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A FUZZY MODEL FOR COMPUTING BACK-SCATTERING RESPONSE FROM LINEARLY LOADED DIPOLE ANTENNA IN THE FREQUENCY DOMAIN

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Abstract—This study includes three parts: First is fuzzy modeling of scattered field from unloaded dipole antenna. In second step a fuzzy model for scattered field from a linearly loaded thin dipole antenna is introduced. In both parts, knowledge bases of diameter and load impedance are separately extracted and saved as very simple curves. It is shown that the behavior of scattering dipole antenna is well approximated with the single transmitting dipole antenna obtained in our previous study. In the third step, using the concept of spatial membership functions, two obtained knowledge bases are combined so that the spatial knowledge base including simultaneous effects of diameter and load impedance is extracted. As a result, these spatial knowledge base as well as the behavior of single transmitting dipole antenna are used instead of time consuming and repetitive computations in accurate methods. With the use of this spatial knowledge and behavior of single transmitting dipole antenna, the scattered field from dipole antenna for any load impedance and diameter is predicted. Comparing the predicted results with accurate ones shows an excellent agreement. Moreover the computation time is considerably reduced.

1. INTRODUCTION

As we know, the scattered field from loaded scatterers is superposition of two fields: first is the scattered field from unloaded scatterer and second is the re-radiated field from scatterer in transmitting mode due to load impedance. Hence, loading of scatterers can be used to control scattered field [1–11]. One of the conventional scatterers with load impedance is linearly loaded dipole antenna [12–15] in which the resulted scattered field is a strongly nonlinear function of dipole diameter and load impedance. There are a number of methods, e.g., method of moments [16], MoM, to compute the scattered field. All of them suffer 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. [17, 18], and used by authors to predict the input impedance of two coupled dipole antennas in different arrangements [19] and the induced current of receiving dipole antenna [20] at different incident angles in which behaviors of two mentioned problems were well approximated to the behavior of the single transmitting dipole antenna and knowledge bases of spacing between antennas and incident angles were saved as simple curves.

In this paper, scattering dipole antenna is considered, and attention has been here given to the broadside direction only, since the highest return is in this direction. At first, using the proposed method in [17, 18], the knowledge bases of diameter for unloaded scattering dipole antenna and load impedance 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 to the behavior of the single transmitting dipole antenna the same as [19, 20]. Then using concept of spatial membership functions, two knowledge bases are combined so that spatial knowledge base versus diameter and load impedance 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, $Z_L = 0$, is considered. At first, the scattered field versus normalized length, L/λ, for a number of diameters, Ω 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 [17, 18], the scattered field can be modeled. Therefore, three three-point sets around $L/\lambda = 0.25, 0.75, 1.25$ are chosen so as to define fitted circles and lines. Then using the membership functions introduced

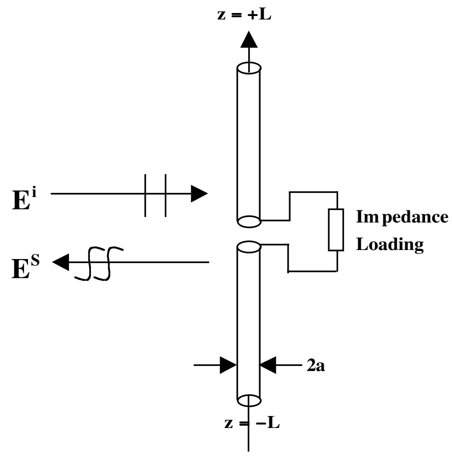

Figure 1. A schematic diagram of linearly loaded dipole antenna illuminated in the broadside direction.

