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Design and Machine Learning based Optimization of 5G Sub-Band Antenna

Vinod Babu Pusuluri[1*], A M Prasad[2], Naresh K Darimireddy[3]

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Abstract: Use of machine learning techniques in today's science and engineering domains, including electromagnetic applications is inevitable. This article communicates the introduction of supervised Decision Tree (DT) Machine Learning (ML) algorithm for the optimization of a microstrip patch antenna at 5G-n78 sub-band frequency 3.3GHz. The proposed antenna is a rectangular patch with dimensions of $0.304\lambda_0$ x 0.238 λ_0 designed using the line feeding technique over FR-4 substrate (ε_r = 4.4) with thickness of 1.6mm and 0.002 loss tangent. The antenna has a return loss of -37.4dB, 1.03 VSWR, and gain of 4.06 dBi at 3.3GHz operating frequency. Application of supervised decision tree technique on the proposed antenna is discussed and dimensions from DT ML techniques are used for fabrication purpose. High Frequency Structural Simulator (HFSS) is used for proposed antenna design and data collection, further ML model is designed in python language by choosing return loss of the proposed antenna as target variable. The Root Mean Square error is calculated for train and test data which is 4.42 & 4.44 respectively. Simulated and measured return loss values from ML model and fabrication are in good agreement. The proposed ML model is capable to optimize the proposed 5G –n78 sub band antenna dimensions which are suitable for wireless WLAN & WiMAX applications.

***Keywords**: Decision Tree, High Frequency Structural Simulator, Machine Learning Algorithm, Microstrip Patch Antenna, Root Mean Square Error.*

1. Introduction

Antenna is an electromagnetic device which converts the electrical signal to electromagnetic one. It is an unavoidable element in any communication system. There exists various antennas like wire, plane, dish, loop and strip antennas etc. Among all the available antennas Microstrip Patch Antenna (MPA) is unique with its versatile nature and applications. It is compact, low weight, works at wide variety of frequencies with required polarization, and it is easy to integrate in any electronic circuit. Further, it is flexible to design with various feeding techniques. Hence the design and optimization of the Micro strip patch is very essential for any microwave engineer. Antenna for emerging technologies particularly for the 5G mobile communication technology highlights, higher data rate, greater capacity, higher bandwidth, increased security, and lower latency creates greater opportunities in advanced society. Various technologies like massive Multi-Input and Multiple-Output (MIMO), hybrid beam forming, mobile broadband speed, potential application at virtual reality & Internet of Things and autonomous car are key feature in 5G [1], millimeter wave (mmWave) band supports the 5G designs particularly at 60GHz bands [2].Compact MIMO 5G antenna design and their challenges along with circular & dual polarization possible at 60GHz bands [3][4][5]. The compact fractal design including MIMO structures at 3G,4G & 5G studies for WLAN, WiMAX, ISM, LTE bands depicted in [6-7].Flexible antenna with multi substrate, body area networks new class of wearable antenna systems with enhanced radiation characteristics by the use of split ring resonator concepts which is part of metamaterial introduction[8][9]. A millimetre wave mobile broad band system operates at very high data rates like one Giga byte per second in hybrid system [10]. 5G wireless network using Defected Ground Structure with multiple split ring structures on ground with coplanar wave guide (CPW) feed technique is explained [11]. The potential of ML in predicting future values is attracting the scientific community to apply ML in high computing Electromagnetic applications. This paper explains the design and dimension optimization of Microstrip Patch Antenna (MAP) using ML and its design flow procedure is mentioned in Figure.1.

[1]Department of ECE, RGUKT & JNTU Kakinada, AP, India*
[2]Department of ECE, JNTU Kakinada, AP, India
[3]Department of ECE, Ledni Institute of Engineering & Technology Jonnada, AP, India
***Corresponding Author:** Vinod Babu Pusuluri*
Department of ECE, RGUKT & JNTU Kakinada, AP, India
Email: vinod@rguktn.ac.in

