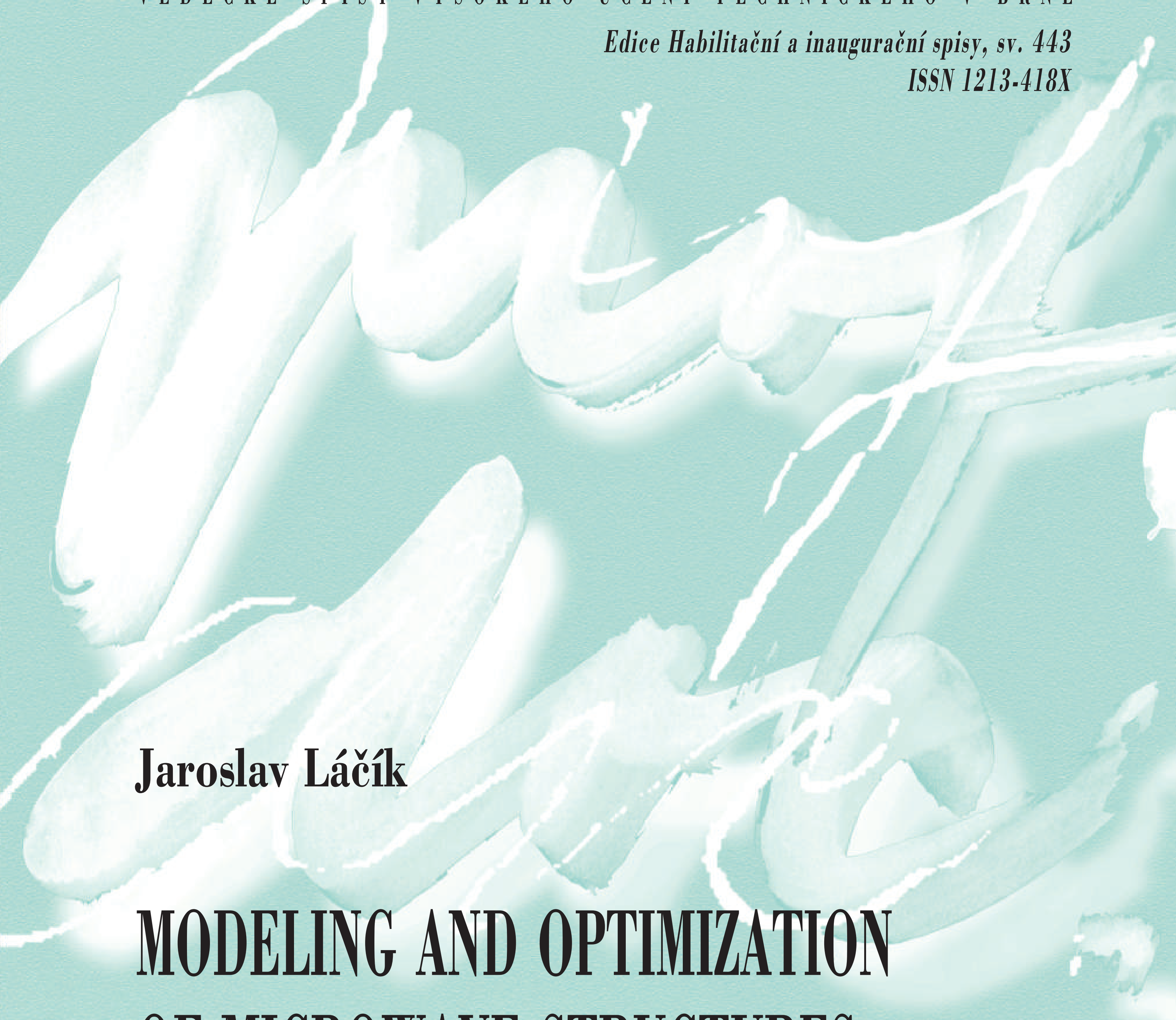
VĚDECKÉ SPISY VYSOKÉHO UČENÍ TECHNICKÉHO V BRNĚ

Edice Habilitační a inaugurační spisy, sv. 443
ISSN 1213-418X



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MODELING AND OPTIMIZATION OF MICROWAVE STRUCTURES IN TIME DOMAIN

BRNO UNIVERSITY OF TECHNOLOGY
FACULTY OF ELECTRICAL ENGINEERING
AND COMMUNICATION
DEPARTMENT OF RADIO ELECTRONICS

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MODELING AND OPTIMIZATION OF MICROWAVE STRUCTURES IN TIME DOMAIN

MODELOVÁNÍ A OPTIMALIZACE MIKROVLNNÝCH STRUKTUR V ČASOVÉ OBLASTI

Short Version of Habilitation Thesis
ELECTRONICS AND COMMUNICATION

VUTIUM

BRNO 2013

KEYWORDS

Time domain integral equation, marching on in time method, method of moments, equivalent dipole moment method, Laguerre polynomials, Hermite polynomials, multicriteria optimization

