

Design of Multilayer Rectangular Microstrip Antenna using Artificial Neural Networks

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Abstract—In this paper, an Artificial Neural Networks (ANN) model has been developed to design the multilayer Rectangular microstrip patch. In the design procedure, synthesis ANN model is used as feed forward network to calculate the resonant frequency. Analysis ANN model is used as the reverse side of the problem to calculate the antenna dimension. The network is trained with the data obtained from measurements and calculated reference values. Levenberg-Marquardt learning algorithm was found to be the best algorithm in comparison to other algorithms. The results obtained from trained artificial neural network are compared with reference values. The average % accuracy in resonant frequency of ANN model for microstrip antenna with cover, Suspended microstrip antenna with cover, Spaced dielectric Antenna and microstrip antenna with two superstrates is 0.25 %, 0.54 %, 0.17 % and 0.076 % respectively. ANN is in very close agreement with reference values. The proposed ANN model requires no complicated mathematical formulas and suitable for CAD applications.

Index Terms—Microstrip antenna, resonant frequency, Multilayer Microstrip Antenna Substrate and Superstrate and Artificial neural networks

I. INTRODUCTION

Microstrip antennas are in greater demands in airborne and space applications because of small size, low weight, cost, ease of installation and low profile. The microstrip antennas possess the shortcomings such as narrow bandwidth, low gain and poor efficiency. These shortcomings can be overcome by using multilayered rectangular microstrip antennas. This can be achieved by proper combination of the substrate and superstrate thickness over and under the patch. Multilayer Microstrip patch is also useful to provide protection to patch from heat, rain, physical damage, and naturally formed ice layers during flight [1-2]. There are many methods available in the literature to calculate the resonant frequency of multilayered rectangular patch based on numerical technique [3-5]. These methods require rigorous and complex analysis which are time consuming and can not be easily included in a CAD system. Present author has reported the simple analytical design expression for four layer rectangular patch antenna [6]. None of the efficient analytical model is available in literature related to multilayered structure to obtain the antenna dimension. The inverse procedure of calculating the antenna dimension for a specific resonant frequency is complicated and non-linear. The difficulty lies in designing these antennas is due to the high number

of physical parameters. Such a situation can be handled efficiently using Neural Networks [7-9]. So far ANN technique has been applied on various shapes of Microstrip patch antenna [10-12] with single substrate. Much of the work has not been reported for designing of multilayered Microstrip patch antenna using ANN. This paper presents the ANN models for multilayered rectangular Microstrip patch. The proposed ANN model does not require any complicated mathematical functions. This is very simple, efficient, accurate and suitable for CAD applications. This is very useful for antenna design engineers to design wide bandwidth and high gain antenna for wireless communication.

II. ANN MODEL FOR MULTILAYER MICROSTRIP RECTANGULAR ANTENNA

The Simple Rectangular microstrip patch is shown in Fig. 1. In this paper, the resonant frequency of multilayer antenna is obtained as a function of patch dimension (W,L), height of the substrates (h_1, h_2) and superstrate (h_3 and h_4) and dielectric constant ($\epsilon_{r1}, \epsilon_{r2}, \epsilon_{r3}$ and ϵ_{r4}) as shown in Fig. 2. The neural network was trained for multilayer rectangular microstrip patch for forward and reverse side of the problem using Levenberg and Marguardt. The feed forward network has been utilized to calculate the resonant frequency of the patch by applying width, length, substrate, superstrate dielectric constant and height as inputs is shown in Fig. 3. This is defined as synthesis ANN model. In the inverse procedure, dimensions of the patch W, L is obtained as a function of input variables like height of the substrate h_1, h_2 , and superstrate h_3, h_4 , and their dielectric constant $\epsilon_{r1}, \epsilon_{r2}, \epsilon_{r3}$ and ϵ_{r4} and resonant frequency using analysis ANN model as shown in Fig. 4.

III. ANN AND TRAINING DATA

In this work, ANN model has been developed to accurately calculate of the resonant frequency and inversely dimension of patch for multilayer rectangular Patch Antenna. The network is trained with the data obtained from [6] and experimental results [2-3]. The various values of width W, length L, substrate and superstrate dielectric constant ($\epsilon_{r1}, \epsilon_{r2}, \epsilon_{r3}$ and ϵ_{r4}) and height (h_1, h_2, h_3 and h_4) are used for training processes. Once you have trained the network, it can calculate the resonant frequency very close to experimental value for any value of dielectric constant, dimension, and height of

the substrate and superstrate within the given range of inputs.

