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Design and Implementation of CPW-fed Reconfigurable MicrostripAntenna with defected ground structure, Synthesis and Analysis using MLP and Machine Learning for Wireless Applications

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***Abstract*—The conventional antenna analysis and synthesis is complex and time consuming, where the use of antennas is increasing rapidly, machine learning analysis and synthesis of antenna has become crucial. In this paper a comparative analysis of regression models and a multilayer perceptron model are built. The basic structure of antenna is considered to have a CPW Feed with defected ground structure and a return loss of -42.004dB at 4.2950GHz with a gain of 3.69dB is obtained. It is observed that, for analysis when Regression model is considered, cubic regression model has the higher correlation coefficient of 0.999 followed by logarithmic regression model with correlation coefficient of 0.994. On comparing Multilayer perceptron and Radial Basis function (RBF), RBF has the least relative error of 0.004221.**

Keywords—Reconfigurable Antenna, Machine learning, Regression, CPW feed, Radial basis function

I. Introduction

Microstrip antennas are ubiquitous and are an in-dispensary interface for wireless communications. These have found the need of machine learning implementation for analysis and synthesis. Reconfigurable antennas are given the importance over these years[1]. For advancedsystems, the use of smart antennas reduces the use of multiple antennas, by improving the efficiency of the existing system

PIN Diode which has a wide intrinsic region and high breakdown voltage, is chosen as switching circuit in this model. [2] ON/OFF action of PIN Diode is responsible for the change in resonant frequency due to the change in current distribution [3,4,5,6], [7] at the slots.

The existing literature work [10] have given a theoretical understanding of machine learning concepts used for antenna analysis and synthesis of antennas. Initially antenna without ground slot is considered and the multilayer perceptron network model is builtand a relative error of 0.00030 is obtained. This work is further extended by considering a ground slot in the basic antenna design and the results obtained are discussed in further sections.

Radial Basis Function (RBF) is considered for further analysis ad synthesis of the antenna along with Multilayer perceptron and Regression models. Radial basis function (RBF) produces an absolute value by assigning real values from each input. An absolute value is considered since it is the measure of distance and it cannot have negative values.

II. Antenna Geometry

TABLE1. ANTENNA MEASUREMENTS

Antennas depicted in Fig.1.and Fig.2.are designed using the dimensions mentioned in Table-1.PIN Diodes are used as the switching elements in this design.
The coplanar waveguide feed is terminated with 50-ohm impedance. Design equations that are used in designing the antenna are mentioned in section-3. Coplanar waveguide is a transmission model which has ground planes extended on either side of the patch with a symmetrical gap [8].
Co-planar wave guide has the similar advantages as that of microstrip, an added degree of advantage is having less parasitic losses when compared to microstrip feed. Length of the port must be equal to width, and width of the port must be similar to the trace of the coplanar waveguide.[8]

S.No.	Parameter	Value(mm)
1	L	60
2	W	40
3	Wg	12.25
4	W1	20
5	W2	3.2
6	S	1
7	h	1.6
8	L1	2.62
9	L2	8.41
10	L3	18.39
11	L4	4.51
12	L5	8.35
13	a	1.525
14	b	3.535
15	Dielectric Const.	4.4
16	Thickness	1.6

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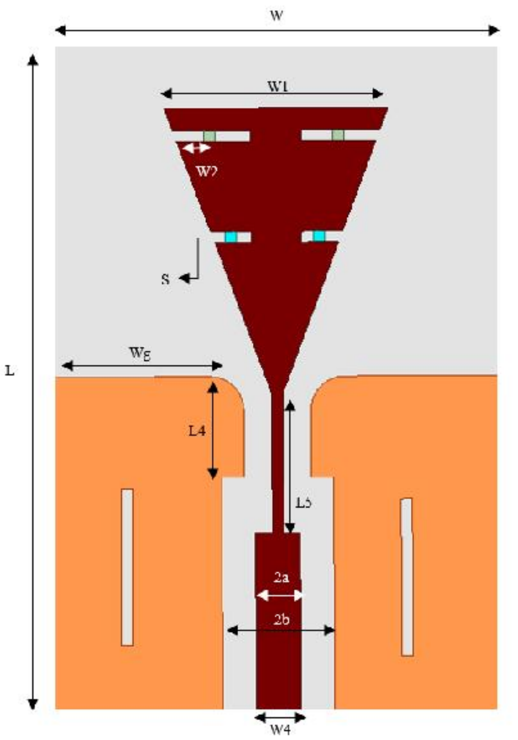

