The Application of Data Interpolation in the Design of Multimode Feed Network

Huawei Zhan1,2 Xiaoqing Li1,2 Weina Liu*1,2 Shuie Shi1,2

1 College of Electronic and Electrical Engineering, Henan Normal University, Xinxiang, Henan 453007, China
2 Key Discipline Open Laboratory of Electromagnetic Wave Characteristic Information Detection of Henan Province, Xinxiang, Henan 453007, China
*Corresponding Author zhanhw@126.com

Abstract — Multimode feed network is a key element in shortwave multimode multi-feed antenna system. Its effective and precise optimizing design will provide the basis to the entire multimode multi-feed antenna system’s optimizing design. To satisfy the requirement of seamless datum, an interpolation algorithm based on the distance reciprocal is proposed and analyzed in this paper. we also present typical mathematical functions as examples of the multivariable interpolation algorithm. The interpolation result indicates that the transmission-line transformer [S] parameter measurement database can achieve effective data interpolation by using the algorithm with proper interpolation precision. The results show the algorithm provides a favorable basis for the entire multimode multi-feed antenna system optimizing design.

Keywords - multimode feed network; theory of substructure; the interpolation algorithm based on the distance’s reciprocal

I. INTRODUCTION
The multimode feed network of multi-mode multi-feed shortwave antenna is composed of impedance transformer and isolator[1]. The function of impedance transformer is for impedance match. The function of isolator is to divide(or synthesize)power and isolate the signal. Both the two substructures are deiced on the transmission-line transformer, the equivalent circuits are shown in Fig.1. In opinion of substructure cascade, the characteristic of feed network can gain through the characteristic of impedance transforming substructure and isolating substructure.

The Several years ago, we brought forward the substructure analyzing method of interconnect-net[2], based on great capacity database, to settle the question that we encountered while researching, for example the difficulty in analyzing and optimizing the complex electromagnetic structure, the certain blindness in designing and machining.
Substructure analyzing method of interconnect-net succeeding in combining microwave engineer with computer technology (database, view-data), and representing the net cell by measure database directly. That method can analyze and optimize and design a kind of non-uniform net in engineer [3].

Substructure can be basic net unit or a set of net unit due to different objects. The aim is to make analyze more quickly and calculate more precise, for the convenience of debug, design and the optimization of system performance. The mainly point is which of definite electronic-magnetism characteristic or net parameter. For the multi-mode feed network usually, we use the S-parameter to describe the port characteristic of a certain substructure [4], for it has some merits as follow:

- Easy to measure and use.
- S-parameter can calculate circuit with Smith chart.

II. BRIEF DEPICTION OF THE DATA INTERPOLATION ALGORITHMS
Interpolation theory is an important branch of mathematics [5]. On the basis of using part of known datas’ information to construct interpolation function, using the value of interpolation function to approach or replace the unknown point’s real value is the basic interpolation thought.
[6]. The analog interpolation, the algebra polynomial interpolation and the subsection polynomial interpolation are the common interpolation algorithms.

This paper presents a kind of multivariable interpolation algorithm based on the weight function of the distance’s reciprocal, it can be briefly described as follows: There are m known points can be described as \( X^j \), \( (x_{ij}, x_{2j}, \ldots, x_{nj}) \) in the n dimensions space and their corresponding function-values can be described as \( y^j \). The m known points are measurement results, so point \( X^j \) can be described as \( X^j = \{ x^j \} \) and its function values can be described respectively as \( y^j \). Evaluate the function \( y^j \) in the neighbor field of the unknown point, and their corresponding function values. The unknown point's function value tends to zero.

The interpolation function can be described as:

\[
y_{\text{measured}} = \sum_{j=1}^{m} k_j y^j
\]

The characters can be concluded from the expression of interpolation function:

- The algorithm is the multivariable algorithm based on linearity interpolation.
- If the interval between an unknown point and a known point is shorter, the weight value is more.
- If known points are symmetric relative to an unknown point, the weight values are same.
- When a known point keeps away from an unknown point, the weight value becomes little; when the distance between a known point and an unknown point tends to infinity, the weight value tends to zero.

To satisfy the seamless requirement of the transmission-line transformer’s S-parameter measurement database, the interpolation algorithm based on the distance’s reciprocal is adopted in this paper.

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III. THE INTERPOLATION EFFECT AND THE ERROR ANALYSIS

The multivariable interpolation algorithm presented in this paper is based on the n dimensions normalizing space, according to the distances’ reciprocal between the selected known points and an unknown point, the function value of the unknown point can be obtained by adding the corresponding function values of selected known points with weight values [8]. So the key to the algorithm is how to design the reasonable interpolation points’ selecting principle in the neighbor field of the unknown point to meet the requirement of efficiency and precision [9]. In order to validate the nonlinearity character of the algorithm, many multidimensional interpolation exemplifications are presented as follows.

A. The Interpolation Effect of one-dimension Interpolation

In order to validate the nonlinearity interpolation effect of the algorithm, this paper presents the damp oscillatory function \( y = e^{-2x} \sin(3.14x) \) as the examples of the one-dimension interpolation exemplifications. Supposing that \( 5 \leq x \leq 15 \), when the selecting interval of axis x is 0.02, thousands of points can be selected. On the basis of calculating their corresponding function values, the measurement database can be composed of these x values, and their corresponding function values.

The weight function can be described as:

\[
k_j = \frac{d_j}{\sum_{k=1}^{m} \frac{1}{d_k}}
\]
In order to validate this interpolation algorithm, supposing that $5 \leq x \leq 15$, when the selecting interval of axis is 0.04, five hundreds points can be selected. The interpolation points selecting principle in the neighbor field of an unknown point is selecting all known points of the measurement database in terms of x value between the unknown point x value’s 0.05. Fig.2 is the comparison of the interpolation results and the calculation results. Fig.3 is the error analysis.

