modeling the inverse coarse model which is used for parameter extraction process during the optimization has been realized. Using multi layer perception in MATLAB ANN toolbox the inverse coarse model has been obtained. The efficiency of the combination of space mapping with inverse difference technique and 3-step modeling strategy will be demonstrated by reconfigurable antenna design example in terms of their convergence and accuracy through its multiple operating frequency characteristics.

To design problem relevant to reconfigurable micro strip patch antenna together with knowledge based 3-step modeling strategy, space mapping with inverse difference technique was applied [17]. The aim of this design problem is to obtain antenna geometry corresponding to optimum frequency condition for minimumS11.

Convergence of SM − ID & 3− step combination can require less number of fine model evaluations than SM −ID & ANN combination to find optimum frequencies. In addition 3-step based inverse coarse model can generate closer coarse model input parameters to the fine model input parameters through its better accuracy than ANN based inverse coarse model. As all things considered, SM −ID & 3−stepcombination can provide efficient optimization technique for design problems.

In another study MEMS antenna was characterized using target detection method in ANN [18]. Here a broadband silicon MEMS antenna was designed to operate at 10GHz to 16GHz. This work was mainly concentrated on imaging applications. The MEMS antenna sensor had a footprint of 4.5mmx4.5mm. Further optimization was done in ANN using target detection method in which the performance of the antenna was improved to 75% accuracy. A novel beam-former array antenna was proposed[19]. Here modified adaptive dispersion invasive weed optimization (MADIWO) method was used to train the network. Here a comparative study was done with adaptive dispersion invasive weed optimization (ADIWO) and modified adaptive dispersion invasive weed optimization (MADIWO), in which the data obtained showed similar behavior in means of side lobe levels and SINR. An analysis of reflectarray antenna was proposed for X-Band using 3-D EM simulationbased Multilayer Perceprtron Neural Network [20]. Further the array antenna was designed using CST MWS. Typical reflection phase characteristics were obtained using the reconstructed data obtained from ANN

An aperture-coupled microstrip antenna using a hybrid neural network was discussed[21]. This hybrid network was formed using radial basis function

(RBF) and back-propagation algorithm (BPA). This network was found to be superior in achieving accurate values than the conventional RBF and BPA. A general sequential quadratic programming model (SQP) optimization algorithm was used to optimize a patch antenna in conjunction with the finite element boundary integral method [22]. The main advantage of SQP is that it is a fast convergence than genetic algorithm methods and reduced number of evaluations. This is of greater advantage in larger antennas where a limited range of parameter values is sufficient for good performance.

A novel optimization technique was introduced in [23]. Here a stacked microstrip patch antenna was proposed with ANN and particle swarm algorithm (PSA). Here in this joint characteristics, size reduction in patch antenna was achieved. This model was named as Neuro-Swarm Optimizer.

Space mapping with inverse difference method is used to obtain optimum frequency for the antenna geometry[24]. This SM-ID and 3-step combination requires less number of fine model evaluation than SM-ID and ANN, which provides efficient optimization for the mentioned problem in reconfigurable antennas.

In [25], ANN was used to calculate the resonating frequency of the microstrip patch antenna using feed forward back propagation algorithm. An analysis and synthesis in design of RMSA and square patch was proposed using feed-forward back propagation algorithm (FFBP) [26]. This stands as an efficient time saving method for optimization than the conventional method. RFID antenna was designed using ANN [27]. Here the key performance parameters bandwidth and impedance values were optimized than the calculated values. The optimized antenna was able to achieve 90MHZ bandwidth. A circular microstrip patch antenna(CMPA) using conjugate gradient algorithm (CGA) was proposed [28]. The experimental results and the calculated results were in good agreement. This algorithm involved no complicated mathematical expressions and found to possess greater accuracy. Also this model was subjected to analysis in EM-ANN. These two ANN models have an unique property of predicting the radius of the circular patch accurately than the literature values. Further a loop antenna was designed implementing in ANN [29]. Here, in loop the best optimum radius was calculated using Self Organizing Map (SOM) method, for electrically driven elements. A low loss RF MEMS switch at microwave and millimeter wave frequencies upto 10GHz [30]. Further feed-forward back propagation algorithm was used to improve the performance of the antenna by increasing the length of the anchor arm-length. In [31] ,an elliptical patch antenna was proposed (EPMSA) for L-band applications. Since the expected accuracy was not achieved in gain at a specific frequency, ANN was used for optimization. Here Radial Basis Function (RBF) network with back-propagation algorithm was used and errors were found to be less than 2%.

