Journal of Artificial Intelligence and Data Science (JAIDA)
e-ISSN: 2791-8335
https://dergipark.org.tr/pub/jaida

Vol. 2, No. 2, pp. 69-75, 2022
Research Article

Designing of Dual Band F-Shaped RFID Antenna Using Machine Learning Techniques

Yusuf NURAY [1,*], Nursel AKÇAM [2]

[1] ASELSAN Inc., Transportation, Security, Energy and Automation Systems Division, Turkey
[2] Gazi University, Engineering Faculty, Department of Electric and Electronic Engineering, Turkey

Abstract
In this paper, using machine learning, a dual-band F-shaped RFID antenna is designed to operate in 867MHz UHF and 2.45GHz WLAN bands. The study's dataset was consisting of a total of 625 samples, and this was received from the simulation software as a consequence of the parametric analysis of the design parameters for the antenna. The success of the algorithms was compared after six of the most popular machine learning algorithms were applied to the same parameters. The Random Forest algorithm, which has a 99.96% for R^2 score and a mean squared error value of 0.0004, has been used to predict the input port scattering parameter. With the best results obtained from this technique, the antenna operating at the desired frequencies was designed.
Keywords: Dual Band Antenna Design; Machine Learning; Radio Frequency Identification; Regression; Scattering Parameters.

1. Introduction

Machine learning technology advancements have kept pace with other technical advancements. in recent years and provide us with accurate results and evaluations by being used in many fields of study such as marketing, engineering, science, medicine, financial market analysis, etc [1]. On the other hand, UHF (860-960 MHz) band radio-frequency identification (RFID) systems have recently grown more appealing for a variety of industrial services, including supply chain, tracking, inventory management, and bioengineering applications. This is due to the system's ability to offer a greater reading range, faster reading speeds, and more storage space[2]. The developments in wireless communication technology have gained another dimension to the antenna, which is one of the most important elements of RFID systems, and antenna designs that can operate at different frequencies at the same time have arisen [3]. Antenna designs are realized with 3D simulation programs in a computer environment, the return loss and input impedance data of the antennas, gain values, and radiation patterns are examined in the simulation environment and appropriate designs are created [4], [5]. The performance of the antenna can be validated using simulation programs individually (in the environment of space) and systemic. On the other hand, as the antenna structure's complexity or system rises, the time required to achieve the desired antenna performance with these programs also rises proportionally to complexity [6]. For the design optimization of antennas utilizing computer-assisted simulations, several optimization algorithms are available in the literature and are easily adaptable. However, there is a basic drawback to these numerical algorithms since it takes numerous simulation cycles to identify an ideal design that can readily scale the design process [7]. Techniques have been implemented to reduce simulation time, and this implementation occasionally caused the verification of antenna performance to be limited. According to the most recent technical advancements, this simulation's runtime can be shortened by employing machine learning algorithms, and reliable outcomes that correspond to simulation data as well as real test data can be obtained [8]. Recently, computer-aided design methods using genetic and Ant colony optimization algorithms and artificial neural network (ANN) techniques have been applied for microwave modeling and system optimization [9]. Similarly, in these investigations [10], [11], the scattering parameter, design parameters, estimations of gain, and efficiency values were adjusted for the antenna design using machine learning approaches.

In Chapter 2, the selected single band F Shaped RFID antenna model's design parameters are discussed, along with the machine learning techniques that will be used to take these parameters into account. The performance statistics of six of the most popular machine learning algorithms are thoroughly detailed in Chapter 3. In Chapter 4, the performance of the dual-band F Shaped RFID antenna designed according to the optimum data obtained from machine learning techniques will be explained and the study's results are interpreted in Chapter 5.

