Accelerating Computations with a MoM-Based Computer Program using a Model-Based Parameter Estimation Algorithm

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Abstract

Electromagnetic research often requires studies within wider frequency ranges. For achieving a fine resolution in the frequency domain, the required computation time is usually high. Here the MoM-based field computation program FEKO working in frequency domain is used for this purpose. In order to reduce the computational costs by minimizing the number of sampling points used, the interpolation algorithm MPBE (Model Based Parameter Estimation) is applied to achieve a mathematically based approximation of the problem. This paper presents the acceleration of computations with FEKO using the interpolation algorithm MBPE. A short introduction to FEKO is given at the beginning. Subsequently the implementation of MBPE as well as three possible adaptive strategies for further shortening the computation time is presented. Finally examples are given that show the advantages of this implemented method.

Introduction

Research in the field of electromagnetic compatibility often requires studies over large frequency ranges. Since the scenarios to be modeled are very complex (e.g. in medical areas) and also the computation time needed for these kinds of investigations is usually very high a new approach has to be developed to fulfill all these requirements. In this paper the MoM-based field computation program FEKO is accelerated using the MBPE algorithm, which is presented in the following.

The Field Computation Program FEKO

FEKO [1], [2] is a field computation program considering objects of arbitrary shape. It is based on a full wave solution of Maxwell's equations in the frequency domain. The accurate Method of Moments (MoM) formulation is used to solve for the unknown surface currents. Asymptotic techniques, Physical Optics (PO) and Uniform Theory of Diffraction (UTD) have been hybridized with the MoM in order to solve electrically large problems. The MoM has also been extended to solve problems involving multiple homogeneous dielectric bodies, thin dielectric sheets and dielectric coated wires. An approach is necessary to speed up computations over large frequency ranges. Therefore, the acceleration of FEKO with the interpolation algorithm MBPE is described in the following.

Model Based Parameter Estimation (MBPE)

In order to reduce the computational costs by minimizing the number of sampling points used, the interpolation algorithm MPBE [3], [4], [5], [6] is applied to achieve a mathematically based approximation of the problems. A function sampled in the frequency domain is approximated with MBPE to represent the original function by a reduced-order physically based approximation called a fitting model.

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The application of such a fitting model means interpolating between samples to reduce the amount of data needed. First frequency f is normalized with respect to the center frequency f_c and the width of the frequency interval f_w.

$$x = \frac{f - f_c}{f_w} \tag{1}$$

Now the fitting models are described by a pole series based on the Padé approximation with rational polynomials

$$F(f) = \frac{N(f)}{D(f)} = \frac{\sum_{v=0}^{n} N_v f^v}{\sum_{v=0}^{d} D_v f^v} \tag{2}$$

with n is order of the numerator and d is order of the denominator. Basically there are three possibilities for determining parameters for fitting models, either from samples of the process to be modeled, alternatively from samples of the derivatives of the process, or from a combination of both. Since the field computation program FEKO is used here and the computational cost of derivative sampling of a process would be much higher, only function sampling is used in this paper. With sampling in frequency domain, there is no need for the samples (f_i) to be uniformly spaced as is usually the case in most time domain solutions. That means that the samples can be chosen in such a way that the yield of information for each sample is a maximum. Equation (2) leads to

$$D(f_i) \cdot F(f_i) = N(f_i), \qquad i = 0,...,D-1 \tag{3a}$$

where $D(f_i) = D_0 + D_1 f_i + D_2 f_i^2 + ... + D_d f_i^d$ (3b)

and $N(f_i) = N_0 + N_1 f_i + N_2 f_i^2 + ... + N_n f_i^n$ (3c)

There are $D = d + n + 2$ unknown coefficients in the two polynomials $D(f_i)$ and $N(f_i)$. An additional condition or constraint is needed and so $D_d = 1$ is chosen (linear predictor constraint). With now determining the $D = d + n + 1$ unknown coefficients $N_0, N_1, N_2 + ... + N_n, D_0, D_1,$ $D_2 + ... + D_{d-1}$ of this equation system a function to represent the original values can be found. Now the complete frequency range is divided into different windows and for every window an equation system according to (3) is solved. In the end all fitting models are combined to give the overall solution function for the entire frequency range.

