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U-slot Loaded Half-Circled Microstrip Patch Antenna Analysis Using XGBOOST Machine Learning Algorithm

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ABSTRACT

Half-circled U-slot loaded antenna is studied using the HFSS and Machine Learning (ML) algorithm. The proposed work is for predicting the resonance frequency of the U-slot loaded antenna by providing the dimensions of the antennas.The proposed antenna is designed for Wi-MAX application with operating frequency of 3.4 GHz.The HFSS tool is being used for designing and analyzing fractal antennas and generating the training data. Parametric analysis of the designed U-slot-loaded half-circled antenna is developed by altering the half-circle radius, length of the U-slot and width. The data set is then given to the XGBoost ML algorithm for training the model. The XGBoost contains remarkably high processing speed and contains features like parallelization, cache optimization, and out-of-core computation which makes the perfect algorithm for predicting the resonance frequencies.U-slot loaded half-circled antenna offers a substantial size reduction, a wide impedance bandwidth, and a uniform radiation pattern on all sides.

Keywords : Microstrip Patch Antenna, U-Slot, Half Circle, Xgboost, Machine Learning, Root Mean Square Error(RMSE)

I. INTRODUCTION

A U-slot microstrip patch antenna is a type of microstrip antenna that is characterized by the presence of a U-shaped slot in the metal conductor pattern. This slot is usually placed along the edge of the patch and can be used for improving the performance of antenna in several ways. One of the main benefits of the U-slot design is that design can increase the antenna's bandwidth radiation pattern and gain effectively. The U-slot design can be useful for the applications such as satellite communications or radar systems and wireless communication systems where a high-gain antenna is required. The u-slot's size and shape can be changed to alter the radiation pattern of the antenna to meet the needs of the application.

There is a greater need for antennas in the communications sector. A microstrip antenna is made up of three layers: patch, dielectric (RT- duroid), and ground. The length of the patch, the dielectric constant, and the slot width were the variables utilised to determine the resonant frequency. Inverse correlation exists between length and resonance frequency [1].The fact that microstrip patch antennas have a U-shaped slot and have a reasonably high resistance (about 30%) is well known. Explains how coupled-mode theory affects the behaviour of a typical U-slot patch shape using characteristic mode analysis [2]. Modern wireless communication systems use ultra-wide-band (UWB) technology because of its advantages in reducing complexity and size. Miniaturised antennas were developed because a multi-hit notch frequency band was required to prevent interference with other narrowband communication systems [3]. A common type of antenna with a particular chip design on one side is a microstrip antenna. One of the most widely used patch antennas is the rectangular one [4]. The antenna's primary function is to absorb frequencies between 3.1 and 10.6 GHz while rejecting frequencies in the C-band and Wi-Fi band. It was made using a copper-etched PCB with a certain chip shape to prevent interference. The Descartes Circle (DC) theorem and iterations of self-similar design were used to produce the circular shape antenna [5], [6].

Techniques for machine learning (ML) include reinforcement, unsupervised, and supervised learning. The difficulty of establishing a relationship between geometric parameters grows with the number of parameters [7], [8]. The 2.4GHz frequency band, which has a resonance frequency in the antenna, is the one used by Wi-Fi. ML seeks to shorten the time required for antenna design by obtaining high precision and making accurate predictions of antenna performance[9]. The suggested antenna was created using a hybrid technique in CST Microwave Studio [10]. A stack patch antenna's dimensions also take into account how far apart the two patches are from one another. The ANN algorithm builds a black-box model for resonance frequency using these inputs[11], [12]. An equilateral triangle-shaped microstrip antenna with a poor ground structure must meet certain design criteria, including patch length and triangle side. This antenna is trained using the Gaussian Process Regression (GPR) algorithm, which outperforms the Artificial Neural Network (ANN) approach [13]. For a UHF U-slot RFID antenna's return loss, an ML algorithm made a prediction. operational resonance frequency. Several ML methods were used for complicated and linear scattering characteristics to measure the models' prediction ability. RFID antenna was built using Antenna Magus. Polynomial regression, random forest, Bayesian ridge, and gradient boosting estimate linear scattering parameters [14], [15]. ML is used for predicting resonance frequency of a square patch microstrip antenna (SPMA). The antenna works in C, X, Ku, and K bands. The GPR model performs better than the ANN model based on simulated resonance frequency [16].

