OIPE 2010

# 11th WORKSHOP ON OPTIMIZATION AND INVERSE PROBLEMS IN ELECTROMAGNETISM

# PROCEEDINGS


**14-18 September 2010, Sofia, Bulgaria**

TECHNICAL UNIVERSITY OF SOFIA

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# WELCOME TO SOFIA


Dear Authors and Participants,

it is our great honor and pleasure to welcome you to Sofia, where OIPE 2010, $11^{th}$ International Workshop on Optimization and Inverse Problems in Electromagnetism will be held from 14 to 18 September 2010.

The OIPE Workshops has gained a high reputation since its establishment more than twenty years ago. We are glad that for the first time the workshop is coming to Bulgaria and to the Balkan region. We do hope that widening the geographical area of OIPE workshop will contribute to its success and development.

The common denominators of all OIPE workshops, Optimization and Inverse Problems, are cross sectional topics with high relevance in many fields of engineering and other sciences. Thus, the OIPE workshops are very multidisciplinary with respect to the covered topics and the contributing scientists. This is in contrast to many other workshops or conferences, which concentrate on specific applications or subfields of science. It not only makes the OIPE series unique but also brings together and promotes interaction between scientists from various backgrounds and from all around the world. We beleive that OIPE 2010 will substantially contribute to the exchange of new ideas and new views in this field.

International PhD Seminar is also a part of OIPE 2010. The seminar is entitled “Computational electromagnetics and optimization in electrical engineering” and is held just before OIPE 2010. The seminar features invited lectures by leading scientists and presentations by PhD students. The financial support from DAAD allowed also participants in the seminar to be able to attend the OIPE 2010 workshop. Thus the young people will be able to participate in the sessions of OIPE 2010 and to get in contact with leading experts in the area of optimization and inverse problems.

For this year's edition of OIPE Workshop we received 83 digests in total, of which 72 were accepted for presentation. Three keynote speakers were also invited to present their recent achievements.
We would like to express our sincere appreciation of the hard work done by the International Editorial Board. We have also to thank the Local Steering Committee for their efforts for the preparation of OIPE 2010.

We wish you a successful workshop and a pleasant stay in Sofia!

Sofia, September 2010

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| Prof. Ivan Yatchev<br>OIPE 2010 Chairman | Prof. Iliana Marinova<br>OIPE 2010 Secretary |

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## General Programme

| Day | Hour | Event |
|---|---|---|
| Tuesday 14 September | 16:30 - 19:00 | Registration |
| | 19:00 - 21:00 | Welcome reception |
| Wednesday 15 September | 9:00 - 9:30 | Opening Session |
| | 9:30 - 11:00 | Oral Session **O1** |
| | 11:00 - 11:30 | Coffee Break |
| | 11:30 - 13:00 | Oral Session **O2** |
| | 13:00 - 14:30 | Lunch |
| | 14:30 - 16:00 | Oral Session **O3** |
| | 16:00 - 16:30 | Coffee Break |
| | 16:30 - 18:00 | Poster Session **P1** |
| | 18:30 - 20:00 | Dinner |
| Thursday 16 September | 9:00 - 10:30 | Oral Session **O4** |
| | 10:30 - 11:00 | Coffee Break |
| | 11:00 - 12:30 | Oral Session **O5** |
| | 12:30 - 14:00 | Lunch |
| | 14:00 - 15:30 | Poster Session **P2** |
| | 15:30 - 16:00 | Coffee Break |
| | 16:00 - 18:30 | ISC Meeting |
| | 18:30 - 20:00 | Dinner |
| Friday 17 September | 9:00 - 10:30 | Oral Session **O6** |
| | 10:30 - 11:00 | Coffee Break |
| | 11:00 - 12:30 | Oral Session **O7** |
| | 12:30 - 14:00 | Lunch |
| | 14:00 - 15:00 | Oral Session **O8** |
| | 15:00 - 15:30 | Coffee Break |
| | 15:30 - 16:00 | Closing Session |
| | 19:00 - 23:00 | Gala Dinner |
| Saturday 18 September | 9:00 - 17:00 | Excursion to Rila Monastery |

# OPTIMIZED TRANSIENT ANALYSIS USING GB-BEM

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**Abstract**. Transient analysis of the thin wire structures via indirect scheme of the Galerking - Bubnov Boundary Element Method (GB-BEM) is performed using simple optimization techniques for frequency to time domain transformation. The common method of uniform frequency domain sampling combined with Fast Fourier Transform (FFT) is replaced by adaptive frequency domain sampling, combined with simple approximate analytical inverse Fourier transform. The present adaptive sampling method is especially effective for highly resonant geometries where order of magnitude improvements in calculation time can be achieved, when compared with simple uniform sampling. For geometries where high number of frequency samples would be required in inverse FFT, simple approximate analytical inverse Fourier transform, using much lower number of samples obtained during adaptive sampling step, is used thus further improving the overall computational efficiency of the algorithm.

**Keywords**: adaptive sampling, Fourier transform, GB-BEM, thin wires, time-domain analysis

## INTRODUCTION

While indirect time-domain methods are typically much easier to implement then direct time-domain methods, they do require calculation to be repeated sufficient number of times in order to obtain adequately accurate results. For geometries witch impulse response spans across larger frequency spectrum, or that are highly resonant, indirect methods are significantly less efficient then direct time domain methods, which require only one calculation, irrespective of the observed geometry. However, since frequency domain methods, which form the basis of indirect time domain calculation, typically don't suffer from stability issues (one of the most serious problems for the direct time-domain methods), and are easier to formulate and implement, they are generally much often used then direct time-domain methods [3]- [5]. By using the well tested frequency domain code (in this case the *Thin Wire Numerical Solver* (TWiNS) [6]) as a basis for indirect time-domain analysis in combination with FFT, a reliable benchmark time-domain results can be achieved [1].