KLÍČOVÁ SLOVA

Integrální rovnice v časové oblasti, metoda postupného výpočtu v čase, metoda momentů, metoda ekvivalentních dipólových momentů, Laguerrovy polynomy, Hermitovy polynomy, multikriteriální optimalizace

STORAGE PLACE

Research Department, FEEC BUT, Technická 10, 616 00 Brno

MÍSTO ULOŽENÍ

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ISBN 978-80-214-4689-2
ISSN 1213-418X

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ABOUT THE AUTHOR

Jaroslav Láčík was born in 1978 in Zlín. He received the Ing. (M.Sc.) degree in 2002, and Ph.D. degree in 2007, both in the specialization “Electronics and Communication“ at the Brno University of Technology (BUT). Since 2007 he has been an assistant professor at the Department of Radio Electronics (BUT).

His teaching activities are focused on modeling and design of microwave structures and electromagnetic wave propagation. Currently, he is engaged with a bachelor’s course “Microwave Techniques“, and a master’s course “Radio Links Design“. He was supervisor of 8 bachelor students, 13 master students and 1 Ph.D. student.

His research activities are focused on the development of computational methods for electromagnetics with the concentration on time-domain methods, and asymptotic methods. His further attention is focused on microwave components based on substrate integrated waveguide technology. He is the author and co-author of more than 10 papers published in international journals and more than 20 papers published in international conferences.

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1 INTRODUCTION

For wideband electromagnetic analysis of scattering and radiation phenomena, it is more appropriate to analyze a desired structure in the time domain due to indisputable advantages of the time domain approach. Firstly, wideband information is obtained in a single simulation run, secondly, such an analysis can be carried out for nonlinear and potentially time-varying structures/systems, and thirdly, only the beginning of a transient response can be evaluated. Nowadays, the time domain approach is used mainly for wideband analysis of antennas, scatterers, microwave structures, or in the area of electromagnetic compatibility (EMC) and electromagnetic interference (EMI).

To obtain a transient response, differential or integral equation type of governing Maxwell equations have to be solved usually by numerical methods. Numerical time domain differential equation (TDDE) based methods (e.g. finite difference time domain (FDTD), and time domain finite element method (TDFEM)) are appropriate for analysing inhomogenous structures since they require volume discretization of an analyzed structure. However, a special technique (e.g. perfectly matched layer (PML)) has to be employed for analysing opened structures. On the contrary, numerical time domain surface integral equation (TDIE) based methods (e.g. marching on in time (MOT) method for TDIE, marching on in degree (MOD) method for TDIE) are appropriate for analysing homogenous structures since they require only surface discreziation of an analyzed structure. Advantages of TDIE based methods are that they impose the radiation condition and are dispersion-free.

From the beginning, TDIE methods have been plagued by late time instability, and inefficiency. These matters have prevented widespread exploitation of these methods for computational electromagnetics.

The marching on in time (MOT) method is probably the most useable method for solving time domain integral equations (time domain electric field integral equation (TD-EFIE), time domain magnetic field integral equation (TD-MFIE), and time domain combined field integral equation (TD-CFIE)). A transient response is gradually computed from its known values in the past. Depending on the length of the time step Δt, an explicit ($\Delta t \leq R_{\min}/c$, where $R_{\min}$ is the shortest distance between any two centers of segments or patches and c is the speed of the electromagnetic wave in the surrounding medium) or implicit ($\Delta t > R_{\min}/c$) scheme can be obtained.

Due to troubles of the MOT approach with late time instabilities, two unconditionally stable methods, the marching on in degree (MOD) method (also referred as the marching on in order (MOO) method) and the finite difference delay modeling (FDDM) method, for solving TDIE have been proposed in recent years. The MOD method is base on the approximation of a transient response by a set of weighted Laguerre polynomials, and the FDDM method is based on the Lubich quadrature.

