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ANN-ABC Model to Estimate the Operating Frequency of Annular Ring Patch Antenna

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Abstract: Annular ring patch antennas (ARPAs) have important features, such as easy adjustment of the resonance modes by changing the ratio of the outer radius to the inner radius. An application of artificial neural network (ANN) model trained by artificial bee colony (ABC) algorithm is presented to estimate the operating frequency of ARPAs that operate at ultrahigh frequency band in this work. For this study, the operating frequencies of 100 ARPAs having different electrical and physical parameters covering band ranges of GSM, LTE, WLAN and WiMAX applications are firstly simulated with the help of a 3D full-wave simulator tool. The ANN-ABC model is constructed with 100 simulation data and the results of simulation are used for training and testing processes of the model. The 80 simulated ARPAs are utilized for training and the remaining 20 ARPAs are used for testing. The proposed ANN-ABC model is validated via measurement data published earlier in the literature. The mean absolute errors (MAEs) regarding the estimated operating frequency for training, testing and validating are calculated as 0.069, 0.075and 0.081, respectively. The results obtained with the ANN-ABC model in the training, testing and validating processes are in harmony with the simulation and measurement results and these results show that the proposed model can be successfully used to estimate the operating frequencies of ARPAs.

Keywords: Annular ring patch antenna, operating frequency, artificial neural network, artificial bee colony

1. INTRODUCTION

Patch antennas (PAs) are widely used in wireless communication system because of having advantageous properties such as low fabrication costs and ease of integration with microwave circuits [1]. Present devices of communication system need small size PAs and one of the ways to obtain small size antennas is slot loading to conventional PAs. Annular ring patch antenna (ARPA) is miniaturized antenna structure obtained by loading anannular slot at the center of the annular shape of the patch. The size of the ARPA is substantially smaller than annular patch antenna (APA) at the same operating frequency [2]. It can be appreciated that the average path length traveled by the current in the annular-ring patch is much longer than the corresponding circular patch for the lowest order mode. Also, by choosing the inner and outer radius of the ring properly, both bandwidth broadening and controlling the separation of resonant modes can be managed [2]. Due to these useful properties, it is the one of the most studied PAs with slot loading in the literature [3-13].

Antenna analysis describes pronounces the process of computing the performance parameters such as resonant frequency, bandwidth, gain, radiation patterns, etc. Estimating the operating frequency of the ARPAs is an analysis problem and analysis is useful for antenna designers to find the best possible antenna solution. Simulator tool packages such as Agilent ADS [14], Ansoft HFSS [15], CST microwave studio [16], HyperLynx® 3D EM [17] etc. commonly are used to facilitate the analysis process. The using of these simulation packages may be relatively difficult for fast determination of antenna performance parameters in regard of design procedures and computation time. Artificial intelligence techniques such as artificial neural network (ANN) can be used to make the antenna analysis process easier and more efficient. In this way, the antenna designers get rid of rigorous computations and consuming time.

During the learning process of ANN, weight and bias values are adjusted using different learning algorithms such as Levenberg Marquardt algorithm, Bayesian regularization, cyclical order incremental update, conjugate gradient algorithms, one step secant for the best output/outputs of network. The performance of learning algorithms depends on the application areas in which ANN is used and they are selected taking into account their own benefits and constraints. Because the artificial bee colony (ABC) [18] algorithm is simple and there are not many parameters to tuned, an ANN model trained by ABC algorithm is presented to estimate the operating frequency of ARPAs in this study. Firstly, the operating frequency values of 100 ARCMAs are obtained by means of the IE3D™ software. The simulation parameters of 80ARPAs are used to training and the accuracy of proposed model is then tested with remaining 20 ARPAs. The results of the ANN-ABC model obtained in this study was also validated by the measurement results published earlier in the literature.

2. PROPOSED ANN-ABC MODEL AND DATA PREPARATION

An ANN model combining with an ABC algorithm (ANN-ABC) is used for estimation the operating frequency of ARPAs according to their physical and electrical parameters with high accuracy.

2.1. ANN-ABC Model

The ANN model was emerged by inspiration from the process of biological nervous system information. Multilayer Perceptron (MLP) is one of the most used ANN structures and it may have one input layer, one output layer and one or more hidden layers. For training of the networks, the weights between neurons in each layer are adjusted to obtain appropriate output and different learning algorithms are used for this purpose. The main idea of learning algorithms is to reduce the error between actual and estimated results until learning of network is completed.

The ABC algorithm is an optimization tool, which provides a population-based search procedure.The ABC algorithm structure was developed by inspiration of the behavior of the honey bee rides' food search. The ABC algorithm structure was developed by inspiration of the behavior of the honey bee swarm's food search. The colony of artificial bees has employed bees, onlookers and scout bees [18].

