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On the Design of Multilayer Circular Microstrip Antenna using Artificial Neural Networks

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Abstract— **In this paper, we propose an artificial neural network (ANN) as a design technique for multilayer circular microstrip antennas based on Levenberg - Marquardt training algorithm for modelling, simulation and optimization. Levenberg – Marquart (LM) algorithm has been used to train the Multi- Layer Perceptron Neural Networks (MLPNNs). In the design procedure, the feed forward network is defined as a synthesis ANN model. Analysis ANN model is used as the reverse side of the problem to calculate the antenna dimension. The results of neural models has been compared with the measurements and calculated results. The results calculated by ANN model are found very close to the reference results. The average % accuracy in resonant frequency of ANN model for circular microstrip antenna with and without cover, Spaced dielectric Antenna and microstrip antenna with two superstrates is 0.35 %, 0.065 %, 0.43 % and 0.066 % respectively. The proposed ANN model requires no complicated mathematical formulas and suitable for CAD applications to design wide band, and high gain antenna.**

Index Terms—**Artificial neural networks, resonant frequency , multi layer, Microstrip Patch, Substrate and Superstrate**

I. INTODUCTION

Microstrip antennas are wisely used in satellite and ground based systems because of small size, less weight, low cost. The limitation of microstrip antennas are narrow bandwidth, low gain and poor efficiency [1]. These can be over come by using multilayered microstrip antennas. Multilayer Microstrip patch is also useful to provide protection to patch from heat, rain and physical damage [2-4], wide band width and high gain. There are many methods available in the literature to design the multilayered patch based on numerical technique [5-7]. 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 and circular microstrip patch antenna [3-4] 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 of multilayer microstrip antennas for center frequency is complicated and non-linear in nature. This Neural Networks can provide an efficient solution for such problem. So far ANN technique has been applied on various shapes of Microstrip patch antenna [8-10] with single substrate. Much of the work has not been reported regarding the design of multilayered circular Microstrip patch antenna using ANN. This paper presents the ANN models based on LM algorithm [11-12] for multilayered circular Microstrip patch. The proposed ANN model does not require any complicated mathematical functions. This is very simple, efficient, accurate and suitable for CAD applications to design wide bandwidth and high gain antenna for wireless communication.

II. ANN MODEL FOR MULTILAYERED CIRCULAR MICROSTRIP ANTENNA

In this paper, the artificial neural network was trained for multilayer circular microstrip patch for forward and reverse side of the problem. The feed forward network has been utilized to calculate the resonant frequency of the patch by inputting radius of patch, substrate, superstrate dielectric constant and height as shown in Fig. 1. This is defined as synthesis ANN model. In the inverse procedure, dimensions of the patch i.e. radius 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 ε_{r1} , ε_{r2} , ε_{r3} and ε_{r4} and resonant frequency using analysis ANN model as shown in Fig. 2.