Fig.1. Antenna Design1

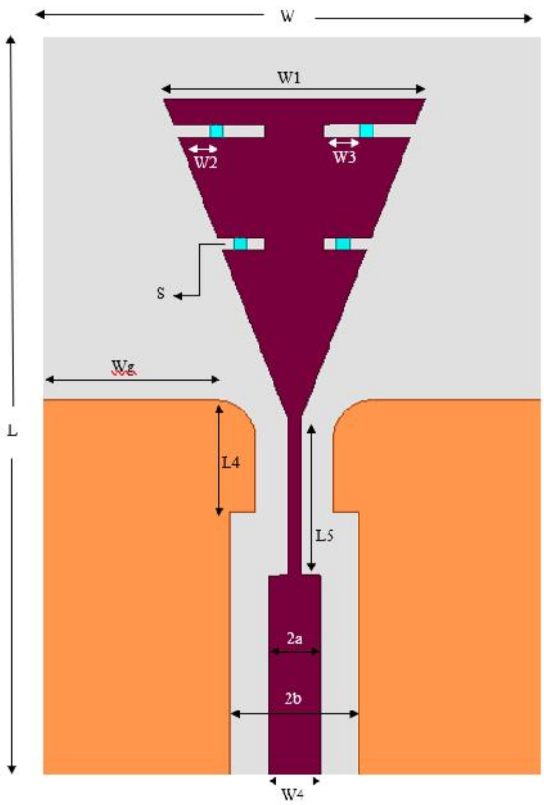

Fig.2. Antenna Design2

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III. Design Equations

Width of Microstrip patch antenna is given by where f_0 is the operating frequency of the antenna

$$W = \frac{c}{2f_0}\sqrt{\frac{2}{\varepsilon_r + 1}}$$

Length of rectangular patch

L where L_{eff} is given by

$$L_{eff} = \frac{c}{2f_r\sqrt{\varepsilon_{reff}}}$$

where f_r is the resonant frequency of the designed antenna

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

$$\Delta L = 0.412\,\frac{(\varepsilon_{eff} + 0.3)\left(\frac{w}{h} + 0.264\right)}{(\varepsilon_{eff} - 0.258)\left(\frac{w}{h} + 0.8\right)}$$

Design equations for CPW Feed [9]

$$k' = \sqrt{1 - k^2}$$

$$k1 = \frac{S_c}{S_c + 2W}$$

$$k2 = \frac{\sinh\frac{\pi a}{2h}}{\sinh\frac{\pi b}{2h}}$$

$$\frac{K(k)}{K'(k)} = \begin{cases} \dfrac{\pi}{\ln\left(\frac{2(1+\sqrt{k'})}{1-\sqrt{k'}}\right)}, & 0 \le k \le 0.707 \\ \dfrac{\ln\left(\frac{2(1+\sqrt{k'})}{1-\sqrt{k'}}\right)}{\pi}, & 0.707 \le k \le 1 \end{cases}$$

$$Z_{ocp} = \frac{30\pi}{\sqrt{\varepsilon_{eff}}}\frac{K'(k1)}{K(k1)}$$

IV. Results and Discussion

A. ANTENNA RESULTS IN HFSS

Referring to Fig.1 the antenna is designed using HFSS and the results are discussed further in this section. Different cases are obtained based on the ON/OFF state of the diode. A few of them are mentioned in this section.