II. Antenna Geometry

Electromagnetic waves are simulated in many structures, including antennas, using the well-known programme High-Frequency Structure Simulator (HFSS). With the aid of HFSS, it is possible to build antennas of various sizes and forms and then simulate how they might react in various scenarios. Users of HFSS have a wide range of options at their disposal. Antenna wizards, parameter sweeps, optimisation algorithms, and post-processing tools are some of these tools. By using these instruments, you can better your antenna's functional capabilities, characterise its behaviour, and investigate the design space for your antenna. The radiation effectiveness, impedance matching, and reflection coefficient of existing antennas can also be assessed using HFSS. Antenna optimisation and troubleshooting will be simple with

this.Here is a picture of the proposed U-slot loaded half-circle microstrip patch antenna.
Fig. 1.

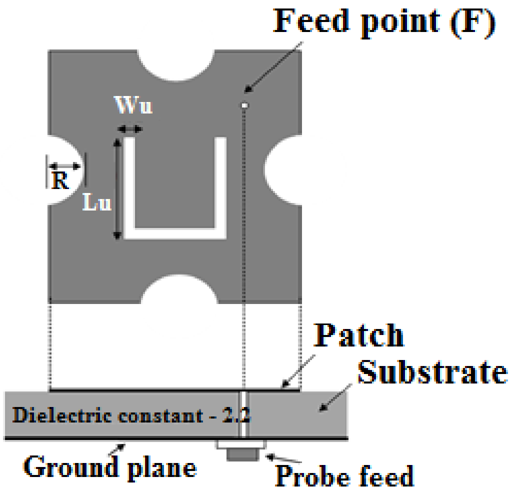

Fig. 1. The proposed patch antenna design

Construction of U-slot Loaded Half Circle Patch Antenna using HFSS software

The antenna has a resonance frequency of 3.5GHz and is built using HFSS software as a U-Slot loaded Half-circled Patch Antenna with coaxial feed. The length and breadth of the U-slot, the radius of the half-circles, the length and width of the patch, and the length of the coaxial feed are all elements in the antenna design. These parameters are listed in Table 1. The frequency, emission pattern, and other characteristics of the antenna are controlled by these factors. The substrate of the antenna is fabricated from a base material with dielectric properties, such as RT-Duroid. based on the ground plane and patch's measurements, the material is divided into a particular dimension and form. The substrate is then positioned below the ground plane, which is formed of copper material and has the same dimensions as the substrate. The patch is then attached to the substrate using copper material after being measured according to the specified operating frequency (3.5GHz). The U-slot in the patch is then created by shrinking the patch to a specific shape and dimension dependent on its length and width. The recommended antenna length is selected using equation 1.

$$f = \frac{c}{2L\sqrt{\varepsilon_r}} \quad (1)$$

Where f = Resonating frequency of the antenna
L = Electrical length of the patch
ε_r = Relative permittivity of the substrate
c = Velocity of the Light

The antenna's frequency will be raised and its emission characteristics will be strengthened thanks to the U-slot. The signal travels through the coaxial feed from the ground plane to the patch and is then transferred to the antenna. The length of the coaxial input is another important component that has an impact on the antenna's resistance and effectiveness. The completed antenna construction is displayed in Fig. 2.

TABLE I. MICROSTRIP PATCH ANTENNA DESIGN PARAMETERS

SL. NO	NAME OF THE PARAMETER	VALUE	UNIT
1.	Length of U-Slot	5	mm
2.	Width of U-Slot	1.5	mm
3.	Radius of half circle	3	mm
4.	Length of Patch	26	mm
5.	Width of Patch	20	mm
6.	Length of Co-axial feed	4	mm

After the simulation has started, there will be some downtime. Check the simulation results to see if they meet the performance criteria, including those for S-parameters, radiation pattern, and efficiency. You must change the patch and U-size slots in order to enhance the design and get the necessary performance. When attaching an antenna to a coaxial feed, the antenna's design is crucial to ensuring that the feed and antenna are properly matched. Additional potential fixes include adjusting the feed's position and size as well as the matching network's elements, like the quarter-wave transformer.