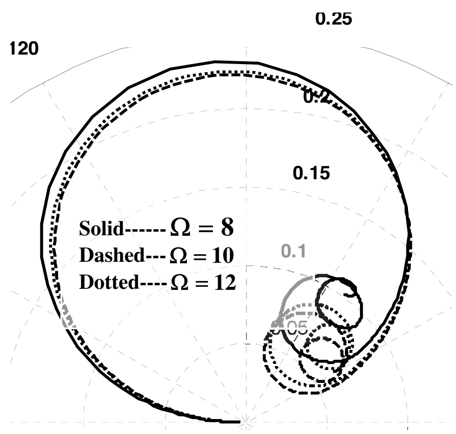

Figure 2. Scattered fields (mA/V) of dipole antenna versus different diameters ($\Omega = 2Ln(2L/a)$).

in [21] and Takagi/Sugeno's method [22], these circular movements and Partial Phases, a new definition for phase defined as the phase respect to the centre of fuzzy derived circles for each L/λ, are easily modeled. Further information about membership functions, modeling moving circles and Partial Phase can be found in [19]. The membership functions through modeling moving circles and Partial Phase for a few samples as well as membership functions of single transmitting dipole

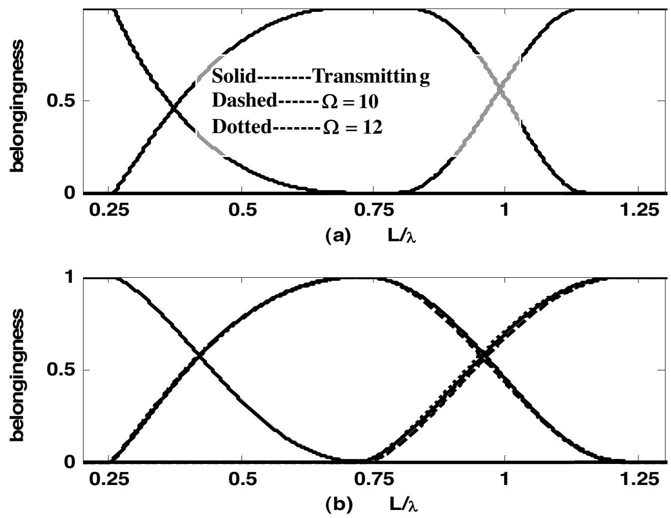

Figure 3. The membership functions through modeling moving circles and Partial Phase as well as single transmitting ones. (a): for moving circles (b): for partial phase.

antenna obtained in our past study [20] are shown in Figure 3.

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 the transmitting dipole antenna. 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 and obtained through the proposed algorithm. The Knowledge base of diameter for unloaded scattering dipole antenna which is computed by MoM for a few diameters as star/circle/square is shown in Figure 4. Since the coordinates, and radii of circles, and slopes and biases of lines, are not in the same scale, they are normalized to individual single transmitting ones.

As shown in Figure 4, the normalized coordinates and radii of circles and normalized slopes and biases of lines can be fitted by very simple curves (even sometimes by horizontal lines). It means, we don't need to compute fitted circles/lines for other diameters by MoM any more. Now by reading fuzzy inputs through these fitted curves, and membership functions of single transmitting dipole antenna, the scattered field for any diameter can be predicted. For instance, a sample with $\Omega = 10$ is run. The predicted result is shown in Figure 5. Comparing modeled results by three methods, Fuzzy, MoM

