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An ANN–Based Synthesis Model of Wide-Band Microstrip–Line-Fed Antenna with Defected Ground Structure

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***Abstract* :** An artificial neural network (ANN) based synthesis model is proposed to obtain physical dimensions of wide-band microstrip-line-fed antenna (WBMLFA) with defected ground structure (DGS). The model can be designed for various defected structure such as circular, rectangular, triangular etc. In this paper a circular shape defect is integrated in the ground plane to achieve wide band. The training data sets for ANN-based synthesis model are collected from the empirical formulas. To achieve an accurate synthesis model, Levenberg-Marquardt (LM) algorithm and three hidden layered MLPs network is trained. At last, the model is validated by comparing its result with the electromagnetic simulation and measurement, which shows good agreement among them. The synthesis model may be a good choice to antenna engineers for directly obtaining patch dimensions of the WBMLFA with DGS.

***Keywords* :** Artificial neural network, computer-aided design, defected ground structure (DGS), synthesis model, wide band microstrip antenna

1. INTRODUCTION

Microstrip patch antenna (MPA) are used in many communication application due to their simplicity, conformability, low manufacturing cost, light weight, low profile, reproducibility, reliability, and ease in fabrication [1-3]. MPA has also the capability of integration with others devices [4]. The main disadvantages of conventional MPA are narrow bandwidth, low gain and cross-polarized radiation characteristics [5]. Thus, enhancement of bandwidth and gain of MPA has become a challenging current research area. In many literatures, MPA with defected ground structure (DGS) has been reported for improving the performance of patch antenna [6-9]. D.Guha et. al. has been reported, MPA with DGS for cross polarization suppression [6]. JY Jan et. al. has been reported bandwidth enhancement using rotated square shape defect in the ground plane [7]. AK Gautam et. al. has been reported a novel dual-band asymmetric slit with DGS for circular polarization operation [8]. MK Khandelwal et. al. has been reported DGS microstrip-line-fed antenna in Ku band application [9].

Almost in all DGS structure design process, the resonant frequency and other parameters must be determined by empirical formulas, electromagnetic simulation, or by practical measurement. We know that electromagnetic simulation takes tremendous efforts (head and trial basis) and practical measurement is much costly. Thus empirical

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formulas are one of the best solutions to calculate the resonant frequency and other parameters. However, empirical formulas are more complex and the physical dimensions of MPA cannot be directly calculated. Therefore, a CAD model is required to find out the optimized physical dimension of patch.

In recent few years CAD model based on artificial neural network (ANN) have been applied for analysis and synthesis for MPAs in various form such as circular, rectangular, triangular [10-13]. The resonant frequencies calculation for MPAs is normally done by analysis model. The synthesis model is used to compute physical dimensions for required design specification of MPA, with ANN inverse modeling method [14-15]. An ANN synthesis model for a single feed corner-truncated circularly polarized square microstrip antenna with and without air gap is reported in [16-17]. However, there is no synthesis model is available in the literature for any structure of wide-band microstrip-line-fed antenna with defected ground.

In this paper, an ANN-based synthesis model of WBMLFA with circular DGS is proposed. And at last, antenna with synthesized parameter it design, simulated and measured to validate this model.

2. ANTENNA STRUCTURE AND DESIGN THEORY

Figure 1(*a*) shows the proposed geometry of MPA. A circular slot of radius '*a*' is integrated in the ground plane. The radius of the slot is chosen same as in simple circular microstrip patch antenna (MPA) [12]. An open ended microstrip line (50-Ω) of width w_{ml} and length l_{ml} is placed on opposite side of the ground plane. A circular defect of same radius is taking in the ground plane, shows wide band characteristics. The feeding distance r_1 between the open-end-edge of microstrip-line and centre of the circular slot, controls return loss level of antenna. The MPA etched into a dielectric substrate of D × D with a thickness of *h*, loss tangent of tan δ and relative permittivity of $_r$. The radius of defected circular slot *a* is determined as [5]

$$a = \frac{F}{[1 + (50\,h / \pi\varepsilon, F)\{\ln\{\pi F/50h) + 1.7726\}]^{1/2}} \tag{1}$$

where *h* and $_r$ is the thickness and dielectric constant of the substrate respectively, and F is

$$F = \frac{8.791 \times 10^9}{f_{\min}\sqrt{\varepsilon_r}} \tag{2}$$

where $f_{\min}$ is the lowest frequency of the design antenna. This is considered as the designing frequency of wideband MPA and in this paper it is 10 GHz.