A first example (IEEE German EMC chapter: benchmark problem no. 3) for the functionality of the algorithms is given with a monopole antenna on an infinite ground plane and a nearby wire loop (see figure 1). The exciting frequency of the antenna is varied in the range from f = 1 MHz to 30 MHz. The resulting complex current induced in the wire loop is shown in figure 2.

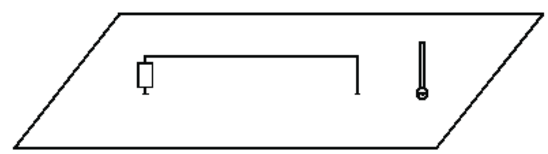

Fig. 1. Geometry in principle for the benchmark problem no. 3 defined by the German IEEE/EMC chapter.

If 30 equidistant sample points (i.e. sampling every 1 MHz) are linearly interpolated the curve shown in figure 2a results. In this case resonant peaks are cut off. An exact result can be achieved using uniformly and closely sampled points (in this case 581 samples, i.e. sampling every 50 kHz) as shown in figure 2b. The same curve results with using the 30 sample points and interpolating with MBPE (see figure 2c).

Overlapping fitting models always containing $N_N + N_D + 1 = 7$ sample points were used to approximate this problem. The orders of the polynomials for every fitting model were chosen $N_N = N_D = 3$. The first seven sample points were used for determining the coefficients of the first model representing the first part of the solution. For the second fitting model samples 2 to 8 are used to compute its model coefficients and so on. In the end all fitting models were set together to achieve the overall solution with only 30 sample points. The computation time rises linearly with the number of sample points used in total, so in this case the overall computation was accelerated with using the MBPE algorithm by an acceleration factor of $\frac{581}{30} = 19.4$.

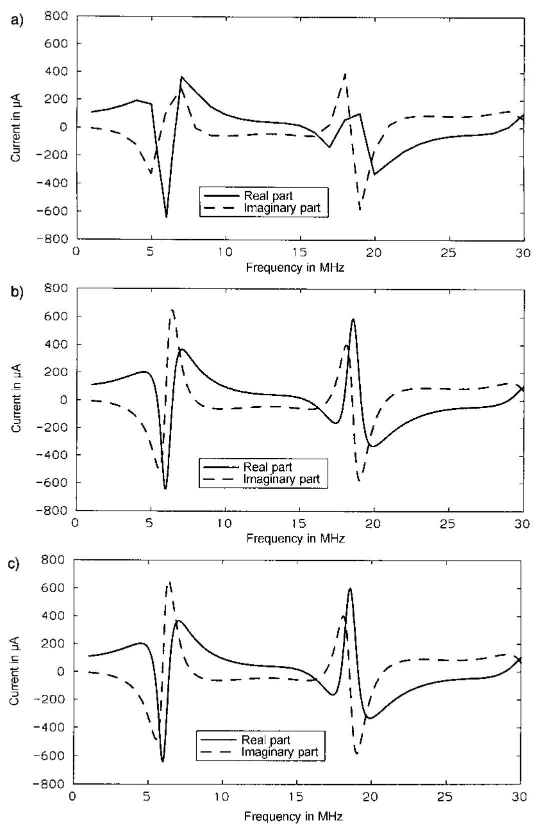

Fig. 2. Complex current induced in a wire loop.

Adaptive Sampling

With "adaptive sampling" a more flexible algorithm is applied to further minimize the number of required sample points by exploiting the fact that in the frequency domain no uniformly spaced samples are required. The computation is started with a small set of sampling points and with these a set of overlapping windows is determined. The whole frequency range is covered by overlapping windows so that a maximum error between two fitting models

$$E_{i,j}(f_k) = \frac{|W_i(f_k) - W_j(f_k)|}{|W_i(f_k) + W_j(f_k)|} \quad (4)$$

can be determined for every frequency. Where the error is a maximum, a new sample point will be added. If a window is containing too much sample points, it will be split up into two. The algorithm is terminated when the error falls under a certain threshold.