*Corresponding author e-mail address: yusufnuray@gmail.com

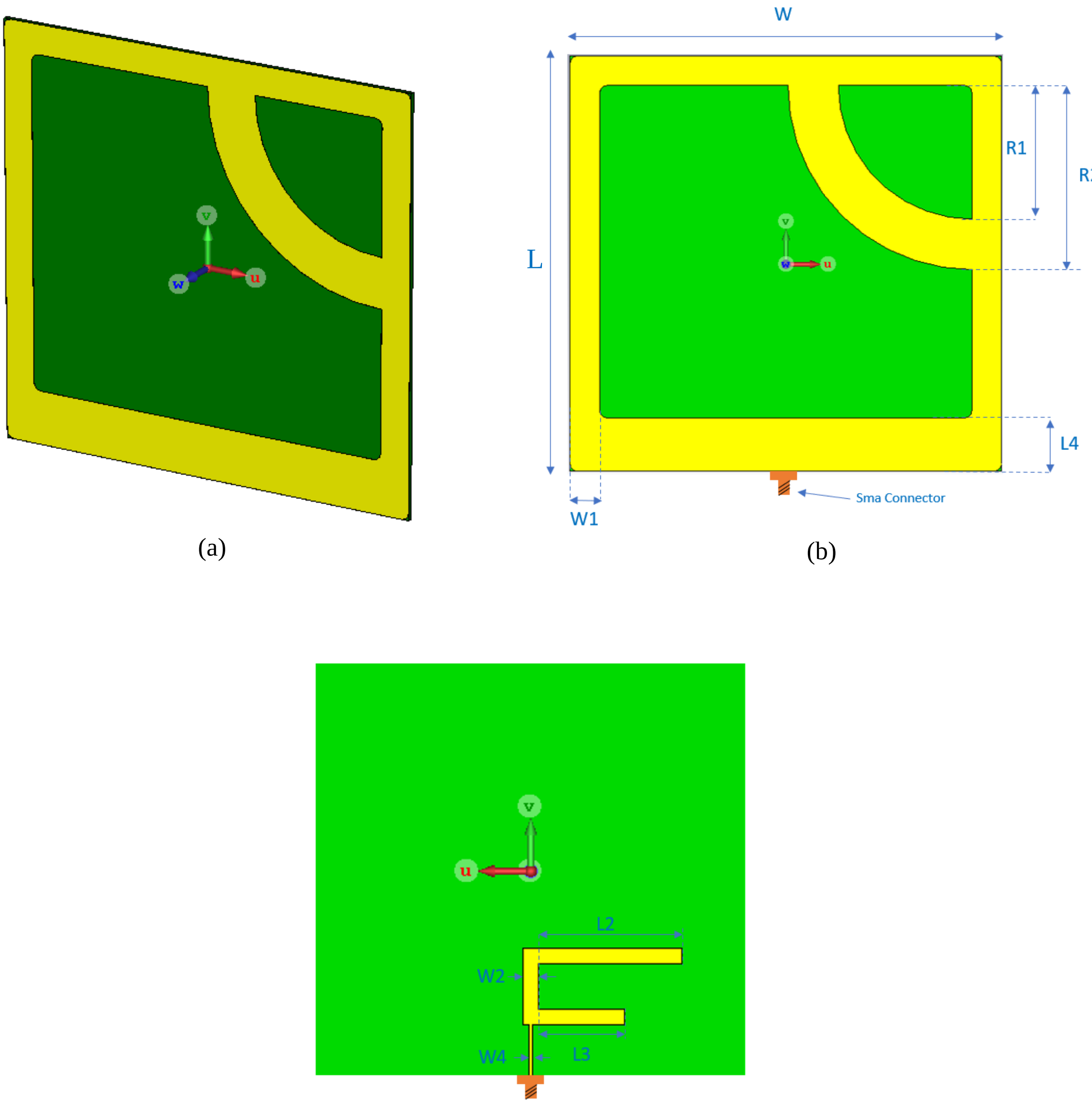
Received: 31/10/2022; Accepted: 20/11/2022

2. Materials & Methods

This section presents the selected Dual Band F Shaped RFID antenna's design parameters and provides details on the development process. Additionally, offered are machine learning models that predict scattering parameters for the suggested antenna design's UHF RFID and WLAN resonance frequencies. An accurate and properly formed data collection is required to apply machine learning techniques. This section also contains essential details regarding this dataset.

