Fuzzy Modeling of Nonuniform Transmission Lines

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Abstract

Fuzzy inference abilities were implemented to electromagnetic problems for the first time by the authors. After very successful results of applying the developed fuzzy modeling method to input impedance of a general monopole antenna and uniform transmission lines, in this paper we apply the abilities of the proposed fuzzy inference method to make a qualitative model for nonuniform transmission lines. It is shown that because of using a novel qualitative view point, a very simple fuzzy system based on newly introduced parameters may model the behavior of a highly nonuniform sample easily. Simple set of membership functions can save the system knowledge and a very little number of input data is needed to make a full model.

Keywords: nonuniform transmission lines, fuzzy modeling, fuzzy applications

1 Introduction

Toward investigating new applications for qualitative analysis methods in the field of engineering electromagnetic problems, a novel analysis method and a modeling algorithm were established utilizing fuzzy inference methods for the first time by the authors of the present article [1, 2]. It has been shown that a simple, fast and accurate model can be made based on some newly introduced parameters. The system behavior (dominant rules) were derived through applying the proposed algorithm and the knowledge of parameters were extracted as simple curves. Finally as a worthy benefit it was understood that using a human understanding based method has given us the ability of applying the human expertness knowledge to the system (e.g. through changing the membership functions). All the above have encouraged us to generalize the idea to the field of basic electromagnetic parameters. In this paper, using human direct understandings, we are going to face with nonuniform transmission lines to show the capabilities of the proposed method in modeling of complicated electromagnetic phenomena. We would like to emphasize excellent results obtained considering the method simplicity.

2 Nonuniform Transmission Line

To show the ability of the proposed method we have chosen a quite complicated example of a highly nonuniform transmission line like what is shown in Fig.1. The characteristic impedance of the transmission line is supposed to be a function of x, which is the variable along its length as shown schematically. Here the nonlinearity is chosen as an exponential function of Eq.1, where $Z_0(0)$ and q are the characteristic impedance at $x = 0$ and the factor of nonlinearity, respectively.

$$Z_0(x) = Z_0(0).e^{2qx} \quad (1)$$

As a first order approximation, the transfer matrix elements of a nonuniform transmission line can be written as Eqs.2 and 3 [4]. Where u and ω are the propagation velocity and an-

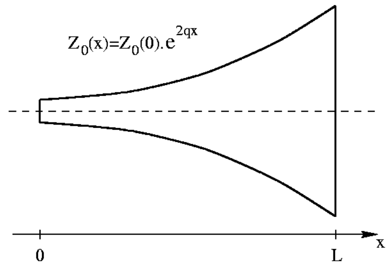

Figure 1: Schematic view of an exponentially nonuniform transmission line

gular frequency, respectively.

$$T = \begin{bmatrix} A & B \\ C & D \end{bmatrix} \tag{2}$$

where

$$\begin{cases} A = \frac{1}{1-qL}\left(cos\left(\omega\frac{L}{u}\right) - q\frac{u}{\omega}sin\left(\omega\frac{L}{u}\right)\right) \\ B = \frac{Z_0(0)}{1-qL}\left(-jsin\left(\omega\frac{L}{u}\right)\right) \\ C = \frac{exp(-2qL)}{Z_0(0)(1-qL)} \\ \quad .\left(-jsin\left(\omega\frac{L}{u}\right) + q\frac{u}{\omega}sin\left(\omega\frac{L}{u}\right)\right) \\ D = \frac{exp(-2qL)}{1-qL}cos\left(\omega\frac{L}{u}\right) \end{cases} \tag{3}$$

The input impedance can be simply determined using the transfer matrix as Eq.4. Where the Z_l is the load impedance.

$$Z_{in} = \frac{A + \frac{B}{Z_l}}{C + \frac{D}{Z_l}} \tag{4}$$

Utilizing the Eqs.3 and 4, input impedance of an exponentially nonuniform transmission line as Eq.1 with nonlinearity factor of $q = 5$, $Z_0(0) = 10\Omega$ and $L = 50cm$ when it is terminated by a load of $Z_l = 10 - j7\Omega$ is calculated in the frequency range of 200 to 1000 MHz and the result is shown in Fig.2 (solid line). As it is clear although the line is highly nonuniform, the resulted curve seems very smooth and this is the main point we mentioned in previous works [2]. This curve also may be interpreted by human as a moving circle changing in diameter and center position when frequency (variable) increases which is our basic interpretation of impedance curves in polar plane.

