

# Analysis and Synthesis of Equilateral Triangular Ring Microstrip Antenna using Support Vector Machine

Ahmet Kayabasi

Department of Electrical and Electronics Engineering  
Engineering Faculty, Karamanoglu Mehmetbey University, Karaman, 70100, Turkey  
ahmetkayabasi@kmu.edu.tr

**Abstract** — A support vector machine (SVM) based analysis and synthesis models are presented for the equilateral triangular ring microstrip antennas (ETRMAs) that operate at ultrahigh band applications. The analysis and synthesis of irregularly shaped microstrip antennas (MAs) require complex, lengthy and time consuming mathematical procedures and artificial intelligence techniques such as SVM eliminate great effort and time. In this paper, two models based on SVM are constructed for analysis and synthesis of ETRMAs. The number of 100 ETRMAs with various geometrical and electrical parameters ( $L$ ,  $l$ ,  $h$  and  $\epsilon_r$ ) are simulated in terms of resonant frequency ( $f_r$ ) with the aid of an electromagnetic simulator program to obtain the data set. Two different SVM models are designed to obtain the resonant frequency and slot dimension of ETRMAs by using the simulation data set. The obtaining the resonant frequency and slot size are analysis and synthesis processes, respectively. The SVM models are trained with the simulated data set of 75 ETRMAs and tested with remainders 25 ETRMAs. A prototype of ETRMA is then fabricated to verify the proposed models in this paper. The testing results of the SVM are compared with the simulation/measurement results and the models are found to be successful. Antenna designers can use the proposed models quickly and simply in analysis and synthesis process of ETRMAs without the need for complex processes.

**Index Terms** — Analysis, microstrip antenna, synthesis, support vector machine, triangular ring microstrip antenna.

## I. INTRODUCTION

Microstrip antennas (MAs) have significant advantages such as low size, lightness, robustness, ease of production, low production cost and physical compatibility with the surfaces. Because of these advantages, MAs are widely used in portable/non-portable wireless communication applications that require miniaturized geometry [1]. The smaller size antennas can be produced by using the substrate having high dielectric

constant but this leads to a reduction of performance efficiency and bandwidth parameters [1]. Therefore, performing the requirements of mobile communication devices is difficult by using the traditional patch geometries of MAs such as rectangular, triangular, circular, square. The miniaturized MAs are produced by applying some modification such as shorting pins, slits or slots on the traditional geometry structures [1]. Equilateral triangular ring microstrip antennas (ETRMAs) are constructed by triangular slot loading in the center of triangular patch. According to the same size triangular microstrip antenna, the resonant frequency is reduced due to slot loading into the triangular patch. For the same resonant frequency, the size of ETRMA reduces compared to the equilateral triangular microstrip antenna (ETMA).

Antenna analysis involves the process of calculating performance parameters such as resonance frequency, gain, bandwidth, radiation patterns, etc. On the other hand, antenna synthesis is the process of deriving physical structure for the given performance parameters reverse of antenna analysis. Several analytical and numerical methods having some disadvantages are generally used for analysis process [2]. The numerical methods give good results by using mixed mathematical operations. The numerical methods such as finite difference time domain method, finite element method and method of moment require much more time in solving Maxwell's equations including integral and/or differential computations. So, it becomes time consuming since it repeats the same mathematical procedure even if a minor change in geometry is carried out. Moreover, the analytical methods such as the cavity model and the transmission line model are accurate but they are based on physical assumptions. These methods are more suitable for conventional MAs because of their regular shapes. In addition, these approaches require a new solution for every small change in the patch geometry [3]. Antenna designers need the synthesise to find the best antenna solution. Simulator tool packs such as HyperLynx® 3D EM [4], Ansoft HFSS [5], CST microwave studio [6], Agilent ADS [7] are commonly

used to simplify the synthesis process. These simulation packages do not themselves produce a synthesized antenna, but they only analyze the antenna structure and provide calculated performance results for a synthesized antenna. Hence, artificial intelligence techniques are widely preferred as a faster and accurate alternative methods to accomplish these challenges associated with the traditional techniques in analysis and synthesis processes of MAs [3, 8]. Artificial intelligence models such as artificial neural network (ANN) [9], support vector machine (SVM) [10] and adaptive neuro fuzzy inference system (ANFIS) [11] eliminate the complex mathematical procedures and time consuming for processes of antenna design. These models have been widely used for analysis and synthesis of various MAs in the literature [12-25]. In [12-18], analysis studies were carried out to determine some performance parameters of MAs having various shapes with artificial intelligence techniques such as ANN, SVM and ANFIS. Also, synthesis models were proposed for MAs and microwave devices in [19-25]. In this study, SVM is preferred because of the following advantages: SVM often converges on global minimum rather than local minimum in high nonlinear problem. The overfitting problem and calculation procedures are less in the SVM method according to ANN and ANFIS. SVM requires less memory than other modeling methods.