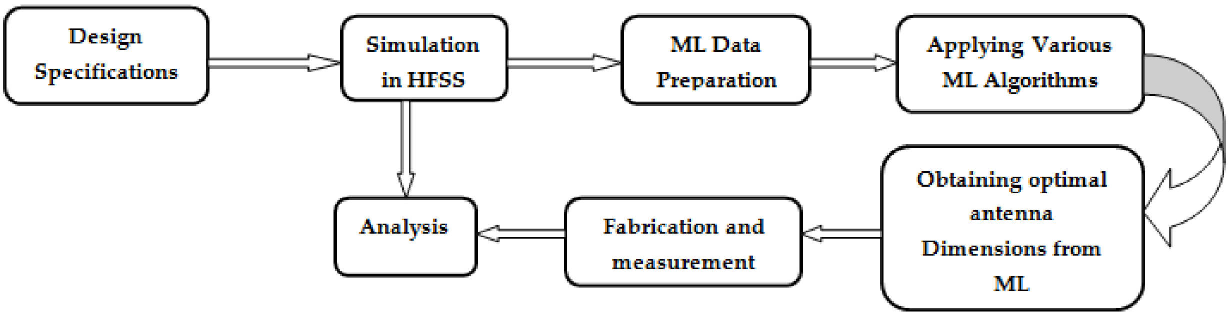


Fig 1 Design Flow Procedure

A comprehensive review on the design exploration and optimization of antennas using machine learning algorithms and techniques is available in [12][13][14]. Authors in [15] introduced dimension optimization of microstrip patch antenna in X/Ku bands via Artificial Neural Networks; fabrication of the antenna from machine learning dimensions and its validation in terms of root mean square error is not reported. [16] Explains the dimensional reduction of the antenna with very less number of records. Shilpa Pavithran et al.., in [17] explains the 5G antenna design using decision tree and random forest techniques, higher order polynomial and extreme gradient boos techniques to overcome the over fitting problems is un available. Researchers in [18] introduced the application of neural networks in smart array antennas. VV Reddy et al.., in [19] applied ML techniques for C-Slot loaded Minkowski Fractal Antenna; however validation through proper fabrication is not reported. Validation of the proposed antenna from ML model through proper fabrication is need of the hour.

2. PROPOSED ANTENNA DESIGN

The basic design of the microstrip patch antenna followed in this article is shown in Figure.2. Basic design consists of a metallic patch of length 21.66 mm length , 27.66 mm width over a relative dielectric constant of 4.4 with 1.6mm .The microstrip line feed techniques is used and the feed line length is adjusted in such a way that it matches to 50Ω line impedance with the port. Few Basic antenna designs using patch models along with their design equations were discussed in [20]-[22] and the design equations of the regular patch antenna are mentioned from eq 1 to 5, where c the velocity of light in m/s. In this communication HFSS which works based on finite element method full wave EM solver is used for design purpose. The proposed antenna is radiating at 3.3GHz with a return loss of -37.4dB, VSWR of 1.03 and 4.06dBi Gain. The return loss which is going to be the target variable of the proposed antenna for ML approximation is mentioned in Figure.3.

$$W = \frac{c}{2 f_r}\sqrt{\frac{2}{(\varepsilon_r + 1)}} \tag{1}$$

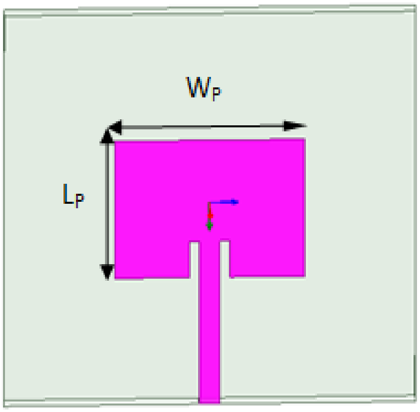
$$L = \frac{c}{2 f_r \sqrt{\varepsilon_{eff} + 1}} - 2\Delta L \tag{2}$$

Where

$$\Delta L = 0.421h \frac{\varepsilon_{eff} + 0.3}{\varepsilon_{eff} - 0.258}\left[\frac{\frac{w}{h} + 0.264}{\frac{w}{h} + 0.8}\right] \tag{3}$$

$$\varepsilon_{eff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left[1 + 12\frac{h}{w}\right]^{-\frac{1}{2}} \tag{4}$$

$$\frac{\Delta L_{eff}}{h} = 0.421h \frac{(\varepsilon_{eff} + 0.3)\left(\frac{w}{h} + 0.264\right)}{(\varepsilon_{eff} - 0.258)\left(\frac{w}{h} + 0.8\right)} \tag{5}$$