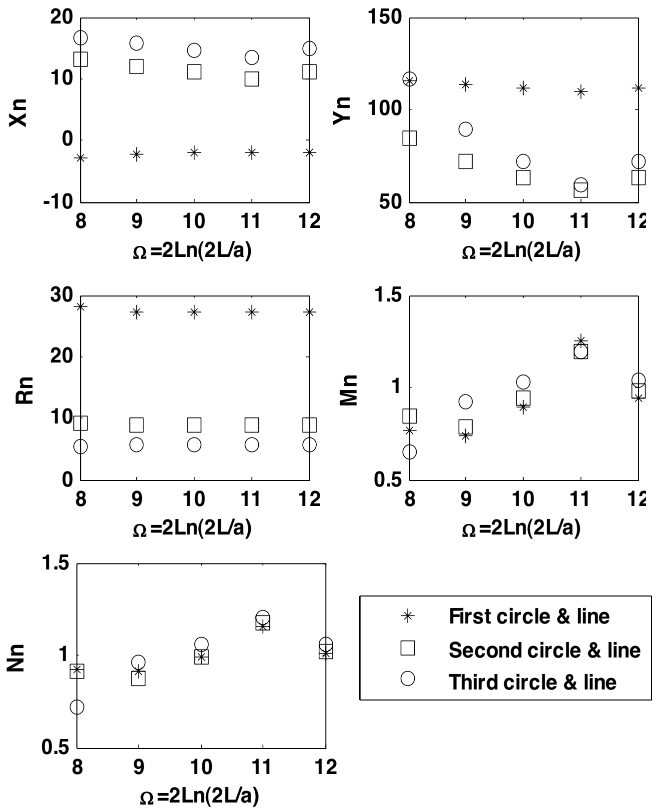

Figure 4. The normalized knowledge base of diameter for unloaded dipole antenna.

and Variational [12], shows an excellent agreement of Fuzzy with MoM and also very short execution time by Fuzzy-based method is achieved.

3. FUZZY MODELING OF SCATTERED FIELD FROM LINEARLY LOADED THIN DIPOLE ANTENNA

In this section, scattering from a thin dipole antenna loaded linearly is considered. Without loss of generality, it is assumed that load impedance is 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.

As it is seen in Figure 6, the scattered field from loaded thin dipole antenna has the same circular movement as previous section. Therefore

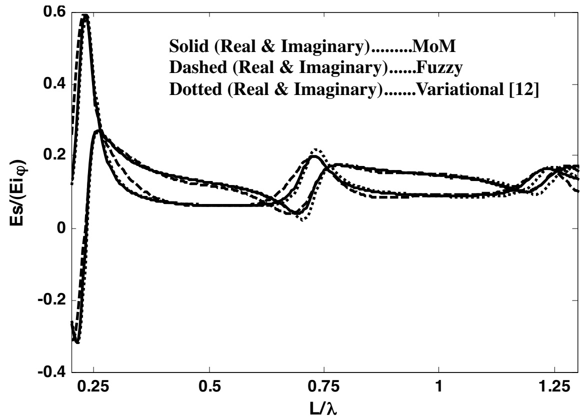

Figure 5. Comparing the computation of the scattered field (mA/V) from unloaded dipole antenna by three methods.

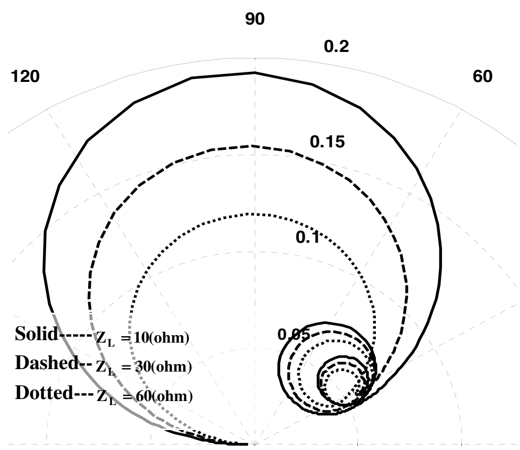

Figure 6. The computed scattered field (mA/V) from thin dipole antenna by MoM for different load impedances.

the proposed algorithm [17, 18] is again used to model moving circles and Partial Phase. The membership functions through modeling moving circles and Partial Phase are obtained and shown in Figure 7.