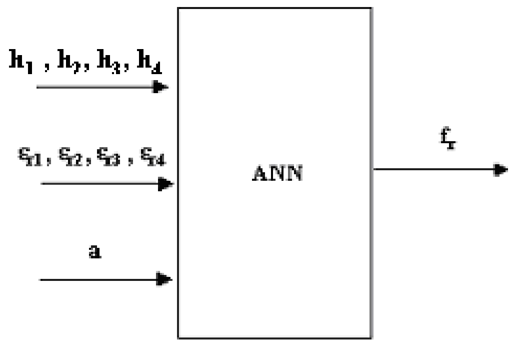

Figure 1. Synthesis ANN model

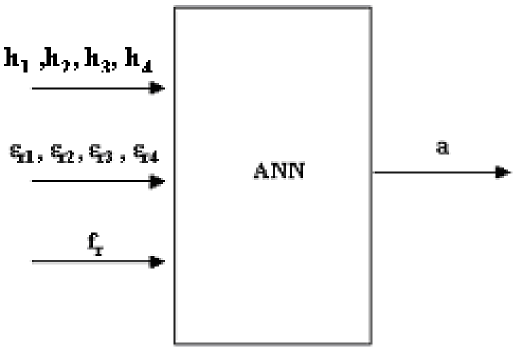

Figure 2 Analysis ANN model

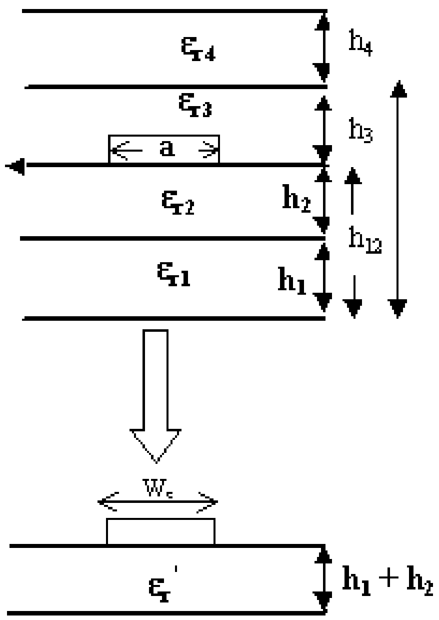

Figure 3. Multilayer Circular microstrip Patch with single layer Reduction

III. DESIGN EXPRESSIONS

The multilayered microstrip structure is shown in Figure 3. A simple more general expression for calculating resonant frequencies of TMnm mode for circular microstrip patch with and with air gaps, with and without superstrates can be written as

$$f_{r\,mn} = \frac{\alpha_{nm} C}{2\pi\, a_{eff} \sqrt{\varepsilon_{reff}}} \quad (1)$$

Where c is free space velocity and ε_{reff} – effective dielectric constant of multilayered circular patch. The a_{eff} effective radius of the patch in presence of multilayered dielectric is given ; $a_{eff} = a\,\sqrt{(1+g)}$, Where g is the parameter determine the fringing field effect. One or more dielectric layers above the circular microstrip patch cause the change in the fringing fields between the patch and the ground plane and that effect is accounted by the effective dielectric constant ε_{eff}. The general formulations for a circular patch [4] can be extended to calculate ε_{eff} of multilayered circular patch of radius a. Equation (2) is derived from an equivalence relation between a circular patch (radius = *a*) and a rectangular patch with length *L*. Equal circumference was considered as the basis of equivalence to account for equal static fringing fields. The effective dielectric constant $\varepsilon_{eff}(0)$ of multilayered circular microstrip patch can be calculated by following expression

$$\varepsilon_{eff}(0) = \varepsilon_{r2}\, q_1 + \varepsilon_{r2}\,(1-q_1)^2 \times [\,\varepsilon^2_{r3}\, q_2\, q_3 + \varepsilon_{r3}\, \varepsilon_{r4}\,(q_2\, q_4 + (q_{3+}\, q_4)^2\,] \times [\varepsilon^2_{r3}\, q_2\, q_3\, q_4 + \varepsilon_{r2}\,([\varepsilon_{r3}\, q_3 + \varepsilon_{r4}\, q_4)\,(1-q_1 - q_4)^2 + \varepsilon_{r3}\, \varepsilon_{r4}\, q_4\,(q_2\, q_4 + (q_{3+}\, q_4)^2)]^{-1} \quad (2)$$

This expression for effective permittivity can be used to calculate the resonant frequency of multilayered circular microstrip patch i.e. spaced dielectric CMP for intentional or unintentional air-gap, composite/suspended CMP with and without superstrate, and CMP with two superstrates. Expression for filling fractions $q_{1,}\, q_{2,}\, q_{3,}$ and q_4 are used as follows

$$q_1 = 1 - h_1/2w_e \ln(\pi/h_1 w_e - 1) - q_4 \quad (3)$$

$$q_2 = 1 - q_1 - q_3 - 2q_4 \quad (4)$$

$$q_3 = (h_1 - g)/2\ w_e \ln\,[\pi\ w_e\ /\ h_1 \cos\ (\pi g/\ 2h_1)/\pi(h_2/h_1 + 0.5) + 0.5g\pi/h_1 + \sin(0.5g\pi/h_1)] \quad (5)$$

$$q_4 = h_1/2\ w_e\ .\ln\ (\pi/2 - h_1/2\ w_e) \quad (6)$$

$$g = 2h_1/\ \pi.\ \arctan\ [\pi(h_2/h_1 - 1)/\ (\pi/2\ w_e/\ h_1 - 2] \quad (7)$$