Optimization of L-band Pyramidal Horn antenna was done using ANN for accuracy in gain and frequency[32]. The errors through calculation was merely reduced below 1.3% when used in ANN-radial basis function method (RBF). Another comparative study was done in [33] . Here the optimization of RMSA was done in ANN which was more promising than the calculated values. Here Feed Forward Back-Propagation, Resilient Back Propagation, Levenberg-Marquardt and Radial Basis Function was used and compared for the accuracy and optimum values. When compared with all these algorithms and methods, RBF algorithm produced high accuracy in resonant frequency and efficient performance of the RMSA. It was concluded that for calculating resonant frequency, RBF algorithm is best suitable in ANN. For a given length, width, and dielectric constant of RMSA, resonant frequency is determined using neural network [34]. When compared with the theoretical results of RMSA, The results obtained through ANN was more promising. Here back propagation model was used to train the ANN. A comparative study of RBF and ANFIS was done [35]. Here the % errors obtained through ANFIS was less than the errors obtained through RBF ANN. It was stated that the ANFIS model requires less time to predict the errors and had more accuracy in the values.

III. CONCLUSION

In this paper various designs of microwave antennas were analyzed using different algorithms of Artificial neural Networks (ANN), in which each antenna was optimized for their performance parameters. This aforementioned analysis was done using various algorithms like Genetic Algorithm(GA), Levenberg Marquardt algorithm, Neuro Spectral Method, Reflect Array Element and Pattern Synthesis Method, Radial Basis Function Method, conjugate Gradient algorithm. Here these algorithms were used to enhance the performance parameters of antennas. Each algorithm showed its key role in enhancing specific parameters like gain of the antenna, minimizing reflection in antenna. Each algorithm and novel methods had their uniqueness in differentiating themselves from one another. The need for optimization in meeting the current requirements in design of antennas can be accomplished using any one of the algorithms discussed in this paper using artificial neural networks(ANN) which is time saving method than the conventional methods available in literature. Since the optimization process can be carried in a speedy manner and to achieve higher accuracy, ANN is preferred by researchers and scholars currently.