As shown in Figure 7, membership functions through modeling moving circles and Partial Phase are slightly changed around single transmitting ones. Hence the same as previous section, they are approximated to membership functions of single transmitting dipole

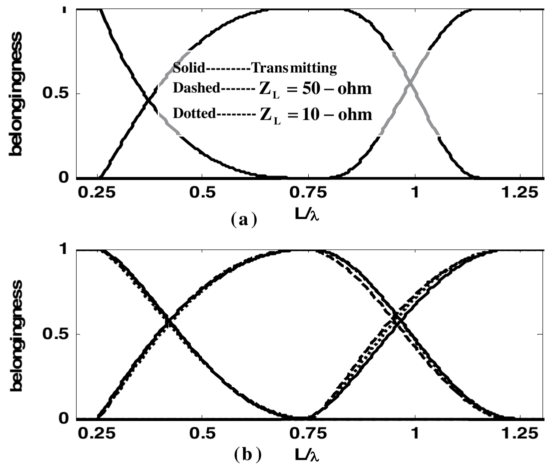

Figure 7. The membership functions from modeling moving circles and lines as well as single transmitting ones. (a): for moving circles (b): for partial phase.

antenna. Therefore, the knowledge base of load impedance for a few loadings is computed by MoM as star/circle/square and shown in Figure 8.

Note that the coordinates and radii of circles and also slopes and biases of lines are normalized to the individual single transmitting ones. As seen in Figure 8, this knowledge base can be fitted by very simple curves. In other words, it is not needed to use MoM for defining fitted circles/lines of other loadings any more. Now, by reading fuzzy inputs through these fitted curves, and membership functions of single transmitting dipole antenna, the scattered field for any loading is predicted, and it is obvious that the run-time computation is considerably reduced. A sample with $Z_L = 35$ (ohm) is chosen and results of Fuzzy, MoM and Variational [12] are shown in Figure 9. As it is seen in Figure 9, an excellent agreement with vanishingly short execution time is achieved.

4. EXTRACTING SPATIAL KNOWLEDGE BASE OF DIAMETER AND LOAD IMPEDANCE

In the previous sections, the knowledge bases of diameter and load impedance for unloaded dipole antenna and thin dipole antenna were separately extracted as very simple curves and the behavior of scattering dipole antenna was approximated to the behavior of single

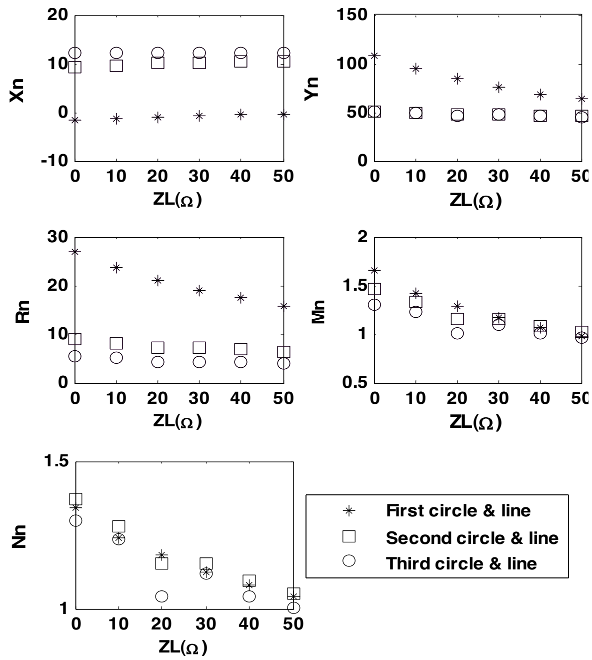

Figure 8. The normalized knowledge base of load impedance for scattering thin dipole antenna.

transmitting dipole antenna. In this section, using concept of spatial membership functions introduced for the first time by Shouraki et al. [23] for combining the knowledge bases of two independent variables, spatial knowledge versus simultaneous effects of diameter and loading is extracted. The spatial membership functions with two fuzzy sets are shown in Figure 10.