In this work, SVM-based analysis and synthesis models is proposed as a tool for the design of ETRMAs. Using SVM technique, the resonant frequency ( $f_r$ ) and slot size ( $l$ ) of the ETRMAs are obtained as a function of input variables. For this purpose, ETRMA is designed and a two SVM models are constructed with a 100 ETRMAs simulation data set. The simulations are performed with the aid of a 3D full wave simulator using the method of moment (MoM) [26]. The data set of 75 ETRMAs are used to train the SVM models and remainders 25 ETRMAs are utilized to test the accuracy of models. The testing data set is not included in training process. The SVM models are then verified through the measured data set of a prototyped ETRMA in this study.

## II. ETRMA STRUCTURE AND SIMULATION PROCESS

ETRMA is formed by loading an equilateral triangular slot with size " $l$ " on an equilateral triangular patch of size " $L$ " as shown Fig. 1. The constituted ETRMA patch is placed on a substrate with  $h$  thickness and  $\epsilon_r$  dielectric constant, all over on the ground layer. The ETRMA is fed at the point of  $x$  and  $y$ . The equilateral triangular slot causes to a reduction in resonant frequency compared to an ETMA of the same size. Also, the size of ETRMA is smaller than the size of ETMA in the same resonant frequency. These situations are seen in the simulation results given in Table 1 and Fig. 2.

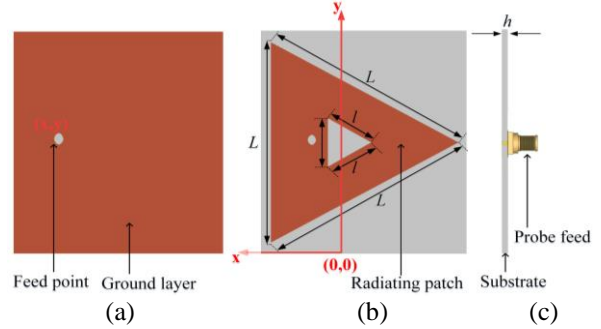


Fig. 1. Geometry of the ETRMA: (a) back view, (b) front view, and (c) side view.

Table 1: Comparative simulation results for ETMA and ETRMA

Antenna	Patch Dimension (mm)			$\epsilon_r$	$f_r$
	$L$	$l$	$h$		
ETMA	52	0	1.6	2.33	2.432
ETRMA	52	17.2	1.6	2.33	2.226
ETRMA	43.3	25.8	1.6	2.33	2.432

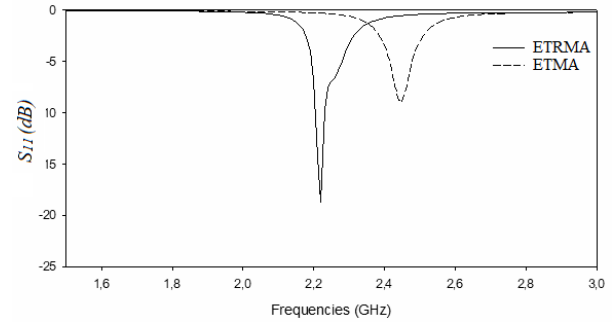


Fig. 2. The compared  $S_{11}$  parameters of simulated ETMA and ETRMA for the same size

The 100 ETRMA with 4 parameters ( $L$ ,  $l$ ,  $h$  and  $\epsilon_r$ ) are simulated to determine the resonant frequency ( $f_r$ ). A total of 100 data set are generated, 75 of which are used for training the SVM models. The remaining 25 are used for testing the performance of the trained SVM models on inputs. From the data set, 75 and 25 ETRMAs are uniformly selected to train and test the accuracy of the models according to 75% and 25% of ETRMA data, respectively. These ratios used for training and testing data are widely preferred in the literature. The 25 testing data are not used in the training process. For this purpose, simulations of 100 ETRMAs are performed with the respect to the resonant frequency according to parameters given in Table 2. The " $h$ " and " $\epsilon_r$ " values given in Table 2 belong to the substrate materials commonly used in the literature. Because the proposed analysis and synthesis models cover ETRMAs operating in the ultrahigh band, the patch dimensions are determined accordingly.

Table 2: Geometrical and electrical parameters of simulated ETRMAs

Number of Simulations	Patch Dimensions (mm)			Dielectric Constant ( $\epsilon_r$ )
	$L$	$l$	$h$	
20	26	3.44, 6.88, 10.32, 13.76, 17.2	1.6, 2.5	2.33, 4.4
20	34	5.16, 10.32, 15.48, 20.64, 25.8		
20	52	8.6, 17.2, 25.8, 34.4, 43		
20	69	17.2, 25.8, 34.4, 43, 51.6		
20	86	25.8, 34.4, 43, 51.6, 60.2		

The ETRMA structures are modelled/simulated according to topology in Fig. 3 by means of computational electromagnetic software HyperLynx® 3D EM [4] using method of moment (MoM) [26]. In the simulations, 1 Volt wave source with coaxial fed is used for the ETRMAs. The antenna models are meshed with lines per wavelength ratio of 40 and maximum frequency of 5 GHz. It is simulated between the frequency of 0 GHz and 5 GHz. The HyperLynx® 3D EM's built-in optimization module was used to determine the feed point with the objective function  $S_{11}$  (dB)  $< -10$  for the resonant frequencies.

