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COMPARATIVE STUDY OF TRANSMISSION LINE AND CAVITY MODEL OF RECTANGULAR MICROSTRIP ANTENNA

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ABSTRACT

In this paper a comparative study is carried out to estimate the performance of transmission line and cavity models of rectangular microstrip antenna mounted on six dielectric substrate materials with variable substrate heights. An artificial intelligence technique, namely: MATLAB based Adaptive Neuro-Fuzzy Inference System is used to optimize the length and width of the antenna. Random data sets are generated and experimental data are used to carry out the optimization of various antenna parameters to cover almost entire cellular spectrum. With operating frequency of 2.1GHz, we analyze the bandwidth of the antenna of both the models. The simulation results predict that the cavity model of rectangular microstrip antenna perform well over transmission line model with thick substrate while transmission line model is better at low dielectric constant and thin substrate.

Keywords: Artificial intelligence, Bandwidth, Cavity model, Dielectric constant, Transmission line.

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Contribution/ Originality

The manuscript is the outcome of original research work carried out by the authors

1. INTRODUCTION

The Microstrip Antenna (MSA) consists of a metallic patch on a grounded substrate. Due to its inherent qualities, namely: (i) light weight, (ii) compact size and (iii) conformable to mount structure, the microstrip technology is being widely used in space and mobile applications [1].

1.1. Related Works

In the year 2009, Guney and Sarikaya [2] presented a comparative study on performance of Mamdani and Sugeno Fuzzy Inference System (FIS) models for resonant frequency computation

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of rectangular microstrip antenna (RMSA) mounted on thin and thick substrates. Their findings predict that Sugeno type FIS model trained by the least squares algorithm (LSA) is consistent with the experimental results and can be used conveniently for design of patch antenna, because the model require least computer memory.

In the year 2012, Rop, et al. [3] studied parametric optimization method of rectangular microstrip antenna using Adaptive Neuro-Fuzzy Inference System (ANFIS).

In the year 2013, Shivendra, et al. [4] presented the design of rectangular MSAs using artificial neural networks.

In the year 2014, Vishal and Upadhyay [5] presented a review of Soft Computing Techniques for design of rectangular MSAs.

Considering the importance of the subject, we propose to study the transmission line and cavity models of RMSA by simulating the antenna parameters with simulation software Matlab (Version 7.8). We used ANFIS, implemented in Matlab to optimize the length and width of the proposed antenna and analyze the performance of both the models for computations of bandwidth (BW).

2. DESIGN CONSIDERATIONS

The MSA has different propagation constants in air and dielectric media. Therefore, effective dielectric constant is considered to account for fringing length extension [1]. The rectangular configuration is considered for the analysis with patch length L and width W in dielectric medium. The patch metallization thickness is considered to be negligible. The dielectric substrate thickness is taken to be within 1.5 mm $\leq h \leq 8mm$. The dielectric constant of the substrate ε_r is considered in the range of $1.05 \leq \varepsilon_r \leq 11.9$ for generation of random data to optimize length and width of the RMSA in the frequency range of 0.845-7.245 GHz. With the emphasis on low cost substrate materials, various dielectrics, such as R03006, Duroid 5880, DiClad880, Silicon, FR4 Glass-Epoxy and Alumina are used for simulation to determine the best possible parametric values for the RMSA.

3. THEORETICAL FORMULATIONS

The RMSA can be analyzed using a two aperture transmission line model or cavity model loaded with dielectric materials [1]. The transmission line model representation of RMSA can be thought as a lossless two parallel lines of thickness equal to the aperture dimensions constituting the patch width W and height h separated by a distance equal to patch length L . While the lossless cavity model can be constructed by assuming the patch and the ground plane to be perfect electric conductors representing the top and bottom walls of the cavity and side walls representing the magnetic walls circumscribe along the perimeter of the space so that contributions of all the four slots can be taken into consideration [6].

The effective value of permittivity (ε_{ef}) is a strong function of substrate thickness and patch width. The performance of antenna degraded at extremely high frequency. However, for thin substrate within few GHz frequency range ε_{ef} can be expressed as Balanis [1]:

$$\varepsilon_{ef} = \frac{(\varepsilon_r+1)}{2} + \frac{(\varepsilon_r-1)}{2}\left[1 + 12\frac{h}{W}\right]^{-\frac{1}{2}} \qquad (1)$$

where $\boldsymbol{\varepsilon_r}$ is the relative permittivity of the substrate, h and W represents thickness and patch width respectively.

