Prediction of the Input Impedance of two Coupled Monopole Antennas Using Fuzzy Modeling

S. R. Ostadzadeh, M. Soleimani and M. Tayarani

***Abstract*—In this paper, a fuzzy model for the input impedance of the two monopole antennas in the coupled form is proposed. Here, we use the results of the HP-HFSS simulator. Behavior of the problem is saved as a set of unchanged membership functions and the Knowledge of the spacing effect between two antennas are extracted as very simple curves of starting parameters. Then input impedance of the coupled monopole antenna for any spacing can be predicted very easily by applying the starting parameters calculated from the achieved simple curves to fuzzy system. Comparing fuzzy model results with HP-HFSS simulator shows very good agreement while execution time is surprisingly short even for wide bandwidth.**

***Index Terms*—** Fuzzy modeling, Input Impedance, Coupled Monopole Antenna

I. INTRODUCTION

Wire antennas are widely used in communication systems from low to ultra-high frequencies, either in the form of individual elements or arranged with other similar elements to form a phased array. As we know, there are several analytical and numerical methods to analyze monopole antenna, either in the individual or in coupled form, which are suffering from the complex and time-consuming calculations when good accuracy is required. In contrast with the mentioned methods, qualitative inferences and soft calculating methods can be taken into consideration. At first, a new modeling approach by using fuzzy inference was introduced [1], [2], [3] for computing input impedance of a general monopole antenna in the individual form. The question of the coupling between two monopole antennas was not addressed. In this paper, by using the same method, we compute input impedance of two monopole antennas in the coupled form. Finally, we will show that our modeling results are in close agreement with HP-HFSS results (real data) while execution time is considerably reduced even for wide bandwidth.

II. FUZZY MODEL OF THE COUPLED-MONOPOLE ANTENNA

The input impedance of two coupled monopole antennas, supplied uniformly but phase difference equals to 180°, with $L = 20Cm, a = 1.2mm \quad d = 15cm$ (figure.1) is calculated using HP-HFSS Simulator (as a tool to obtain real data) and is shown in figure.2 (L, a are antenna length and radius respectively and d is spacing between two antennas). According to reasons mentioned in [1], [2], [3] and [4] for modeling, the polar plane is choosed.

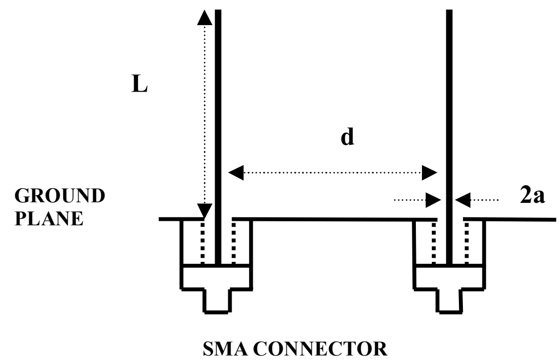

Fig. 1. Two monopole antennas in the coupled form

As shown in figure.2, three three-star sets in the vicinity $L/\lambda = 0.41, 0.85, 1.33$ have been used (* marks) to define second, third and forth circles respectively. These circles are shown in Fig.2. (b) (Dashed line).

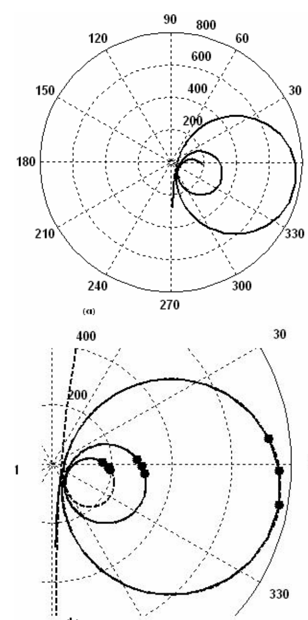

Fig. 2. (a) Input impedance for the sample (Amplitude vs. phase). (b) the section (a) with fitted circles (dashed line).

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The most important part of input impedance is around odd resonances and it seems that the circles are changing from one to another smoothly at these portions. This smooth movement can be modeled easily using fuzzy membership functions. Four fuzzy sets are defined in the range and could be extended for longer antennas. The membership functions, which are used here, were defined by S.Bagheri Shouraki [5] and are selected because of their flexibility and smoothness as shown in Fig.3. The general form of membership functions, which are used in Fig.3, can be expressed as in eqs. (1) and (2):

$$\alpha(x)=\begin{cases}\frac{1}{2}(1+\cos\pi(\frac{x-a}{b-a})^{\beta_1}) & for \quad x:a\to b\\ \frac{1}{2}(1-\cos\pi(\frac{x-a}{b-a})^{\beta_2}) & for \quad x:a\to b\end{cases} \tag{1}$$

For expansion around the regions where x is a, and contraction around the regions where x is b, and

$$\alpha(x)=\begin{cases}\frac{1}{2}(1-\cos\pi(\frac{x-a}{b-a})^{\beta_1}) & for \quad x:a\to b\\ \frac{1}{2}(1+\cos\pi(\frac{x-a}{b-a})^{\beta_2}) & for \quad x:a\to b\end{cases} \tag{2}$$

For contraction around the regions where x is a, and expansion around the regions where x is b. β_1,β_2 are optimizing parameters.