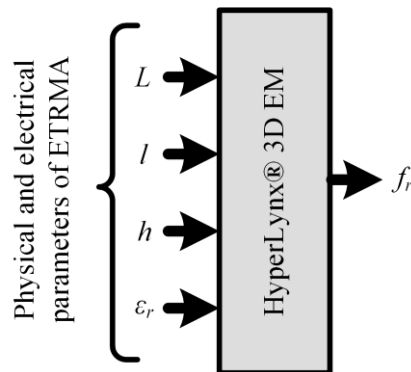


Fig. 3. The topology of the simulation process by HyperLynx® 3D EM software.

### III. PROCESS OF SVM MODELS CONSTRUCTION

The process of SVM models construction is outlined in Fig. 4 for analysis and synthesis of ETRMAs. The resonant frequency and slot dimension of ETRMAs are obtained in the analysis and synthesis process, respectively. The SVM models are trained with 75 antenna data so that fitting the models' outputs to results of simulation in the objective of minimizing MAPE calculating the mean absolute percentage error between the targets and outputs.

#### A. SVM modelling

Analysis and synthesis models based on SVM are proposed for the design of ETRMAs according to the topology shown in Figs. 5 (a) and 5 (b). Machine learning methods are used for classification, regression and clustering problems. SVM is a new generation supervised learning model which used for regression analysis in machine learning [10]. In the nonlinear problems such as analysis and synthesis of antennas, SVM depends on the principle which is separation of two data groups by N-dimension optimum hyperplane by using the Kernel functions. The key point in SVM is linear discriminant function called hyperplane reflecting the characteristics of data-set. SVM effectively establishes an optimum hyperplane having equidistant from both of the data in a high or infinite dimensional space. [27].

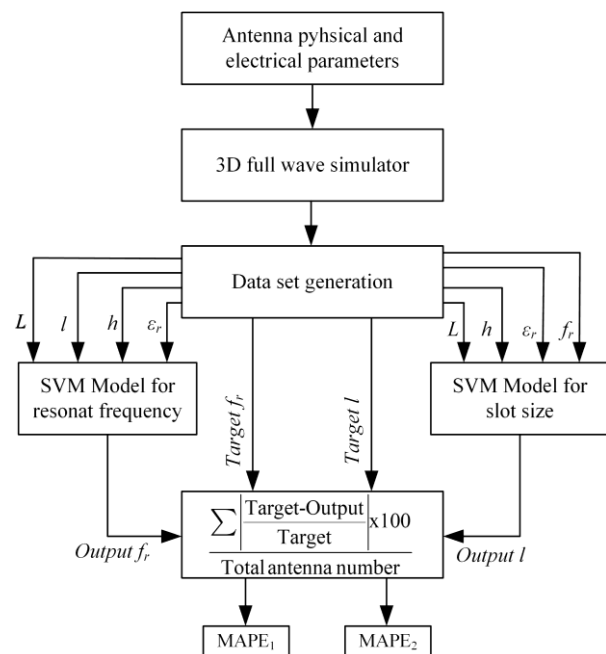


Fig. 4. The working principle of the SVM models.

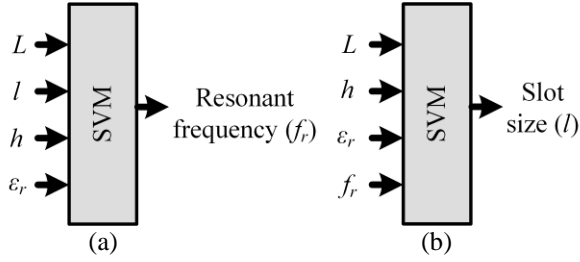


Fig. 5. The topology of SVM models: (a) for analysis, and (b) for synthesis.