The fringing of field is responsible for extension of the patch length beyond its geometrical dimensions, the amount of incremental distance $\boldsymbol{\delta L}$ can be expressed as [1]:

$$\delta L = 0.412h\frac{(\varepsilon_{ef}+0.3)(W/_h+0.264)}{(\varepsilon_{ef}-0.258)(W/_h+0.8)} \qquad (2)$$

The length and width is given as Balanis [1]:

$$L = c/2f\sqrt{\varepsilon_{ef}} - 2\delta L \qquad (3)$$

$$W_e = \frac{c}{2f}\sqrt{2/(\epsilon_r + 1)} \qquad (4)$$

Where c is speed of light and f frequency

The Cavity model BW formula (CAD) can be expressed as Kai Fong and Wei [7]:

$$\mathrm{BW} = \frac{1}{\sqrt{2}}\left[\left(\frac{16}{3}\right)\left(\frac{pc_1}{\epsilon_r}\right)\left(\frac{h}{\lambda_0}\right)\left(\frac{W_e}{L_e}\right)\left(\frac{1}{e_r^{sw}}\right)\right] \qquad (5)$$

The Transmission line model BW formula can be given as Rop, et al. [3]:

$$\mathrm{BW} = 3.77(\epsilon_r - 1)/\epsilon_r^2(W/L)(h/\lambda_0) \qquad (6)$$

3.1. Adaptive Neuro-Fuzzy Inference System (ANFIS)

The modeling techniques based on FIS are attractive and have found many successful applications in various fields. The fuzzy approaches are rule-based structures and are able to capture the dependency between inputs and outputs of a system. The fuzzy linguistic variables provide a natural way to deal with uncertainties and are capable of modeling nonlinear systems. The singular and linguistic outputs can be easily formed and are also insensitive to random noise. When FIS tune with an Artificial Neural Network (ANN) the capability of the system increased. Since ANFIS is a combination of ANN and FIS, so they works together for a given input and output sets of data, adjust the FIS membership function parameters using either back propagation algorithm or in combination with a least square type of method [3]. The ANFIS support Sugeno FISs which can be used to accurately model highly nonlinear systems. The ANFIS architecture consists of five layers, namely: (a) fuzzy layer, (b) product layer, (c) normalized layer, (d) de-fuzzy layer, and (e) output layer to process the data and acquire a single output.

4. SIMULATIONS

ANFIS is an efficient tool which can be utilized to optimize the parameters of RMSA. In the first run, we provide the inputs as substrate height h, resonant frequency f_r, and dielectric constant $\boldsymbol{\varepsilon_r}$ and acquire outputs as optimized width W. In the second run we use all the four parameters as inputs and get optimized length L. We have used some of the optimized data of Guney and Sarikaya [2]; Rop, et al. [3] for training and testing. Finally the optimized W and L are used to compute BW to perform comparative analysis. ANFIS technique is implemented in MATLAB. Using the Eqn.1 to Eqn. 4, training data sets are generated. ANFIS model has only one output and two similar design stages were formulated to optimize W & L.

5. RESULTS AND DISCUSSION

The effective dielectric constants of six different substrate materials are calculated to get the patch dimensions W and L. ANFIS model is simulated to optimize W and L of the RMSA as listed in Table-I. It is observed that the optimized value of W is slightly less than the calculated values when we use triangular membership function (TMF). This could be due to choice of membership function, while optimized length remains almost constant. In the design of MSA, the resonant frequency and types of substrate material used are fundamental in determining other physical parameters. Fig.1 illustrates the first stage indicating the number of variables used. The membership values were specified in such a way that the total number of rules become 36. At the end of the training, the root mean square error (RMSE) was 0.0068 at epoch number 300. The optimized patch width is then used in optimization for the second stage. The second stage of ANFIS model produced an optimized patch length. With four variables as shown in Fig. 3 specified as inputs, optimization is carried out which results in an RMSE error of 1.66e-04. The simulation of ANFIS model and membership functions for first and second optimization stages is shown in Fig.2 and Fig.4. We have used TMF in the FIS model for optimization. The optimized width and length as function of frequency in the range of 0.845GHz-7.345 GHz for 15 data point for each dielectric substrate is carried out and the responses are shown in Fig.5-6. It is observed that the Cavity model perform well for same data values with thick substrate while Transmission line model out performs cavity model for low value of dielectric constant and thin substrate.