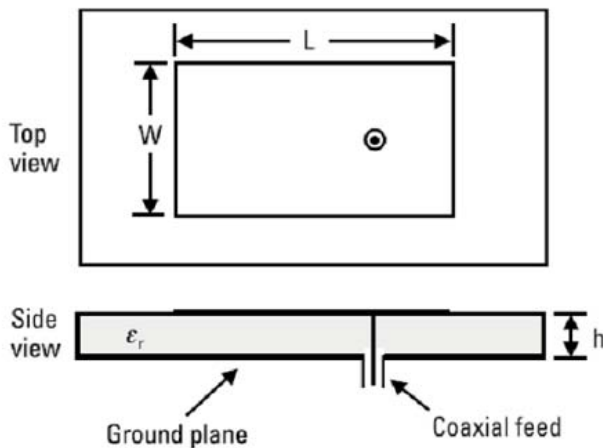


Figure 1. Rectangular Microstrip Patch

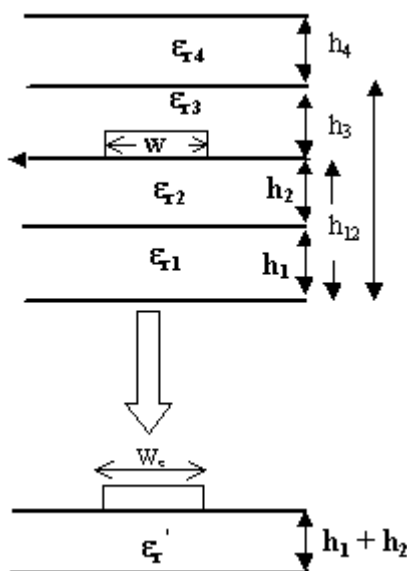


Figure 2. Multilayer Microstrip Structure with Single layer Reduction

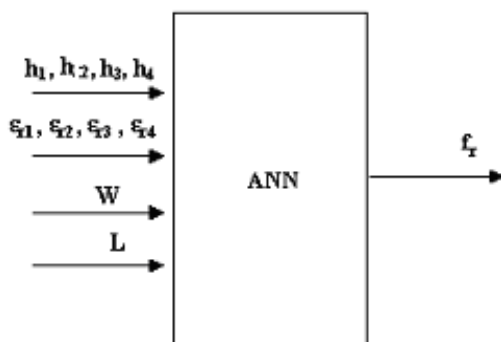


Figure 3. Synthesis ANN model

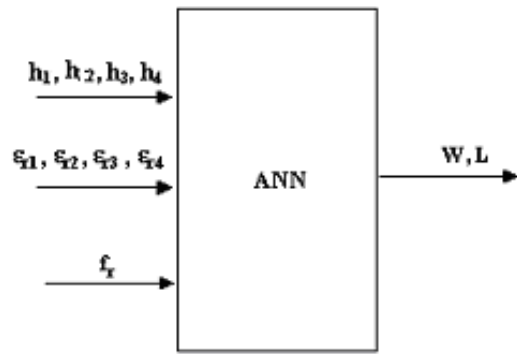


Figure 4. Analysis ANN model

IV. DESIGN EXPRESSION

The multilayer rectangular microstrip antenna which consist of a rectangular patch of width W , and length L , dielectric constant ϵ_{r1} , ϵ_{r2} , ϵ_{r3} , ϵ_{r4} and thickness of substrate h_{11} , h_{12} , and superstrate h_3 , h_4 is used to obtain the data to train the ANN model. The resonant frequency of the multilayer rectangular microstrip patch antenna shown in Fig. 2 can be calculated by the expression given below;

$$f_r = \frac{C}{2(L + 2 \Delta L) (\epsilon_{eff}(f))^{1/2}} \quad (1)$$

where L is the length of the patch antenna, C is the velocity of light in free space, ΔL is length extension due to end effect and $\epsilon_{eff}(f)$ is the frequency dependent effective dielectric constant of multilayer microstrip structure. To calculate $\epsilon_{eff}(f)$, first frequency independent effective dielectric constant $\epsilon_{eff}(0)$ of multilayer microstrip structure can be calculated using the following expression