**B. Training the SVM models**

The SVM models are trained through 75 of total 100 ETRMA data set according to flow chart given in Fig. 6. They are constructed using parameters in Table 3 for obtaining the resonant frequency and slot size of ETRMAS as shown in Figs. 7 (a) and 7 (b). The SVM models are coded in MATLAB® software. In this work, the used gaussian kernel function is given as

$$K(x, x_i) = \exp\left(-\frac{\|x - x_i\|^2}{2\sigma^2}\right). \quad (1)$$

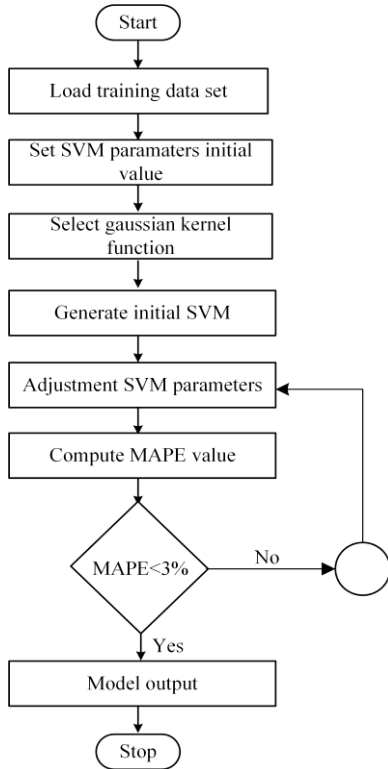


Fig. 6. Flow chart of the SVM models in the training phase.

As it is seen from the Fig. 8, that the results of proposed SVM models and obtained from simulations are in a good harmony and MAPEs are achieved as 0.312% and 2.741% respectively for analysis ( $f_r$ ) and synthesis ( $l$ ) in the training process. The synthesis problem is more nonlinear than the analysis problem, therefore the MAPE calculated as a result of analysis is lower than the MAPE of synthesis.

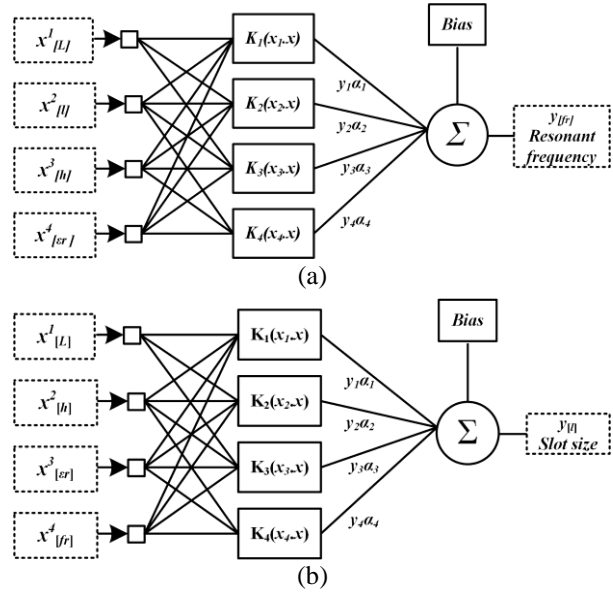


Fig. 7. The proposed SVM models: (a) for resonant frequency, and (b) for slot size.

Table 3: The used SVM parameters for analysis and synthesis of ETRMA

Models	Parameters	Set Type/Value
Analysis model	Kernel function	Gaussian
	Kernel function coefficient ( $\sigma$ )	28
	Penalty weight ( $C$ )	1000000
	Slack variables (epsilon- $\zeta$ )	0.001
	Number of input	4
	Number of output	1
Synthesis model	Kernel function	Gaussian
	Kernel function coefficient ( $\sigma$ )	13
	Penalty weight ( $C$ )	1000000
	Slack variables (epsilon- $\zeta$ )	0.0025
	Number of input	4
	Number of output	1

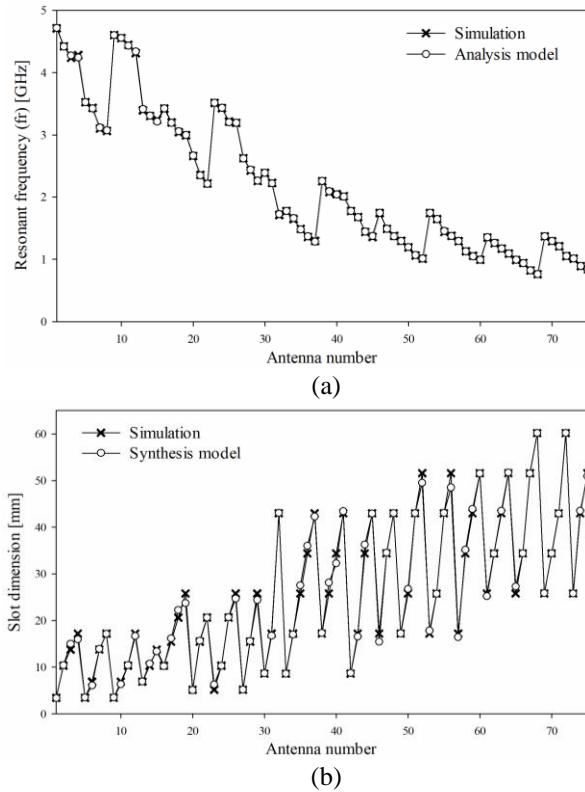


Fig. 8. Comparative results of the simulation and SVM models: (a) for analysis and (b) for synthesis.

