STUDY OF RESONANT FREQUENCY OF CIRCULAR MICROSTRIP PATCH ANTENNA USING ARTIFICIAL NEURAL NETWORKS

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Abstract:

In recent years, engineers have gained great momentum in the field of wireless communication by utilizing Artificial Neural Networks. This paper presents the use of Artificial Neural Networks in designing of circular microstrip patch antenna and further use ANN for determining its resonant frequency. ANN model is developed to calculate the antenna dimensions for the given resonant frequency, dielectric constant and the height of the substrate. ANN is designed using radial basis function network. The results obtained show better agreement with the trained and tested data of ANN models. This presented ANN model is practically an alternative to the conventional detailed electromagnetic design of circular microstrip antenna. Furthermore, the neural model presented possesses high accuracy and requires no complicated mathematical function. The analysis and the synthesis of the model of ANN gives better results.

Keywords:

Circular microstrip patch antenna, Artificial Neural Network, closed form model, resonant frequency, effective patch radius.

Introduction :

Microstrip antennas (MSAs) have found great acceptance among the electromagnetic and microwave theory practitioners due to their numerous advantages. Hence, considerable amount of studies have been devoted to the characterization of their structures with different- geometries.

Microstrip patch antenna is used for high performance spacecraft, aircraft, missile and satellite communication [1], where size, weight, performance, cost of installation, and aerodynamic profile are constraints. These patch antennas are low profile, conformable to planar and non-planar surfaces, simple and inexpensive to manufacture using modern printed circuit technology. They are also mechanically robust when mounted on rigid surfaces. When a particular patch shape and excited mode are selected, they are very versatile in terms of resonant frequency, polarization, radiation pattern and impedance.

A circular microstrip patch resonator can be used either as a separate antenna or as a component of oscillators and filters in MWICs. It is quite important to develop accurate expressions for the calculation of these resonant frequencies, since the bandwidth of MSAs around their operating resonant frequencies is very narrow.

In order to develop simple closed form expressions for the effective patch radius of a circular microstrip antenna [2-4], the usual approach is to incorporate the influence of the fringing field at the edges and the dielectric inhomogeneity via a parameter called the 'effective patch radius', a_{eff}, which is slightly larger than the physical patch radius'a'as seen in fig.[1]. It is evident from the literature that a_{eff} of a circular MSA is determined by the relative dielectric constant of the substrate (ϵ_r), the physical patch radius(a) and the thickness of the substrate(h). The resonant frequency of circular MSAs for fundamental mode is calculated approximately using this effective radius expression.

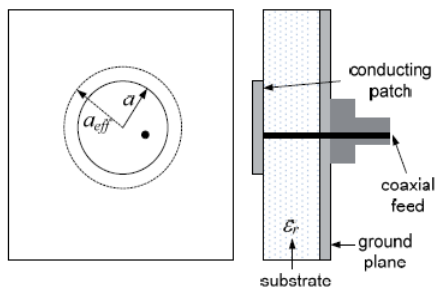

Fig. (1) Geometry of circular microstrip patch antenna.

In fig.(1) ,the circular MSA consists of a patch of radius 'a', which is parallel to the ground plane; and this patch is separated from the ground plane by a dielectric substrate with relative permittivity ϵ_r, and thickness 'h'. For this geometry, the resonant frequencies of the TM_{nm} modes can be computed as,

$$f_{nm} = \frac{\alpha_{nm}}{2\pi a\sqrt{\mu_0 \varepsilon}} = \frac{\alpha_{nm} c}{2\pi a\sqrt{\varepsilon_r}} \quad \text{---- (1)}$$

Where, α_{nm}= m^{th} zero of the derivative of the Bessel

n= order of the function.

c= velocity of light in free space

The value of α_{nm} for n=m=1 is 1.84118 for the dominant mode of the circular patch, which is TM_{11}. This TM_{11} mode of the circular microstrip patch is widely used in microstrip antenna applications.

In 2000, Akdagli and Guney [5] , constructed a closed form model for the effective patch radius depending on a, h and ϵ_r; and further computed the relevant co-efficients in their assumed model using the corresponding experimental data.

The rectangular and circular patch, fig. (2)is the basic and most commonly used design for microstrip antennas.