2.1. F-Shaped RFID Antenna Design

The selected Broadband Circularly Polarized Antenna with Square Slot antenna design was submitted by Jui-Han Lu and Sang-Fei Wang for UHF RFID reader applications [12]. This particular antenna is solely intended for use with the UHF band. The purpose of this paper is to determine the parameters that will operate this single-band antenna on both RFID and WLAN frequencies using machine learning techniques. Since numerous geometric parameters can be determined on this antenna, there are more inputs available for machine learning algorithms, which is why this antenna is selected. Figure 1 presents the parametric data for a selected antenna in detail.



(c)

Figure 1. *Design of selected antenna; a) Antenna's top layer b) Antenna's top layer design parameters, c) Antenna's bottom layer design parameters*

The selected antenna with a total antenna size of 126x121 mm^2 is printed on a double-sided FR-4 substrate. This 0.8mm thick substrate has the following electrical properties ε_r=4.4, loss tangent value = 0.0245. Table 1 provides the design specifications for the selected antenna.

Table 1. *The Selected Antenna's Design Specifications*

Parameter	Value (mm)	Parameter	Value (mm)
L	126	W	121
L2	38	W1	15
L3	38	W2	6.2
L4	20	W4	1.48
R1	71	R2	62

2.2. Dataset Preparation for Machine Learning Algorithms

To estimate the input port reflection coefficient of the selected antenna in machine learning algorithms, a dataset is needed. First, to create this required data set, it was examined how the S_{11} graph of the selected antenna at the desired frequencies responds to the change of the geometric parameters on the antenna and the parameters to be used in machine learning were determined as W1, L4, R1, and R2. In addition, information such as step size, number of samples, and the change intervals of the determined parameters are shown in Table 2.

Table 2. *Antenna Design Parameters for Dataset Preparation*

Parameter	Change Rate (mm)	Step Size (mm)	Number of Samples
W1	[10 20]	2.5	5
L4	[15 25]	2.5	5
R1	[62 74]	3	5
R2	[45 60]	3.75	5
Total Data:			625

The input port scattering parameter of the antenna selected with the different design parameters specified in Table 2 was simulated in the 3D simulation environment and a dataset was created with the results. There are 625 samples total in the dataset, of which 20% are used for testing and 80% for training.

The Dual Band F-Shaped RFID antenna's simulation performance is realized using 625 data. The simulation program also yielded the following other sorts of scattering parameters: The scattering parameter's real (S_{11} Real), imaginary (S11 Img), and linear forms are selected as in the S_{11} machine learning model as output. The input and output values for the dataset were found to be appropriate for the regression algorithms used in machine learning after the examination.

Multiple-output regression techniques were utilized in addition to single-output regression types to evaluate performance because the simulation program generates different types of scattering parameters. The single output dataset was subjected to Random Forest, Gradient Boosting, Bayesian Ridge, and Polynomial Regression methods. Also, the voting regression technique, which may run many regression algorithms simultaneously was applied in addition to single regression performances, and performance comparisons were done.

3. Numerical Results

This chapter presents the performance metrics of the models that were created with machine learning techniques. The Python programming language was used to create the regression methods described in the preceding section, which were then used to apply to the necessary models and evaluated for performance metrics.

Random Forest, Bayesian Ridge, Polynomial, Gradient Boosting and Voting regression techniques were applied to the linear scattering parameter of the selected antenna, shown in Figures 2, 3, 4, 5, and 6 respectively. Figure 7 shows the Multi-Output regression technique. For the Real and Imaginary parts of the selected antenna’s scattering parameter, since an output value is made up of two-part, the Multi-Output regression technique was applied. The graphs below show the actual and predicted values of these techniques based on 20 test data points.