REFERENCES

[1] Youngwook Kim," Application of Artificial Neural Networks to Broadband Antenna Design Based on a Parametric Frequency Model", IEEE Transactions On Antennas and Propagation, Vol. 55, No. 3, March 2007
[2] Zhongbao Wang, Shaojun Fang, "An ANN-Based Synthesis Model for the Single-Feed Circularly-Polarized Square Microstrip Antenna With Truncated Corners",IEEE Tran on antennas and propagation, vol. 60, no. 12, december 2012.
[3] Rabindra K. Mishra," Designing Rectangular Patch Antenna Using the Neurospectral Method" IEEE transactions on antennas and propagation, Vol. 51, No. 8, August 2003.
[4] Pedro Robustillo, Juan Zapata," ANN Characterization of Multi-Layer Reflectarray Elements for Contoured-Beam Space Antennas in the Ku-Band", ieee transactions on antennas and propagation, vol. 60, no. 7, july 2012.
[5] Wonbin Hong," Platform Embedded Slot Antenna Back ed by Shielded Parallel Plate Resonator", IEEE transactions on antennas and propagation, vol. 58, no. 9, september 2010
[6] Giulio Fedi1," Profiled corrugated circular horns analysis and synthesis via an artificial neural network", IEEE transactions on antennas and propagation, vol. 49, no. 11, november 2001.
[7] Shenq Chen," Symmetric complex valued rbf receiver for multiple antenna aided wireless system", IEEE transactions on neural networks, vol. 19, no. 9, september 2008.
[8] Heriberto Jose Delgado," A Novel Neural Network for the Synthesis of Antennas and Microwave Devices", IEEE transactions on neural networks, vol. 16, no. 6, november 2005
[9] Dipak K. Neog1," design of a wideband microstrip antenna and the use of artificial neural networks in parameter calculation",IEEE,Antenna And Propagation Magazine vol.47.no.3.june2005.
[10] Subhash Mishra," Directivity Estimation for short dipole antenna"IEEE,Antenna and Wireless Propagation,vol.14,2015.
[11] Hideo Iizuka," Varactor-Loaded H-Shaped Antenna With RadiationPattern Control", IEEE transactions on antennas and propagation, vol. 56, no. 9, september 2008.
[12] Taimoor Khan," Prediction of Slot-Size and Inserted Air-Gap for Improving the Performance of Rectangular Microstrip Antennas Using Artificial Neural Networks", IEEE antennas and wireless propagation letters, vol. 12, 2013.
[13] Kamal Sarabandi," Characterization of Optimum Polarization for Multiple Target Discrimination Using Genetic Algorithms", IEEE transactions on antennas and propagation, vol. 45, no. 12, december 1997.
[14] Z. Li, P.Y. Papalambros and J.L. Volakis," Frequency selective surface design by integrating optimization algorithms with fast full wave numerical methods".
[15] Bakır, "Efficient Analysis of Phased Arrays of Microstrip Patches Using a Hybrid Generalized Forward Backward Method/Green's Function Technique With a DFT Based Acceleration Algorithm", IEEE transactions on antennas and propagation, vol. 56, no. 6, june 2008.
[16] Gurdeep Singh," Design analysis of an e-shaped slit loaded mpa and parameters estimation using ANN",2016.
[17] Murat Simsek1," Convergence Improvement of Surrogate Based Optimization for Reconfigurable Antenna Design Using Knowledge Based Inverse 3-step Modeling".
[18] Douglas A. Hutchings,"Microwave MEMS Antenna sensor Characterization and Target Detection Using Artificial Neural Networks", IEEE sensors, vol. 14, no. 8, journal august 2014.
[19] Zaharias D. Zaharis, " Design of a Novel Antenna Array BeamformerUsing Neural Networks Trained by ModifiedAdaptive Dispersion Invasive WeedOptimization Based Data", , IEEE trans.vol.59.no.3,september2013.
[20] Selahattin NESIL, Filiz GUNES, "Analysis and Design of X-Band Reflectarray antenna using 3-D EM based Artificial Neural Network Model",IEEE 2012.
[21] T. Bose, N. Gupta," Design of an aperture-coupled micro strip antenna using a hybrid neural network", IET Microw. Antennas Propag., 2012, Vol. 6, Iss. 4, pp. 470–474.
[22] Zhifang li, panos," designing broad-band patch antennas using the sequential quadratic programming method", IEEE transactions on antennas and propagation, vol. 45, no. 11, November 1997.
[23] Sathish K.Jain,"Size Reduction of Stacked Patch Antenna Using Neural Network Based Swarm Optimizer",2015.
[24] Murat Simsek1," Convergence Improvement of Surrogate Based Optimization for Reconfigurable Antenna Design Using Knowledge Based Inverse 3-step Modeling",
[25] Vandana Vikas Thakare," Calculation of Resonating Frequency of a Rectangular Microstrip Antenna Using Artificial Neural Network", 2008IEEE.
[26] Abhilasha Mishra," Design of Square and Rectangular Microstrip Antenna with the use of FFBP algorithm of Artificial Neural Network", 2009 IEEE.
[27] Ning Zhang," RFID Tag Antenna Quick Design and Optimization by Using Artificial Neural Network Modeling Technique", 2010 IEEE
[28] Abhilasha Mishra," The Design of Circular Microstrip Patch Antenna by using Conjugate Gradient algorithm of ANN", 2011 IEEE.
[29] Kumaesh Sarmah," Design Optimization Of Loop Antenna Using Competitive Learning ANN", 2011 IEEE.
[30] Paras Chawla," Design and Optimization of RF MEMS Switch for Reconfigurable Antenna using Feed-Forward Back-Propagation ANN Method",2013 IEEE.
[31] Anuj Y. Modi," Synthesis of Elliptical Patch Micro-strip Antenna Using Artificial Neural Network",2013 IEEE.
[32] Anuj Y. Modi,,"Design of Optimum Gain L-Band Pyramidal Horn Using Artificial Neural Network",2013 IEEE.
[33] Bablu Kumar Singh," Design of Rectangular Microstrip Patch Antenna based on Artificial Neural Network Algorithm",2015 IEEE.
[34] Bishal Dey Sarkar," Resonant Frequency Determination of RectangularPatch Antenna using Neural Network"sept,2015. [35]Aarti Gehani," Design of a Circularly Polarized Elliptical Patch Antenna using Artificial Neural Networks and Adaptive Neuro-Fuzzy Inference System".