The effective width of the multilayered microstrip patch can be calculated [4]. The multilayered circular microstrip structure is shown in Fig. 3 an be made equivalent to single layer circular microstrip structure shown in Fig. 3 by using single layer reduction technique applied by [3-4]. In this, effective dielectric constant $\varepsilon_{eff}(0)$ calculated by equation (2) of multilayered circular 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 radius of patch which provides width of the patch CMP, which is replaced by effective width and substrate height for calculating resonant frequency of antenna. The resonant frequency of composite/suspended substrate circular microstrip patch with and without cover, spaced dielectric with intentional or uninternal air-gap and circular microstrip patch with two superstrates can be calculated by expression (1). Various configurations of circular microstrip antenna can be achieved from Figure 3, and their resonant frequency can be calculated using the formulation given [4].

IV. TRAINING ALGORITHM

Neural models based on multilayered perceptrons for computing the resonant frequency of rectangular microstrip antennas has been studied. Eleven learning algorithms, Levenberg-Marquardt(LM)[11-12], conjugate gradient of Fletcher-Reeves(CGF), conjugate gradient of Powell-Beale(CGB), bayesian regularization, scaled conjugate gradient(SCG), Broyden-Fletcher-Goldfarb-Shanno, resilient backpropagation (RP), conjugate Gradient of Polak-Ribiére(CGP), variable learning rate backpropagation (GDX), one-step secant(OSS), and backpropagation with momentum, are used to train the multilayered perceptrons. When the performances of neural models are compared with each other, the best result is obtained from the multilayered perceptrons trained by Levenberg-Marquardt algorithm. A comparison is shown in Fig. 4.

The proposed ANN model is designed with five neuron input layer, one hidden layers with 20 neuron and a single neuron output. 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 circular Microstrip antenna.

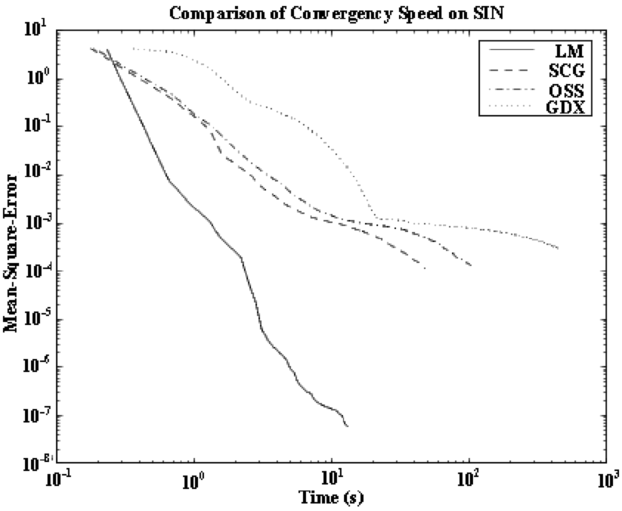

Figure 4. Comparison for Convergence of Algorithm

V. RESULTS AND DISCUSSION

ANN Model was used to design the circular 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 radius a, dielectric constant of various layers and their thickness. The results obtained are compared in tables with the calculated resonant frequency by reference values [4]. Inverse procedure is also applied to calculate the antenna dimension.

A. S*imple Circular Microstrip Antenna*

Simple circular microstrip antenna has been made by putting $h_4 = h_3 = h_1=0$, $\varepsilon_{r4} = \varepsilon_{r3} = \varepsilon_{r1}=1$ in Fig. 3. The resonant frequency was calculated by inputting the radius of patch a, height of the substrate and their dielectric constants using ANN model. table 1 compares experimental resonant frequencies [13-14] of simple microstrip antenna with calculated by ANN. The resonant frequency of the antenna has been calculated for various radius of the patch, dielectric constant and height of the substrate. The resonant frequency of microstrip antenna calculated by ANN is very close to the experimental resonant frequencies. The average accuracy of ANN model against experimental values is 0.35 %.