$$\epsilon_{eff}(0) = \frac{(\epsilon_{p1}\epsilon_{p2}(q_1+q_2)^2 / (\epsilon_{p1}q_2 + \epsilon_{p2}q_1)) + \epsilon_{p3}\epsilon_{p4}(1-q_1-q_2)^2}{(\epsilon_{p3}\epsilon_{p4}(1-q_1-q_2-q_3-q_4) + q_3 + q_4)} \quad (2)$$

where q_1 , q_2 , and q_3 are taken from [6]. The expression of q_4 after taking into account the effect of thickness of fourth layer is given as

$$q_4 = 1 - q_1 - q_2 - q_3 - \frac{(h_{13} - v_e / 2W_e) \log(2W_e / (2h_{14} - h_{12} + v_e))}{\cos(\pi v_e / 2h_{12}) + \sin(\pi v_e / 2h_{12})} \quad (3)$$

The effective width of the multilayer microstrip can be calculated using the following expression.

$$W_e = \sqrt{\epsilon_r' / \epsilon_{eff}} [w + 0.882h + 0.164h(\epsilon_r' - 1) / (\epsilon_r')^2] + \sqrt{\epsilon_r' / \epsilon_{eff}} \frac{h}{(\epsilon_r' + 1) / (\epsilon_r')^2 \ln[17.08(W / 2h_1 + 0.92) + 1.451]} \quad (4)$$

The multilayer microstrip structure can be made equivalent to single layer microstrip structure as shown in Fig. 2 by using single layer reduction technique applied by present author [6].

In this, effective dielectric constant $\epsilon_{eff}(0)$ calculated by equation (2) of multilayer microstrip structure will be equivalent to effective dielectric constant of single layer microstrip structure with equivalent relative permittivity ϵ_r' of single layer structure and width of the patch is

replaced by effective width and substrate height is taken $h_{12} = h_1 + h_2$. So, the frequency dependent effective permittivity $\epsilon_{eff}(f)$ can be calculated by following expression

$$\epsilon_{eff} = \epsilon_r - \frac{\epsilon_r' - \epsilon_{eff}(0)}{1 + P(f)} \quad (5)$$

The open end extension in length ΔL [6] due to fringe effect in multilayer microstrip configuration is calculated by using the permittivity ' ϵ_r ' obtained from (5) and width 'u' are replaced by equivalent permittivity ϵ_r' and effective width /height ratios $u' = W_e / (2h_{12})$. The optimum value of strip width for good efficiency is taken $W = \lambda_0 / 2((\epsilon_r' + 1)/2)^{-1/2}$, Where λ_0 is the free space wavelength.

ANN model over the specified range of input parameters is trained. The inverse problem is also applied to calculate antennas dimension from the specified operating frequency and dielectric constant and their height. The inverse problem is non-linear for which no expression is available. The major advantage of ANN modelization is that, after proper training, a neural network completely bypasses the repeated use of complex iterative processes for the new design presented to it.

V. ARCHITECTURE OF MULTILAYER PERCEPTRON NETWORK

The proposed ANN model is designed with five neuron input layer, one hidden layers with 20 neuron and a single neuron output as shown in Fig. 5. This is called Multi Layer Perceptron (MLP) Models. MLP Models are the simplest and therefore most commonly used neural network architectures. They have been utilized for the calculation of the resonant frequency and inversely the dimension of the Multilayered rectangular Microstrip antenna..

In this work, MLPs are trained with the Back Propagation algorithm. The back propagation algorithm assumes feed forward neural network architecture. In this architecture, network is partitioned into layers numbered 0 to L, where the layer number indicates the distance of a node from the input nodes. The lowermost layer is the input layer numbered as layer 0, and the topmost layer is the output layer numbered as layer L. Back propagation algorithm addresses networks for which $L > 2$, containing "hidden layers" numbered 1 to L - 1. Hidden nodes neither directly receive inputs nor send outputs to the external environment. The presentation of the algorithm also assumes that the network is strictly feed forward algorithm assumes that network's only nodes in adjacent layers are directly connected.