The feeding distance r_1 is chosen as the input impedance of the slot is to be 50 Ω at the end edge point of microstrip line for perfect matching because a 50 Ω microstrip line is used to excite the circular slot in ground plane, which works as a tuning stub. The variation in the length of stub affects the reflection coefficient of the antenna and controls the return loss level. The feeding distance r_1 can be calculated by [18]

$$R(r_1) = \frac{1}{G_T}\frac{J_1^2(k.r_1)}{J_1^2(k.a)} \tag{3}$$

where k is the propagation constant and G_T is the total conductance due to ohmic, dielectric and radiation losses. Feeding distance r_1 is calculated for the value of 50 Ω of the input impedance R(r_1). The parameters used in equation are calculated as [18] and the Bessel function of order one, J_1 is expanded in terms of polynomial [19], for $-3 < t < 3$:

$$J_1(t) = t\begin{pmatrix} 0.5 - 0.56249985\,(t/3)^2 + 0.21093573\,(t/3)^3 \\ -\,0.03954289\,(t/3)^6 + 0.00443319\,(t/3)^8 \\ -\,0.0031761\,(t/3)^{10} \end{pmatrix} \tag{4}$$

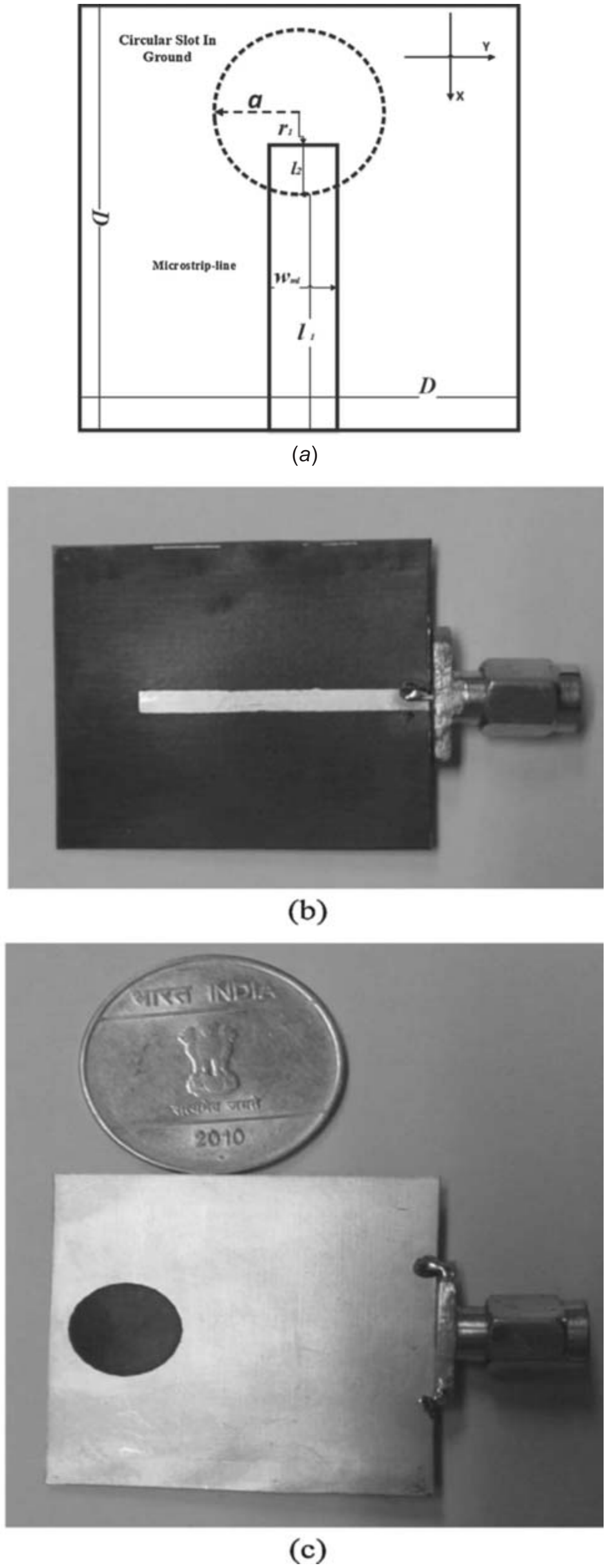

Fig. 1. Proposed microstrip patch antenna (*a*) Geometry, (*b*) fabricated top view, (*c*) fabricated bottom view.

The length of microstrip line L is divided in two part l_1 and l_2. There is no ground plane under the length l_2 and its work as a matching stub for the defected ground structure. The length L of microstrip line is taken as

$$\mathrm{L} = l_1 + l_2 = \frac{5}{4}\,\lambda_{eff} \tag{5}$$

where,
$$\lambda_{eff} = \frac{c}{f_{\min}\sqrt{\varepsilon_{eff}}} \tag{6}$$

where c is free space light speed and λ_{eff} is the effective dielectric constant of microstrip line [5]. The length l_{ml} and width w_{ml} of microstrip line are calculated as 27.41 mm and 2.30 mm respectively for proper matching.