However, the efficiency concerns can lead to considerable problems for geometries where a larger number of frequency-domain results are to be calculated. In a straightforward application of the indirect method, the number of data samples used in FFT is the same as number of frequencies that are calculated via TWiNS, i.e. the number of samples used to construct transfer function of the system The approximate transfer function obtained this way can then be resampled for use in inverse FFT by interpolation. If appropriate adaptive sampling is used in selection of the frequencies to be calculated, the final time-domain results can have only marginal accuracy decrease, while at the same time keeping the overall calculation time significantly less then with simple uniform sampling [2].

Taking the basic idea a step further, the usage of high enough number of points in FFT can be circumvented altogether and the unknown current in the frequency domain can be approximated as a series of known functions spanned by the points determined during the adaptive sampling step. This way, a significantly smaller number of samples are used to calculate the time domain inverse of the frequency domain current by subjecting the approximate function to the analytical inverse Fourier transform. This method also has the additional advantage that the complete inversion doesn't have to be repeated for the each iteration, but only for additional segments determined by the adaptive sampling algorithm.

## INDIRECT TIME-DOMAIN ANALYSIS USING GB-BEM

The procedure of calculating time-domain results via indirect method based on GB-BEM can be divided in several steps. First, the transfer function of the analyzed geometry $H(f)$ is obtained by executing TWiNS code sufficient number of times so that $H(f)$ curve is accurate enough. If excitation with magnitude 1 and phase 0 is used for all frequencies, the obtained frequency domain current results represent the impulse response of the system. Then, time-dependant voltage source $V(t)$ is sampled and FFT is performed, resulting in a frequency spectrum of the excitation $V(f)$. Next, excitation frequency spectrum and structure transfer function are multiplied in the frequency domain thus obtaining frequency-domain current distribution on the observation point at the analyzed structure $I(f)$. Finally, $I(t)$ is calculated from $I(f)$ via FFT.

Straightforward way to perform time-domain analysis via some frequency-domain method, such as GB-BEM, is to simply calculate set of values at uniformly distributed frequencies up to some maximum frequency. However, for geometries characterized by highly pronounced narrow peaks in a transfer function this simple method requires very high number of samples so that the narrow peaks are sampled with sufficient accuracy, thus leading to the obvious degradation in computational efficiency.

## EXPANSION WITH ADAPTIVE SAMPLING ALGORITHM

The basic idea is to use higher sampling density only in areas of transfer function that have higher impact on accuracy of final results, thus reducing overall number of frequency domain samples that are to be calculated. The uniform frequency domain sampling is used only as a initial step, forming an initial set of frequencies $F_0$. Executing frequency domain code [6] on each of the frequencies in set $F_0$ yields a respective result vector $\boldsymbol{H}_0$. Based on these values, a new set of frequencies $F^N$ is estimated, and the calculation is repeated again, yielding a new result vector $\boldsymbol{H_m}$. The frequencies in $F^N$ are chosen to have the greatest impact on the accuracy of the results. By repeating the process, the results are gradually refined with each new iteration. The core of the algorithm is determining the set of frequencies in $F^N$. During this step, each of the $N_{m-1}$ pairs $(f_i, h_i)$, from $F_{m-1}$, $\boldsymbol{H_{m-1}}$ are assigned error estimate value $e_i$, thus forming interpolation error estimation vector $\boldsymbol{E}$:

(1) $$\boldsymbol{E} = \left\{ e_1, e_2, ..., e_{N_{m-1}} \right\}.$$

The error estimation for i-th member of the previous iteration result vector $\boldsymbol{H_{m-1}}$ is

(2) $$e_i = \left| |h_i| + \frac{f_{i+1} - f_i}{f_i - f_{i-1}} (|h_i| - |h_{i-1}|) - |h_{i+1}| \right|.$$

After the errors for each pair $(f_i, h_i)$ are estimated, only frequencies with estimated error $e_i$ greater then some minimum value $e_{\min}$ are taken in consideration in forming a set of new frequencies $F^N$. The value of $e_{\min}$ can be determined using standard deviation of all estimated errors.

## INVERSE FOURIER TRANSFORM OF THE APPROXIMATE FUNCTION

Instead of using inverse FFT and resampling the transfer function to obtain time domain results, a simple method, that requires only samples acquired during adaptive sampling estimation in previous step, can be used. The basic idea is to use simple linear interpolation to approximate the segment of the unknown *I(f)* function as analytical function fully described by the two neighboring samples. This segment is subjected to the analytical inverse Fourier transform, resulting in a simple closed-form expression. The sum of these expressions for all the segments for a given time instant *t* represent the unknown transient current value *I(t)*. In following iteration, only values for newly added segments have to be evaluated to obtain *I(t)*.

## CONCLUSIONS

An expansion of the indirect time-domain method based on TWiNS with the simple adaptive sampling algorithm is presented in this work. This expansion significantly improves the computation time of the overall method in case a highly resonant structure is analyzed. Adaptive sampling algorithm uses recursive method where transfer function curve is gradually refined with each iteration, based on a simple heuristic error estimate function. The results indicate up to an order of magnitude improvements in total computation time.

Further improvements in the computational efficiency are obtained by avoiding the repetitive usage of FFT with potentially large number of samples in the each iteration. Instead, a simple analytical approximation based on the small number of non-uniformly spaced frequency domain samples to obtain the time domain response of the geometry is used.

## REFERENCES


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## AUTHORS' INDEX