#### IV. TESTING RESULTS OF ANALYSIS AND SYNTHESIS PROCESS FOR ETRMA

In the last section, SVM models are constructed and trained with properly parameters. The accuracies the SVM models are now tested through 25 ETRMAs data set not included in the training phase. As shown Figs. 9 (a) and 9 (b), graphical user interfaces (GUIs) are designed in MATLAB® software to use the SVM models for the antenna designer. Antenna designers be able to use this GUIs practically in ETRMA analysis and synthesis process.

##### A. Testing results of analysis process

The accuracy of the SVM-based analysis model for obtaining the resonant frequency is tested through 25 ETRMAs data that is not utilized in training the model. The parameters of 25 simulated antennas with respective resonant frequency values and results of analysis model are given in Table 4. It is seen from the results; model successfully obtains the resonant frequency with MAPE of 1.109%. Also the harmony of simulation and SVM model results is seen in Fig. 10.

##### B. Results of synthesis process

The validity of the synthesis model based on SVM for obtaining the slot dimension is tested through 25

ETRMAs. The testing data set for the synthesis model are not included in the training process. The parameters of 25 simulated antennas and testing results of synthesis model are given in Table 5. Although the problem of obtaining slot dimension is a high nonlinearity problem, the results of the SVM-based synthesis model are harmony with the simulation results as shown in Table 5 and Fig. 11. The slot dimension with MAPE of 5.507% is obtained by the proposed model.

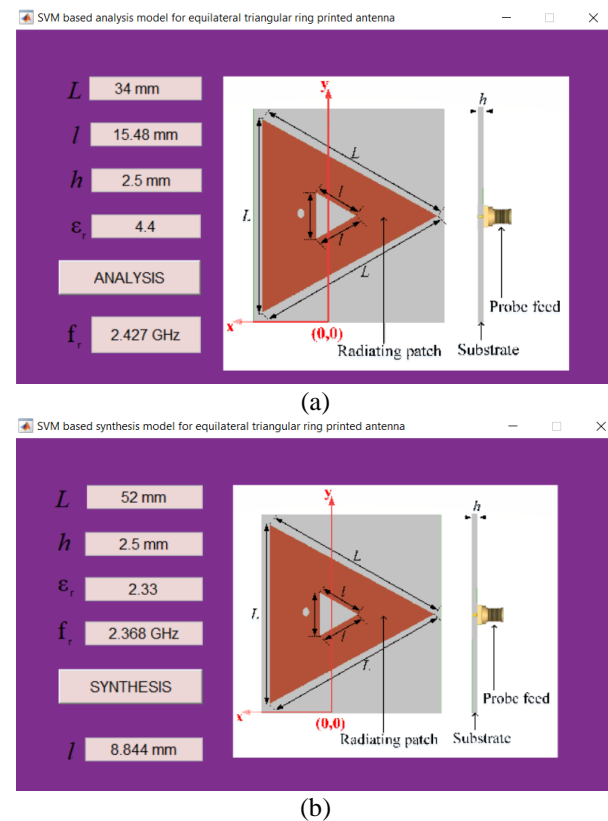


Fig. 9. The screenshots for GUI of the SVM models: (a) for analysis and (b) for synthesis.

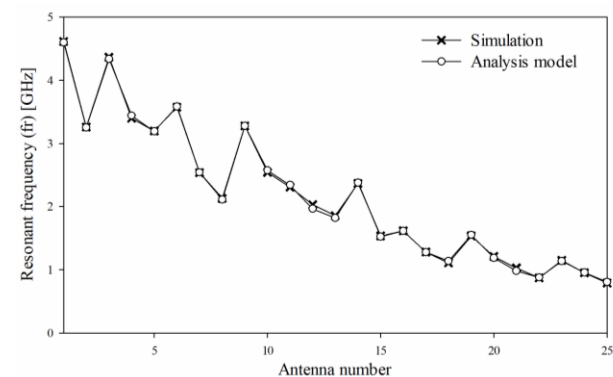


Fig. 10. Comparative results of the simulation and analysis model in the testing process.

**C. Fabrication of ETRMA**

The accuracy and validity of SVM analysis/synthesis models are verified on the fabricated ETRMA. ETRMA illustrated in Fig. 12 is printed on FR4 PCB substrate of which dielectric permittivity, tangent loss and thickness are 2.22, 0.02 and 1.6 mm, respectively. All parameters related to the antenna are given in Table 6. The prototyped antenna is measured by using Keysight Technologies N5224A PNA network analyzer. The measured  $S_{11}$  parameter is shown in Fig. 13 in comparison with the simulated one. The results of measured and the analysis/synthesis models are listed in Tables 6 and 7 in order to evaluate the testing process in detail.