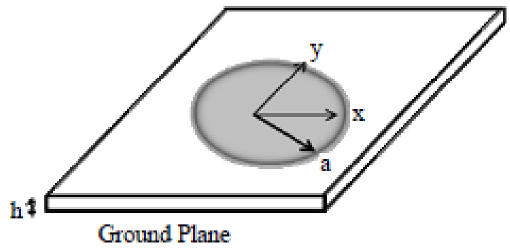

Fig. (2) Circular Microstrip Antenna (CMSA)

ANN is the most powerful optimizing tool in the field of computational electromagnetics. The basic characteristics of ANN are its ability to learn and generalize fault tolerance, non- linearity and adaptivity. When ANN undergoes learning in an unsupervised manner, it extracts the features from the input data based on a predetermined performance measure .When ANN undergoes learning in supervised manner, it is presented with the input pattern and the desired output patterns. The parameters of the ANN are adapted such that the application of an input pattern results in the desired pattern at the output of the ANN [6]. The Quasi Newton (QN) is one of the proven universal approximator in ANN design.

2. Design of Microstrip Patch Antenna

Microstrip patch antennas consist of very thin metallic strip (patch) placed on the ground plane, where the thickness of the metallic strip is restricted by $t<<\lambda_0$ and the height is restricted by $0.0003\ \lambda_0 \leq h \leq .05\ \lambda_0$ [7-9] .The microstrip patch is designed so that its maximum radiation pattern is normal to the patch. For rectangular patch, the length L of the element is usually $\lambda_0/3<L<\lambda_0/2$ .There are numerous substrates that can be used for designing microstrip antennas and their dielectric constants usually lie in the range of $2.2 \leq \epsilon_r \leq 12$ .To implement the microstrip antennas, usually Fr-4 (ϵ_r =4.9), Rogers TMM4 (ϵ_r =4.5) , Taconic TLY-5(ϵ_r =2.2), Alumina(96%) (ϵ_r =9.4), Teflon (PTFE) (ϵ_r=2.08), Arlon AD5 (ϵ_r =5.1) dielectric materials are used as the substrate .

The performance of the microstrip antenna depends on its dimension. The dimensions of the operating frequency also influence the other related parameters such as radiation, efficiency, directivity, return loss etc. For an efficient radiation, the practical width of the patch can be determined as follows [7,8,10].

$$w = \frac{1}{2 f_r \sqrt{\mu_0 \varepsilon_0}} \times \sqrt{\frac{2}{\varepsilon_r + 1}} \qquad \text{---- (2)}$$

And the length of the antenna is given as,

$$L = \frac{1}{2 f_r \sqrt{\varepsilon_{eff}}\ \sqrt{\varepsilon_0 \mu_0}} - 2\Delta L \qquad \text{---- (3)}$$

where ,

$$\Delta L = 0.41h \frac{\varepsilon_{eff} + 0.3}{\varepsilon_{eff} - 0.258} * \frac{\left(\frac{w}{h} + 0.264\right)}{\left(\frac{w}{h} + 0.8\right)}$$

---- (4)

and

$$\varepsilon_{eff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2\sqrt{1 + 12\frac{h}{w}}}$$

---- (5)

where, λ=wavelength

f_r=resonant frequency

L=length of the patch element

w=width of the patch element

ϵ_r = Dielectric Constant

Fig.(3) shows an antenna that has been designed to cover operating frequency of 10GHz and the quarter wavelength transformer method is used to match the impedance of the patch element with the transmission line [7-8].

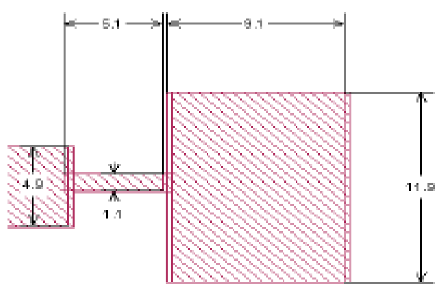

Fig. (3). Single element microstrip patch antenna.

3. Designing circular microstrip antenna (CMSA) using the closed form expression

The performance of circular microstrip antennas has been studied extensively, both analytically and experimentally. Consider the circular microstrip antenna with radius 'a' , height 'h' and permittivity constant ϵ_r ,whose resonant frequency in the dominant TM_{11} mode as explained by Guney [11] is given by

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

---- (6)

and

$$f_r = \frac{1.84118c}{2\pi a\left[\varepsilon_{eff}\left\{1+\frac{2h}{\pi\varepsilon_r a}\left(ln\left(\frac{a}{2h}\right)+(1.44\varepsilon_r+1.77)+\frac{h}{a}(0.268\varepsilon_r+1.65)\right)\right\}\right]^{1/2}} \quad \text{---- (7)}$$

where , c= velocity of light

a= radius of circular patch

f_r= resonant frequency of circular patch.

h= height of dielectric substrates.