Table-I. Comparison of transmission line and cavity model of RMSA with optimized parameters

Calculated (mm)				Optimized output in mm		Optimized		BW%	
ε_r	h	W	L	W_{opt}	L_{opt}	p_{fac}	η_r Efficiency	T-lineeqn.(7)	Cavityeqn.(6)
2.32	1.6	55.439	46.179	55.414	46.179	0.84	95.5	1.2432	1.2361
3.7	3.2	46.595	36.024	46.574	36.020	0.89	85.5	2.1542	2.3352
6.15	7.97	37.786	25.480	37.760	25.479	0.93	63.6	4.2489	6.3184
9.8	1.58	30.738	22.647	30.720	22.646	0.95	88.4	0.5186	0.5617
10	2.2	30.457	22.227	30.448	22.227	0.95	84.5	0.7160	0.8124
11.9	1.57	28.125	20.544	28.110	20.544	0.96	88	0.4167	0.4538

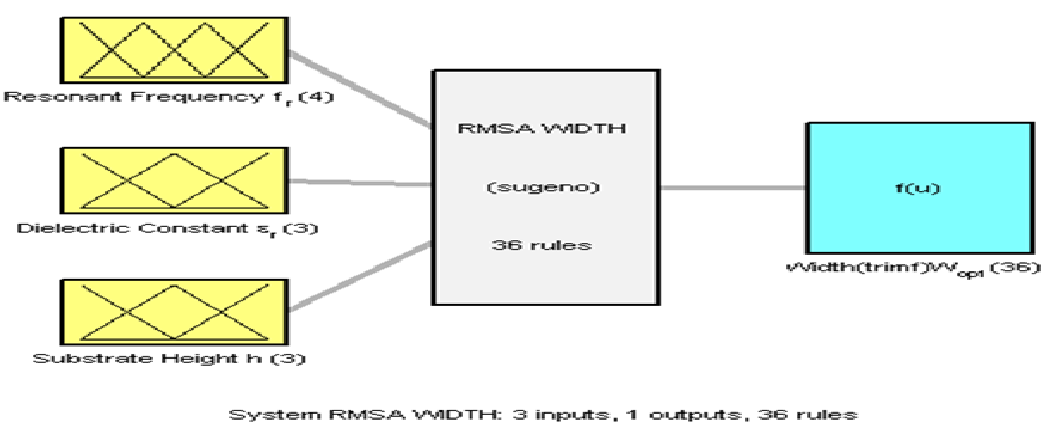

Figure-1. First stage of ANFIS model for optimization of patch widths

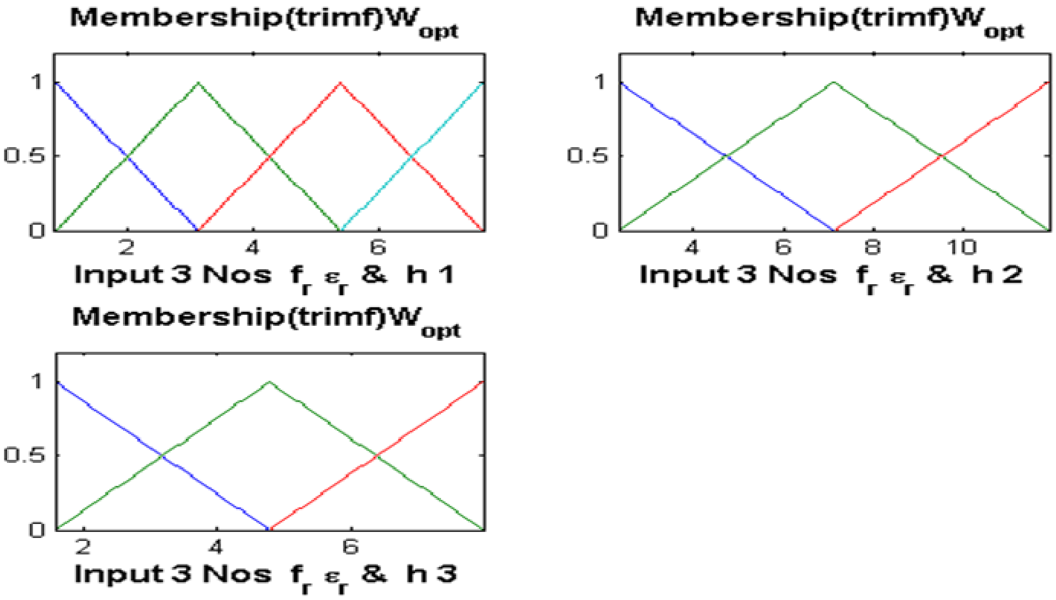

Figure-2. First stage of initial membership values (FIS model) with 3 inputs

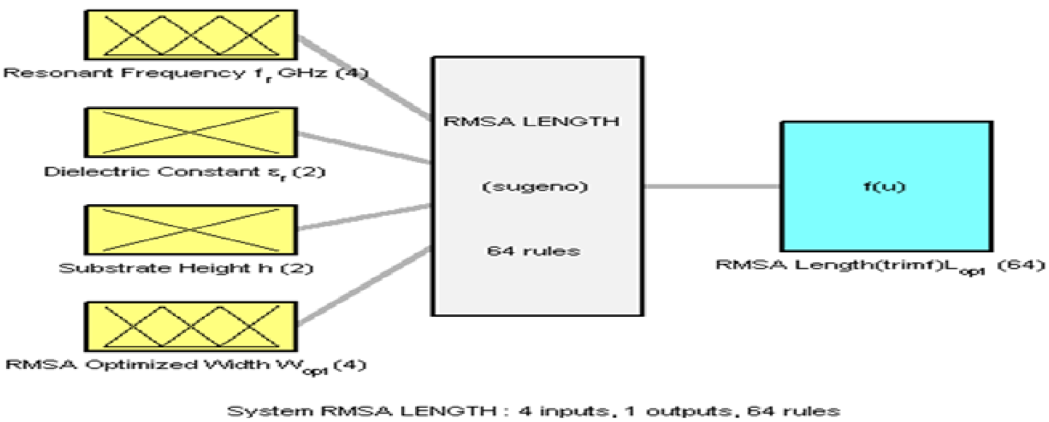