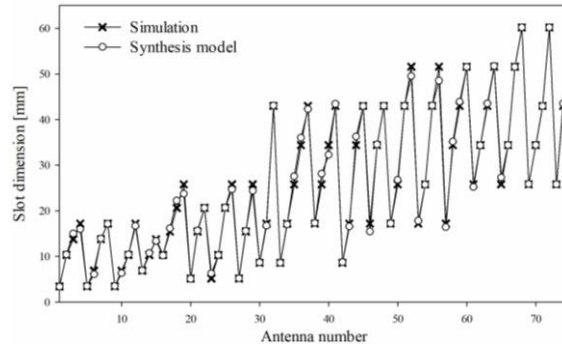


Fig. 11. Comparative results of the simulation and synthesis model in the testing process.

Table 4: Data set of testing for resonant frequencies and obtained results

Antenna Number	Inputs				Outputs of Simulation [GHz]	Outputs of SVM [GHz]	Absolute Percentage Error (APE)
	$L$ [mm]	$l$ [mm]	$h$ [mm]	$\epsilon_r$	$f_{r\_simulation}$	$f_{r\_SVM}$	
1	26	6.88	1.6	2.33	4.614	4.599	0.325
2	26	10.32	1.6	4.4	3.261	3.254	0.227
3	26	13.76	2.5	2.33	4.365	4.338	0.625
4	26	3.44	2.5	4.4	3.401	3.441	1.179
5	26	17.2	2.5	4.4	3.198	3.195	0.102
6	34	5.16	1.6	2.33	3.576	3.585	0.253
7	34	10.32	1.6	4.4	2.538	2.543	0.188
8	34	25.8	1.6	4.4	2.130	2.114	0.773
9	34	15.48	2.5	2.33	3.278	3.279	0.031
10	34	10.32	2.5	4.4	2.544	2.575	1.223
11	34	20.64	2.5	4.4	2.309	2.342	1.446
12	52	25.8	1.6	2.33	2.030	1.964	3.245
13	52	34.4	1.6	2.33	1.856	1.821	1.874
14	52	8.6	2.5	2.33	2.368	2.378	0.430
15	52	25.8	2.5	4.4	1.536	1.524	0.784
16	69	25.8	1.6	2.33	1.616	1.614	0.114
17	69	51.6	1.6	2.33	1.280	1.277	0.209
18	69	34.4	1.6	4.4	1.110	1.139	2.589
19	69	34.4	2.5	2.33	1.536	1.552	1.035
20	69	25.8	2.5	4.4	1.210	1.189	1.734
21	86	60.2	1.6	2.33	1.030	0.981	4.709
22	86	43	1.6	4.4	0.870	0.878	0.936
23	86	51.6	2.5	2.33	1.150	1.136	1.208
24	86	34.4	2.5	4.4	0.950	0.957	0.789
25	86	60.2	2.5	4.4	0.790	0.803	1.685
Mean absolute percentage error (MAPE)							1.109

Table 5: Data set of testing for slot sizes and obtained results

Antenna Number	Inputs				Outputs [mm]		Absolute Percentage Error (APE)
	$L$ [mm]	$h$ [mm]	$\epsilon_r$	$f_r$ [GHz]	$l_{simulation}$	$l_{SVM}$	
1	26	1.6	2.33	4.614	6.88	5.731	16.702
2	26	1.6	4.4	3.261	10.32	11.18	8.291
3	26	2.5	2.33	4.365	13.76	13.60	1.184
4	26	2.5	4.4	3.401	3.44	3.64	5.718
5	26	2.5	4.4	3.198	17.20	15.34	10.820
6	34	1.6	2.33	3.576	5.16	5.56	7.700
7	34	1.6	4.4	2.538	10.32	9.35	9.339
8	34	1.6	4.4	2.130	25.80	23.81	7.686
9	34	2.5	2.33	3.278	15.48	17.62	13.817
10	34	2.5	4.4	2.544	10.32	9.473	8.208
11	34	2.5	4.4	2.309	20.64	21.79	5.597
12	52	1.6	2.33	2.030	25.80	26.69	3.463
13	52	1.6	2.33	1.856	34.40	35.61	3.544
14	52	2.5	2.33	2.368	8.60	8.844	2.839
15	52	2.5	4.4	1.536	25.80	28.37	9.971
16	69	1.6	2.33	1.616	25.80	24.89	3.504
17	69	1.6	2.33	1.280	51.60	50.39	2.341
18	69	1.6	4.4	1.110	34.40	35.48	3.160
19	69	2.5	2.33	1.536	34.40	35.02	1.807
20	69	2.5	4.4	1.210	25.80	25.74	0.205
21	86	1.6	2.33	1.030	60.20	59.87	0.544
22	86	1.6	4.4	0.870	43.00	44.37	3.208
23	86	2.5	2.33	1.150	51.60	49.38	4.294
24	86	2.5	4.4	0.950	34.40	34.64	0.718
25	86	2.5	4.4	0.790	60.20	58.37	3.035
Mean absolute percentage error (MAPE)							5.507

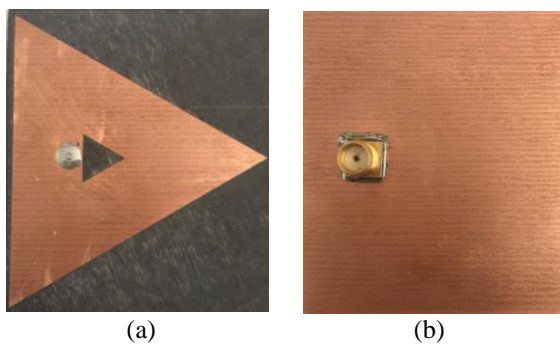


Fig. 12. The photograph of prototyped ETRPA: (a) front view and (b) back view.