Case:1- All switches off condition

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TABLE-2 RESULTS OF CASE-1

	Frequency (GHz)				
	f1	***f2***	***f3***	***f4***	***f5***
	4.0925	5.217	6.7475	8.9975	10.302
RL	-13.46	-14.07	-14.78	-24.76	-11.88
Gain	3.63	3.63	3.63	3.63	3.63

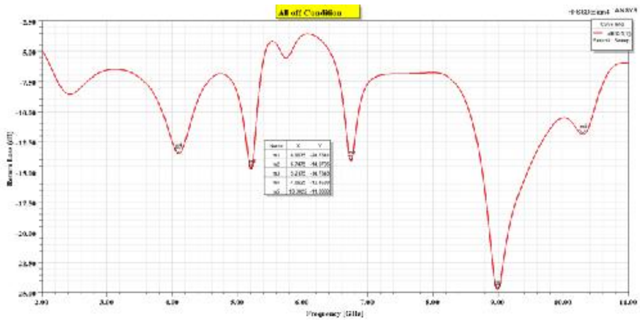

Fig.3. Frequency vs Return loss for all off condition

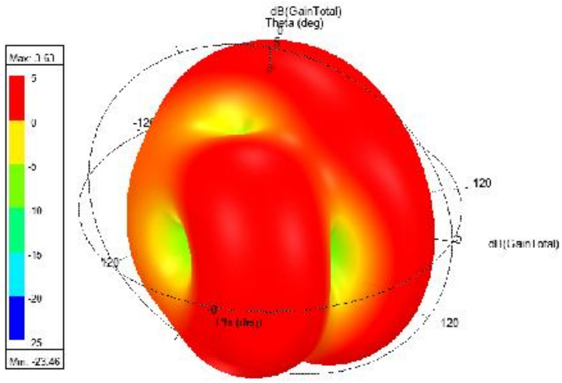

Fig.4. Gain plot for all off condition

Considering all the switches to be in off state, a gain of 3.63dB is obtained and a return loss of -24.7541dB at 8.990GHz is obtained which can be used for the application of Ultrawide band transmitter for tank level probing radar.
At 5.2175GHz a return loss of -14.7845dB is obtained.
Referring to Fig.2. this has found it's applications at Weather Radar, Mobile Communications, WLAN, C-Band etc., with a gain of 2.7dB which is less as compared to the present model-1

Case-2: Diodes 1,2,3 ON and 4 OFF

TABLE-3: RESULTS OF CASE-2

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	Frequency (GHz)	
	f1	***f2***
	4.2950	9.1325
RL	-42.004	-15.635
Gain	3.6	3.6