Figure-3. Second stage of ANFIS model for optimization of patch lengths

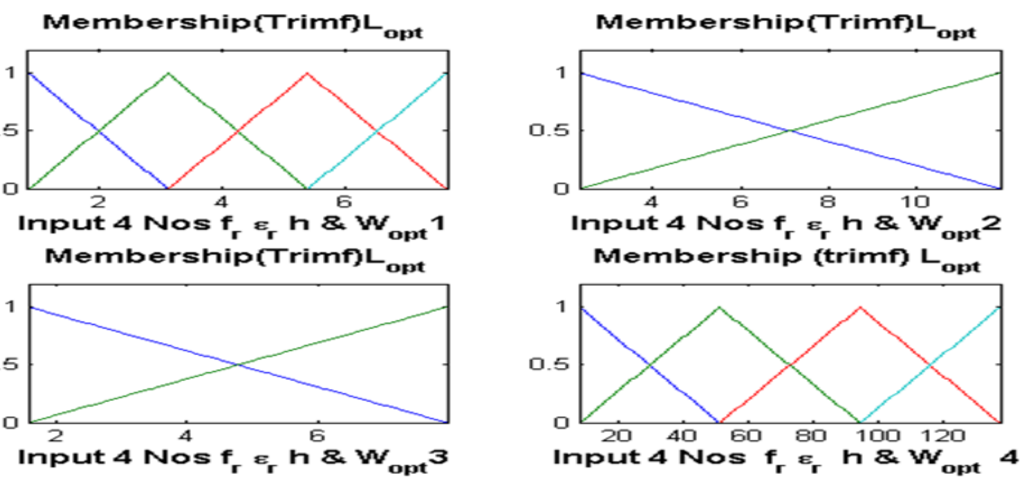

Figure-4. Second stage of initial membership values (FIS model) with 4 inputs

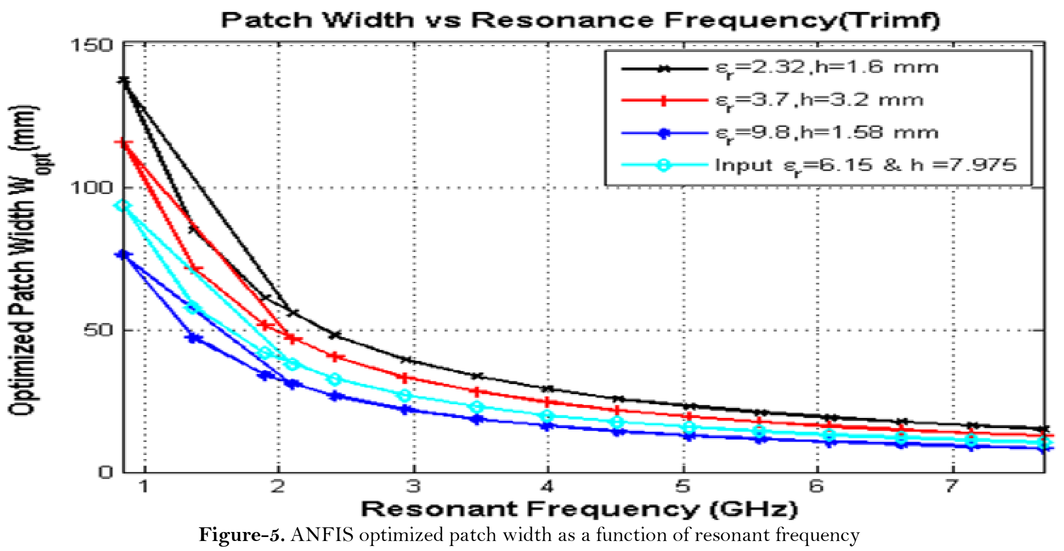

Figure-5. ANFIS optimized patch width as a function of resonant frequency

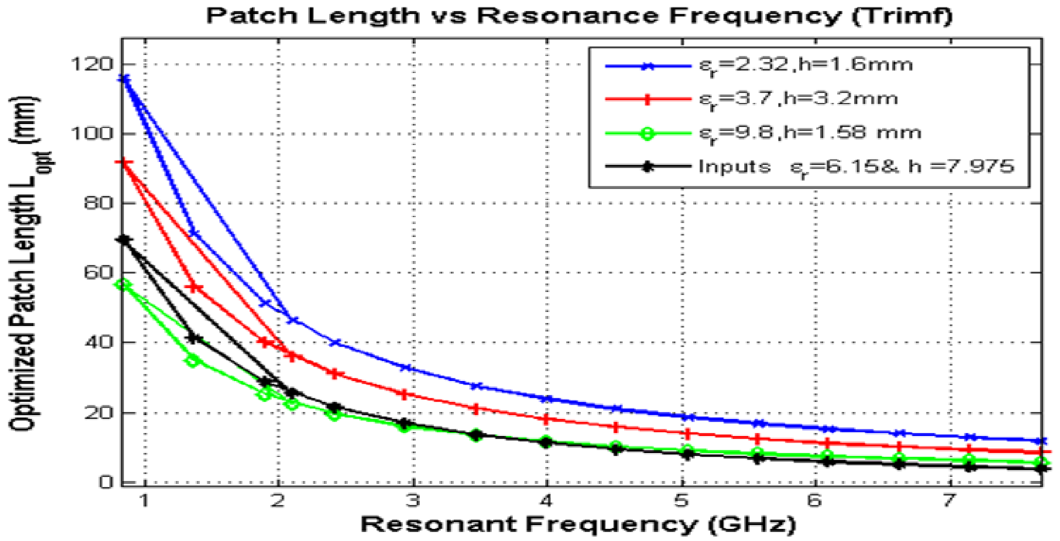

Figure-6. ANFIS optimized patch length as a function of resonant frequency

6. CONCLUSIONS

The theoretical analysis and simulation of the RMSA model with six different substrate materials is being carried out to obtain the optimum dimensions of the proposed RMSA to compute **BW**. The RMSA has been designed using ANFIS optimization technique. We have used four parametric variables for simulation, namely: (i) frequency, (ii) substrate thickness, (iii) permittivity, and (iv) length extension for the design of RMSA which can be tuned to operate at 2.1 GHz when its length and width are optimized properly. We have calculated its p-factor and radiation efficiency to compare transmission line and cavity model BW of the RMSA. From the simulated and theoretical analysis it is observed that dependence of substrate thickness and dielectric constant on the BW of RMSA is not the same for a given model. It differs from model to model, and in general for wide band application thicker substrate is preferable at the cost of efficiency. Thus, we may conclude from our analysis that the transmission line model of RMSA is valid for low dielectric thin substrate while cavity model is more realistic with thicker substrate with high to medium values of dielectric constant.

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