Note that the MOD and FDDM methods are unconditionally stable only from the viewpoint of “high frequency” instability, the “DC“/“low frequency“ and “resonant“ instabilities still have to be suppressed.

This habilitation thesis follows the author’s Ph.D. thesis (submitted in 2006) and shortly describes the author’s new contribution in the field of time domain modeling of microwave structures. In addition, the author’s contribution in the field of optimization of antennas in the time domain is also included. The research of the presented results was carried out at the Department of Radio Electronics from 2007 to 2011.

2 MARCHING ON IN TIME METHOD

As mentioned in the introduction, the marching on in time (MOT) method for solving time domain integral equations (TDIEs) have been plagued by late time instability, and inefficiency. In this chapter, our contribution to the development of the MOT method is described and given in context with results of other researches.

2.1 Stability Improvement of the MOT Method

There are “high frequency“, “DC“/”low frequency” and “resonant“ instabilities in the MOT method for TDIE. The high frequency instabilities, which usually take the form of exponentially growing sinusoids whose frequencies are outside the spectrum of excitation (in publications sometimes denoted by the term “late time oscillation”), probably reside in improper discretization of TDIE (TD-EFIE, TD-MFIE, TD-CFIE) [6]–[29]. The DC/low frequency or resonant instabilities reside in spectral properties of the continuous TD-EFIE operator as being discretized [31]–[34].

To eliminate high frequency instabilities of the MOT method, several techniques/approaches have been proposed: averaging/filtering techniques [6]–[9], [60], implicit time stepping schemes [11]–[19], using special kinds of temporal basis functions [20]–[25], [61], and exact integration [27]–[30]. Apart from these techniques, several methods have been proposed: the finite difference delay modeling (FDDM) method based on the Lubich quadrature [30], or methods which use orthogonal polynomials as entire-domain temporal basis functions (chapter 3). However, these methods do not belong to the MOT approach.

The averaging technique in time, the averaging technique in time and space and the filtering technique [6]–[9] are able to improve the stability of the MOT method. However, they do not provide stable solution at all times. What’s more, these techniques usually decrease the accuracy of the MOT method and it is difficult to choose the right order of a filter in the case of applying the filtering technique [9]. To minimize the mentioned drawback, in [60], where we are focused only on the filtering technique in time, we proposed a procedure for a proper filter design using an optimization technique. Thanks to the fact that the proposed procedure considers an important part of the spectrum of the excitation signal, the designed filter does not decrease the accuracy of the MOT approach. Further, in [60], we proposed a procedure for efficient stabilization of the MOT method by a set of filters of different orders. The principle of this procedure is that filters are not used until instabilities appear. When they appear, filters from a lower to a higher order are gradually used (from the time instant at the time response where instabilities started) until a currently used filter is not able to suppress the instabilities. The example of computed transient responses by this procedure is depicted in Figure 2.1.

The drawback of all averaging/filtering techniques is decreasing efficiency of the MOT method. Thus, such techniques should be combined with other techniques for improving the stability of the MOT method, and used when the other ones fail [60].

Implicit schemes instead of explicit ones were proposed to stabilize the MOT method. Implicit time stepping schemes with different difference schemes (e.g. backward difference, 3-point backward difference, central difference) were proposed and analyzed [11]–[19]. Although the stability of MOT was significantly improved, these schemes can provide in some cases an instable solution (the stability depends on the length of the time step).