It should be noted that for wide band operation when the required design frequency f_{min} and the supplied substrate (h, λ_r, tan δ) are given, the physical dimension of WBMLFA for circular DGS patch (a and r_1) can't be directly obtained from equation (1)-(6). To solve this type of problem, ANN inverse modeling method [14-15] is used to construct the nonlinear relation between (f_{min}, ${}_r$, tan δ, h) and (a, r_1) in next section. After synthesis the optimized dimensions of proposed antenna is listed in table 1 and design figure shown as figure 1(b), figure 1(c).

Table 1. Final optimised design parameter

parameter	***(mm)***	***parameter***	***(mm)***
a	5.54	l_{ml}	27.41
r_1	1.52	h	0.762
w_{ml}	2.30	D	36

3. ANN-BASED SYNTHESIS MODEL

ANN is one of the most popular and intelligent tool to model nonlinear relation, simulation, and optimization [20-21]. Two special class of ANN architecture, Multi-layer Perceptrons (MLPs) [22] and Radial-basis Function Networks (RBFNs) [10] have been widely used to synthesize this type of problem. In this paper MLP network architecture is used. An MLP consist with three types of layers: an input layer, an output layer and one or more hidden layers. The results of MLPs for a particular problem depend on the use of learning algorithm. After several trials, the Levenberg-Marquardt (LM) algorithm gives better results than other.

The aim of this paper is to develop an accurate ANN-based synthesis model of WBMLFA for circular DGS patch. Fig.2 gives an ANN-based synthesis model for proposed patch. This ANN-based synthesis model can be used to calculate the physical dimension of WBMLFA for circular DGS patch (a and r_1) with required design frequency f_{min} and the parameter of dielectric substrate (h, ${}_r$, tan δ).

Table 2. Comparison of MLP-based synthesis model with different hidden layer configuration