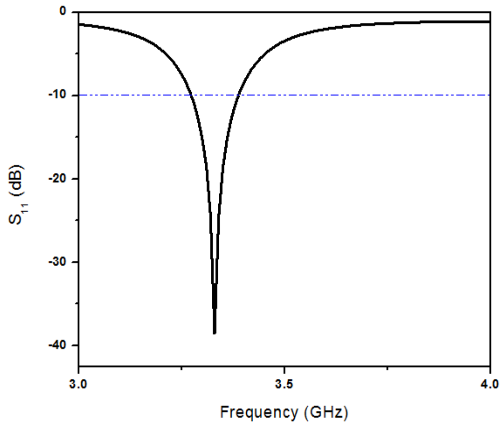


Fig.3 Return loss of the proposed ant **Fig.2** Proposed Antenna

3. MACHINE LEARNING

Machine Learning (ML) which is the subset of Artificial Intelligence (AI) is one of the emerging technological solutions for all domains due its wide variety of applications. It uses the mathematical statistical computation analysis in designing the mathematical model interims of input and output variables. It is mostly of data driven system, where it expects huge data which may be trained or untrained. Based on the type of data given and type of learning system it executes to provide the mathematical model that best suits for the given problem in identifying the optimum solution [23]. The block diagram of any Machine learning approach is as shown in Figure.4.

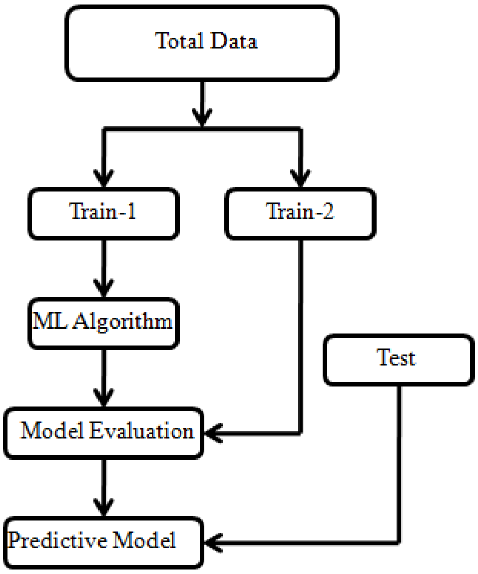


Fig 4 Block Diagram of ML Approach

3.1 DECISION TREE ALGORITHM:

It is a supervised ML algorithm applicable for both regression and classification methods. Decision Tree (DT) is one of the visible AI Model and best suits for explanation which is similar to tree structure. It gives all possible solutions from the given data set for the target variable. It starts with root node; subsequently it divides the given data in recursive mode as decision nodes and leaf node at the end of the tree. A decision node has branches where as leaf node represents output or prediction of the branches. As the tree depth grows, it divides the data set into smaller segments. Two or more branches can exist in a decision node. The root node in a tree refers to the best predictor and is weighted parameter in modelling. The root node is chosen in such a way that, the attribute has lowest Gini value or entropy, where Gini index measures the impurity of the feature. Increase in the depth of the tree leads to better accuracy in decision making, and lesser the over fitting and under fitting problem in machine learning techniques. Measure of any DT is done using eq 6 to 9 mentioned below. Where N is total number of incidence, Pi is probability of an event.

$$Gini = 1 - \sum_{i=1}^{N} (P_i)^2 \tag{6}$$

$$output\,error = Desired\,output - Predicted\,output \tag{7}$$

$$Mean\,Square\,Error : (MSE) = \frac{1}{N} \sum_{i=1}^{N} (O.E)^2 \tag{8}$$

$$Root\,Mean\,Square\,Error : (RSME) = \sqrt{MSE} \tag{9}$$

3.2 PARAMETRIC ANALYSIS OF DECISION TREE MODEL

The sample data of 2000 records is collected from HFSS simulator by keeping S_{11} as the target variables and frequency of operation and length, width of the patch as Independent variables and all other parameters are kept constant. Multiple simulations were conducted to create the data set. Out of 2000 records 80% of data (1600 records) is considered as training data and remaining 20% that is 400 records is kept for testing purpose. The decision tree is applied on the data points along variable length by keeping width of the patch is constant vice versa. Figure.5 represents the decision tree obtained for the given data. The tree obtained of depth 8 and the Root Mean Square error of 4.44 for train data and 4.42 for test data respectively. The return loss variation over the variable dimensions of the patch is shown in Figure.6. The tree obtained in Figure.5 is used in subsequent chapters for the validation purpose.