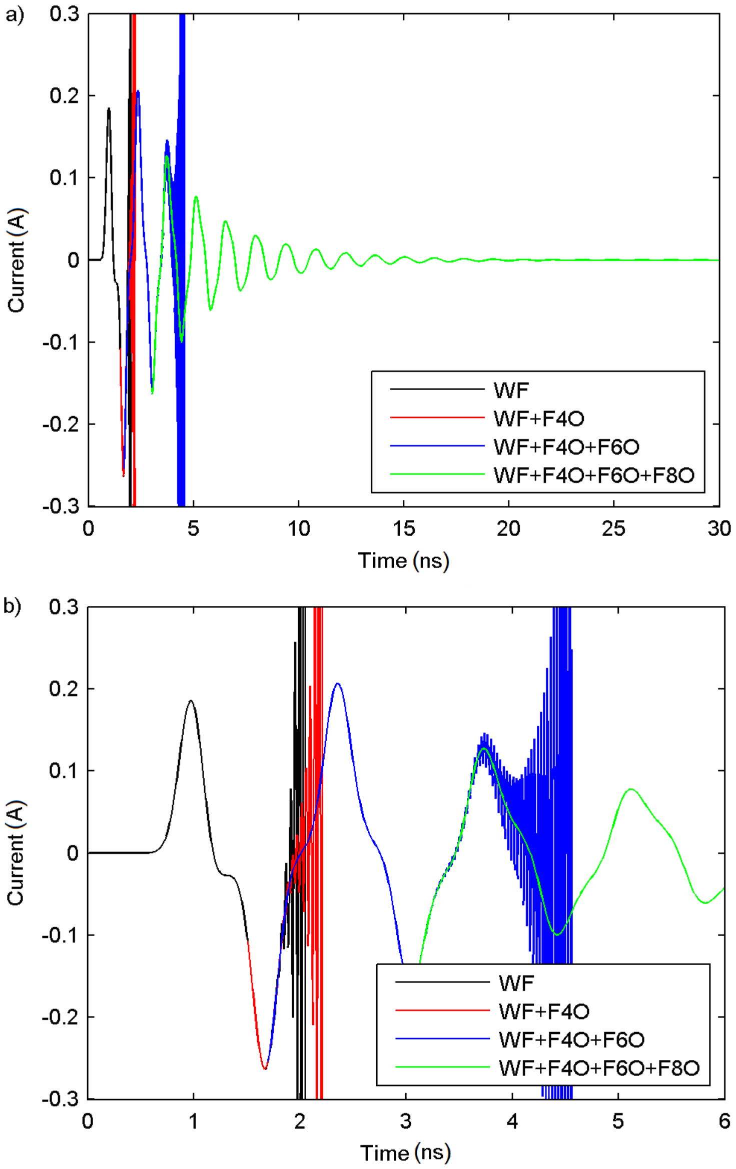

Figure 2.1: Computed transient responses at the center of symmetric strip dipole by a set of filters. a) the whole responses, b) an enlarged detail. WF – without filtering, FnO means FIR filter of n order.

There have been several attempts to stabilize the MOT method by using special kinds of temporal basis functions [20]–[25]. In [21]–[23], it was presented that temporal smooth basis functions with less high-frequency content than usually used interpolators increase the stability of the MOT method. In [61], we investigated two causal temporal basis functions (a cosine square one and an optimized exponential one) with less high-frequency content than the conventional triangular ones. We observed that a causal temporal basis function which has less high-frequency content does not have to guarantee a more stable MOT method. In [25], non causal band-limited interpolation functions (BLIFs) were proposed for temporal discretization. Since these functions are non causal, the current value at a desired time step depends on its value in future time steps. Thus, an extrapolation procedure has to be used. However, due to such a procedure, the MOT method with BLIFs works only for small lengths of time step and can be unstable.

Several researchers believe that the stability of MOT method depends mainly on the accurate evaluation of MOT matrix elements resulting from a Galerkin discretization of TDIE [26]–[29]. However, the accurate evaluation of all matrix elements is very time consuming.

Although lots of effort has been carried out in the area of eliminating high frequency instabilities, it seems that all proposed techniques/approaches only postpone instabilities to later times and are not able to solve the problem completely.

Let's shortly comment on the FDDM method [30] since there is no space for it in this thesis. Although the FDDM method brings an unconditionally stable scheme from the point of high frequency instabilities, it suffers a high computation complexity $O(N_t^2 N_s^2)$ (where N_t is the number of time steps, N_s is the number of unknown quantities in space) due to a series of transformations. In comparison, the computational complexity of the classical MOT method is $O(N_t N_s^2)$.

DC/low frequency instabilities reside in the null space of the TD-EFIE and differentiated TD-EFIE operator. They appear due to divergence-free static currents producing zero electric fields. In the past, these instabilities were eliminated by loop tree decomposition [31], but not completely [34]. Resonant instabilities reside in the null space of the TD-EFIE operator. In the past, these instabilities were suppressed by TD-CFIEs [32]. Now, it seems that both DC/low frequency and resonant instabilities can be eliminated by the application of time domain Calderón identities [33], [34].