In this work, for training the network, performance goal was set as 0.001, number of hidden nodes as 20 and the number of output node is 1. The number of input nodes is a variable parameter which in turn depends on the

complexity of the problem. The number of hidden layers, output layers respectively are set as 1 and the maximum number of epochs / iterations have been fixed as 5000. Using supervised learning, the network is trained with the known set of parameters (reference values).

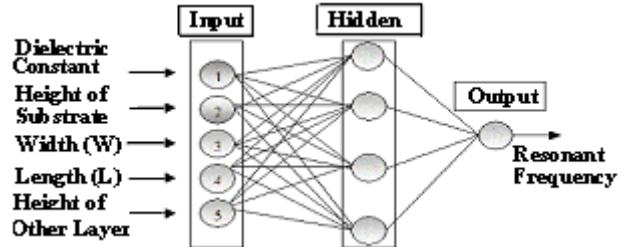


Figure 5. Architecture of Multilayer Perceptron Network

VI. RESULTS AND DISCUSSION

Multi Layer Perceptron (MLP) Model was used to design the microstrip antenna in multilayer environment. The network was trained with the known set of parameters in the input to get the desired output in the initial phase. After training, the ANN model was used to calculate the resonant frequency f_r for any arbitrary values of rectangular width W, length L, dielectric constant of various layers and their thickness. The results obtained are compared in tables with the calculated resonant frequency by reference values [6]. Inverse procedure is also applied to calculate the antenna dimension. The ANN models has been configured for various configuration of multilayered Microstrip rectangular patch antenna. These configurations are Simple Microstrip Patch Antenna, Microstrip patch with cover, Suspended Microstrip antenna with cover, Spaced Dielectric patch antenna and microstrip patch antenna with two superstrates which can be used to design high gain, wider bandwidth of antenna and protecting the patch from environmental effect.

A. Simple Microstrip Antenna

Simple Rectangular microstrip antenna has been made by making $h_4 = h_3 = h_1 = 0$, $\epsilon_{r4} = \epsilon_{r3} = \epsilon_{r1} = 1$ in Figure 2. For this configuration, performance goal was set as 0.001, number of input nodes as 10, number of hidden nodes 5, number of output node is 1. The number of input, hidden, output layer is set as 1. The resonant frequency was calculated by inputting the W, L, height of the substrate and superstrate and their dielectric constants using analysis ANN model. 100 epochs were required to achieve the desired performance goal. Table 1 compares the dimension of simple microstrip antenna calculated by ANN and [6]. The dimension of the antenna was calculated by applying resonant frequency, dielectric constant $\epsilon_{r2} = 2.2$, or $\epsilon_{r2} = 4.3$, and $h_2 = 1.53$ mm. The dimension of microstrip antenna calculated by ANN is very close to the reference value.

TABLE 1
COMPARISON OF CALCULATED DIMENSION OF ANTENNA BY ANN AND PM FOR MICROSTRIP ANTENNA

$\epsilon_{r2}=2.2, h_2=1.52 \text{ mm}$				
f_r GHz	L (mm) ANN	W mm ANN	L mm (PM)	W mm PM
6.087	14.99	18.03	15.05	18.2
5.733	16.07	20.04	16.06	20.2
5.476	16.98	17.08	16.98	17.05
5.156	17.98	21.99	18.07	21.12
4.908	18.99	23.03	19.05	23.09
4.6	19.9949	16.1479	20.88	16.23
$\epsilon_{r2}=4.3, h_2=1.53 \text{ mm}$				
3.6	20.0299	14.862	19.76	14.12
3.8	18.4332	22.528	18.275	22.8
4	17.8411	15.268	17.55	15.497
4.2	16.7223	18.195	16.519	18.32
4.4	16.0065	15.717	15.8	15.7
4.6	14.9932	20.822	14.865	20.82

B. Microstrip Antenna with Cover

Rectangular microstrip antenna with covered dielectric has been made by making $h_4 = h_1=0, \epsilon_{r4} = \epsilon_{r1}=1, \epsilon_{r2} = \epsilon_{r3} \neq 1$ in Figure 2. Table 2, compare the calculated resonant frequency from ANN model and experimental value [2] as the superstrate thickness increases from 0.5mm to 12.72mm. The resonant frequency has been calculated by using W, L, dielectric constant ($\epsilon_{r2}, \epsilon_{r3}$) and thickness (h_2, h_3) as inputs to the ANN network. The frequency calculated from ANN model is very close to the experimental reference values [2]. The average deviation in resonant frequency calculated by ANN model against reference [2] is 0.25 %.