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. The form of spatial fuzzy sets here used is as follows:

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

in which

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

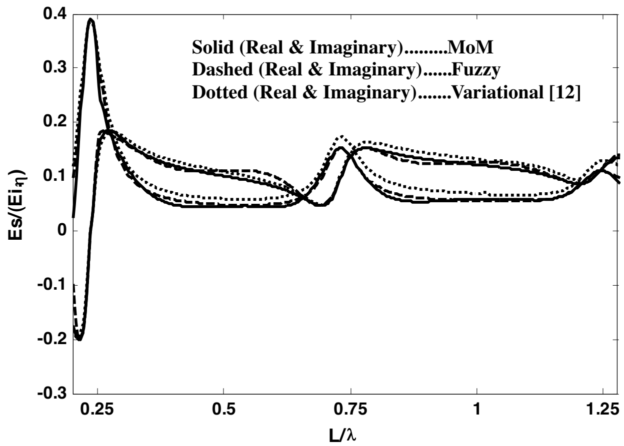

Figure 9. Comparing computations of scattered field (mA/V) by three methods for $Z_L = 35$ (ohm).

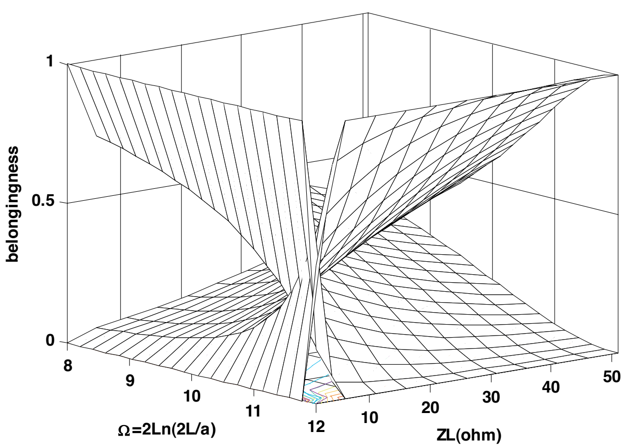

Figure 10. Spatial membership functions with two fuzzy sets for combining knowledge bases of loading and diameter.

and $i = \Omega, Z_L$.

The equations for combining two knowledge bases in order to extract spatial knowledge base are as following:

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

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

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

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

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

where $x_j(i), y_j(i), r_j(i),\ i = \Omega, Z_L,\ j = 1, 2, 3$ are coordinates and radii of three circles and similarly $m_j(i), n_j(i)$ are slopes and biases of three lines obtained in the previous sections (fitted curves). Finally $x_j(\Omega, Z_L), y_j(\Omega, Z_L), r_j(\Omega, Z_L), m_j(\Omega, Z_L), n_j(\Omega, Z_L),\ j = 1, 2, 3$ are the inferred coordinates, radii, slopes and biases of circles and lines respectively.

The spatial variations of coordinates and radius of first circle versus dipole diameter and load impedance are shown in Figure 11.