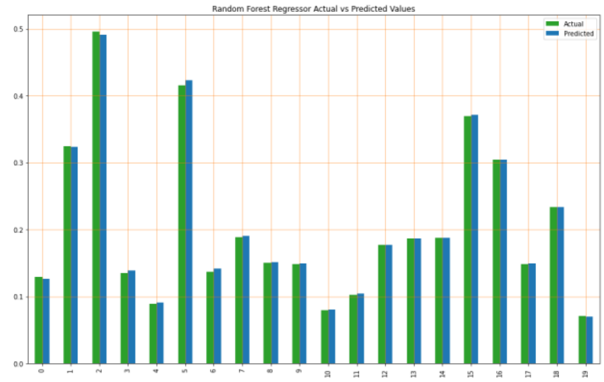


Figure 2. *Random Forest Regressor Actual vs Predicted Data*

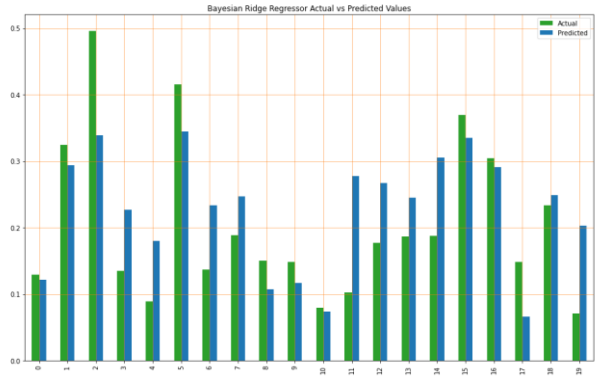


Figure 3. *Bayesian Ridge Regressor Actual vs Predicted Data*

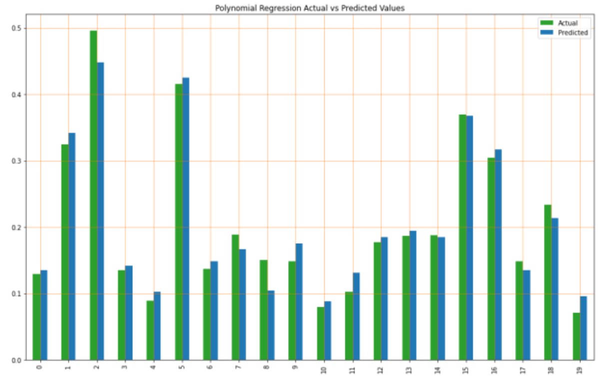


Figure 4. *Polynomial Regressor Actual vs Predicted Data*

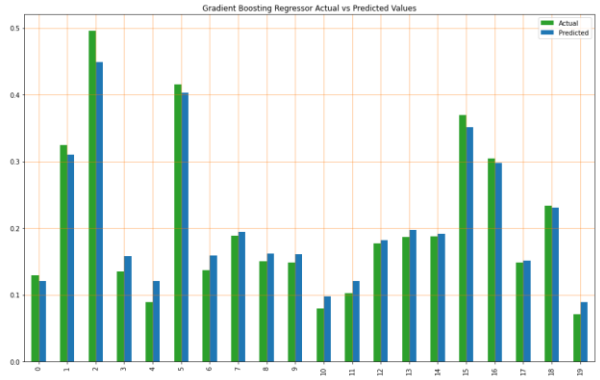


Figure 5. *Gradient Boosting Regressor Actual vs Predicted Data*

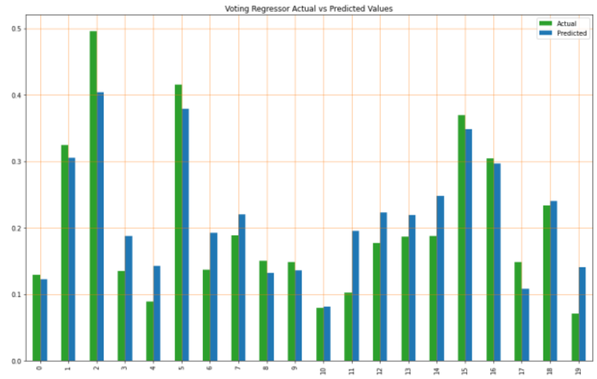


Figure 6. *Voting Regressor Actual vs Predicted Data*

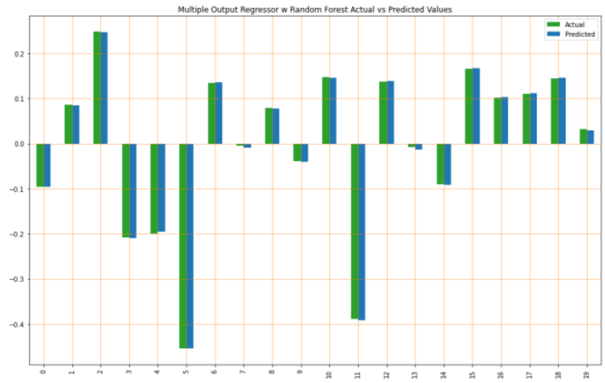


Figure 7. *Multiple Output Regressor Actual vs Predicted Data*

The Random Forest Regressor has the best prediction performance after the test data were analyzed, as shown in Table 3, which displays all the performance metrics.

Table 3. *Regression Methods Comparison Table*

(%)	Random Forest Regressor	Bayesian Ridge Regressor	Polynomial Regressor	Gradient Boosting Regressor	Voting Regressor	Multiple Output Regressor