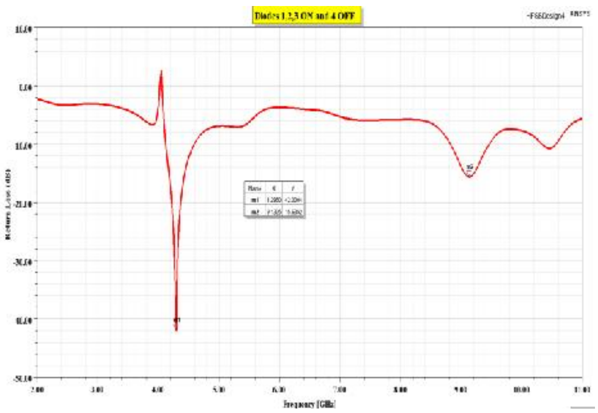

Fig.5. Frequency vs Return loss for case-2

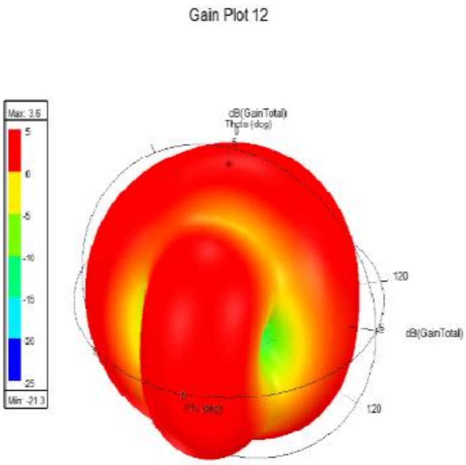

Fig.6. Gain plot for case-2

In this case it considered that the switches 1,2 and 3 are turned ON and switch-4 is turned off. In such condition gain of 3.6dB is obtained and a return loss of -42.004dB at 4.2950 GHz is obtained that can be used for long distance radio and telecommunications that is C-Band application. Another band at 9.1325GHz is obtained with a return loss of -15.635dB that can be used for Ultra-wideband transmitter for tank level probing radar application.
Referring to Fig.2. this model has obtained the applications at Weather Radar with a return loss of -29.231dB, C-Band with a return loss of -13.146, whereas for the same application a return loss of -42.023dB is obtained for the model-1, from the discussed results we can tell that model-1 performs better for the following case

B. MACHINE LEARNING RESULTS

Analysis of antenna using machine learning is done using Regression model, multi-layer perceptron and Radial Basis function.

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From table-4 we can observe that Cubic Regression model have R square value of 0.999, Logarithmic Regression with r square value 0.994 followed by Exponential Regression model with R square value of 0.993. Among the three models Cubic Regression is considered since it has greater R squared value compared to other models.

TABLE-4: REGRESSION RESULTS

Dependent Variable: Frequency

Equation	Model Summary			
	R Square	F	df1	df2
Linear	.966	836.160	1	29
Logarithmic	.994	5137.709	1	29
Inverse	.993	4211.227	1	29
Quadratic	.992	1753.652	2	28
Cubic	.999	6665.192	3	27
Power	.976	1187.979	1	29
Exponential	.993	4010.349	1	29

TABLE-5 NETWORK INFORMATION

Network Information

Input Layer	Covariates	1	Width
		2	Length
	Number of Units		2
	Rescaling Method for Covariates		Standardized
Hidden Layer	Number of Units		9[a]
	Activation Function		Softmax
Output Layer	Dependent Variables	1	Frequency
	Number of Units		1
	Rescaling Method for Scale Dependents		Standardized
	Activation Function		Identity
	Error Function		Sum of Squares

a. Determined by the testing data criterion: The "best" number of hidden units is the one that yields the smallest error in the testing data

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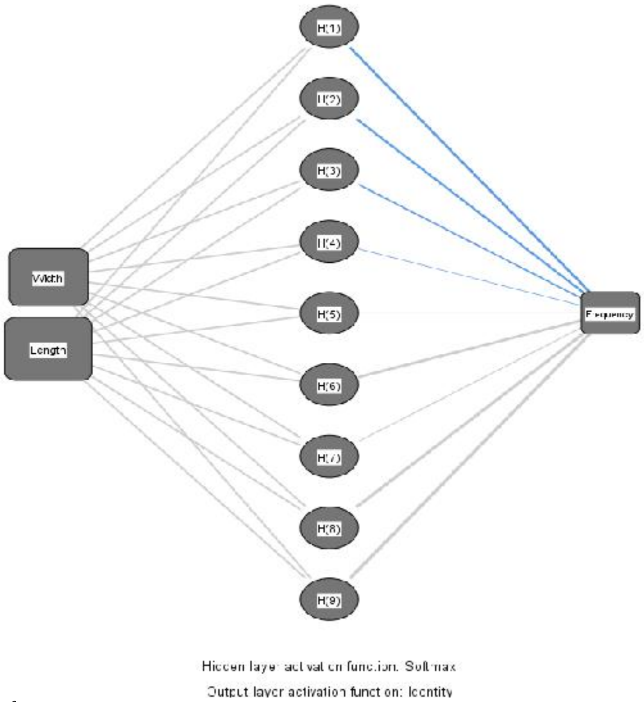

Fig.7. Network Model built for analysis of antenna

TABLE-6 MODEL SUMMARY

Model Summary

Training	Sum of Squares Error	.004
	Relative Error	.000
	Training Time	0:00:00.01
Testing	Sum of Squares Error	.012[a]
	Relative Error	.004

Dependent Variable: Frequency

Table-6 shows the model summary of Radial Basis function model and it is observed that the error obtained is 0.004 which is relatively smaller and the activation functions used are Identity function for output layer and softmax is used for hidden layers.