Configuration of hidden layers			***Two hidden layers***			***Three hidden layers***		
			16*16	16*20	16*25	16*20*4	16*20*6	16*20*8
Training Time			800sec	998sec	1078sec	944sec	1002sec	1153sec
ARE(%)	a	Training Test	0.5720.781	0.4960.623	0.7740.982	0.2430.289	0.2110.258	0.2010.264
	r_1	Training Test	0.891.01	0.7440.982	0.5590.861	0.6230.842	0.4720.632	0.4390.617
MRE(%)	a	Training Test	2.443.21	2.122.97	4.765.93	2.102.97	1.932.22	2.172.42
	r_1	Training Test	5.326.51	4.056.11	6.427.46	2.642.88	2.322.41	3.123.41
MSE(mm)	a	Training Test	$2.91*10^{-9}$ $1.77*10^{-4}$	$2.25*10^{-9}$ $1.34*10^{-4}$	$5.62*10^{-8}$ $2.72*10^{-4}$	$1.54*10^{-9}$ $1.86*10^{-4}$	$2.25*10^{-9}$ $1.34*10^{-4}$	$5.62*10^{-8}$ $2.72*10^{-4}$
	r_1	Training Test	$3.02*10^{-9}$ $2.12*10^{-4}$	$2.87*10^{-9}$ $1.99*10^{-4}$	$3.91*10^{-8}$ $3.22*10^{-4}$	$2.15*10^{-9}$ $2.72*10^{-4}$	$2.70*10^{-12}$ $1.75*10^{-5}$	$2.11*10^{-11}$ $3.45*10^{-5}$

The accuracy of ANN-based synthesis model is depends on training data sets used during training. The training and test data sets generated from equation (1)–(4) for $0.2 \text{ mm} \le h \le 32$ mm, $1 \le {}_r \le 14$, $10^{-4} \le \tan\delta \le 10^{-16}$ and 1 mm ≤ a ≤ 10mm. In generated data sets, the data sets beyond $h \le 0.1\lambda_g$) were removed (h is thickness of dielectric substrate and λ_g is the guided wavelength in dielectric substrate. Because the experiment performed in [23] has demonstrated that the formula based on the transmission line model is accurate for common engineering application ($h \leq 0.1\lambda_g$). Now the collected data sets were arranged in four-row input matrix (h, $_r$, tan δ, and f) and two-row output matrix (a and r_1). Before training, the data sets were scaled in [–1, + 1] to each row of input as well as output matrix for easier learning process. In this proposed model 9000 data sets generated, out of which 8000 are used for training and 1000 are used to test the trained model.

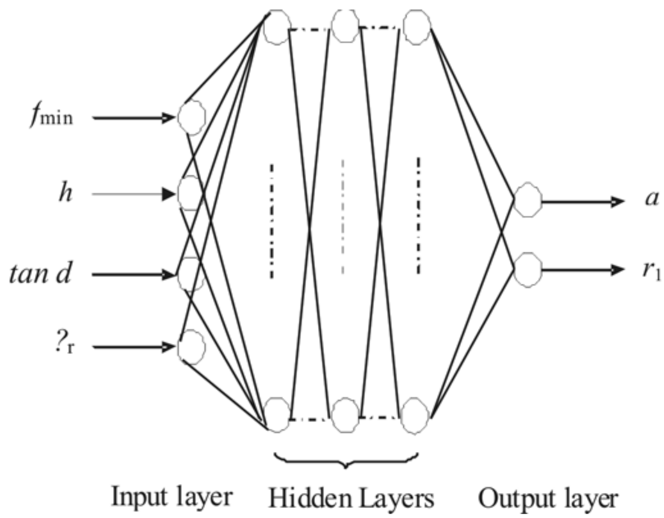

Fig. 2. Ann-based synthesis model for proposed microstrip patch antenna

The accurate ANN-synthesis model needed a suitable number of neurons in hidden layers. For proper configuration of hidden layers of proposed model, many experiments were carried out. After many trials, by changing the epoch, neurons and activation functions in layers, high accuracy is achieved using MLP with three hidden layered network. Hence, the model has total 5 layers (three hidden layers, one input layer and one output layer). The best suitable network configuration were found $4 \times 5 \times 22 \times 8 \times 2$, mean that the number of neurons are 4, 5, 22, 8, 2 in Input layer, 1st, 2nd, and 3rd hidden layers and output layer respectively. The linear activation function found suitable for input and output layer and tangent sigmoid activation function found suitable for hidden layers. Initial weights of ANN model are set up randomly. The weights adoption used mean square error (MSE) between target and output of ANN. The training epochs was found 859 for accurate model.