R2 Score	99.96	57.49	98.56	97.52	87.56	99.95
Mean Squared Error	0.0004	0.622	0.0201	0.036	0.1820	0.0008
Root Mean Squared Error	0.214	7.886	1.148	1.904	4.266	0.2869
Mean Absolute Error	0.146	6.396	1.129	1.466	3.465	0.193
Maximum Error	1.749	22.97	6.995	6.301	11.68	-

To verify the success result of the Random Forest Regressor, estimations were made with five different parameters. The estimates are compared with the actual results and are shown in Table 4.

Table 4. *Random Forest Regressor Output vs Actual Result Comparison*

Input Parameters Freq (GHz), W1, L4, R1, R2 (mm)	Estimated Output Values (S_{11} Linear)	Actual Output Values (S_{11} Linear)
[2.4327, 10.0, 25.0, 71.0, 45.0]	0.19594009	0.195118490
[0.8734, 20.0, 25.0, 68.0, 48.7]	0.45746467	0.457240705
[0.8690, 10.0, 15.0, 68.0, 45.0]	0.06500955	0.064487627
[2.4552, 17.5, 17.5, 68.0, 60.0]	0.2428978	0.242507910
[0.8554, 20.0, 15.0, 66.5, 56.2]	0.49278992	0.50385024

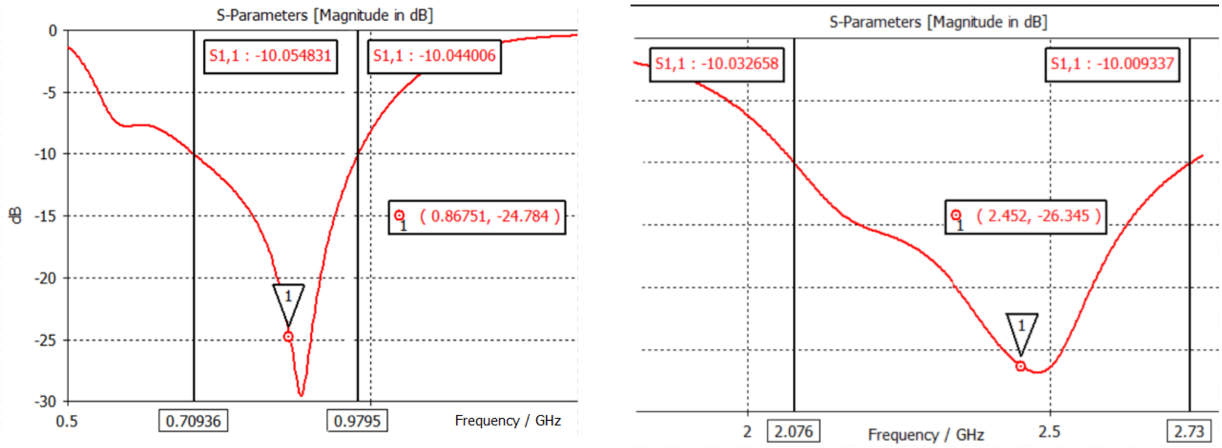
4. Designing of Dual Band F-Shaped RFID Antenna