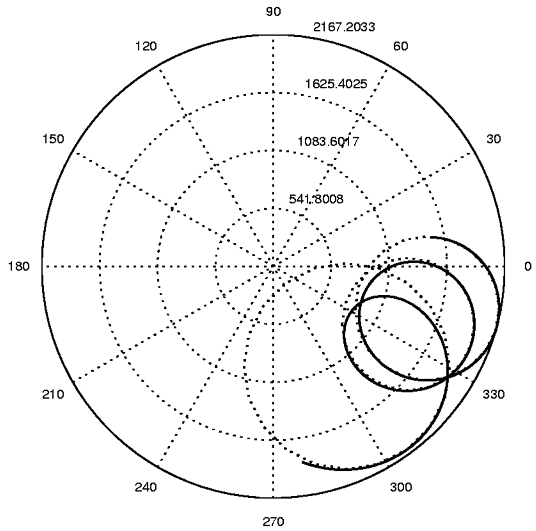

Figure 2: Input impedance of the exponentially nonuniform transmission line with fitted basic circles

3 Fuzzy Modeling of Transmission Line Input Impedance

Basically our proposed method uses some initial circles expressing the *periodicity* as starting data. These circles have different radius because of *loss* and a moving center because of some *parasitics*. The circles shown in dotted lines in Fig.2 are the proper initial ones for this example and the decision rule for them is explained below. Supposing known starting circles the fuzzy modeling algorithm steps are summarized as shown in flow chart of Fig.3. In Fig.2 we define three starting circles (dotted circles) to fit the impedance curve around the maximum value of absolute impedance $|Z_{in}|$. Actually in our interpretation these points are supposed as deviated resonance points of $Z_{in} > Z_0$ because of parasitics in a general meaning. These circles are basic parameters we use in our qualitative calculation since, paying attention to Fig.2, it seems that the impedance curve is generated from these three circles transfiguring from one to another. We may assert consequently that the impedance curve of Fig.2, can be regenerated by mixing these basic circles through properly defined fuzzy sets and membership functions.

Suppose the deviated resonance positions named as $Res1$, $Res2$, and $Res3$, respectively by increasing frequency. Fig.4 shows how

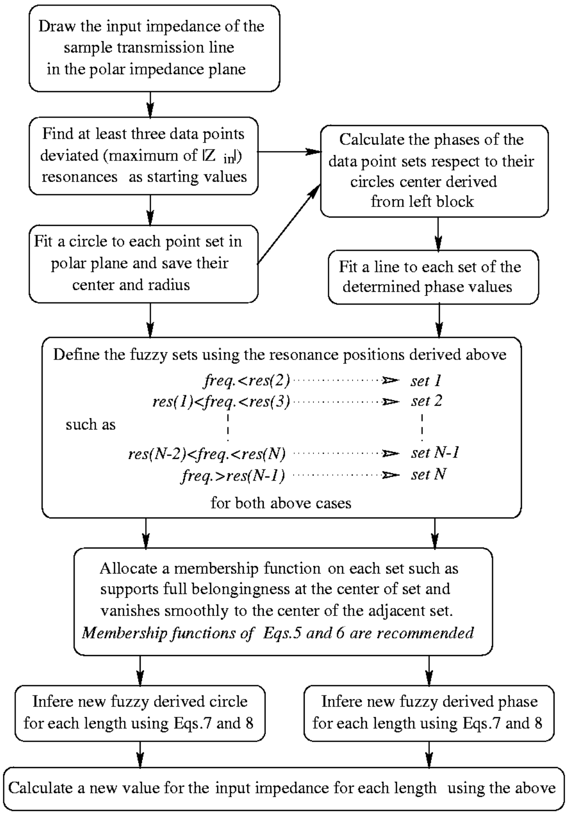

Figure 3: Modeling steps used for input impedance of a transmission line

fuzzy sets are determined and membership functions are allocated using the resonance positions. Here we use membership functions those are defined by Bagheri Shouraki because of their flexibility and smoothness [3]. The implications ($if - then$ rules) used in the proposed method can be simply written as Eq.5.

$$\begin{cases} if\ freq.\ is\ S & then\quad 1^{st}\ circle \\ if\ freq.\ is\ M & then\quad 2^{nd}\ circle \\ if\ freq.\ is\ L & then\quad 3^{rd}\ circle \end{cases} \tag{5}$$

where S means $freq. < Res2$, M means $Res1 < freq. < Res3$, and L means $freq. > Res2$.

Applying the above implications to the membership functions like those are shown in Fig.4, new circles can be inferred for each $freq.$ using simple inferences of Eq.6.

$$\begin{cases} x(freq.) & = \sum_{i=1}^{3} x_i \alpha_i(freq.) \\ y(freq.) & = \sum_{i=1}^{3} y_i \alpha_i(freq.) \\ r(freq.) & = \sum_{i=1}^{3} r_i \alpha_i(freq.) \end{cases} \tag{6}$$

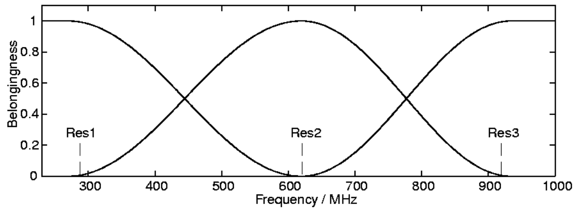

Figure 4: Fuzzy sets decision and membership functions allocating

where x_i, y_i are center coordinates and r_i is the radius of the basic circles respectively, α_i is the fire strength or belongingness of desired $freq.$ derived from Fig.4 and finally the newly inferred circles are specified by x, y and r as center coordinates and radius respectively.