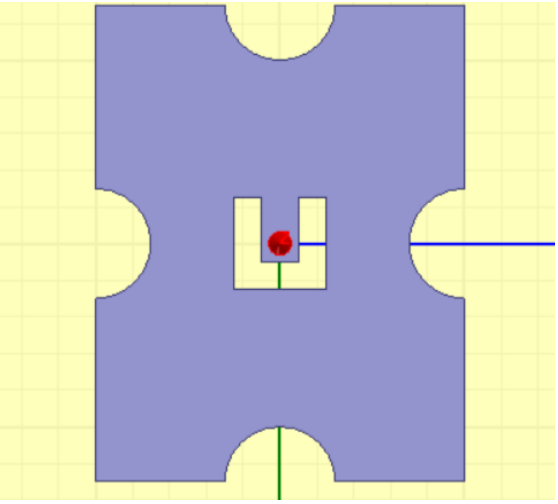

Fig. 2. U-slot loaded half-circle design in HFSS software

III. Results and Discussion

A U-slot loaded half-circle microstrip patch antenna designed with frequency is subjected to parametric analysis using HFSS software. The parametric analysis is performed using the following parameters shown in Table 2. In addition to monitoring changes in the antenna's performance metrics, such as its resonance frequency, bandwidth, and radiation pattern, this requires altering the U-dimensions slot and the radius of the half circle. The HFSS programme features parametric analysis. Choose the simulation's sweep and frequency range, as well as other desired settings. Add the U-shaped slot's radius and the half-circle's radius as new variables. After choosing the preferred simulation type, specify the parameter ranges and stages. Once the stimulation is finished, begin the simulation study. Analyse the simulation study's findings, paying particular attention to the antenna's performance metrics for each combination of parameters. Figure 3 displays the final waveforms produced during the parametric analysis. The data is loaded into the.csv file for further analysis following the completion of the parametric analysis. To attain the desired performance, alter the design's specifications. It is feasible to see how the U-shaped slot and the half-radius circle affect an antenna's bandwidth, radiation pattern, and resonance frequency by varying these two parameters. For example, expanding the U-width slot could result in a lower resonance frequency, while extending the half-circle's radius could result in a higher bandwidth.

TABLE II. PARAMETRIC ANALYSIS OF THE DESIGNED PATCH ANTENNA

SL.NO	NAME OF PARAMETER	DESCRIPTION
1.	Length of U-Slot	Linear step from 2.5mm to 5mm, step=0.5mm
2.	Width of U-Slot	Linear step from 1mm to 2.4mm, step=0.5mm
3.	Radius of half circle	Linear step from 1mm to 5mm, step=0.1mm

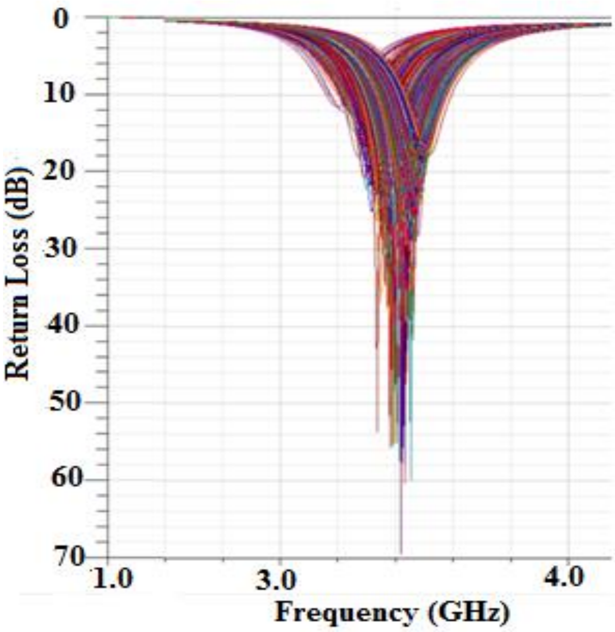

Fig. 3. Parametric Analysis of the patch antenna

B. *Antenna analysis using XGBoost Machine Learning algorithm*

One of the ML techniques that could be applied to create patch antennas is XGBoost. The gradient boosting method is made easy to use by the open-source toolkit known as Extreme Gradient Boosting

(XGBoost). By continuously adding new trees that match the residual mistakes of the previous trees, the gradient-boosting technique creates an ensemble of decision trees. The properties of XGBoost make the algorithm appropriate for patch antenna construction. To predict continuous variables for patch antennas, such as resonance frequency, or discrete values, such as antenna type, XGBoost provides regression and classification tasks. The method provides a wide range of objective and loss functions that may be tailored to meet various antenna performance characteristics, including as gain, return loss, bandwidth, and others. Regularisation techniques like L1 and L2 regularisation are encouraged by XGBoost because they may reduce overfitting while boosting generality. The distributed and parallel processing capabilities of XGBoost enable the method to handle sizable data sets and speed up training.