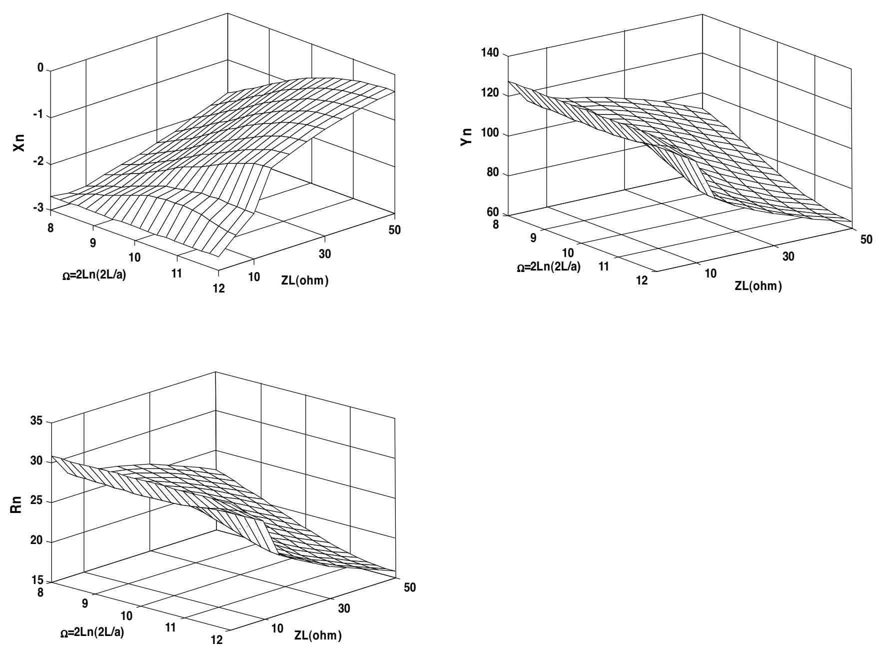

Figure 11. Normalized spatial variations of coordinates and radius of the first circle using spatial membership functions.

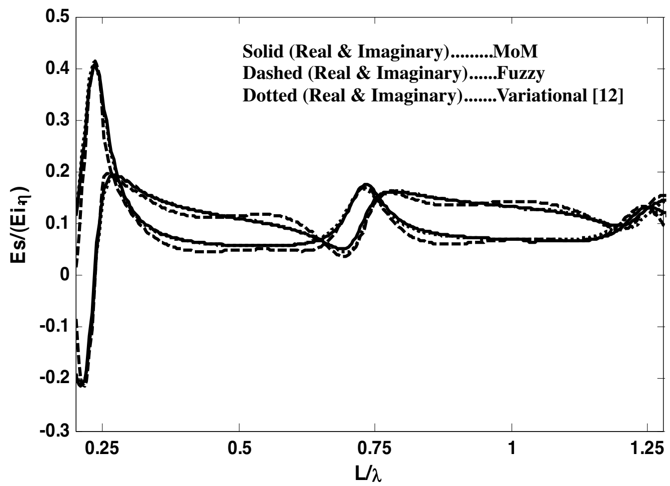

Figure 12. Comparing the computations of scattered field (mA/V) by three methods.

Table 1. Comparing run-time of scattered field by three different methods.

Method / Problem	Method Of Fuzzy	Method Of Moment (MoM)	Method Of Variational [12]
Unloaded Dipole Antenna	0.45 sec	123 sec	105 sec
Loaded Dipole Antenna	1.12 sec	138 sec	117 sec

Now, using the inferred knowledge and the membership functions of the single transmitting dipole antenna, our fuzzy system is completed, and the scattered field for any diameter and load impedance is generated. Our fuzzy system is run for a sample with $\Omega = 11$, $Z_L = 30$ (ohm) and the modeled results are shown in Figure 12. As shown in Figure 12, an excellent agreement is achieved in addition, the execution time is considerably reduced. Table 1 shows the run-time of scattered field from unloaded and loaded dipole antenna by three different methods. Meanwhile, The run-time computed by method of fuzzy in Table 1 is valid when our completed method of fuzzy is used.

5. CONCLUSION

In this paper, our previously fuzzy inference approach was used to model the scattered field from a linearly loaded dipole antenna. Throughout the modeling, knowledge bases of diameter and load impedance were separately extracted and saved as very simple curves. In addition, the behavior of scattering dipole antenna was well approximated with behavior of single transmitting dipole antenna. It is confirmed again that membership functions have the behavior of the system and this is a reason for similar membership functions in transmitting [19], receiving [20], and scattering (this paper) cases. Finally, using the concept of spatial membership functions, the spatial knowledge base versus diameter and load impedance was easily extracted. It is emphasized that these spatial knowledge base and membership functions of single transmitting dipole antenna are used instead of time consuming and repetitive computations. Therefore, the run-time will be very short. Comparing the modeled results with accurate ones showed an 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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