Because of the robustness and flexibility advantages of population-based optimization algorithms, the ABC algorithm is used as a learning algorithm in the ANN model. All processes related to proposed ANN-ABC model are illustrated in Fig. 1. Firstly, weight and bias values of ANN are converted into the objective function along with the simulation parameters of ARPAs. In order to find the optimal weight and bias parameters, the objective function is then fed to the ABC algorithm. These values are then tuned by the ABC algorithm based on the error calculation between target and estimated results.

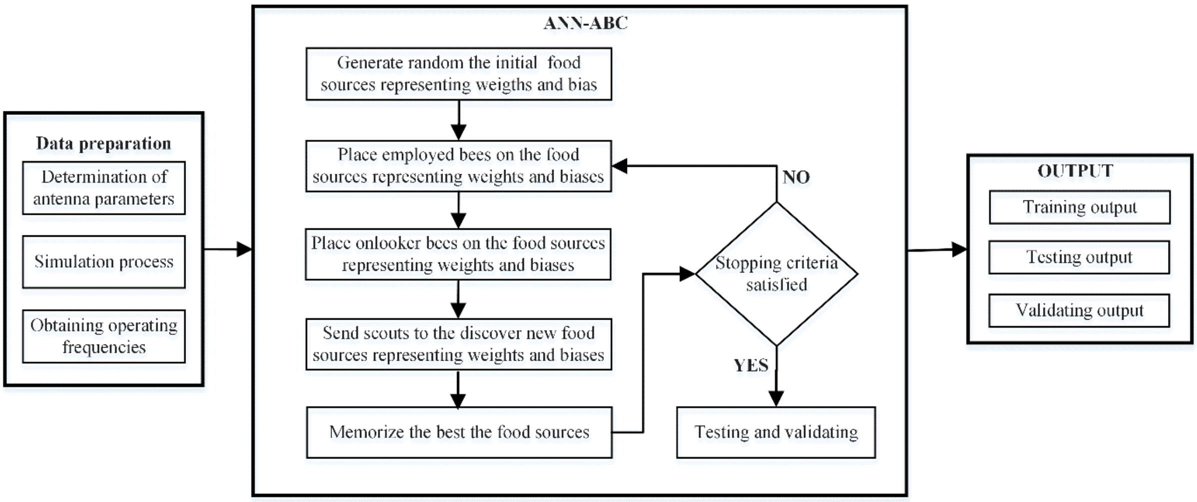

Figure 1.Proposed ANN-ABC model process

2.2 Data Preparation

ARPA is formed by loading an annular slot with radius Ri at the center of the annular shape with radius Ro of the patch having εr relative dielectric constant as shown Fig. 2.

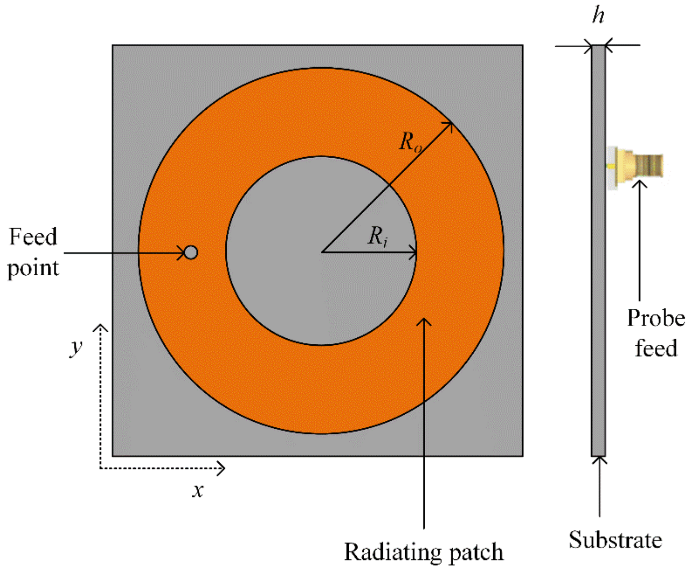

Figure 2.The geometry of ARPA

For constituting data set, 100 ARPAs having different physical dimensions(R_o, R_i, and h) and various substrate dielectric constants (ε_r) are simulated by IE3D™ EM software [19]. The physical and electrical parameters of simulated ARPAs are tabulated in Table 1. As a result of the simulations, the operating frequencies are obtained for each antenna. The ARPAs operate over the frequency range 0.55 –3.71 GHz corresponding to UHF band.