Sample Data from Parametric Analysis Dataset

Sl. No	Radius of the Half Circle	U-slot Length	U-slot Width	Frequency
1.	1.2	4	1	3.482
2.	1.6	2.5	2	3.478
3.	2.1	2.5	2	3.454
4.	2.4	5	2.4	3.443
5.	3.4	5	1.5	3.337
6.	3.7	3.5	1	3.363
7.	3.9	2.5	2	3.335
8.	4.4	4	1.5	3.303
9.	5	4	1	3.247

First, the required libraries are imported: scikit-learn for calculating mean absolute error and train-test split, and pandas for data handling. The target variable is then allocated to Y, and the columns to be used as features are specified and assigned to X.The sample data from the dataset is displayed in Table 3 with the antenna parameters of Half Circle Radius, U-Slot Length, U-Slot Width, and Frequency being taken into account. The train _test_split function in scikit-learn is then used to divide the dataset produced by parametric analysis into a training set and a validation setAfter importing the XGBoost regressor, a fresh instance of the regressor model is created. The fit my model approach is then used to train the regressor model using the training data. On the validation set, predictions are made using the predict approach, and the mean absolute error is calculated using the sci-kit-learn mean_absolute_error function. Although this step seems unnecessary, another set of predictions are made on the validation set.

The trained XGBoost regressor is applied to a fresh set of data after being prepared using the NumPy library. After that, the anticipated value is printed.The XGBoost regression approach uses a gradient-boosting framework to add decision trees to the model in a sequential manner, with each tree repairing the errors caused by the one before it. To reduce the loss function, the approach employs a gradient descent optimisation algorithm. The mean absolute error serves as the loss function in the suggested methodology.The predict function of the XGB Regressor package is then used to generate model predictions on the validation collection based on equations 2 and 3.

$$Residuals = Observed\ values - Predicted\ values \quad (2)$$

$$Output\ value\ (O_v^2) = \frac{Sum\ of\ Residuals}{Number\ of\ Residuals + \lambda} \quad (3)$$

Where □□is the Regularization parameter

Using the RMSE function from the Sklearn metrics module, the RMSE is then calculated using the estimated values and actual values from the validation set. The RMSE is calculated using formula 4, and the RMSE between the training and testing datasets is shown in Fig. 4.

$$RMSE = \sum_{i=1}^{n} L(y_i, p_i) + \frac{1}{2}\lambda O_v^2 \quad (4)$$

Where y_i= observed values on y-axis

p_i = predictions corresponding to y values

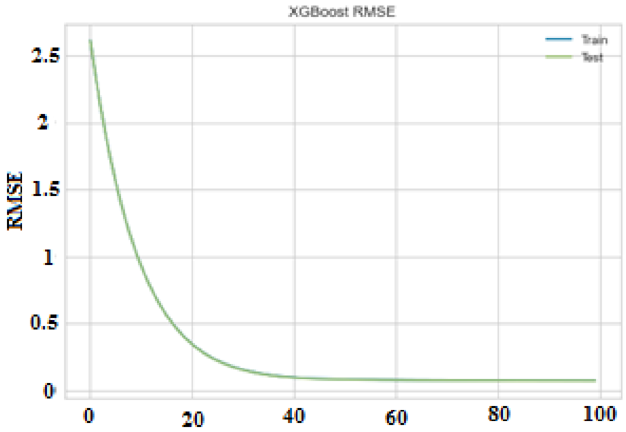

Fig. 4. Plot of XGBoost RMSE between Train and Test values

Fig. 5 depicts a scatter diagram of a ML model's predicted values versus its actual values. Actual values are showed on the x-axis, while predicted values are showed on the y-axis. Each pixel in the image represents a data point from the gathering. The diagonal line on the plot represents the ideal scenario in which the predicted and real values precisely match up. As the data points get closer to this line, the algorithm's effectiveness increases. The plot depicts the model's accuracy graphically and can be used to identify patterns or trends in the model's errors. This plot can also be used to detect abnormalities or data points that the algorithm cannot correctly predict. The comparison of training data and predicted data is given in Table 4.

