# Prediction of Scattered field from Linearly Loaded Dipole Antenna Using Fuzzy Inference

S. R. Ostadzadeh
*Iran University of Science and Technology*
*Ostadzadeh@iust.ac.ir*

M. Tayarani
*Iran University of Science and Technology*
*m_tayarani@iust.ac.ir*

M. Soleimani
*Iran University of Science and Technology*
*soleimani@iust.ac.ir*

## Abstract

*In this paper, our fuzzy-based approach is used to predict scattered field from linearly loaded dipole antenna. At first, knowledge bases of diameter for unloaded scattering dipole antenna and impedance loading for thin scattering dipole antenna are separately extracted as very simple curves. In extracting these knowledge bases, the behavior of scattering dipole antenna is well approximated to the behavior of single transmitting dipole antenna. Then using concept of special membership functions, two knowledge bases are combined so that the spatial knowledge base of scattering dipole antenna including diameter and impedance loading effects is extracted. Finally, comparing fuzzy modeling results with method of moments, MoM shows an excellent agreement. Moreover, the execution time is considerably reduced.*

## 1. Introduction

Impedance loading of scatterers is a technique used so as to control scattered field. One of conventional scatterers is linearly loaded dipole antenna. In such applications, the scattered field is a very nonlinear function of impedance loading and antenna diameter. There are a number of accurate methods, e.g. method of moments (MoM) [1], in order to compute scattered field suffering from repetitive, complex and time consuming computations especially when good accuracy is required.

In contrast with these methods, qualitative and soft computing methods can be taken into consideration in order to remove these mentioned drawbacks. A qualitative method based on fuzzy inference was proposed by Tayarani et al [2], and used by authors to predict the input impedance of two coupled dipole antennas in different arrangements [3] and the induced current of receiving dipole antenna [4] at different incident angles in which behaviors of two mentioned problems were well approximated to single transmitting dipole antenna (the same as accurate methods) and knowledge bases of spacing between antennas and incident angles were saved as simple curves.

In this paper, scattering dipole antenna is considered. At first, using the proposed method in [2], the knowledge bases of diameter for unloaded scattering dipole antenna and impedance loading for thin scattering dipole antenna are separately extracted and saved as very simple curves. In extracting these knowledge bases, the behavior of scattering dipole antenna is well approximated with the behavior of single transmitting dipole antenna discussed in our past studies [3, 4]. Then using concept of spatial membership functions, two knowledge bases are combined so that spatial knowledge base versus diameter and impedance loading is easily computed. Comparing the modeled results with accurate ones, MoM, shows an excellent agreement while the execution time is vanishingly short.

## 2. Fuzzy modeling of scattered field from unloaded dipole antenna

A schematic diagram of dipole antenna illuminated in broadside direction by an incident plane wave is shown in figure 1. In this section, unloaded dipole antenna, is considered. At first, the scattered field versus normalized length, $\mathbf{L/\lambda}$, for a number of diameters, $\mathbf{\Omega}$ is a measure of diameter, is computed by MoM and shown in figure 2 in polar plane. As it is seen in figure 2, and based on [2], the curve of scattered field can be easily modeled. Therefore, three three-point sets around $\mathbf{L/\lambda = 0.25, 0.75, 1.25}$ are chosen so as to define circles and lines. The membership functions through modeling moving circles and Partial Phase for different diameters as well as single transmitting ones are shown in figure 3. The membership functions form here used is the same as [5].

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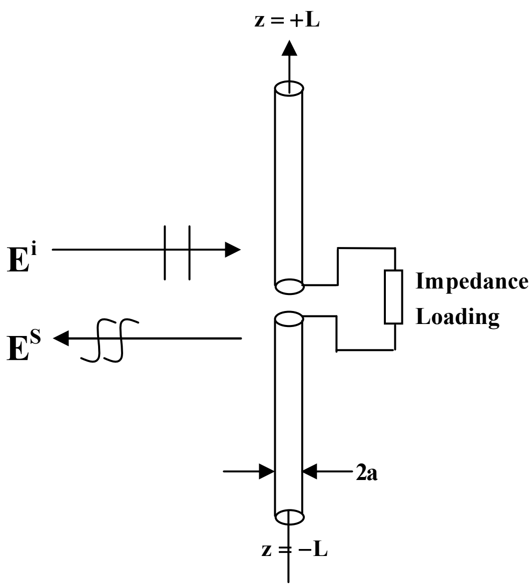


Figure 1. A dipole antenna illuminated in broadside direction.