TABLE 1
COMPARISON OF RESONANT FREQUENCIES CALCULATED BY ANN WITH EXP. VALUES FOR CIRCULAR MICROSTRIP ANT.ENNA

a (mm)	h_2 (mm)	ε_r	fr GHz (Exp)	fr GHz (ANN)
7.4	1.587	2.65	6.634[13]	6.6152
8.2	1.587	2.65	6.074[13]	6.0426
9.6	1.587	2.65	5.224[13]	5.2107
12.7	0.794	2.5	4.07[14]	4.0737
49.5	2.35	4.55	0.825[14]	0.8197

B. Circular ***Microstrip Antenna with Cover***

Circular microstrip antenna with covered dielectric has been made by substituting $h_4 = h_1=0$, $\varepsilon_{r4} = \varepsilon_{r1}=1$, $\varepsilon_{r2} = \varepsilon_{r3} \neq 1$ in Fig. 3. The antenna configuration is useful to calculate the effect of dielectric or radome on resonant frequency and also useful to design the high gain antennas. Table 2, compares the calculated resonant frequency from ANN model with reference values [4,14] as the ratio of superstrate/substrate thickness increases from 1 to 9.. The frequency calculated from ANN model is very close to the reference values [4,14]. The average deviation in resonant frequency calculated by ANN model against reference [4] is 0.065 %.

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

a/h_2 = 5mm; h_2 = 1.5875mm; ε_{r1} =1, $\varepsilon_{r2} = \varepsilon_{r3}$ = 2.5, ε_{r4} = 1, h_1 = 0, h_4 = 0.			
h_3/h_2	fr [15] GHz	fr GHz [4]	fr GHz (ANN)
1	5.765	5.7565	5.7465
1.5	5.735	5.7257	5.7228
2.5	5.708	5.6846	5.679
3	5.69	5.6702	5.6646
4	5.67	5.6483	5.6510
5.5	--	5.6271	5.6291
6	--	5.622	5.6250
7	--	5.6137	5.6123
9	--	5.6024	5.6027

C. Suspended Microstrip Antenna with cover dielectric

Circular suspended microstrip antenna with one superstrate can be achieved by putting $h_4 = 0$, $\varepsilon_{r4}=1$, $\varepsilon_{r1} = \varepsilon_{r2} = \varepsilon_{r3} = \neq 0$ in Fig. 3. This configuration of antenna is useful for designing the wide band antenna. The cover over the patch antenna protects antenna from enviromental effect and dielectric cover also used for gain enhancement. Table 3 compares the dimension of patch calculated from ANN model with the reference values calculated in [4] for different designed frequencies. This accurany of ANN model is very good to the reference values.

TABLE 3
COMPARISON OF PATCH DIMENSION CALCULATED FROM ANN MODEL AND PRESENT METHOD [4] OF SUSPENDED CIRCULAR MICROSTRIP ANTENNA WITH COVER

ε_{r1} = 1, h_1 = 0.5; ε_{r2} = 2.2; h_2 = 0.5mm, ε_{r3} = 3.27, ε_{r4} = 1 ; h_4 = 0				
fr (GHz)	PM [4]		ANN	
	Radius (mm)	h3/h2	Radius (mm)	h3/h2
3.43	19.999	0.95	19.9977	0.9495
3.73	18	3.59	18.0101	3.5785
4.5	14.951	8.58	14.999	8.5798
5.5	12.011	1.36	11.9792	1.3483
6.5	9.989	1.51	9.9906	1.499
7.7	7.9963	7.19	7.9793	7.191
10	6	3.76	6.0006	3.7605

D. Spaced Dielectric Microstrip Antenna

The spaced dielectric Circular microstrip patch antenna configuration can be achieved from Figure 3 by substituting h_1 = 1, ε_{r1} =1, ε_{r3} =1. The configuration of antenna is useful to calculate the effect on resonant frequencies due to intentional or unintentional air-gap over the patch. The resonant frequencies for various thickness of space dielectric have been tabulated in table 4. The resonant frequency calculated by ANN has been compared with [4,14]. The average accuracy of ANN model and reference values is 0.425% , 0.253% h_3 = 0.4 mm and 0.1 mm respectively against [4].

