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Parallel computation of arbitrary shaped thin wire antennas

***Abstract**. An important group of antennas is that one, which antennas have been settled from thin wires. We can build complicated shaped antennas, and complex antenna-systems with these elements. In general case demand of counting of the 3-dimensioned model is too large. Mostly it is true in that case, if we use this one applying fine discretization. For this reason it is important to work out the parallel algorithm, where it is possible. At this work the method of moments has been used for discretization of the equations.*

***Streszczenie.** Ważną grupą anten są anteny wykonane z cienkich przewodów. W takim przypadku anteny mogą posiadać skomplikowane kształty i pracować w złożonych systemach. W przypadku ogólnym obliczanie modeli 3-D może być trudne. Istotnym jest w takim przypadku opracowanie algorytmu równoległego pozwalającego na obliczenia tego typu problemów. W artykule wykorzystano metodę momentów do dyskretyzacji równań. (**Obliczenia równoległe anten o dowolnym kształcie**)*

Keywords: thin wire, arbitrary shape wires, method of moments, parallel computation.
Słowa kluczowe: cienkie obwody, obwody o dowolnym kształcie, metoda momentów, obliczenia równoległe.

Introduction

The thin conducting wire elements are important parts of the antenna theory, because in the practise the antenna consists of completely or partially such elements. In this case the thin wire elements are such conductor elements which have much smaller diameter than the used wavelength.

In the efficient antenna design an appropriate computational model is elementary. This model must be easy to use, modularly easily connectable, acceptably accurate, and give the result within an acceptable time. The aim is to develop such a program for computer, which allows tuning the most parameters. Some special parameters of the model allow to extremely reduce the computational time, but these cases oppose of the universally applicability of the model. The other method for reducing the running time is the parallelization therefore it is important to study the parallelization possibilities.

The presented running times in this paper are relative values, the real times depend on the applied hardware, operating system and the programming technology, but the hereby given times are appropriate to compare the presented methods.

Parameters used in the examples are as follows. Wave length: 0.5 m; wire of radius: 0.0001m; delta-gap source: U=1V, Δz: 0.001m; shape of wire: (sin(u), sin(u),u) , 0 ≤u≤π.

Theoretical introduction

The generated electromagnetic field depends on the current relation in the observed wire, the other physical values can be calculated based these currents. In the wire at the coordinate r, the approximation of the intensity current is given by formula (1) [1], in which I is the current, t the unit vector for the conductor, i.e., the tangent of an idealized curve, fn the nth basis function given on the curve, and an the weight belonging to it [2],

$$I(\bar{r}')\bar{t}(\bar{r}) \approx \sum_{n=1}^{N} a_n \bar{f}_n(\bar{r}) \tag{1}$$

The basis function can be chosen in many ways, a simple method is the usage of triangle basis function according to formula (2)

$$f_n(x) = \frac{x - x_{n-1}}{x_n - x_{n-1}}\ . \qquad x_{n-1} \le x \le x_n \tag{2}$$

Applying the approximating equation (1) to the integral equation of the electric field, we obtain equation (3) [1],

$$-\frac{j}{\omega\mu}\left[\bar{t}(\bar{r}) \cdot \bar{E}^i(\bar{r})\right] = \left[1 + \frac{1}{k^2}\nabla\nabla\cdot\right]\int_L I(\bar{r}')\bar{t}(\bar{r}')G(\bar{r},\bar{r}')d\bar{r}'\ . \tag{3}$$

where E is the electric field intensity, ω is the angular frequency, j is the complex imaginary unit, μ is the permeability, k is the wavenumber, G is the three dimensional Green function as

$$G(\bar{r},\bar{r}') = \frac{e^{-jk|\bar{r}-\bar{r}'|}}{4\pi|\bar{r}-\bar{r}'|}\ . \tag{4}$$