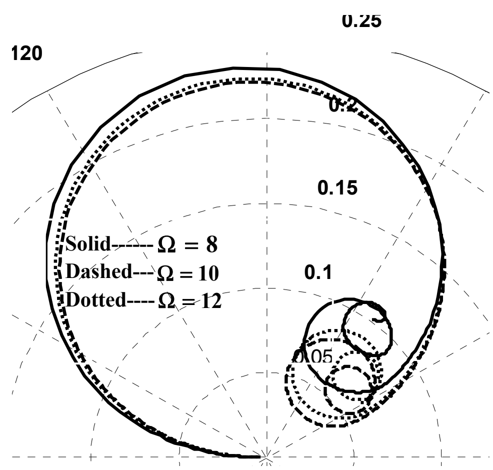


Figure 2. Scattered fields of dipole antenna for different diameters ($\Omega = 2\mathrm{Ln}(2L/a)$).

As it is seen in figure 3, the membership functions through modeling moving circles are not changed at all and the membership functions through modeling Partial Phase are slightly changed around single transmitting ones. Therefore, they are approximated to single transmitting ones as a first order approximation. Hence, the only parameters changed for different diameters are starting points that can be supposed as knowledge base through the proposed algorithm. The Knowledge base of diameter for unloaded scattering dipole antenna is shown in figure 4. Since the fuzzy specifications of circles are not in the same range, they are normalized to individual single transmitting ones.

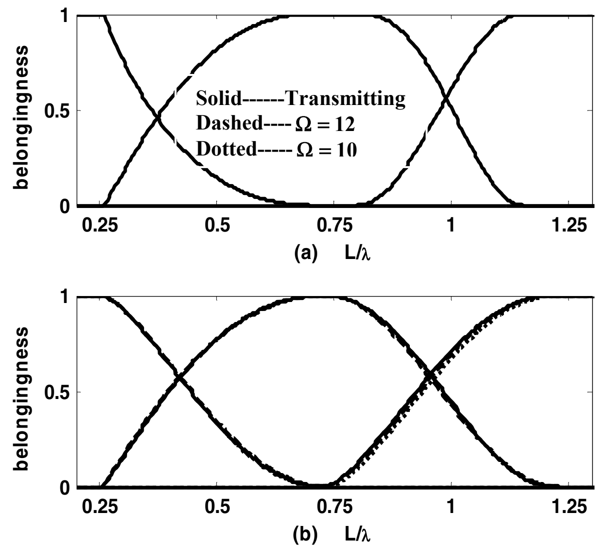


Figure 3. The membership functions through modeling moving circles and lines as well as single transmitting ones. (a): for moving circles (b): for Partial Phase.

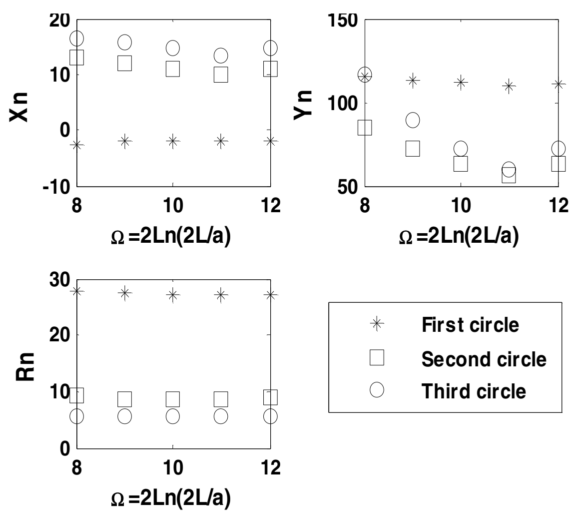


Figure 4. The normalized knowledge base of diameter for unloaded dipole antenna.

As shown in figure 4, the normalized coordinates and radii of circles can be fitted by very simple curves (even by horizontal lines). Now by reading fuzzy inputs through figure 4, and membership functions of single transmitting dipole antenna, the scattered field for any diameter can be predicted. For instance, a sample with $\mathbf{\Omega = 10}$ is run. The predicted result is shown in figure 5. Finally, an excellent agreement with very short execution time is achieved. In the next section, the scattered field from thin dipole antenna is considered.