TABLE 4
COMPARISON RESONANT FREQUENCY CALCULATED BY ANN AND [4,,15] FOR SPACED DIELECTRIC

a =11.78 mm, ε_{r1} = 1; h_1 = 0; ε_{r2} = 2.43; h_2 = 0.49 mm; ε_{r3} = 1; ε_{r4} = 3..2				
h_3 = 0.4 mm				
h_4/h_3	fr (FDTD [15] GHz	f_r GHz [4]	f_r GHz ANN	%Dev ANN
1	4.446	4.416	4.412	1.042
2.5	4.435	4.401	4.403	0.719
5	4.41	4.390	4.392	0.419
7.5	4.39	4.382	4.381	0.198
12.5	4.37	4.368	4.366	0.091
14	4.36	4.345	4.357	0.078
h_3 = 0.1 mm				
h_3/h_4	Fr FDTD [15]	f_r GHz ANN)	f_r GHz [4]	% Dev ANN
0.2	4.41	4.369	4.375	0.126
0.4	4.435	4.406	4.401	-0.12
0.6	4.45	4.415	4.415	0.0
1	4.45	4.431	4.415	-0.36
2	4.46	4.455	4.433	-0.50
3	4.475	4.473	4.457	-0.36
5	4.49	4.491	4.492	0.065

In analytical ANN model, results are obtained by reversing the input-output data of the network. In this analytical ANN network have been used to calculate the dimension of the patch for air-gap (h_3 = 0.4, 0.1 mm) for the different resonant frequencies. Here, the ANN network is very useful for such a problem to calculate the dimension of space dielectric antenna for which no closed-form expression is available. The calculated dimension of ANN model are very close to reference dimension calculated by [4] as shown in Table 5.

TABLE 5
COMPARISON RESONANT FREQUENCY CALCULATED BY ANN AGAINST REFERENCE VALUES [4] FOR SPACED DIELECTRIC

ε_{r1} = 1; h_1 = 0; ε_{r2} = 2.43; h_2 = 0.49 mm; ε_{r3} = 1; ε_{r4} = 3.2				
h_3 = 0.4 mm				
f_r (GHz)	[4]		ANN	
	Radius mm	Height mm	Radius mm	Height mm
2.65	20	5.465	19.9775	5.4409
3.09	16.994	6.5	17.0203	6.4643
3.1	17	3.24	17.0188	3.2230
3.7	13.999	8.5	13.9555	8.4819
4.6	11.054	9.38	11.0309	9.38
4.7	10.991	0.81	10.9564	0.8131
9.36	5	9.6	4.9834	9.6407
9.4	5.005	7.847	5.0036	7.8313
9.5	4.9996	4.985	4.9993	4.9656
9.7	5	0.465	4.9993	0.4602
h_3 = 0.1 mm				
f_r (GHz)	[4]		ANN	
	Radius mm	Height mm	Radius mm	Height mm
2.7	19.999	0.462	19.9983	0.4676
3.2	17	2.857	16.9991	2.8460
3.8	13.99	0.345	13.9977	0.3419
4.8	10.996	0.545	11.0132	0.5437
6.6	8	1.992	8.0143	1.9856
10	5.0063	0.458	4.9921	0.4544
10.4	5.0059	4.62	5.0020	4.6120

E. Microstrip Antenna with Two Superstrates

The Circular microstrip patch with two superstrates configuration can be achieved from Fig. 3 by substituting h_1 = 1, ε_{r1} =1. This configuration of antenna is useful for designing the high gain antennas and to protect patch from enviromental effect. 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 [4,15]. Both are in close agreement.. The average % deviation in resonant frequency calculated by ANN model against [4] for ε_{r3} = 2.5515, ε_{r4} = 3.2 superstrate is 0.066% . Table 7 calculate the dimension of patch antenna using ANN model and compared with [6]. Both are in close agreement.

TABLE 6
COMPARISON OF THE RESONANT FREQUENCY CALCULATED FROM ANN MODEL AGAINST [4] FOR MICROSTRIP PATCH WITH TWO SUPERSTRATE

a = 11.78 mm ; ε_{r1} = 1; h_1 = 0; ε_{r2} = 2.43; h_2 = 0.49 mm; ε_{r3} = 2.5515; h_3 = 0.49 mm; ε_{r4} = 3..2				
h_4 mm	fr (FDTD) [15] GHz	f_r GHz [4]	f_r GHz (ANN)	% Dev ANN
0.3	---	4.3836	4.387	-0.0776
0.5	4.39	4.3579	4.3642	-0.1445
1	4.36	4.3416	4.3438	-0.5067
2	4.34	4.3231	4.3234	-0.0069
3.5	--	4.3056	4.3054	0.00465
4.5	--	4.2966	4.2964	0.00465
6	--	4.2852	4.2909	-0.133

In table 7, the dimension of the patch and required height of second superstrate have been calculated by ANN model for designed frequencies. The dimension calculated by ANN model has been compared with the value calculated by the PM method. Both are very close.