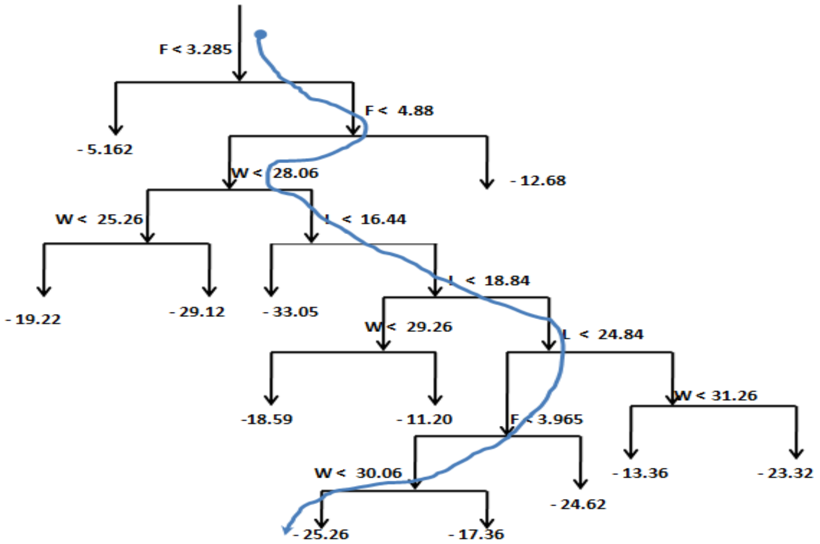


Fig.5 Decision tree model for return loss target variable

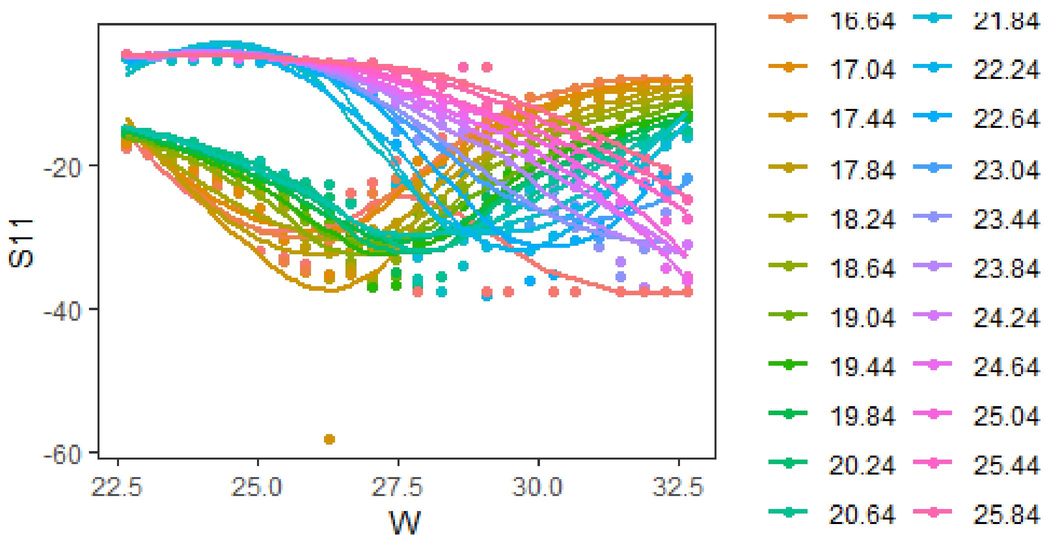


Fig.6 Return loss for variable L & W from DT

4 MACHINE LEARNING MODEL VALIDATION:

Among all available ML models used for the optimization of the proposed antenna Decision Tree is unique with its simplicity and visible outcome. The Optimization of patch dimensions is done by choosing return loss as target variable for validation purpose. The fabrication dimensions are obtained from the below tree in Figure.5. After careful observation the validation path from the return loss is shown in blue line over the tree. The range of length, width and operating frequencies are 18.84 < L < 30.06, 28.06 < W < 30.06 & 3.285 < F < 3.965 respectively from the validation patch, decision tree has wide range of values as it is prone to over fitting problems. Patch length of 18.97mm, width of 28.5mm and 3.3GHz frequency of operation is selected from the range for verification. The real time fabricated antenna from ML dimensions over the test bed is in Figure.7. Simulated return loss of original design, dimensions obtained from ML model is compared with fabricated one which is shown in Figure.8. It is observed that fabricated and simulated results are in good agreement