If we put a name on each of fuzzy sets, like Short, Medium, Intermediate and Long from the left to right in Fig. 3, the implications used here can be written simply as:

$$\begin{cases}\text{If } L/\lambda \text{ is short then first circle}\\ \text{If } L/\lambda \text{ is medium then second circle}\\ \text{If } L/\lambda \text{ is intermediate then third circle}\\ \text{If } L/\lambda \text{ is Long then forth circle}\end{cases} \tag{3}$$

Where the first, second, third and forth circles are those defined in Fig.2 (b), a new circle can be inferred for each L/λ using simple inferences of eq. (4).

$$\begin{cases}x(\frac{L}{\lambda})=\sum_{i=1}^{4}x_i\alpha_i(\frac{L}{\lambda})\\ y(\frac{L}{\lambda})=\sum_{i=1}^{4}y_i\alpha_i(\frac{L}{\lambda})\\ r(\frac{L}{\lambda})=\sum_{i=1}^{4}r_i\alpha_i(\frac{L}{\lambda})\end{cases} \tag{4}$$

Where x_i, y_i and r_i are coordinates of center and radius of the basic circles (fitted circles in figure.2. (b)) respectively, and α_i is the fire strength or belongingness of desired L/λ derived from figure.3 and finally the new circles are specified by x, y and r as center coordinates and radius for each L/λ respectively. The only remaining problem is how to choose the proper point on the resulted circle.

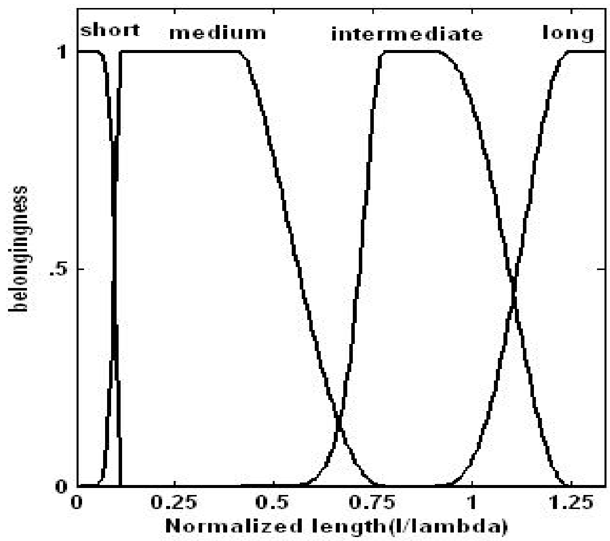

Fig. 3. Fuzzy sets and membership functions used for mixing original circles

III. Appropriate partial phase generation

By the above procedure, for each value of L/λ, there is only one circle for possible impedances on the polar plane. Here, we use the definition mentioned in [1]. For the choosed sample, variation of the desired phase versus normalized length is shown in figure.4.

At least there are four linear parts in this curve, one at the beginning that we assume that is almost horizontal, and other three parts in the middle, intermediate and end.

The marked phases in the linear parts are phases belonging to the three three-point sets, which are used in the pervious section.

Using Takagi/Sugeno's method [6], it is an easy task to model this phase curve by using the above-mentioned four lines. In this case also, four fuzzy sets with suitable membership functions are used as shown in figure.4 (b) and the rules are the same as eq. (3) but circles modify to lines and eq (4) reduces to:

$$\begin{cases}m(\frac{L}{\lambda})=\dfrac{\sum_{i=0}^{i=4}m_i\alpha_i'(\frac{L}{\lambda})}{\sum_{i=1}^{4}\alpha_i'(\frac{L}{\lambda})}\\ n(\frac{L}{\lambda})=\dfrac{\sum_{i=0}^{i=4}n_i\alpha_i'(\frac{L}{\lambda})}{\sum_{i=1}^{4}\alpha_i'(\frac{L}{\lambda})}\end{cases} \tag{5}$$

Where m_i and n_i are slopes and biases of four lines and α_i' is the fire strength or belongingness of desired L/λ

deriving from figure.4 (b) and finally the new lines are specified by m, n as slope and bias for each L/λ respectively. Finally, with only three three-point sets in the vicinity $L/\lambda = 0.41, 0.85, 1.33$, and optimizing parameters β_1, β_2 by simplex Nelder-Mead method, the model can be made easily.