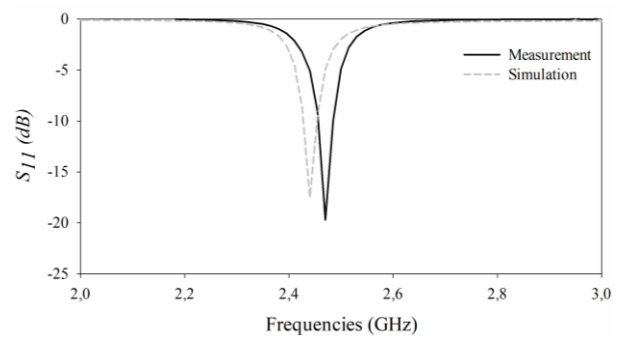
Fig. 13.  $S_{11}$  parameters of simulated and measured prototyped ETRMA.

Table 6: The comparative results for resonant frequency

Inputs				Resonant Frequency [GHz]		
$L$ [mm]	$l$ [mm]	$h$ [mm]	$\epsilon_r$	$f_{sim}$	$f_{mea}$	$f_{SVM}$
52	8.6	1.6	2.22	2.438	2.468	2.391

Table 7: The comparative results for slot size

Inputs				Outputs [mm]	
$L$ [mm]	$h$ [mm]	$\epsilon_r$	$f_r$ [GHz]	$l_{mea}$	$l_{SVM}$
52	1.6	2.22	2.468	8.600	8.427

From Tables 6 and 7, the results of SVM models are much close to the simulated/measured results. Therefore, the SVM models can be successfully used to obtain the resonant frequency ( $f_r$ ) and slot size ( $l$ ) of the ETRMAs without handling sophisticated mathematical functions and transformations. Moreover, the proposed models can be modified or improved to use similar tasks of nonlinear electromagnetic problems. The antenna designers can use practically the proposed models for analysis and synthesis of ETRMA.

## V. CONCLUSION

In this work, two SVM models are implemented for analysis and synthesis of the ETRMAs. A data set of 75 ETRMAs are used for training and the remainders 25 data set are utilized for testing the SVM models. The four antenna parameters are input the model to obtain the resonant frequency of ETRMA in the analysis process. In this design process, synthesis is defined as the forward side and then analysis as the reverse side of the problem. At the output of the synthesis model, slot dimension of ETRMA is also obtained by inputting length of antenna, height/dielectric constants of the chosen substrate and resonant frequency. The results achieved in this study show that proposed SVM models can be successfully used to obtain the resonant frequency and slot size of ETRMAs with high accuracy. The SVM technique may be preferred as a faster and accurate alternative methods according to the traditional techniques in analysis and synthesis processes of MAs.