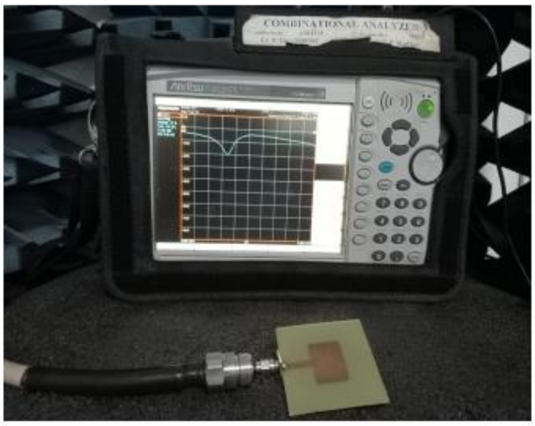


Fig.7 Fabricated antenna

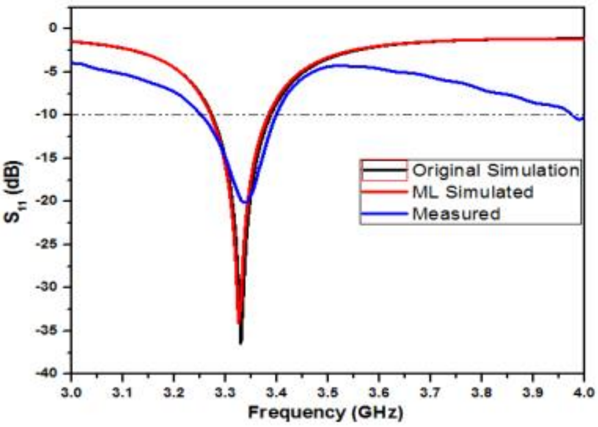


Fig.8 Returns loss comparison

5. RESULTS & DISCUSSIONS

The proposed 5G n78 sub band antenna at 3.3GHz over an FR-4 substrate of 1.6mm thickness with 4.4 dielectric constant values is designed. Return loss of -37.4dB, 1.03 VSWR and 4.06dBi of gains are obtained from HFSS with inset feed and 50Ω Impedance match. The design dimension optimization of the proposed is antenna is performed using Decision tree, by choosing return loss as its target variable. HFSS is used for data collection in case of both training and test data set and root mean square error is observed for performance metric. Simulation and fabricated validation of the design is done for the dimensions obtained from DT technique. Dimensions obtained from the ML model were used for fabricating the antenna such as 18.97mm length, 28.5mm width & 3.3GHz frequency. It is observed that, ML modelled antenna, simulated and measured performance is clearly matching which is in line with original simulated design. Performance analysis of the proposed design is compared with existing literature in table.5.

Table.5 Comparison table with the existing literature

Ref. No	Machine Learning Model	Validation of ML Model
[14]	Not Available	Not available
[15]	Not Available	Not available
[16]	ANN model available	ML Validation & Fabrication not available
[17]	Regression model	ML Validation & Fabrication not available
[18]	Decision Tree and Random Forest	ML Validation & Fabrication not available
[19]	Decision Tree, Random Forest, XGBosst	ML Validation & Fabrication not available
Present Work	Decision Tree	ML Validation with fabrication Completed

6. CONCLUSIONS

In this communication 5G n78 sub-band microstrip patch antenna at 3.3GHz operating frequency is designed in full wave electromagnetic solver HFSS and return loss of -37.4dB, 1.03 VSWR and gain of 4.02dBi is achieved. The substrate is of Roger FR-4 with relative dielectric constant of 4.4 & 1.6mm as thickness and 0.02 loss tangents. The proposed antenna is optimized using supervised decision tree machine learning techniques for return loss as target variable and same is used for validation purpose to obtain the dimensions through proper fabrication. In addition to the return loss optimization, their mean absolute error & root mean square errors are also reported. The decision tree model root mean square values are 4.42 & 4.44 for train and test data sets. The dominant antenna dimensions from decision tree model are of length 18.97mm, width 28.5mm with operating frequency of 3.3GHz. The fabricated antenna from ML model is in full agreement with the simulated once as shown in Figure.7 & 8 interim of its return loss and other parameters. In DT ML technique the error rates are under permissible level and there will not be any question of over fitting and under fitting problem as RSME for train and test is in close agreement. Hence the conventional electromagnetic solvers with powerful Machine Learning techniques with large amount of data sets are essential for better microwave device design & optimization in near future. The proposed antenna at 3.3GHz frequency is suitable for 5G WiMAX applications.

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