TABLE 2
COMPARISON OF RESONANT FREQUENCY CALCULATED FROM ANN MODEL AND EXPERIMENTAL RESULTS OF COVERED MICROSTRIP PATCH

$L=33.25, W=32.25, h_1=0, \epsilon_{r1}=1, \epsilon_{r2} = \epsilon_{r3} = 2.32, h_2=3.18$					
h_3 (mm)	f_r [1] GHz	f_r (PM) GHz	f_r (ANN) GHz	%Dev. (PM)	%Dev. (ANN)
0.5	2.7469	2.759	2.7623	-0.44	-0.56
0.787	2.7405	2.746	2.7540	-0.2	-0.492
1.588	2.7358	2.739	2.7256	-0.116	0.372
3.18	2.718	2.712	2.713	0.22	0.183
6.36	2.6966	2.693	2.6952	0.133	0.051
9.54	2.6855	2.682	2.6837	0.130	0.067
12.72	2.6768	2.670	2.6776	0.254	-0.029

C. Suspended Microstrip Antenna with cover dielectric

Rectangular suspended microstrip antenna with one superstrate can be achieved by putting $h_4 = 0, \epsilon_{r4}=1, \epsilon_{r1} = \epsilon_{r2} = \epsilon_{r3} \neq 0$ in Figure 2. Table 3 compares the resonant frequency calculated from ANN model against the reference values calculated in [6]. The average % deviation between reference resonant frequency [6] and

calculated by ANN is 0.54 %. This accuracy of ANN model is better than practically acceptable values.

TABLE 3
COMPARISON OF RESONANT FREQUENCY CALCULATED FROM ANN MODEL AND PRESENT METHOD OF SUSPENDED MICROSTRIP ANTENNA

h_1	f_r [6]	f_r (ANN)	% Dev. (ANN)
0.065	3.4302	3.4640	-0.98
0.129	3.6091	3.6293	-0.56
0.193	3.7522	3.7701	-0.48
0.258	3.8688	3.8889	-0.52
0.323	3.9648	3.9886	-0.60
0.451	4.1113	4.1405	-0.71
0.645	4.2538	4.2825	-0.67
1.29	4.4162	4.4243	-0.18
1.94	4.3966	4.4031	-0.20

D. Spaced Dielectric Microstrip Antenna

The spaced dielectric Rectangular microstrip patch antenna configuration can be achieved from Figure 2 by putting $h_1 = 1, \epsilon_{r1}=1, \epsilon_{r3}=1$. The resonant frequencies for various thickness of air gap between superstrate and patch, and various dielectric constant of spaced dielectric have been tabulated in table 4. The resonant frequency calculated by ANN has been compared against the experimental values [2]. The average accuracy of ANN model and PM against experimental values is 0.17% and 0.367% respectively which is practically very good.

TABLE 4
COMPARISON RESONANT FREQUENCY CALCULATED BY ANN AND PM [6] AGAINST REFERENCE VALUES [3] FOR SPACED DIELECTRIC

$L=28.6\text{mm}, W=36.7\text{mm}, h_1=0, \epsilon_{r1}=1, h_2=1.52, \epsilon_{r2}=2.986, \epsilon_{r3}=1, h_4=5\text{mm}$						
h_3 mm	ϵ_{r4}	f_r (Exp) [3]	f_r (PM) [6]	f_r (ANN)	%ANN	%PM
3.5	2.35	2.94	2.941	2.941	-0.040	-0.037
3.5	2.98	2.949	2.942	2.939	0.227	0.339
3.5	10.4	2.922	2.945	2.902	-0.780	0.677
7.5	2.35	2.946	2.947	2.946	-0.02	-0.01
7.5	2.98	2.940	2.948	2.947	-0.272	-0.258
7.5	10.4	2.905	2.905	2.919	0	-0.499
12.8	2.35	2.948	2.949	2.937	-0.027	0.379
12.8	2.98	2.954	2.950	2.934	0.125	0.670
12.8	10.4	2.954	2.953	2.941	0.020	0.429

In synthesis ANN model , results are obtained by reversing the input-output data of the network. In thi report the synthesis ANN network have been used to calculate the values of the length and width of the patch for space dielectric antenna from the resonant frequency, dielectric constant and height of substrates and superstrates. The calculated dimension of ANN model are very close to reference dimension calculated by [6] as shown in Table 5.