TABLE-7 VARIABLE DEPENDANCE

Independent Variable Importance

	Importance	Normalized Importance
Width	.463	86.2%
Length	.537	100.0%

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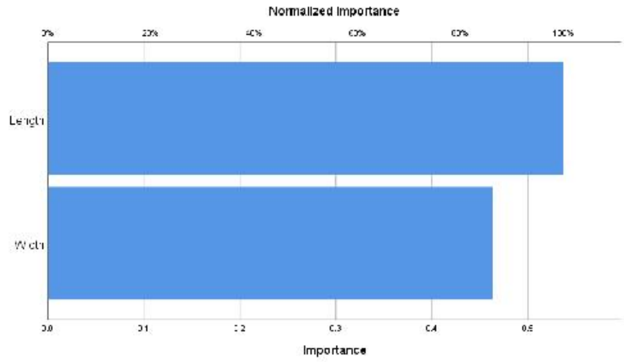

Fig.8. Graph showing the importance of variables

From table-7 and fig.7 we can tell that length is dependant on frequency with a Normalized importance of 100% and width having normalized importance of 86.2%

TABLE-8 NETWORK INFORMATION OF MLP FOR ANALYSIS

Network Information

Input Layer	Covariates	1	Width
		2	Length
	Number of Units[a]		2
	Rescaling Method for Covariates		Standardized
Hidden Layer(s)	Number of Hidden Layers		2
	Number of Units in Hidden Layer 1[a]		2
	Number of Units in Hidden Layer 2[a]		2
	Activation Function		Hyperbolic tangent
Output Layer	Dependent Variables	1	Frequency
	Number of Units		1
	Rescaling Method for Scale Dependents		Standardized
	Activation Function		Identity
	Error Function		Sum of Squares

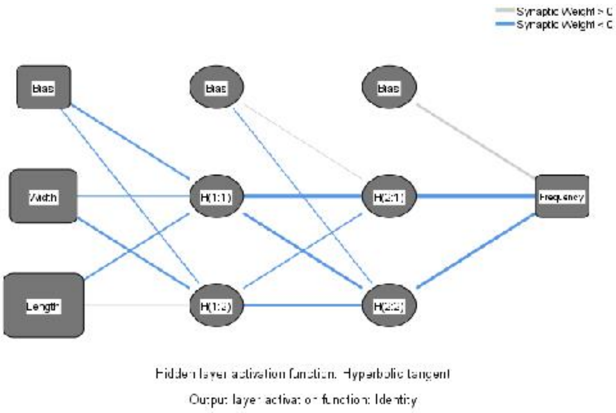

Fig.9. Network model built for analysis of antenna

TABLE-9 MODEL SUMMARY OF MLP FOR ANALYSIS OF ANTENNA

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Model Summary

Training	Sum of Squares Error	.062
	Relative Error	.006
	Stopping Rule Used	1 consecutive step(s) with no decrease in error[a]
	Training Time	0:00:00.00
Testing	Sum of Squares Error	.061
	Relative Error	.012

Synthesis of antenna using machine learning is carried out using multi-layer perceptron and Radial Basis function

TABLE-10 NETWORK INFORMATION FOR SYNTHESIS OF ANTENNA

Network Information

Input Layer	Covariates	1	Frequency
	Number of Units[a]		1
	Rescaling Method for Covariates		Standardized
Hidden Layer(s)	Number of Hidden Layers		2
	Number of Units in Hidden Layer 1[a]		2
	Number of Units in Hidden Layer 2[a]		2
	Activation Function		Hyperbolic tangent
Output Layer	Dependent Variables	1	Length
		2	Width
	Number of Units		2
	Rescaling Method for Scale Dependents		Standardized
	Activation Function		Identity
	Error Function		Sum of Squares