TABLE 7
COMPARISON OF THE DIMENSION CALCULATED BY [4] AND ANN MODEL FOR MICROSTRIP ANTENNA WITH TWO SUPERSTRATES

ε_{r1} = 1; h_1 = 0; ε_{r2} = 2.43; h_2 = 0.49 mm; ε_{r3} = 2.5515; h_3 = 0.49 mm; ε_{r4} = 3..2				
f_r (GHz)	PM		ANN	
	Radius mm	Height mm	Radius mm	Height mm
2.5	18.639	3.4	19.0485	3.4058
4.57	10.999	5.38	10.9925	5.3545
4.64	10.999	0.645	10.9921	0.6488
6.1	8	5.994	8.0001	5.9960
9.2	5	7.37	4.9886	7.3481
9.5	5	0.732	5.0016	0.7335

VI. CONCLUSION

An efficient design technique for multilayer circular microstrip patch antenna based on LM 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 by passes 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 layers.

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REFERENCES

[1] I. J. Bahl et. al, "Design of microstrip antennas covered with a dielectric layer," IEEE AP- 30, Mar.1982, pp.314-18.

[2] H. Y. Yang et .al,"Gain enhancement Methods for printed circuit antenna through multiple superstrate", IEEE Trans. AP. 35 (1987), pp.860-63.

[3] Raj Kumar and P. Malathi," Effects of Superstrates on the Resonant frequency of rectangular microstrip antennas", Microwave and Optical Tech. Letters, Vol. 49, No. 12, Dec. 2007, pp.2946-50.

[4] Raj Kumar, et. al ,"On the Design of Four Layered Circular Microstrip Patch Antenna", Microwave and Optical Techn Letters, Vol. 50, Dec. 2008, pp. 3206-12.

[5] V. Losada, R.R Boix , and M. Horno,"Resonant modes of Circular microstrip patches in multilayered substrate," IEEE Trans. MTT-47 (1999), 488-497.

[6] O. M. Ramahi et.al,"Superstrate effect on the resonant frequency of microstrip antenna s", MOLT,No. 5, 1992, pp. 254-257.

[7] R. Shivit ," Dielectric cove r effect on Rectangular Microstrip Antenna array",IEEE AP-42. 1994, pp.1180-84.

[8] R. K. Mishra, et.al.," Neutral network-based CAD model for the design of a square-patch antennas," IEEE , AP- 46, 1890-1891, 1998.

[9] S. Sagiroglu, K. Guney, M. Erler," Resonant frequency calculation for circular microstrip antennas using artificial neural networks", International Journal of RF and Microwave Computer-Aided Engineering, Vol. 8, No.3, pp. 270-277, 1998.

[10] S. Sagiroglu, K. Guney," Calculation of resonant frequency for an equilateral triangular microstrip antenna using artificial neural Networks" Microwave Opt. Technology Lett., Vol. 14, pp. 89-93, 1997.

[11] K. Levenberg, "A method for the solution of certain problems in least squares,Quart. Appl. Math., 1944, Vol. 2, pp. 164–168.

[12] D. Marquardt, "An algorithm for least-squares estimation of nonlinear parameters,"*SIAM J. Appl. Math.*, 1963, Vol. 11, pp. 431–441.

[13] F. Abboud, et.al, ''New Determination of Resonant Frequency of Circular Disc Microstrip Antenna: Application to Thick Substrate,'' *Electron. Lett.*,Vol. 24,No.17, 1988,pp. 1104-1106.

[14] T. Itoh and R. Mittra, ''Analysis of a Microstrip Disk Resonator,'' *Arch. Electron. U¨bertrugungs.*,Vol. 27, No. 11, 1973, pp. 456]458.

[15] 3D Electromagnetic Simulator "Concerto" of Vector Field Limited, UK.