Garlekin type momentum method [1] applied to (3) gives a linear system of equations. The matrix elements of the equation array are calculated as [1]

$$\begin{aligned} z_{mn} = &\int_{\bar{f}_m} \bar{f}_m(\bar{r}) \cdot \int_{\bar{f}_n} \bar{f}_n(\bar{r}')G(\bar{r},\bar{r}')d\bar{r}'d\bar{r} - \\ &\frac{1}{k^2}\int_{\bar{f}_m} \nabla\cdot\bar{f}_m(\bar{r})\int_{\bar{f}_n} \nabla'\cdot\bar{f}(\bar{r}')G(\bar{r},\bar{r}')d\bar{r}'d\bar{r} \end{aligned} \tag{5}$$

while the elements of the excitation vector are generated as

$$b_m = -\frac{j}{\omega\mu}\int_{\bar{f}_m} \bar{f}_m(\bar{r}) \cdot \bar{E}^i(\bar{r})d\bar{r}\ . \tag{6}$$

In the case, if we wish to vary the basis functions freely in the model, then in (5) additional analytic simplifications are not possible.

Discretization

The segmentation of the three-dimensional curve given by g(x(u),y(u),z(u)), on the parameter interval u1<u<u2, and the system of the basis functions can be formulated according to Fig. 1.

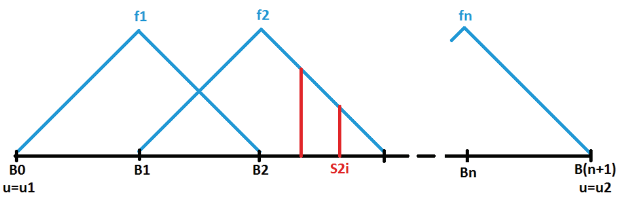

Fig. 1. Triangle basis functions defined on the parameter interval

The size of the linear equation to be solved is determined by the number of the basis points of the dividing points of the parameter interval on the studied curve. More the basis point, the more accurate is the model, but simultaneously the computational demand increases rapidly as it is demonstrated in Fig. 2.

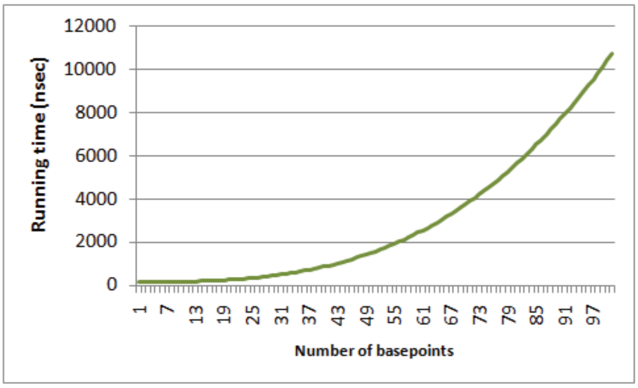

Fig. 2. Running time according to number of basis points

The basis functions provide the distribution of the weight values corresponding to the basis points. This technique is not simply a subsequent smoothing, since the geometry of the curve arcs between the basis points may receive a role in the selection of the number of the sampling points for the computation of differentials and integrals in (5). Fig. 3 shows the necessary time to the compute the elements of the matrix as a function of the sample number between the basis points.

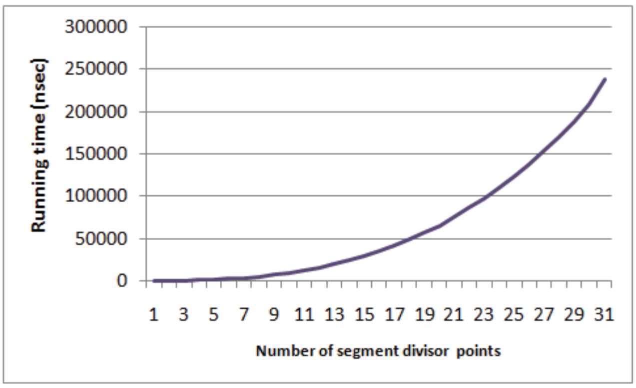

Fig.3. Changing of the running time according to inside segment points, in case of 50 basis points

Accuracy

If we accept that we obtain a more accurate solution with the increase of the number of the base points, it makes sense to compare the less delicate approaches to a particular more detailed arrangement.