$\epsilon_{r=}$ permittivity of dielectric substrate

α_{nm}= 1.84118C (for n=m=1)

The six patches of CMSA are designed by considering height h=0.235 and ϵ_r=4.55 with variation of radius a.

The resonance frequency f_r calculated by the Guney's equation was tested in four different and independent experiments. Their results when compared, show very little variation [12-15]. The deviations for resonant frequency of CMSA developed, as measured by Abbound [12], Howell [13], Wolff [14] and Derneryd [15] are 0.179880, 0.07276, 0.0783328, 0.234236 respectively, which are very low as presented in table 1. This explains the reason why researchers choose Guney's equation for studying ANN- modeling.

f_r(GHz)[6]	Abboud[7]	Deviation	Howell[8]	Deviation	Wolff[9]	Deviation	Derneryd[10]	Deviation
5.43489	4.945	0.43978	5.353	0.08267	5.308	0.12378	4.848	0.58588
4.09053	3.75	0.32063	3.963	0.12827	3.95	0.14163	3.661	0.41626
2.15468	2.003	0.16086	2.061	0.09286	2.067	0.08823	1.965	0.18238
1.43883	1.36	0.07289	1.379	0.06024	1.384	0.05293	1.332	0.10524
1.07843	1.03	0.04543	1.037	0.04234	1.042	0.03843	1.009	0.06655
0.863	0.825	0.03970	0.833	0.03002	0.836	0.028	0.814	0.04911
Average Deviation		0.179880		0.072760		0.078832		0.234236

Table 1. Analysis of deviation of measure result from Guney's Equation

5. **Analytical designing of circular microstrip antenna using QN-ANN model.**

In this model, the accurate value of resonant frequency has been calculated by using equation (6) and (7). The input parameters are permittivity ϵ_r, the height of substrate 'h' and patch dimension in terms of radius 'a'. Fig. (4) shows the analysis model of ANN.

The QN-ANN model consist of three layers, i.e the input layer, the hidden layer and the output layer. The neurons for input layer are 3 and for hidden layer are 12; while the output layer has only one neuron as shown in Fig. (5). The performance result of testing is graphically displayed in Fig. (6).The result of only six patches is shown in the table 2. The output of ANN model is compared with the target data where QN-ANN model shows a little error of 0.001211 and is therefore considered the best ANN analysis model for the design of CMSA.

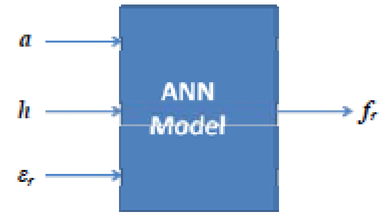

Fig (4).Analysis model of ANN.

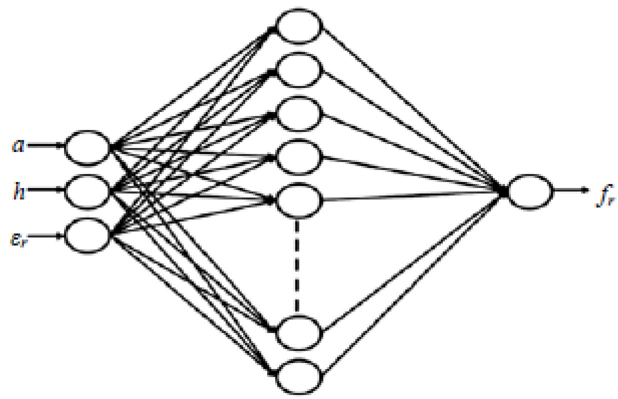

Fig (5). QN structure of analysis design of CMSA

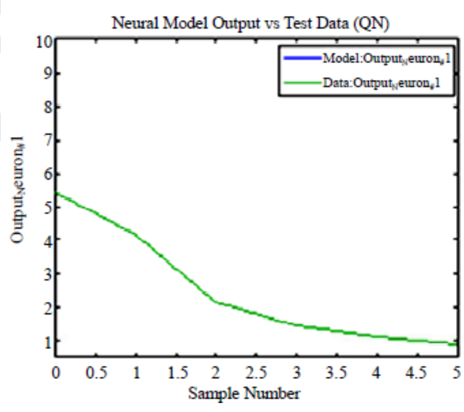

Fig (6) Performance result of testing QN-ANN model of CMSA

Input Parameter			Target	QN	
a(radius)	h	ϵ_r	f_r(GHz)	ANN O/P(GHz)	Error (GHz)
0.77	0.235	4.55	5.441315	5.441164	-0.000151
1.04	0.235	4.55	4.086281	4.090526	0.004245
2	0.235	4.55	2.15468	2.154862	0.000182
2.99	0.235	4.55	1.439682	1.439156	-0.000526
3.975	0.235	4.55	1.078185	1.078434	0.000249
1.95	0.235	4.55	0.863001	0.866268	0.003267
AVERAGE VALUE			2.510524	2.511735	0.001211