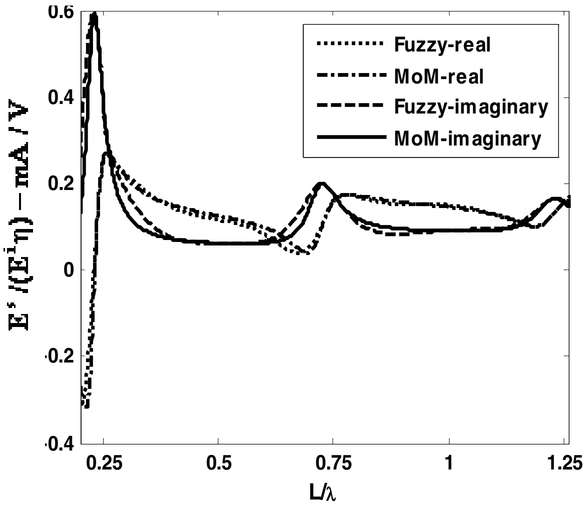


Figure 5. Comparing the computation of scattered field by two different methods.

## 3. Fuzzy modeling of scattered field from linearly loaded thin dipole antenna

In this section, the scattered field from a thin dipole antenna with impedance loading is considered. Without loss of generality, the impedance loading is assumed to be resistance. In the same manner of previous section, the scattered field from thin dipole antenna, $\Omega = 12$, for different loadings are computed by MoM and shown in polar plane in figure 6.

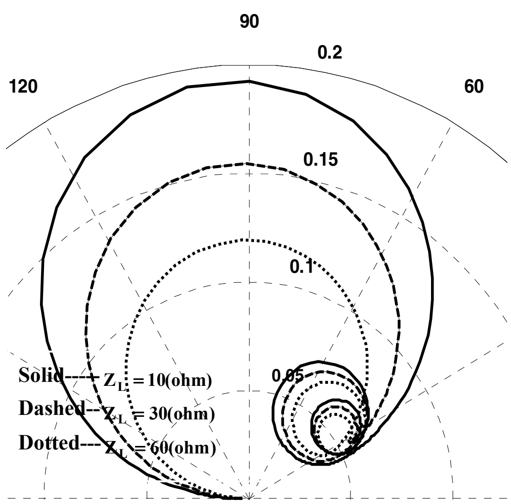


Figure 6. The computed scattered field of thin dipole antenna by MoM for different impedance loadings.

As it is seen in figure 6, the scattered field from thin dipole antenna with impedance loading has the same circular movement as previous section.

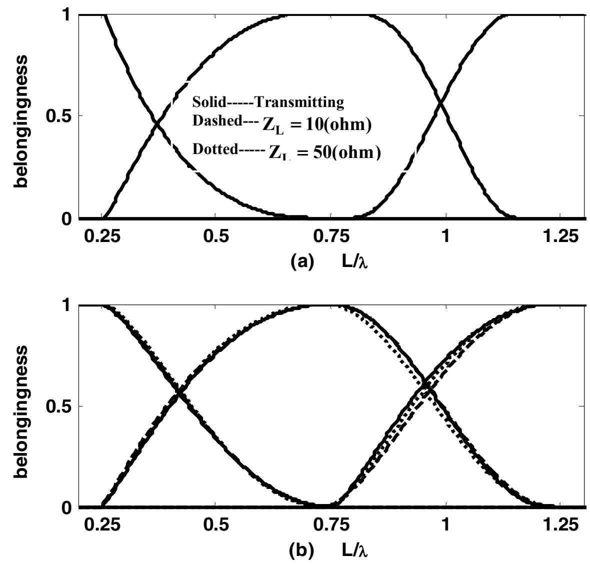


Figure 7. The membership functions through modeling moving circles and Partial Phase as well as single transmitting ones. (a): moving circles (b): Partial Phase.

Hence, membership functions through modeling moving circles and Partial Phase are obtained and shown in figure7.

As shown in figure 7, membership functions through modeling moving circles and Partial Phases are slightly changed around membership functions of single transmitting dipole antenna the same as previous section. Hence the same as previous section, they are approximated to membership functions of single transmitting dipole antenna. Therefore the knowledge base of impedance loading is easily extracted and shown in figure 8.