Table 1.Physical and electrical parameters of simulated ARPAs

Simulation Numbers	Antenna dimensions (mm)			ε_r
	R_o	R_i	h	
	15	2, 4, 6, 8, 10	0.640	4.50
	20	3, 6, 9, 12, 15	0.640	4.50
	25	4, 8, 12, 16, 20	0.640	4.50
	30	5, 10, 15, 20, 25	0.640	4.50
	35	6, 12, 18, 24, 30	0.640	4.5
	15	2, 4, 6, 8, 10	1.570	2.33
	20	3, 6, 9, 12, 15	1.570	2.33
	25	4, 8, 12, 16, 20	1.570	2.33
	30	5, 10, 15, 20, 25	1.570	2.33
4 x 25	35	6, 12, 18, 24, 30	1.570	2.33
	15	2, 4, 6, 8, 10	2.500	9.80
	20	3, 6, 9, 12, 15	2.500	9.80
	25	4, 8, 12, 16, 20	2.500	9.80
	30	5, 10, 15, 20, 25	2.500	9.80
	35	6, 12, 18, 24, 30	2.500	9.80
	15	2, 4, 6, 8, 10	3.175	2.20
	20	3, 6, 9, 12, 15	3.175	2.20
	25	4, 8, 12, 16, 20	3.175	2.20
	30	5, 10, 15, 20, 25	3.175	2.20
	35	6, 12, 18, 24, 30	3.175	2.20

3. RESULTS OF ESTIMATION BY ANN-ABC MODEL

The ABC optimization algorithm has been used in the ANN model as learning algorithm and the results obtained during the training, testing and validation process have been given in the subsections.

3.1. Training Process of ANN-ABC Model

The physical and electrical parameters (R_o, R_i, $h$andε_r) of ARPAs are given as inputs and their respective operating frequencies are given as output to the ANN-ABC model. The data set of 80ARPAs representing the overall problem space is used to train the ANN-ABC model and the remainders 20 ARPAs that are not included in the training process are utilized to test the accuracy of the model. ANN-ABC model based on MLP having one input layer with four neurons, one hidden layer with four neurons and one output layer with one neuron was constructed, as shown in Fig. 3. "Log-sigmoid" function is used for input and output layers while "tangent sigmoid" function is utilized for the hidden layer. The parameters of the ANN-ABC model used in this work are listed in Table 2. The training results are checked according to the following mean absolute error (MAE) and the value of MAE for the operating frequencies calculated by the ANN-ABC model isobtained as 0.069 for the 80 ARPAs' training data.

$$MAE = \frac{\sum |f_{sim.} - f_{ANN-ABC}|}{\text{Number of antennas}} \quad (1)$$

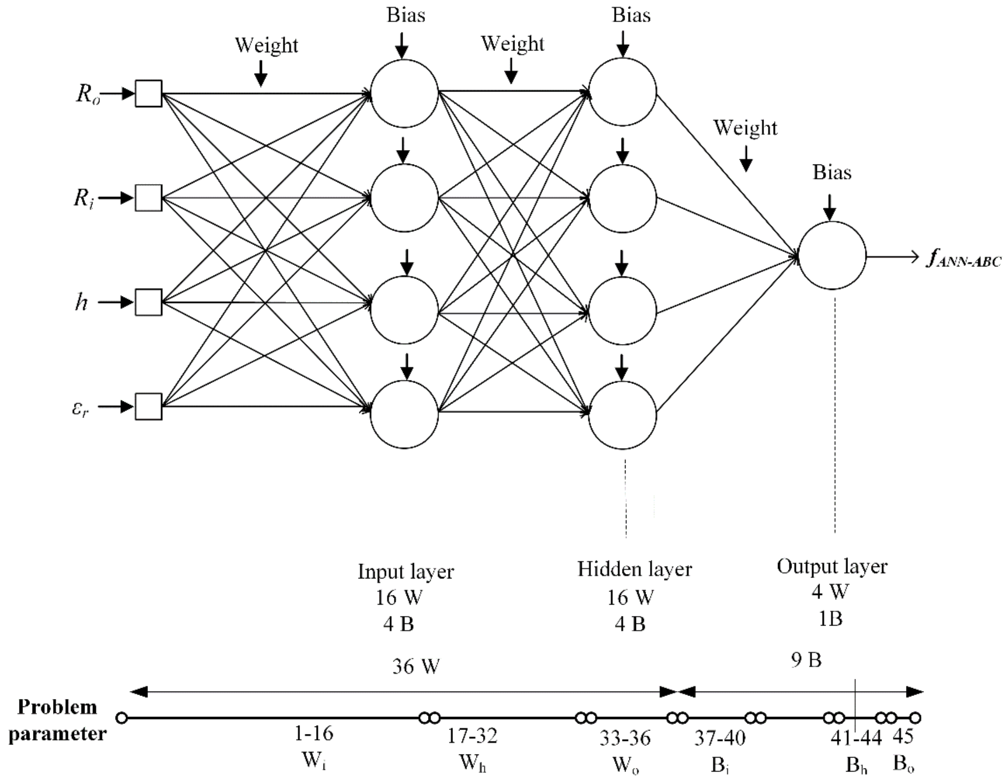

Figure 3.ProposedANN-ABC model and problem parameters

Table 2.The parameters used to set the ANN-ABC model

Parameter	Set type/value
Swarm number (NP)	150
Dimension (D, the sum of weight and bias numbers)	45
Limit	0.2*NP*D
Upper bound	15
Lower bound	-15
Maximum cycle number	500000