For increasing number of equidistant dividing points on the parameter domain the corresponding basis are determined. These points together with the basis functions give a solution, but it is not necessary, that the basis points and the segment dividing points between basis points cover the basis points of the etalon solution. For this reason it is necessary to determine the values corresponding to these missing points of the etalon or to those, which are given for the comparison of the solutions. Of course, the proper basis function definitions have to be taken into account. The deviations of the examined bases points from the relative vector norms compared of this etalon functioned can be analysed, in this case we receive the results according to Fig. 4.

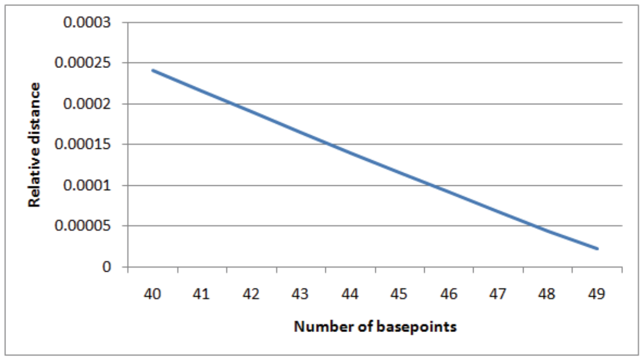

Fig. 4. Relative deviations correlated to 50 basis points with 1 inside segment division point

The same examination can be carried out with growing segment divisor points between the basis points. The results are shown in the Fig. 5.

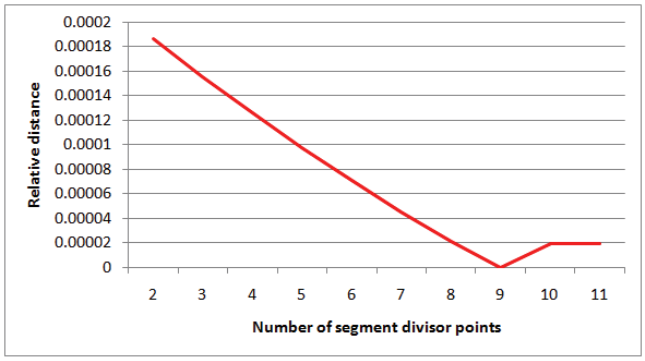

Fig. 5. Relative deviations owing 19 basis points according to changing of inside segment divisor points

We can conclude that by suitable choosing the distribution to some extent the accuracy of the solution can be adjusted by this method. Of course time demand according to Fig. 2. and in Fig. 3. has to be taken into account.

Parallelization

The matrix of the linear system of equations given by (5) – (6) is not a rare matrix, during its solution no essential simplification opportunity is offered. But if we look at the preparatory calculations, i.e., formula (5), we may see that certain calculations steps, which do not need sequential execution, can be carried out independently. Because the quota of preparatory calculations from the complete calculation are possible considerable, for this reason may be worth accelerating this part (Fig 6.).
Equation (7) shows the re-formalised form of equation (5) for calculation units,

(7) $$A(BC) + D(EC)$$

Since the computational demand of blocks C and is nearly identical, these calculations can be started on two parallel threads. Other calculation concerning an element of the respective matrix may not precede these calculations. The result publishing of these threads can be followed by execution of BC-t and EC separately. Th result of BC is a vector, while the result of EC is scalar quantity, thus the execution time of the next step is again nearly identical on these threads. Fig. 7 visualizes the time gained using only at most two computational threads.