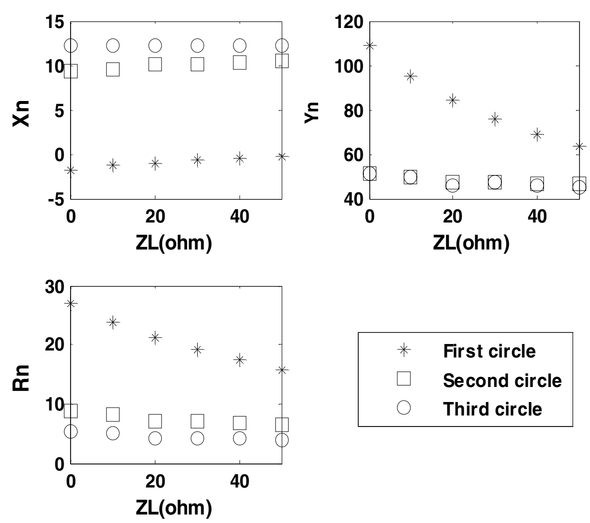


Figure 8. The normalized knowledge base of impedance loading for scattering thin dipole antenna.

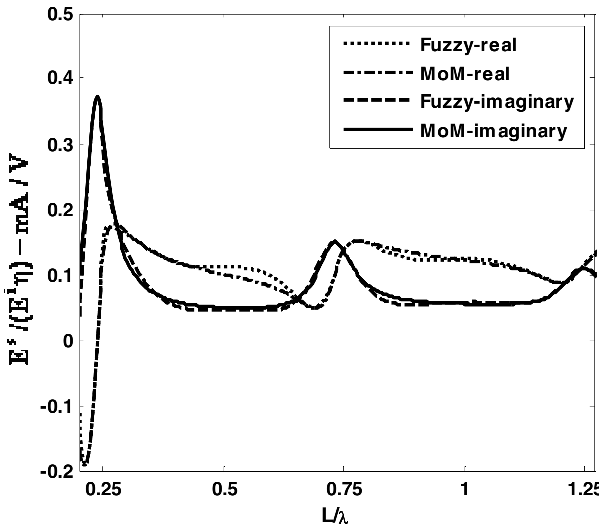


Figure 9. Comparing computations of scattered field by two methods for $Z_L = 35(\text{ohm})$.

Note that the coordinates and radii of circles are again normalized to single transmitting ones. It is shown in figure 8 that the knowledge base can be fitted again by very simple curves. Now, by reading fuzzy inputs through figure 8 and membership functions of single transmitting dipole antenna, the scattered field for any impedance loading is predicted.

A sample with $Z_L = 35(\text{ohm})$ is chosen and results of fuzzy and MoM are shown in figure 9. An excellent agreement with vanishingly short execution time is achieved.

## 4. Extracting spatial knowledge of diameter and impedance loading

In two previous sections, the knowledge bases of diameter and impedance loading for unloaded dipole antenna and thin dipole antenna were separately extracted respectively. In this section, using concept of spatial membership functions [6] used for combining the knowledge bases of two independent variables, spatial knowledge for any diameter and loading is extracted. The following spatial membership functions with two fuzzy sets are used and shown in figure 10.

$$\alpha_i(\Omega, Z_L) = \begin{cases} \frac{1}{2}\left(1 - \cos\pi\left[\frac{\psi - \varphi_2}{\varphi_1 - \varphi_2}\right]^{\beta_1}\right) & \text{for} \quad \varphi_1 \to \varphi_2 \\ \frac{1}{2}\left(1 + \cos\pi\left[\frac{\psi - \varphi_2}{\varphi_1 - \varphi_2}\right]^{\beta_2}\right) & \text{for} \quad \varphi_1 \to \varphi_2 \end{cases}$$

in which

$$\psi = \tan^{-1}\left(\frac{\Omega}{Z_L}\right), \ \beta_1, \beta_2 = \text{optimizing parameters}$$

and $i = \Omega, Z_L$.

As it is seen in figure 10, each fuzzy set has belongingness value of one at its individual axis and it is smoothly decreasing to zero at the other axis.