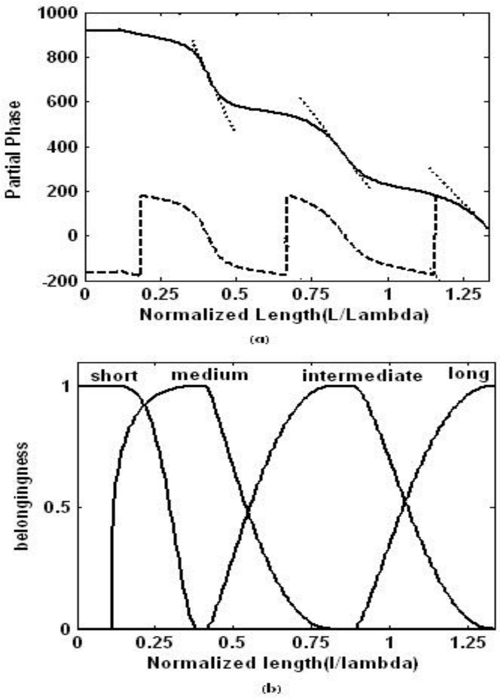

Fig. 4. (a). Phase variation of the sample vs. normalized length with original lines (dotted line) and (b) Fuzzy sets and membership Functions

The modeling results for the sample are shown in Figure. 5. and compared with HP-HFSS results.

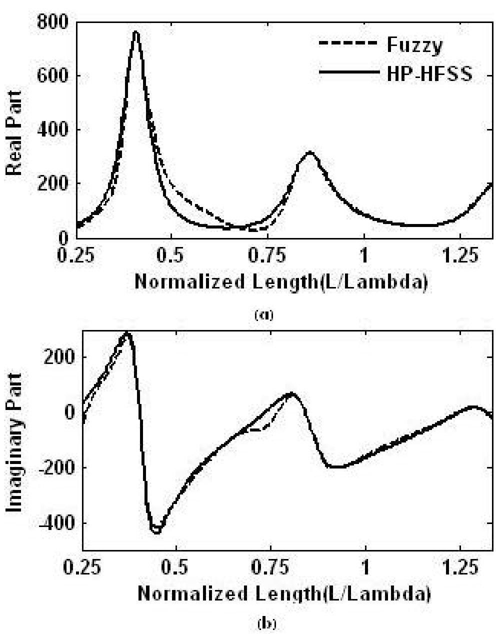

Fig. 5. Comparing results of Fuzzy and HP-HFSS model for d=15 Cm
(a) real and (b) Imaginary

IV. SPACING EFFECT

To make a complete model for the coupled monopole antenna, we are to going to consider the effect of spacing between two antennas on its input impedance. In this way, input impedance of a number of samples has been calculated and the results are shown in figure. (6).

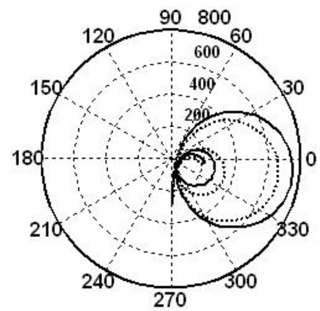
Fig. 6. Samples of Input impedance with spacing as parameter.
Solid line (d=20Cm), Dotted line (d=10Cm)

As it is shown, changing spacing, d, results in new impedance curves but still belongs to category generated in [1]. Thus, we can approximately assume that the membership functions remain unchanged at least for $10Cm \le d \le 20Cm$. Under this assumption, we will obtain close agreement with real data .Thus; the only parameters that change by changing spacing are the initial point values in the vicinity of $L/\lambda = 0.41, 0.85, 1.33$.

Using these initial values for samples $(such\ as\ d = 18Cm)$ the original circles and lines (fuzzy inputs) are achieved and using membership functions saved, input impedances for these samples are generated. Comparing our results and HP-HFSS results shows that close agreement has been achieved while execution time considerably is reduced (figure. 7).

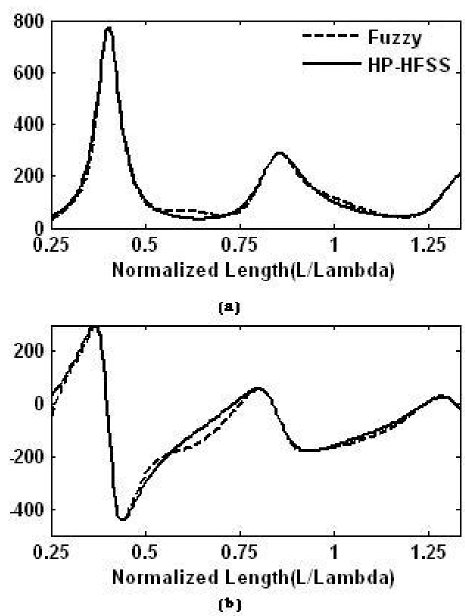

Fig. 7. Comparing results of Fuzzy and HP-HFSS model for d=18 Cm
(a) real and (b) Imaginary