3.2. Training Process of ANN-ABC Model

The testing data including 4 parameters of 20 ARPAs, their testing results including estimated operating frequency results and corresponding absolute errors are tabulated in Table 3. The ANN-ABC model estimates the operating frequencies with MAE of 0.075 in the testing process.The obtained results in the test process show that the ANN-ABC model is successful to estimate the operating frequency of ARPAs.

Table 3.The testing results of operating frequency with the ANN-ABC model

Antenna number	Antenna parameters				Operating frequency (f)	Results	
	Outer radius (R_o)	Inner radius (R_i)	Patch height (h)	Dielectric constant (ε_r)		$f_{ANN\text{-}ABC}$	Absolute error (AE)
1	15	6	3.175	2.2	3.625	3.682	0.057
2	15	10	1.57	2.33	3.003	3.193	0.190
3	15	8	0.64	4.5	2.114	2.249	0.135
4	15	4	2.5	9.8	1.734	1.857	0.123
5	20	6	3.175	2.2	2.742	2.845	0.103
6	20	9	1.57	2.33	2.375	2.401	0.026
7	20	12	0.64	4.5	1.502	1.468	0.034
8	20	15	2.5	9.8	1.033	1.108	0.075
9	25	8	3.175	2.2	2.156	2.223	0.067
10	25	12	1.57	2.33	1.833	1.927	0.094
11	25	16	0.64	4.5	1.165	1.205	0.040
12	25	20	2.5	9.8	0.799	0.836	0.037
13	30	5	3.175	2.2	1.891	2.064	0.173
14	30	10	1.57	2.33	1.667	1.695	0.028
15	30	15	0.64	4.5	1.057	1.146	0.089
16	30	20	2.5	9.8	0.697	0.767	0.071
17	35	12	3.175	2.2	1.499	1.608	0.109
18	35	18	1.57	2.33	1.263	1.265	0.003
19	35	24	0.64	4.5	0.800	0.802	0.002
20	35	30	2.5	9.8	0.555	0.595	0.040
Mean absolute error (MAE)							0.075

3.3. Validating of the ANN-ABC model

The proposed ANN-ABC model also is tested for validating over several measurement data of ARPAs published earlier in the literature for verify the validity of model. It should be noted that these measurement parameters are not employed for training the ANN-ABC model. It is clearly seen from the Table 4, estimated operating frequency results are generally in very good harmony with the measured results and MAE is calculated as 0.081%.

Table 4.Parameters of ARPAs published earlier in literature and validating results

Antenna number	Antenna parameters				Operating frequency (f)	Results	
	Outer radius (R_o)	Inner radius (R_i)	Patch height (h)	Dielectric constant (ε_r)		$f_{ANN\text{-}ABC}$	Absolute error (AE)
[3]	50	25	1.59	2.32	0.878	0.927	0.049
[4]	20	10	3.18	2.32	2.450	2.325	0.125
[5]	50	25	1.59	2.32	0.891	0.846	0.045
[6]	14.2	7.1	0.355	2.65	2.880	2.754	0.126
[7]	17.2	8.6	1.6	4.2	1.989	2.109	0.120
[8]	70	35	1.59	2.32	0.625	0.687	0.062
[9]	70	35	1.59	2.3	0.626	0.599	0.027
[10]	30	10	0.8	4.4	1.243	1.328	0.085
[11]	35	17.5	1.53	4.3	0.940	0.964	0.024
[11]	17.5	8.75	1.53	4.3	1.960	1.837	0.123
[12]	13	2	2.54	4.5	3.000	2.896	0.104
Mean absolute error (MAE)							0.081

4. CONCLUSION

In this study, the ABC optimization algorithm is used in the ANN model as learning algorithm. ABC updates the weight/bias values and minimizes a linear combination of squared errors. It also modifies the linear combination so that at the end of the training the resulting network has good generalization qualities. The proposed ANN-ABC model is trained, tested and validated using 80 simulated ARPAs, 20 simulated ARPAs and 11 measurement ARPAs respectively. It was seen that estimated results with ANN-ABC model for training, testing and validatingresults are in a good agreement with the simulation and measurement results. The approach of ANN-ABC model is fast and simple to estimate the operating frequency of ARPAs. Thus, the antenna designers can reach the results in their studies on ARPAs with less processing time and least errors.

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