THE SAMPLE TRAINING DATA AND PREDICTED DATA

Indentation radius (D mm)	**U-slot width (W_c mm)**	**U-slot length (L_c mm)**	**Resonance Frequency (GHz) obtained from HFSS**	**Predicted Resonance Frequency (GHz) from XGBoost**
1	1	1	3.473237	3.471942
2	2	2	3.412709	3.412039
3	3	3	3.331916	3.331639
4	4	4	3.183592	3.187105
5	5	5	3.021511	3.009025

The model performs better when RMSE is lower since a lower RMSE suggests more accurate predictions from the model.The residuals of a successfully fitted regression model should be randomly distributed about the zero line, which connects the expected and observed values, showing that the model accurately identified the underlying patterns in the data. The model may need to be changed or enhanced if the residuals exhibit a trend or propensity that indicates that not all of the pertinent information in the data has been taken into account.

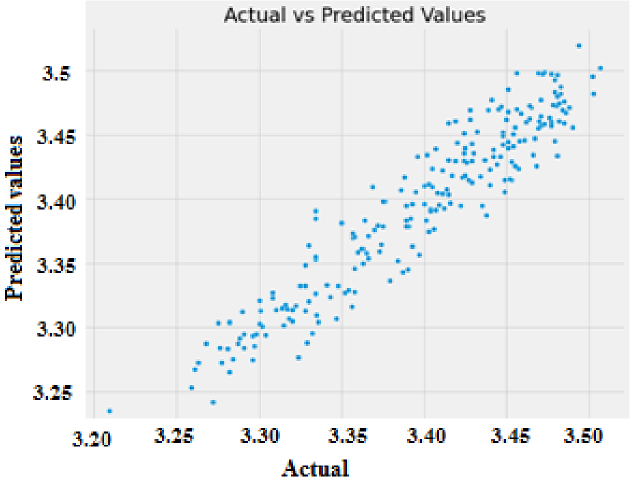

Fig. 5. Graph between Actual and Predicted values

Figure 6's residuals appear to be randomly distributed around the zero line, which suggests that the regression model is well-fit. The absence of any discernible pattern or propensity in the residuals suggests that the model has captured the fundamental relationships between the predictor and responder variables.

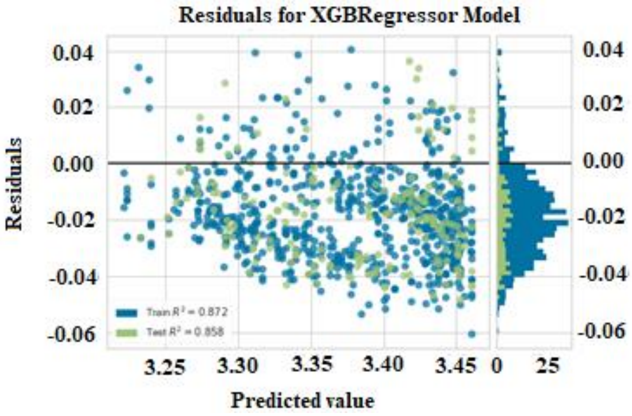

Fig. 6. Plot between Residuals of train and test values

We can predict how well a model will perform on the untested data by evaluating the model's performance on the validation set. A new data point is defined as a collection of values for the expected factors following a model performance review. Then, utilising this additional data point, a prediction is made using the predicting technique. On the screen, the expected frequency value is displayed .Fig. 7 displays the plot for feature importance. Knowing which variables are most crucial for forecasting a model's outcome can be understood thanks to XGBoost's ability to produce feature relevance rankings. The phrase "feature importance" refers to how much each feature contributes to the overall accuracy of the model, and it can be used to decide which features are most crucial for the given dataset. Based on the information gain of each feature, which represents the reduction in entropy (or uncertainty) produced by splitting the data based on that feature, XGBoost provides feature importance ratings. Whereas other antenna parameters have a less effect on frequency, the radius of a half circle has a greater impact.