V. PREDICTION OF INPUT DATA FOR FUZZY SYSTEM

As mentioned, inputs of our fuzzy system are basic circles and lines extracting using HP-HFSS simulator and explained method. Centers and radii of first, second, third and forth circles can be fitted by very simple curves to predict fuzzy inputs for other spacings. The same could be done for bias and slope of basic lines. This means that as a first approximation for input impedance of a monopole antenna in the coupled form, the only information needed to save is some simple curves those specify the original circles and lines for each value of spacing (d). Now, we can read input data for any arbitrary spacing (such as d=13 Cm and d=17Cm) from these curves. The results are shown in figures. (9), (10) and compared with HP-HFSS results. As it is seen, the results are in very good agreement while execution time is decreased to a few seconds comparing with about three hours for HP-HFSS simulator.

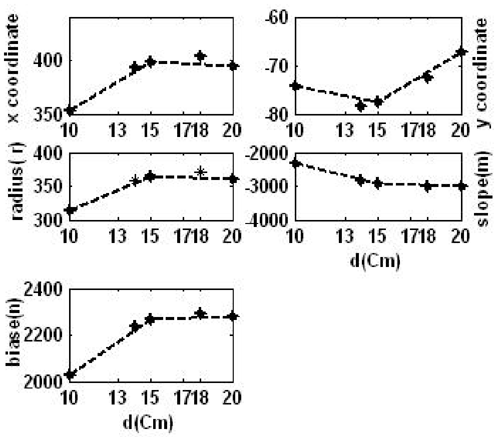

Fig. 8. Variation of center, radius, slope and bias of the second original circle by spacing between two antennas (d)

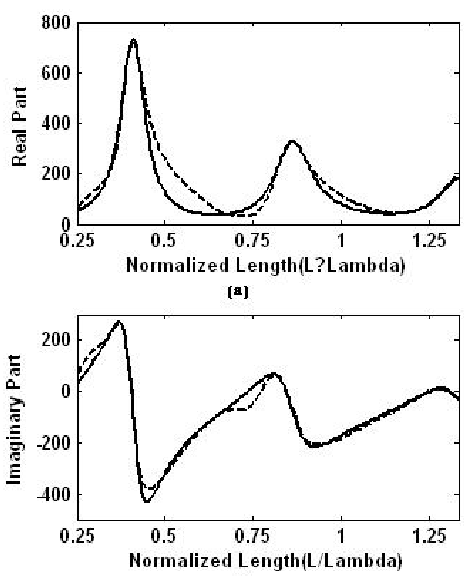

Fig.9. Prediction of the input impedance by fuzzy model in comparison with HP-HFSS simulator for d=13Cm (a) real and (b) Imaginary

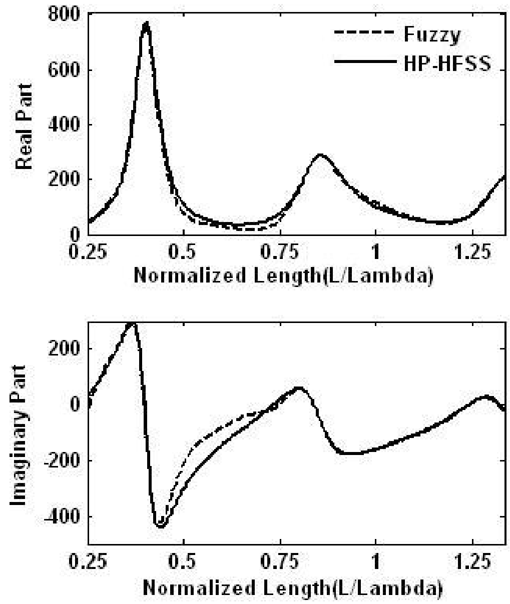

Fig. 10. Prediction of the input impedance by fuzzy model in comparison with HP-HFSS simulator for d=17Cm

VI. CONCLUSION

In this paper, fuzzy modeling was used for computing input impedance of the coupled monopole antenna resulted in two membership function sets which have saved the system behavior and knowledge of problem was extracted by the very simple curves. Note that, in this method we assume that membership functions remain unchanged for $10Cm \le d \le 20Cm$; for the longer range, we can divide the spacing to multiple ranges and repeat this method for each range to decrease the error. Computing input impedance using fuzzy model showed a very good agreement with the results of the HP-HFSS simulator (as real data). Execution time for the qualitative method is surprisingly short and this makes it suitable for applications, which need repetitive calculations of input impedance such as active antenna array design.

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