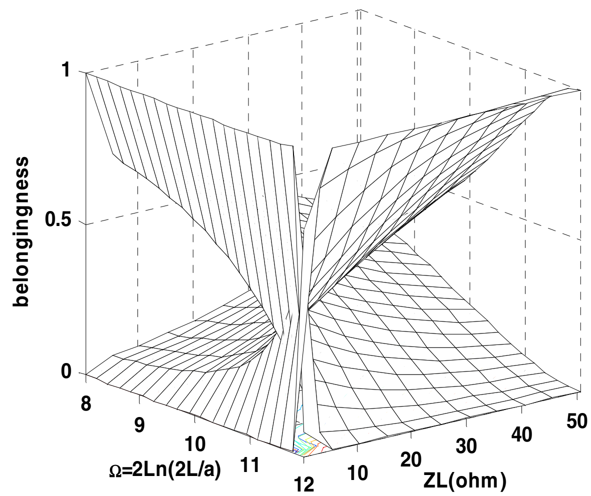


Figure 10. Spatial membership functions for combining knowledge bases of impedance loading and diameter.

The equations for extracting spatial knowledge are as following:

$$x_j(\Omega, Z_L) = \frac{x_j(\Omega)\alpha_\Omega(\Omega, Z_L) + x_j(Z_L)\alpha_{Z_L}(\Omega, Z_L)}{\alpha_\Omega(\Omega, Z_L) + \alpha_{Z_L}(\Omega, Z_L)}$$

$$y_j(\Omega, Z_L) = \frac{y_j(\Omega)\alpha_\Omega(\Omega, Z_L) + y_j(Z_L)\alpha_{Z_L}(\Omega, Z_L)}{\alpha_\Omega(\Omega, Z_L) + \alpha_{Z_L}(\Omega, Z_L)}$$

$$r_j(\Omega, Z_L) = \frac{r_j(\Omega)\alpha_\Omega(\Omega, Z_L) + r_j(Z_L)\alpha_{Z_L}(\Omega, Z_L)}{\alpha_\Omega(\Omega, Z_L) + \alpha_{Z_L}(\Omega, Z_L)}$$

in which $x_j(i), y_j(i), r_j(i), \ i = \Omega, Z_L, \ j = 1,2,3$ are coordinates and radii of circles obtained in previous sections. Finally $x_j(\Omega, Z_L), y_j(\Omega, Z_L), r_j(\Omega, Z_L)$ are the inferred coordinates and radii of circles respectively. Now, using the inferred spatial knowledge and the membership functions of the single transmitting dipole antenna, the scattered field for any diameter and impedance loading is generated. Our fuzzy system is run for a sample with $\Omega = 11, Z_L = 30(\text{ohm})$ and shown in figure 11. As shown in figure. 11, an excellent agreement is achieved in addition, the execution time is considerably reduced.

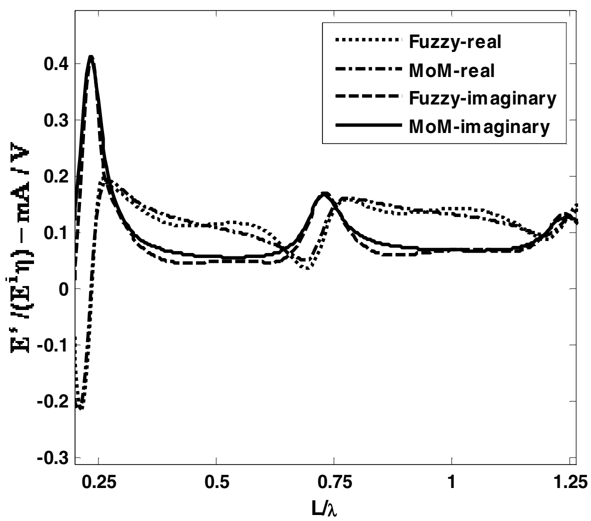


Figure 11. Comparing the computation of scattered field from linearly loaded dipole antenna by two methods.

## 5. Conclusion

In this paper, our previously fuzzy inference approach was used to model the scattered field from linearly loaded dipole antenna in which knowledge bases of diameter and impedance loading were separately extracted and saved as very simple curves. In addition, the behavior of problem was well approximated to behavior of single transmitting dipole antenna the same as [3, 4]. It is confirmed again that membership functions have the behavior of the system and this is a reason for similar membership functions in transmitting, receiving and scattering cases. Finally, using the concept of spatial membership functions, the spatial knowledge base of diameter and impedance loading was extracted. Comparing the modeled results with accurate ones showed excellent accuracy with vanishingly short computation time and this makes our proposed method suitable in repetitive applications. Fuzzy modeling of nonlinearly loaded dipole antenna at different harmonic frequencies is the second step that is under way.

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