With the model created with Random Forest Regressor, the most suitable parameters were determined for the dual-band F-shaped RFID antenna at RFID (867MHz) and WLAN (2.45GHz) frequencies. When the model was estimated using the intervals in Table 2, the most appropriate parameters for these frequencies considering input port scattering parameters are shown in Table 5.

Table 5. *Dual Band F shaped RFID Antenna Parameters & S11 at 867 MHz and 2.45GHz*

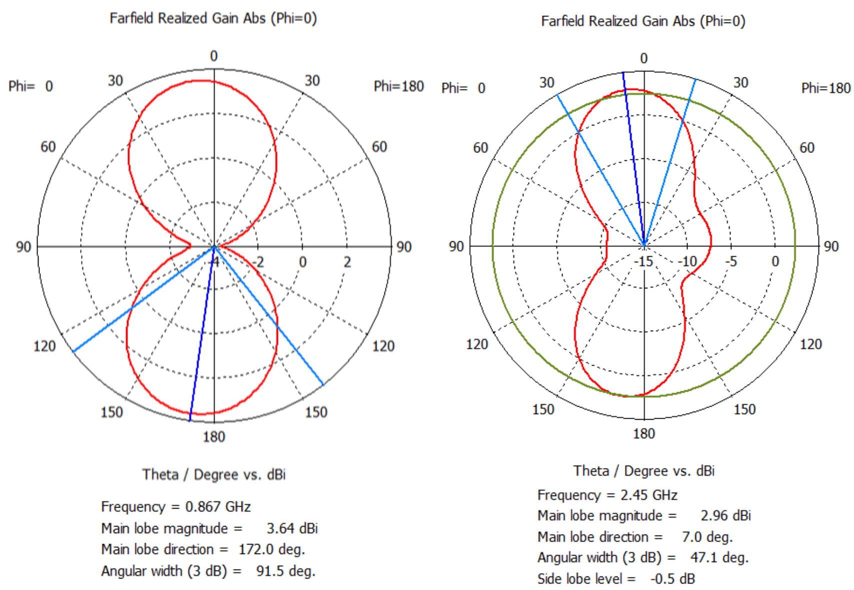
Parameter	Value (mm)	Estimated Output Values (S_{11} dB)	
W1	10	867MHz	2.45GHz
L4	18	-25.16	-25.95
R1	62		
R2	45		

The simulation environment was used to run simulations using the parameter values listed in Table 5. Input port scattering parameters and gain results are shown in Figure 8 and Figure 9, respectively.



(a) (b)

Figure 8. *Input Port Scattering Parameter of Dual Band F-Shaped Antenna at a) 867MHz b) 2.45GHz*



(a) (b)

Figure 9. *Gain of Dual Band F Shaped Antenna at a) 867MHz b) 2.45GHz*

5. Conclusion

This work examines the performance metrics of different machine-learning approaches to estimate the scattering parameter of the selected F-shaped RFID antenna. A dataset with 625 samples was obtained after the antenna's design parameters were modified parametrically and in relation to one another. The dataset was split into a training and test dataset, and the accuracy of various machine learning techniques was evaluated. The model with the highest accuracy rate was the Random Forest Regressor, which has a 99.96% for R^2 score and a mean squared error value of 0.0004. The antenna working in the UHF band was redesigned to work in both the UHF and WLAN bands. As a result of the study, an antenna that can operate in both UHF and WLAN bands with bandwith about of 270MHz at UHF and 700MHz at WLAN has been designed.