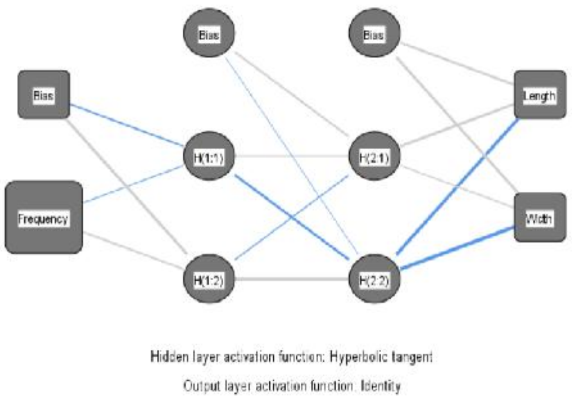

Fig.10. Network model built for synthesis of antenna

TABLE-11 MODEL SUMMARY OF MLP FOR SYNTHESIS

Model Summary

Training	Sum of Squares Error		1.135
	Average Overall Relative Error		.052
	Relative Error for Scale Dependents	Length	.038
		Width	.065
	Stopping Rule Used		1 consecutive step(s) with no decrease in error[a]
	Training Time		0:00:00.00
Testing	Sum of Squares Error		.680
	Average Overall Relative Error		.050
	Relative Error for Scale Dependents	Length	.036
		Width	.059

From the above table it is observed that the relative error for length is obtained to be 0.036 and width to be 0.059 with sum of squares error of 0.680.

On comparing Table-12 and Table-11 i.e., the Radial Basis function and the multi-layer perceptron it is observed that Radial Basis function has higher computations and the percentage of error is minimized by using the radial basis function for synthesis of the antenna.

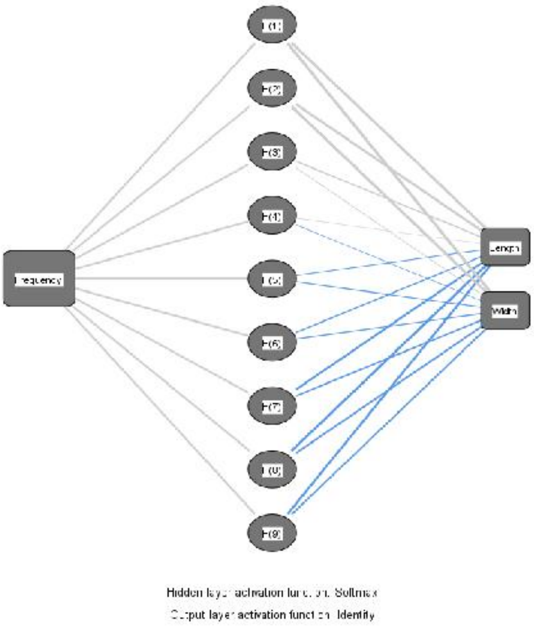

Fig.11. Network model built for Radial Basis function

TABLE-12 MODEL SUMMARY OF RADIAL BASIS FUNCTION FOR SYNTHESIS OF ANTENNA

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Model Summary

Training	Sum of Squares Error		.018
	Average Overall Relative Error		.001
	Relative Error for Scale Dependents	Length	.001
		Width	.000
	Training Time		0:00:00.02
Testing	Sum of Squares Error		.026[a]
	Average Overall Relative Error		.003
	Relative Error for Scale Dependents	Length	.004
		Width	.002

V. CONCLUSION

From the above discussions an antenna using CPW is designed and a return loss of -42.0004dB at 4.2950 GHz frequency for the application of C-Band is obtained and the analysis, synthesis is carried out using machine learning and it is found that Radial basis function has the least error of 0.026 for synthesis and 0.012 for analysis of antenna respectively, which is relatively smaller than the other machine learning models developed.

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