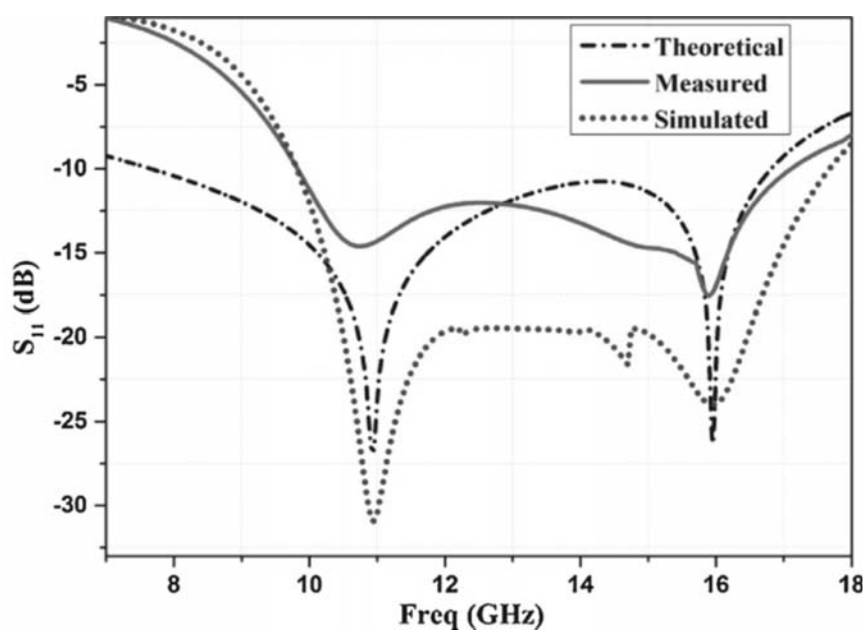

Fig. 3. S_{11} vs Frequency Variation among measured, simulated and theoretical.

4. RESULT AND DISCUSSION

In the proposed WBMLFA for circular DGS patch, ANNs have been successfully introduced. For accurate synthesis model, MLPs are trained with LM algorithms [21] and different hidden layer configurations are investigated. The training times at MatLab R2000a on a Intel(R) Core(TM) i5-3210M CPU @2.50Ghz computer are noticed for comparison, and the accuracy of model is evaluated with maximal relative error (MRE), average relative error (ARE) [16] and MSE [11]. The comparisons are shown in table-2, and it is observed that an MLP with 3-hidden layers has higher accuracy and training efficiency.

The physical dimensions (a and r_1) of the proposed MPA for the required operation frequency f_{min} with the given parameter of dielectric substrate (h, $_r$, tan δ) are obtained from the model. Final optimized value of a and r_1 for proposed wide band antenna is find out 5.54 and 1.52 respectively. To validate this MLPs based model, the results obtained from the synthesis model are compared with HFSS simulation and find out in good agreement. It is also observed that some discrepancy in result is shown which is due to the inaccuracies in ANN calculation, HFSS simulation and from the empirical formulas (formulas have different level of approximation such as imperfect magnetic wall and the fringing field at the open end edge [12]). However, the discrepancy in the model is less than 2%. Therefore, the MLP based model can be used for synthesis of such types of DGS patch.

After successfully validation of model, the proposed MPA is fabricated on RT Duroid-5880 substrate ($_r$ = 2.2, tan δ = 0.0009, and h = 0.762 mm) of dimension 36mm*36mm*0.762mm. The value of a and r_1 is taken from ANN synthesis model. The fabrication of antenna is done by standard photolithography techniques. The return loss of fabricated antenna is measured on Agilent^{TM} Network Analyzer PNA-L Series. We also obtain the return loss by the HFSS simulation. Figure 3 shows the synthesized results for comparison among measured, simulated and theoretical S_{11} variation with frequency. The results are in good agreement with theoretical result.

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