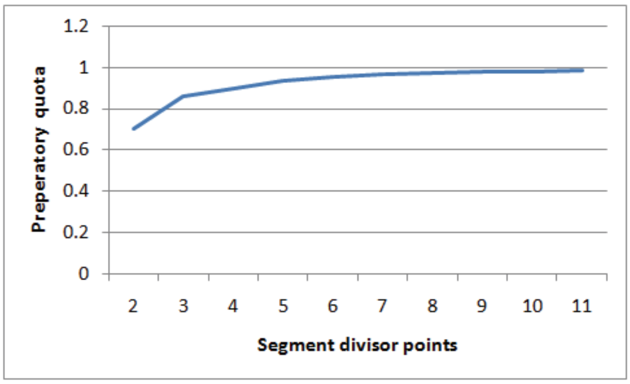

Fig.6. Quota of the time of preparatory calculations compared with complete time, in case of 100 basis points

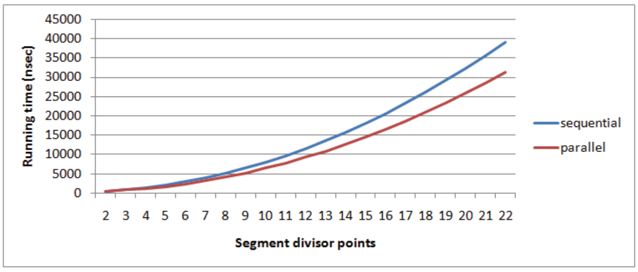

Fig. 7. Time increment with using 2 parallel threads according to segment divisor points, in case of 50 basis points

In the case, if more than two computational units are available (e.g., according to the Fig. 8), we may open then additional paired threads.

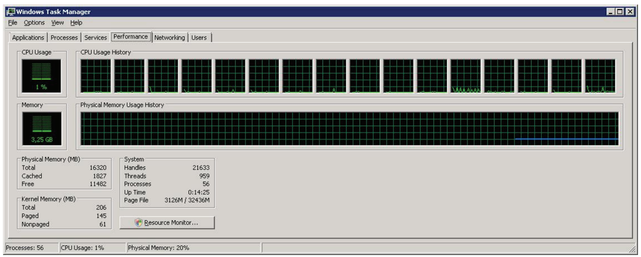

Fig. 8. Computational capacity used in the example

The time gain of the above example is shown in Fig. 9.

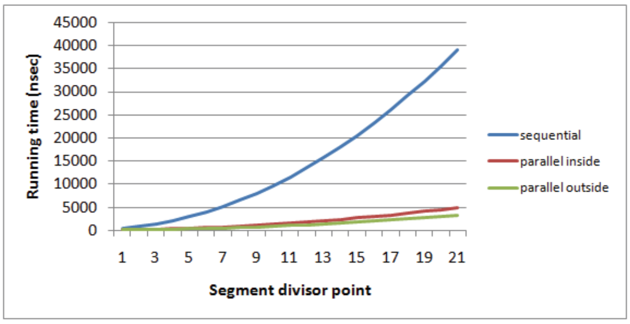

Fig. 9. Time increment in case of 16 processor cores, with parallel of inside part calculation and the all one of expression (5), in case of 50 basis points

We may take advantage of the available computational units the most natural manner, if we share the elements of the matrix in an equal proportion adequately to the computing capacity. Based on the measurements this solution is proved to be the most efficient one.

Volume of current along the wire are computed in the examples, it is showed in Fig.10.

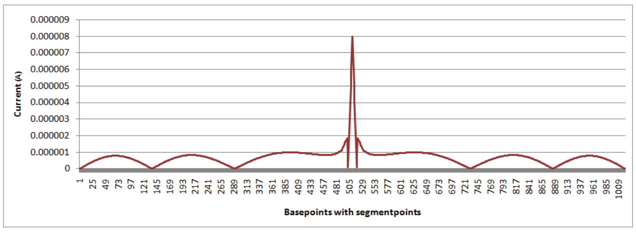

Fig.10. Current length is along the wire, delta-gap is in centre of parameter interval, in case of 51 basis points and 20 segment divisor points

Conclusions

The designer, modeller the option of the software containing complex objects makes the device more easily usable. However, this tool decreases the velocity somewhat. This loss is not significant, it may be well compensated by the preparatory calculations' being parallel. Exact and objective gain indicators are hard to provide, even if we specify the environment to extremities, since two sequent runtimes within the same conditions are proved to be different many times, because the operation system can have other not published activities any time.

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