In this step possible impedances for each frequency are limited to those are lying on related fuzzy derived circle. In other words, we defined a partial locus for each frequency. To find the correct position on the mentioned circles or the correct partial phase, we model the phase curve of the correct impedance points respect to the center of their own fuzzy derived circles individually [1, 2]. What is shown in Fig.5 (solid line) is the partial phase of the example of Fig.2. The dash dotted line is the same phase curve but modified by 360° at discontinuities to show the curve smoothness. All we do to model this curve is mixing three lines those are shown by dashed lines in Fig.5, through exactly the same fuzzy process as applied to basic circles above. Note

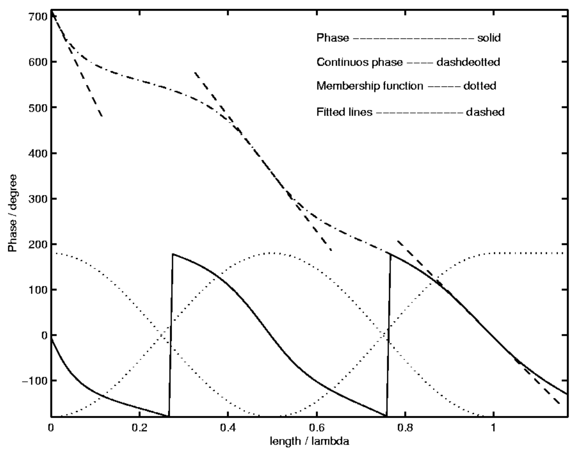

Figure 5: Phase curve calculated respect to the center of individual fuzzy derived circles

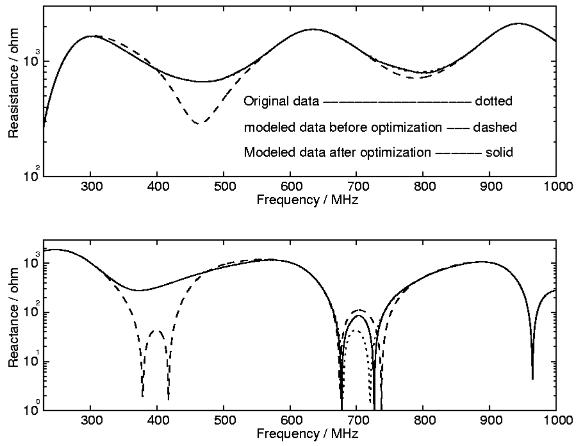

Figure 6: Comparison of the calculated data with modeling results before and after optimization

that these basic lines can be determined easily using the phases of the same points used to define the basic circles respect to the center of them. Therefore no new information should be included.

The method described above was applied to the input impedance of the nonuniform line of Fig.2 and the modeling results without any optimization are shown (dashed) in comparison with original data (dotted) in Fig.6 in Cartesian coordinates to make the errors more visible. The authors would like to emphasize that the proposed method without any optimization and with the membership functions of Fig.4 results in a very good agreement in the case of uniform transmission lines. Here also as it is seen except values around 400 MHz, a quite good agreement is achieved. This can be supposed because of a highly non-uniformity around this frequency as it is seen in Fig.2. Since the deviation is not a linear mapping, the system behavior is changed because of that and the optimum membership functions will be different. The optimized membership functions are shown in Fig.7 and the modeled results are shown in Fig.6 (solid) and as it is seen the agreement is excellent and recognizing the modeled data from calculated one is very difficult even in Cartesian coordinates.

4 Conclusion

The developed fuzzy modeling approach by the authors, which was greatly successful re-

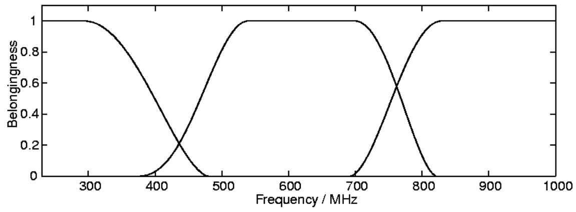

Figure 7: Derived optimum membership functions for the exponentially nonuniform transmission line

garding to monopole antenna was applied with the same structure and a few simplifications to nonuniform transmission lines and excellent results were achieved. It is well worth noting that same modeling algorithm and structure is applicable to two different problems with different analytical formulation. The proposed method presents same calculation complexity in both cases. This is because of newly introduced parameters those are considered as qualitative calculation base. This research may be a promising substrate for electromagnetic expert systems.

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