The second adaptive sampling approach implemented is using a strategy based on Romberg's method. The procedure starts with an interval containing five uniformly spaced samples. With these samples three trapezoidal values are computed (with samples 1,3,5; 1,2,3 and 3,4,5) and an error estimation between these values indicates whether a new sample is required in this interval. If that is the case, two new subintervals are formed from each half of the original interval and Romberg's method is applied to both of them. If new samples are required in either of these subintervals, new sample points are added where indicated. This process is repeated until the error falls under a chosen threshold.

The third approach to reduce the number of sampling points needed is a Genetic Algorithm (GA) to find the orders of the numerator and the denominator for a fitting model representing the whole frequency range. It is started with a very simple model with low order (e.g. $N_N + N_D + 1 = 4$). There are now various possibilities for the orders of the numerator and the denominator ($N_N = 0; N_D = 3$ / $N_N = 1; N_D = 2$ /…). If the three best models of this generation are not sufficient in representing the final result, a new sample point is added and a new set of models (with $N_N + N_D + 1 = 5$) will be determined. In this way the number of sampling points is consequently increased during the steps of the approximation process until the error between the three best models falls under a given threshold.

Results

All three adaptive strategies are now used to achieve an accurate result with less sample points. For the benchmark problem described above the three strategies lead to the following results. The first adaptive approach needed 24 samples and achieved an accuracy of 0.01 while using four overlapping windows (window orders: $N_{N0} = 4; N_{D0} = 3$ / $N_{N1} = 5; N_{D1} = 5$ / $N_{N2} = 8; N_{D2} = 8$ and $N_{N3} = 7; N_{D3} = 6$ arranged in such a way, that always two windows are overlapping). With the second approach at first 33 samples were computed according to Romberg's method and then windows with 13 samples per window ($N_N = 6; N_D = 6$) always overlapping from sample 10 to 13 are used to get the overall function. Finally an accuracy of $6.5 \cdot 10^{-5}$ is achieved. With using the Genetic Algorithm 30 samples were computed and the achieved accuracy is $5 \cdot 10^{-3}$. The resulting three best approximation functions have the orders $N_{N0} = 14; N_{D0} = 15$ / $N_{N1} = 15; N_{D1} = 14$ and $N_{N3} = 13; N_{D3} = 16$.

In the next example [7] there is a small wire loop in a cube shaped metallic housing radiating an electromagnetic field (see figure 3). The shielding effectiveness (the electrical field radiated through the housing's front plate with four small slots in it compared to the electrical field without front plate) is shown in figure 4. Here only 84 samples were used and interpolated with MBPE (GA approach) compared to 901 for a closely and uniformly sampled function. Therefor five windows were computed (100 MHz - 309 MHz: $N_{N0} = 7; N_{D0} = 6$, 309 MHz - 418 MHz: $N_{N1} = 3; N_{D1} = 3$, 418 MHz - 550 MHz: $N_{N2} = 10; N_{D2} = 13$, 550 MHz - 760 MHz: $N_{N3} = 12; N_{D3} = 9$ 760 MHz -1000 MHz, $N_{N4} = 12; N_{D4} = 8$) to achieve the overall solution function. There is almost no difference between the two functions (the maximum error over the whole frequency range in this case is 10^{-4}) and the factor in time saving (acceleration factor) is 901/84 = 10.7.

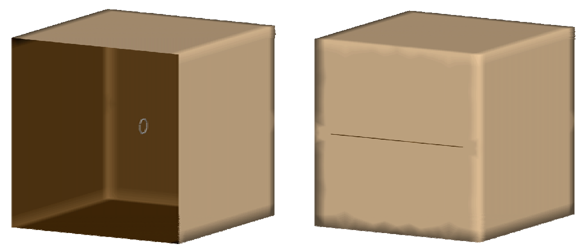

Fig. 3. Housing (without (left) and with (right) front plate) containing a small wire loop radiating an electromagnetic field.