Analysis of the interpolation error can be outlined as follows: on the basis of the boundary points’ extrapolating disposal, the error of all points can be controlled within the $\pm 0.01$, 92.2% of unknown points’ relative errors can be controlled within 0.6%, 96.4% of unknown points’ relative errors can be controlled within 1.0%. The interpolation results indicate that the algorithm has better interpolation effect aiming at one-dimension nonlinearity function.

**B. The Interpolation Effect of Three-dimensions**

Because the character parameters of the equalizer are common three-dimensions, the three-dimensions interpolation effect of the algorithm should be validated. The paper presents $w = (x-1)^2 + \frac{(y-2)^2}{4} + \frac{(z-3)^2}{9}$ as the example of three-dimensions interpolation exemplification. Supposing that $-2.4 \leq x \leq 3.6$, $-2.4 \leq y \leq 3.6$ and $-2.4 \leq z \leq 3.6$, when the selecting intervals of axis x, y and z are 0.02 respectively, thousands of points can be selected. On the basis of calculating their corresponding function values, the measurement database can be composed of these x values, y values, z values and their corresponding function values.

<table>
<thead>
<tr>
<th>X</th>
<th>Y</th>
<th>Z</th>
<th>Interpolation results</th>
<th>Calculat-</th>
<th>Error</th>
<th>Relative error (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.08</td>
<td>1.84</td>
<td>1.6</td>
<td>54.13761</td>
<td>54.10146</td>
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<td>2.08</td>
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<td>1.68</td>
<td>54.33576</td>
<td>54.29941</td>
<td>0.03635</td>
<td>0.06695</td>
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<tr>
<td>2.08</td>
<td>1.84</td>
<td>1.76</td>
<td>54.59311</td>
<td>54.55651</td>
<td>0.0366</td>
<td>0.06709</td>
</tr>
<tr>
<td>2.08</td>
<td>1.84</td>
<td>1.84</td>
<td>54.922</td>
<td>54.88511</td>
<td>0.0369</td>
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</tr>
<tr>
<td>2.08</td>
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<td>1.92</td>
<td>55.33708</td>
<td>55.29984</td>
<td>0.03724</td>
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<tr>
<td>2.08</td>
<td>1.84</td>
<td>2</td>
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<td>55.81807</td>
<td>0.03766</td>
<td>0.06746</td>
</tr>
<tr>
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<td>56.49853</td>
<td>56.46039</td>
<td>0.03814</td>
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<tr>
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<td>0.03941</td>
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<td>59.39879</td>
<td>0.04023</td>
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<tr>
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<td>60.87118</td>
<td>60.83002</td>
<td>0.04117</td>
<td>0.06767</td>
</tr>
</tbody>
</table>

In order to validate this interpolation algorithm, supposing that $-2.4 \leq x \leq 3.6$, $-2.4 \leq y \leq 3.6$ and $-2.4 \leq z \leq 3.6$. But the selecting intervals of axis x, y and z are 0.08 respectively. The interpolation points selecting principle in the neighbor field of an unknown point is selecting all known points of the measurement database in terms of x, y, z value between the unknown point value’s $\pm 0.03$ respectively. The table1 presents the comparison of part interpolation results and calculation results.

The interpolation error can be analyzed as follows: 96% of unknown points’ relative error can be controlled within 0.1%. The interpolation results indicate that the algorithm can achieve better interpolation effect aiming at the nonlinearity function.

**IV. APPLICATION, ANALYSIS AND EXAMPLE**

Because of the different function, the two substructures have the different ends connected together, the different input port and the different output port. In this paper, a impedance transformer is taken as example.

Example: Impedance transformer to be exampled consists of eight tunes of coaxial-line (characteristic impedance is 50 ohm ) wound on a ferrite core, with outer and inner dimensions of 0.061. S-parameter can be measured with HP4395A.

$\varepsilon_{\text{eff}}$ = the effective dielectric constant of the media inside the coil[10] ( $\varepsilon_{\text{eff}}$ of coaxial-line to be used in this example is 2.1).

S-parameter can be measured with HP4395A. In order to validate this interpolation algorithm, measuring frequency from 1.3MHz to 31.3MHz, when the selecting interval of frequency is 0.15MHz, two hundreds points can be selected. The interpolation points selecting principle in the neighbor field of an unknown point is selecting all known points of the
measurement database in terms of frequency between the unknown point frequency value’s 0.15MHz.

Analysis of the interpolation error can be outlined as follows: on the basis of the boundary points’ extrapolating disposal, the relative error of all points can be controlled within ±0.01, most of real part interpolation points’ relative errors can be controlled within 0.5%, most of the imaginary part interpolation points’ relative errors can be controlled within 1.5%. The interpolation results indicate that the algorithm has better interpolation effect aiming at S-parameter measurement database.

V. CONCLUSION

Aiming at the nonlinearity mathematical function, the interpolation effect of the interpolation algorithm based on the distance’ reciprocal is analyzed in the paper. The effective and practical key to the algorithm is how to find out the reasonable interpolation points selecting principle in the neighbor field of an unknown point and how to design the reasonable threshold-value distance between an unknown point and known points. So it is important to find out an
effective and practical selecting algorithm and to analyze the
relation between interpolation error and data denseness
degree of measurement database in the further research.

For the multimode feed network substructure S-
parameter measurement database, the interpolation effect of
the interpolation algorithm based on the distance’ reciprocal
is analyzed in the paper. The interpolation results not only
validate the nonlinearity of the algorithm but also provide
favorable base for the optimum design of the multimode feed
network.

ACKNOWLEDGMENT

This work is supported by Science and Technology
Research Project of The Education Department of Henan
Province(17B510004).

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