TABLE 5
COMPARISON RESONANT FREQUENCY CALCULATED BY ANN AGAINST REFERENCE VALUES [6] FOR SPACED DIELECTRIC

L=28.6mm,W=36.7mm,h ₁ =0, ε _{r1} =1,h ₂ =1.52, ε _{r2} =2.986 ε _{r3} =1,h ₄ =5mm, h ₃ = 3 mm				
f _r (GHz)	W (mm) ANN	L (mm) ANN	W (mm) [6]	L(mm) [6]
2.7993	39.8475	29.9376	40	30
2.8005	30.1359	29.0794	30	30
2.9870	37.5368	27.9936	37.5	28
3.2022	33.2864	26.0083	33	25.999
3.7389	32.29	21.7859	32.29 9	22
4.0799	36.3427	20.0334	36	20
L=28.6mm,W=36.7mm,h ₁ =0, ε _{r1} =1,h ₂ =1.52, ε _{r2} =2.986 ε _{r3} =1,h ₄ =5 mm, h ₃ = 7 mm				
2.8057	31.5386	29.9264	32	30
2.9925	38.5416	28.1049	38.59 9	28
3.2082	32.7815	26.1401	32.7	25.999
3.7458	32.0966	22.08	32	22
4.0874	35.8889	19.9871	36	20

E. Microstrip Antenna with Two Superstrates

The Rectangular microstrip patch with two superstrates configuration can be achieved from Figure 2 by putting h₁ = 1, ε_{r1}=1. The various combination of superstrate dielectric constant and thicknesses were taken to train the network. The resonant frequency calculated by ANN model for any input within the range of trained parameters has been tabulated. Table 6 compares the resonant frequency calculated from ANN model with the reference values [6]. Both are in close agreement. The average % deviation in resonant frequency calculated by ANN model against [6] for ε_{r3} = 2.32, ε_{r3} = 4.3 superstrate is 0.076% and 0.067% respectively.

TABLE 6
COMPARISON OF THE RESONANT FREQUENCY CALCULATED FROM ANN MODEL AGAINST [6] FOR MICROSTRIP PATCH WITH TWO SUPERSTRATE

L=28.6mm,W=36.7mm,h ₁ =0, ε _{r1} =1,h ₂ =1.52, ε _{r2} =2.986, h ₄ =5mm					
		ε _{r3} =4.3		ε _{r3} =2.32	
h ₃	ε _{r4}	f _r (ANN)	f _r [6]	f _r [6]	f _r (ANN)
1.5	2.35	2.8735	2.8722	2.8982	2.8980
2.5	2.98	2.8560	2.8574	2.8906	2.8914
3	10.45	2.8139	2.8106	2.8540	2.8529
3.5	2.32	2.8548	2.8566	2.8941	2.8958
6	3.2	2.8418	2.8395	2.8874	2.8897
7	10.2	2.8149	2.8134	2.8686	2.8718
9	2.35	2.8357	2.8339	2.8869	2.8931

VI. CONCLUSION

An efficient design procedure for multilayer rectangular microstrip patch based on levenberg - marquardt training algorithm has been demonstrated using artificial neural networks. In the analysis network, one can obtain geometrical parameters of antenna by inputting f_r, height and dielectric constant of the substrate and superstrates. In synthesis network, the results are

determined reversing the input-output data of analysis network. ANN model allows the designer to obtain very accurate results and requires no complex computational efforts. The major advantage of ANN model is that, after proper training, a neural network completely bypasses the repeated use of complex iterative processes for the new design presented to it. This ANN model is suitable for CAD applications. Such model can be used for designing the wide bandwidth, high gain antennas and to study the effect of protective layer. This model is suitable for the design of any communication system affected by environment

ACKNOWLEDGEMENT

Authors express sincere thanks to Vice Chancellor of DIAT (DU), Pune and Principle of D.Y. Patil College of Engg., Akrudi, Pune. Authors also acknowledge the support of all the staff of Department of Electronics Engg., Defence Institute of Advance Technology, Girinagar, Pune and the research scholar of Microwave and Millimeter wave Antenna Lab.

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