Declaration of Interest

The authors declare that there is no conflict of interest.

References

[1] C. Maeurer, P. Futter, and G. Gampala, “Antenna Design Exploration and Optimization using Machine Learning,” in *2020 14th European Conference on Antennas and Propagation (EuCAP)*, 2020, pp. 1–5. doi: 10.23919/EuCAP48036.2020.9135530.

[2] A. Desai, I. Akdag, M. Palandoken, C. D. Bui, J. Kulkarni, and T. K. Nguyen, “Wide Slot Circularly Polarized Conductive Oxide-based Transparent Antenna Design for ISM Band RFID Applications,” in *2021 International Conference on Advanced Technologies for Communications (ATC)*, 2021, pp. 217–221. doi: 10.1109/ATC52653.2021.9598335.

[3] C. Göçen, İ. Akdağ, M. Palandöken, and A. Kaya, “2.4/5 GHz WLAN 4x4 MIMO Dual Band Antenna Box Design for Smart White Good Applications,” in *2020 4th International Symposium on Multidisciplinary Studies and Innovative Technologies (ISMSIT)*, 2020, pp. 1–5. doi: 10.1109/ISMSIT50672.2020.9254961.

[4] C. Göçen, A. Kaya, and M. Palandoken, “Data Driven Modelling of Dual Band Microstrip G-Shape Radiator Antenna,” Nov. 2022.

[5] M. Palandöken, “Microstrip antenna with compact anti-spiral slot resonator for 2.4 GHz energy harvesting applications,” *Microw Opt Technol Lett*, vol. 58, no. 6, pp. 1404–1408, 2016, doi: https://doi.org/10.1002/mop.29824.

[6] İ. Akdağ, C. Göçen, M. Palandöken, and A. Kaya, “Estimation of the Scattering Parameter at the Resonance Frequency of the UHF Band of the E-Shaped RFID Antenna Using Machine Learning Techniques,” in *2020 4th International Symposium on Multidisciplinary Studies and Innovative Technologies (ISMSIT)*, 2020, pp. 1–5. doi: 10.1109/ISMSIT50672.2020.9254362.

[7] M. I. M. Ghazali, S. Karuppuswami, and M. H. Jamaluddin, “Machine Learning based Design Optimization of a GPS Antenna on a flexible substrate,” in *2021 IEEE Asia-Pacific Conference on Applied Electromagnetics (APACE)*, 2021, pp. 1–3. doi: 10.1109/APACE53143.2021.9760562.

[8] I. Akdag, C. Gocen, M. Palandoken, and A. Kaya, “A novel circularly polarized reader antenna design for UHF RFID applications,” *Wireless Networks*, vol. 28, no. 6, pp. 2625–2636, 2022, doi: 10.1007/s11276-022-02998-8.

[9] S. Sagiroglu and K. Güney, “Calculation of resonant frequency for an equilateral triangular microstrip antenna with the use of artificial neural networks,” *Microw Opt Technol Lett*, vol. 14, no. 2, pp. 89–93, 1997, doi: https://doi.org/10.1002/(SICI)1098-2760(19970205)14:2.

[10] C. R. M. Silva and S. R. Martins, “An Adaptive Evolutionary Algorithm for UWB Microstrip Antennas Optimization Using a Machine Learning Technique,” *Microw Opt Technol Lett*, vol. 55, no. 8, pp. 1864–1868, 2013, doi: https://doi.org/10.1002/mop.27692.

[11] Z. Zheng, X. Chen, and K. Huang, “Application of support vector machines to the antenna design,” *International Journal of RF and Microwave Computer-Aided Engineering*, vol. 21, no. 1, pp. 85–90, 2011, doi: https://doi.org/10.1002/mmce.20491.

[12] J.-H. Lu and S.-F. Wang, “Planar Broadband Circularly Polarized Antenna With Square Slot for UHF RFID Reader,” *IEEE Trans Antennas Propag*, vol. 61, no. 1, pp. 45–53, 2013, doi: 10.1109/TAP.2012.2220103.