Table-2 Forward modeling for the prediction of resonant frequency

6. **Synthetical designing of circular microstrip antenna (CMSA) using QN**

So many methods are available for the calculation of resonant frequency of different patch antennas. But, the reverse calculation of radius a from the inputs resonant frequency fr, height h and permittivity constant ϵ_r is not available in the literature. The reverse model which is also called the synthesis model, predicts the value of the radius of the circular patch as shown in Fig. (7). The synthesis model consist of three layers: the input layer with three neurons, the hidden layer with 12 neurons and the output layer with one neuron. The hidden layer uses sigmoid function while output layer uses linear function as shown in Fig. (8). The performance graph of testing the synthesis model is presented in Fig (9). The actual error in values is given in table 3 with very less error 0.0006 for the prediction of radius.

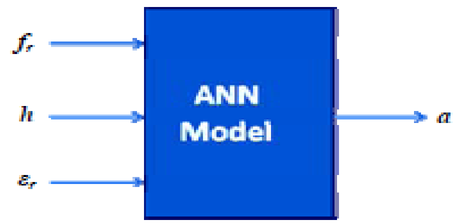

Fig. (7) Synthesis model of ANN

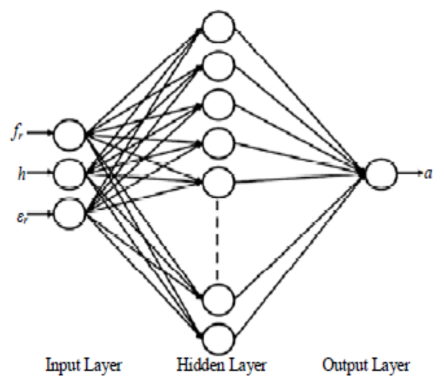

Fig .(8) QN structure of synthesis design of CMSA.

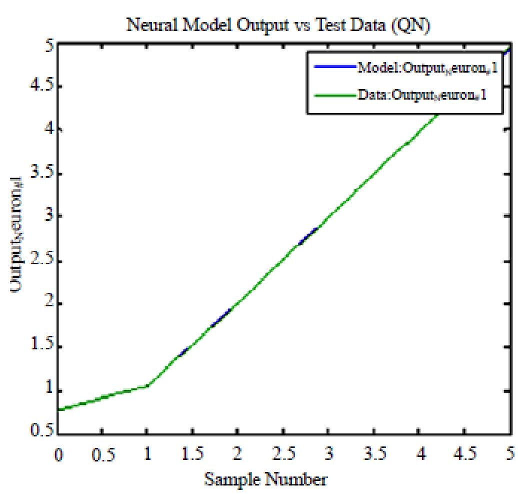

Fig. (9). Performance result of testing QN-ANN model of CMSA.

Input Parameter			Target	QN	
f_r (GHz)	h	ϵ_r	a (radius)	ANN O/P (GHz)	Error (GHz)
5.434885	0.235	4.55	0.77	0.76673	0.00327
4.0905226	0.235	4.55	1.04	1.043208	-0.00321
2.15468	0.235	4.55	2	2.001889	-0.00189
1.438828	0.235	4.55	2.99	2.988124	0.001876
1.078434	0.235	4.55	3.975	3.976177	-0.00188
0.863001	0.235	4.55	4.95	4.945272	0.004729
Average Value			2.620833	2.620233	0.0006

Table-3Reverse modeling for the prediction of radius

Result

The results demonstrate an excellent capacity of the neural model approximation that has been analyzed from Table 1, 2 and 3. The good agreement between the neural models also demonstrates a good generalization capacity of the developed model through the Quasi-Newton modular structure.

Conclusions

Using these models, one can calculate resonant frequency of circular microstrip antenna accurately. Also, the other ANN model of synthesis has unique characteristic of predicting radius of circular patches which is not available in the literature. In this work, the neural models presented possess high accuracy and do not require any complicated mathematical functions. The analysis and synthesis model of ANN gives better results for CMSA design which is found to compare well with the fabricated and measured value .So, both the models are efficient for the prediction of resonant frequency and radius of circular patch.

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