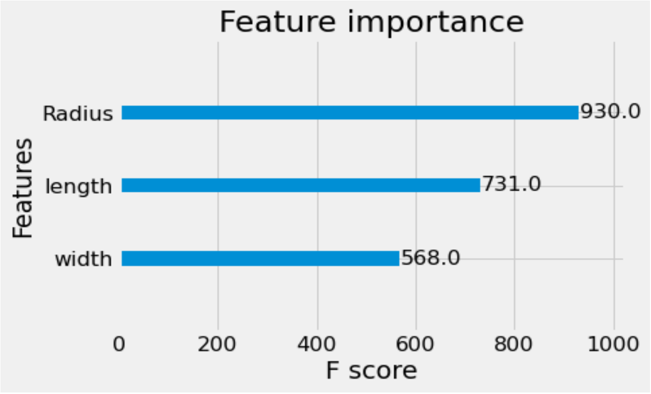

Fig. 7. Plot for feature importance for different parameters of an antenna

The relative significance of each predicted variable in the model is shown on the plot.The XGBoost regression model exhibits good performance results in both RMSE and R-squared values when compared to other ML algorithms when the same dataset was applied to the XGBoost regression model and other different ML models like the Linear Regression model, Decision Tree Regression model, Elastic Net model, Lasso model, and Random Forest Regression model, as shown in Fig. 8.The XGBoost technique iteratively incorporates decision trees into a model to minimise a loss function. Every new branch makes an effort to fix the mistakes caused by earlier plants.The method employs gradient boosting to reduce the loss function by computing the gradient of the loss about the model's forecasts. XGBoost excels at administering large databases with a variety of characteristics due to its high precision and efficiency.

IV. CONCLUSION

The U-slot loaded half-circled microstrip patch antenna can be studied using the XGBoost regression technique, which offers a strong tool for improving the design and performance of the antenna. Due to its small size, low profile, and high gain, the U-slot loaded half-circled microstrip patch antenna is a preferred option for many applications in wireless communication systems, radar systems, and satellite communication systems. In this proposed method, the resonance frequency of a half-circled U-slot-loaded microstrip patch antenna was predicted using the XGBoost regression algorithm. The antenna's working frequency range is determined by the resonance frequency, a crucial design element. The dataset that was used for this research was divided into training and validation sets. The model was trained on the training data using a variety of characteristics, including the patch length, width, length and width of the U-slot, and radius of a half circle.However, researchers have investigated a number of ways, including the use of ML algorithms, to improve the performance of the antenna and address its constraints. This method offers several benefits, such as precise resonant frequency prediction, identification of crucial design factors, study of intricate relationships, and reduction of time and expense.

V. REFERENCES

[1]. K. Sharma and G. P. Pandey, 'Efficient modelling of compact microstrip antenna using machine learning', AEU - International Journal of Electronics and Communications, vol. 135, p. 153739, 2021.

[2]. T. LaPointe, 'Characterization of Wideband U-slot patch antennas through characteristic modal analysis and coupled mode theory', 2018.

[3]. M. Rahman, D.-S. Ko, and J.-D. Park, 'A compact multiple notched ultra-wide band antenna with an analysis of the CSRR-TO-CSRR coupling for portable UWB applications', Sensors, vol. 17, no. 10, p. 2174, 2017.

[4]. K. Djafri, F. Mouhouche, M. Dehmas, and M. Challal, 'A compact double-inverted Ω-shaped dual-band patch antenna for WLAN/WiMAX applications', Frequenz, vol. 76, no. 9–10, pp. 547–554, 2022.

[5]. K. Sumathi, K. Ashwin, P. Santhosh, and D. Shanmitha, 'Design of Semi-circular shaped UWB Antenna for WBAN Applications', in 2021 7th International Conference on Advanced Computing and Communication Systems (ICACCS), 2021, vol. 1, pp. 863–867.

[6]. Abdelhamid and S. R. Alotaibi, 'Deep Investigation of Machine Learning Techniques for Optimizing the Parameters of Microstrip Antennas', International Transaction Journal of Engineering, Management, & Applied Sciences & Technologies, vol. 12, no. 13, pp. 1–15, 2021.

[7]. Y. Kaplan, 'U-Shaped Slotted Patch Antenna Design for 2.4 GHz Wireless Applications'.

[8]. 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.

[9]. Swetha and K. R. Naidu, 'Miniaturized antenna using DGS and meander structure for dual-band application', Microwave and Optical Technology Letters, vol. 62, no. 11, pp. 3556–3563, 2020.

[10]. S. K. Jain, A. Patnaik, and S. N. Sinha, 'Design of custom-made stacked patch antennas: a machine learning approach', International Journal of Machine Learning and Cybernetics, vol. 4, pp. 189–194, 2013.

[11]. K. Sharma and G. P. Pandey, 'Prediction of the resonant frequency of square patch microstrip antenna with DGS using Machine Learning', in 2019 IEEE Indian Conference on Antennas and Propogation (InCAP), 2019, pp. 1–4.

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