## REFERENCES

- [1] K. Wong, *Compact and Broadband Microstrip Antennas*. John Wiley & Sons, Inc., 2002.
- [2] J. R. James, P. S. Hall, and C. Wood, *Microstrip Antenna Theory and Design*. IEE. Peter Peregrinus, 1981.
- [3] Q. J. Zhang and K. C. Gupta, *Neural Networks for RF and Microwave Design*. Artech House Publishers, 2000.
- [4] HyperLynx® 3D EM, Version 15, Mentor Graphics Corporation, 8005 SW Boeckman Road, Wilsonville, OR 97070.
- [5] Ansoft Corporation, HFSS v. 10.1.1 user manual, July 2006. <http://www.ansoft.com>
- [6] CST GmbH-Computer Simulation Technology, CST Microwave Studio 2006 user manual, 2006. <http://www.cst.com>
- [7] Agilent Technologies, EESof EDA, Momentum. <http://eesof.Tm>. [Agilent.com/products/momentum/main.html](http://www.agilent.com/products/momentum/main.html)
- [8] C. G. Christodoulou and M. Georgiopoulos, *Applications of Neural Networks in Electromagnetics*. Artech House, Boston, 2001.
- [9] S. Haykin, *Neural Networks: A Comprehensive Foundation*. Macmillan College Publishing Company, New York, ABD, 1994.
- [10] N. V. Vapnik and A. Y. Chervonenkis, "The Necessary and Sufficient Conditions for Consistency in the Empirical Risk Minimization Method," *Lect. Notes, Comput. Sc.*, vol. 1, no. 3, pp. 283-305, 1991.
- [11] J. S. R. Jang, "ANFIS: Adaptive-network-based fuzzy inference system," *IEEE TSyst. Man. Cy.*, vol. 23, pp. 665-685, 1993.
- [12] A. Akdagli, A. Kayabasi, and I Develi, "Computing resonant frequency of C-shaped compact microstrip antennas by using ANFIS," *Int. J. Elec.*, vol. 102, pp. 407-417, 2015.
- [13] A. Kayabasi and A. Akdagli, "Predicting the resonant frequency of E-shaped compact microstrip antennas by using ANFIS and SVM," *Wireless Pers. Commun.*, vol. 82 pp. 1893-1906, 2015.
- [14] A. Kayabasi, A. Toktas, A. Akdagli, M. B. Bicer, and D. Ustun, "Applications of ANN and ANFIS to predict the resonant frequency of L-shaped compact microstrip antennas," *Appl. Comput. Electrom.*, vol. 29, pp. 460-469, 2014.
- [15] K. Guney and N. Sarikaya, "Adaptive neuro-fuzzy inference system for computing the resonant frequency of circular microstrip antennas," *Appl. Comput. Electrom.*, vol. 19, pp. 188-197, 2004.
- [16] F. Güneş, N. T. Tokan, and F. Gürgen, "A consensual modeling of the expert systems applied to microwave devices," *Int. J. RF Microw. Comput.-aided Eng.*, vol. 20, pp. 430-440, 2010.
- [17] Y. Tighilt, F. Bouttout, and A. Khellaf, "Modeling and design of printed antennas using neural networks," *Int. J. RF Microw. Comput.-aided Eng.*, vol. 21, pp. 228-233, 2011.
- [18] A. R. Venmathi and L. Vanitha, "Support vector machine for bandwidth analysis of slotted microstrip antenna," *Int. J. Comput. Inf. Sci.*, vol. 4, no. 1, pp. 67-61, 2011.
- [19] W. Zhongbao and S. Fang, "ANN synthesis model of single-feed corner-truncated circularly polarized microstrip antenna with an air gap for wideband applications," *Int. J. Antennas Propag.*, 2014.
- [20] H. J. Delgado, M. H. Thursby, and F. M. Ham, "A novel neural network for the synthesis of antennas



- and microwave devices,” *IEEE Trans. Neural Netw. Learn. Syst. NN*, vol. 16, no. 6, pp. 1590-1600, 2005.
- [21] Z. Wang, S. Fang, Q. Wang, and H. Liu, “An ANN-based synthesis model for the single-feed circularly-polarized square microstrip antenna with truncated corners,” *IEEE Trans. Neural Netw. Learn. Syst. NN*, vol. 60, no. 12, pp. 5989-5992, 2012.
- [22] T. Khan, A. De, and M. Uddin, “Prediction of slot-size and inserted air-gap for improving the performance of rectangular microstrip antennas using artificial neural networks,” *IEEE Antennas Wireless Propag. Lett.*, vol. 12, pp. 1367-1371, 2013.
- [23] E. Demircioglu, M. H. Sazlı, S. T. İmeci, and O. Sengul, “Soft computing techniques on multi-resonant antenna synthesis and analysis,” *Microw. Opt. Technol. Lett.*, vol. 55, no. 11, pp. 2643-2648, 2013.
- [24] L. Merad, F. T. Bendimerad, and S. M. Meriah, “Design and resonant frequency calculation of rectangular microstrip antennas,” *Int. J. Numer. Model El*, vol. 24, no. 2, pp. 144-153, 2011.
- [25] N. K. Saxena, M. Khan, P. K. S. Pourush, and N. Kumar, “Neural network analysis of switchability of microstrip rectangular patch antenna printed on ferrite material,” *Int. J. RF Microw. Comput.-aided Eng.*, vol. 20, no. 1, pp. 1-5, 2010.
- [26] R. F. Harrington, *Field Computation by Moment Methods*. IEEE Press, Piscataway, NJ, 1993.
- [27] N. T. Tokan and F. Gunes, “Support vector characterization of the microstrip antennas based on measurements,” *Prog. Electromagn. Res. B*, vol. 5, pp. 49-61, 2008.



**Ahmet Kayabasi** was born in 1980. He received his B.S. and M.S. degrees in EEE from Selcuk University, Turkey, in 2001, 2005 respectively. In 2015, he received his Ph.D. degree in Electrical and Electronics Engineering from Mersin University, Turkey. From 2001 to 2015, he was a Lecturer in the Electronics and Automation Department of Selcuk University. He has been working as Assistant Professor in the Department of Electrical and Electronics Engineering at Karamanoglu Mehmetbey University. His current research interests include antennas, microstrip antennas, computational electromagnetic, artificial intelligent.