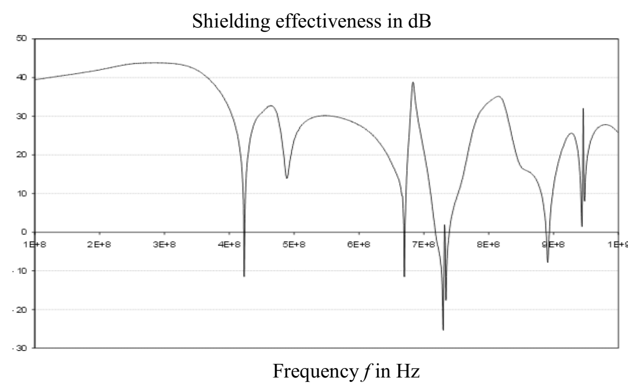

Fig. 4 Shielding effectiveness of the housing in dB.

One other examples containing also very sharp peaks is a simple dipole forked at both ends excited by an incoming plane wave. The resulting magnitude of the input impedance at its ports is depicted over frequency in figure 5. Here only 11 sample points (also shown in the figure) were necessary to interpolate this curve with an accuracy of $5.5 \cdot 10^{-5}$ compared to 1500 uniformly and closely sampled points. This means an acceleration factor of 1000/11=90.9. One window is used to approximate the curve with the orders $N_D = 6$ and $N_N = 4$. With a little lower accuracy this curve could be interpolated with only 10 points, which results in an acceleration factor of 100.

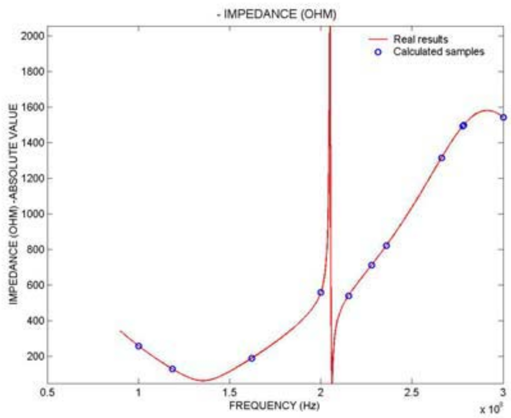

Fig. 5 Input impedance of a forked dipole antenna excited by an incoming plane wave.

Finally it can be said, that with this new approach the computation time has been much reduced and therewith parameter studies and optimizations for larger problems needing a lot of single computations can be done now with the help of this method in an acceptable time.

Conclusions

The successful implementation of Model Based Parameter Estimation and coupling with the field computation program FEKO is presented here. Adaptive sampling for speeding up computations is also described. The implemented algorithm converges and shows good accuracy in first examples, which underline the advantages of the algorithm.

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References

[1] EM Software & Systems, "FEKO User's Manual, Suite 3.2.1", March 2002, www.feko.co.za.

[2] U. Jakobus, "Erweiterte Momentenmethode zur Behandlung kompliziert aufgebauter und elektrische großer elektromagnetischer Streuprobleme“, Nr. 171 in Fortschrittsberichte, Reihe 21, VDI Verlag, Düsseldorf, 1995. Dissertationsschrift.

[3] E. K. Miller, "Model-Based Parameter Estimation in Electromagnetics: Part I. Background and Theoretical Development", *IEEE Transactions on Antennas and Propagation*, vol. 40, no. 1, pp. 42–52, Feb. 1998.

[4] E. K. Miller, "Model-Based Parameter Estimation in Electromagnetics: Part II. Application To EM Observables", *IEEE Transactions on Antennas and Propagation*, vol. 40, no. 2, pp. 51–65, Apr. 1998.

[5] E. K. Miller, "Model-Based Parameter Estimation in Electromagnetics: Part III. Applications to EM Integral Equation", *IEEE Transactions on Antennas and Propagation*, vol. 40, no. 3, pp. 49–66, Jun. 1998.

[6] E. K. Miller and T. K. Sarkar, "An Introduction to Model-Based Parameter Estimation in Electromagnetics", *In Review of Radio Science 1996–1999*, International Union of Radio Science. Oxford University Press, Toronto, pp. 139–174, 1999.

[7] F. Olysager, E. Laermans, D. De Zutter, S. Criel, R. De Smedt, N. Lietaert and A. De Clercq, "Numerical and Experimental Study of the Shielding Effectiveness of a Metallic Enclosure", *IEEE Transactions on Electromagnetic Compatibility*, vol. 41, no. 3, pp. 202–213, Aug. 1999.

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