2.2 Efficiency Improvement of the MOT Method

To increase the efficiency of the conventional classic MOT method, several techniques have been recently proposed. The plane wave time domain (PWTD) algorithm [35]–[36] and the time domain adaptive integral method (TD-AIM) [37] belong among the most used and popular ones. Even though the efficiency of these techniques is higher than the conventional MOT approach, they are mainly appointed for modeling electrically large structures.

In [62], we proposed accelerating the conventional MOT method for the TD-EFIE by using the equivalent dipole moment (EDM) method. Originally, the EDM method was applied for accelerating the moment method in the frequency domain. This technique is based on the idea that if the size of triangles for approximating a body of an analyzed structure is sufficiently small, the fields radiated due to the current on a triangle pair may be beyond the nominal value approximated by radiation of an infinitely small dipole with an equivalent moment. If this condition is not met, the radiation is computed in a conventional way. In [62], an implicit MOT scheme with the EDM method for the TD-EFIE was derived and analyzed. In the analysis of several examples (two strips of different lengths, a square plate, and a rectangular plate) it was shown that the derived scheme is faster than the conventional one, and its efficiency increases with a smaller length of time step and larger dimensions of analyzed structures. The results of this investigation are summarized in Table 2.1.

Since the conventional implicit MOT scheme for the TD-EFIE is sensitive to small changes of its coefficients, the full-value use of the MOT-EDM for the TD-EFIE method requires an appropriate technique (e.g. preconditioning [33], [34], or modification of the MOT approach to its hierarchical versions [38]–[40]) to obtain a well-conditioned scheme. In fact, such a technique should be used even if the conventional MOT method is used to increase the stability of the MOT approach. Recently, the MOT-EDM method has been extended for TD-CFIE [41].

Structure	Dimensions [m x m]	Saved time for $\Delta t = 1.5R_{\mathrm{min}}/c$ [%]	Saved time for $\Delta t = R_{\mathrm{min}}/c$ [%]
Strip 1	2.00 x 0.08	17	24
Strip 2	5.00 x 0.08	38	42
Square plate	1.00 x 1.00	10	15
Rectangular plate	2.00 x 1.00	20	28

Table 2.1: Saved time by the MOT scheme with the EDM method in comparison to the conventional MOT scheme for different lengths of the time step Δt. (where R_{min} is the shortest distance between any two centers of patches (a body of an analyzed structure is approximated by triangular patches) and c is the speed of the electromagnetic wave in the surrounding medium).

2.3 Conclusions

This chapter summarizes the author's contribution in the field of the MOT method development carried out at the Department of Radio Electronics from 2008 to 2011. The following most important results have been achieved:

- Improvement of the accuracy of the filtering technique for the stabilization of the MOT method, and a proposal procedure for the efficient stabilization of the MOT method by a set of filters [60].
- The investigation of the influence of different temporal basis functions (a triangular, exponential, and cosine square function) on the stability of the MOT method and showing that a temporal basis function with a poor high frequency content doesn't have to guarantee a more stable MOT method than the one with rich high frequency content [61].
- Acceleration of the MOT method for TD-EFIE by an equivalent dipole moment method and analysis of this approach [62].

Future work in the MOT method development should be focused mainly on completely eliminating high frequency instabilities since it seems that up to now all proposed techniques/approaches only postpone instabilities to later times.

3 USE OF ORTHOGONAL POLYNOMIALS AS ENTIRE-DOMAIN TEMPORAL BASIS FUNCTIONS

Due to troubles of the MOT method with late time instabilities, the marching on in degree (MOD) method, also referred as the marching on in order (MOO) method, have been proposed in recent years. This method is unconditionally stable and is based on the approximation of a desired transient response by a set of weighted Laguerre polynomials used as entire-domain temporal basis functions [42]–[55], [63].

By using weighted Hermite polynomials as an entire-domain basis function, an unconditional scheme with Hermite polynomials can be obtained. With this scheme, a desired transient response is approximated by a set of weighted Hermite polynomials similarly as with the MOD method. Unfortunately, unknown current coefficients of the scheme with Hermite polynomials are obtained by solving a large matrix equation [56], [64], whereas with the MOD method they are obtained by solving a matrix equation recursively.

Note that the MOD method with Laguerre polynomials and the scheme with Hermite polynomials are unconditionally stable only from the viewpoint of high frequency instabilities.

3.1 MOD Method with Laguerre Polynomials

The MOD method with Laguerre polynomials exploits the weighted Laguerre polynomials as temporal basis and testing functions. There are four characteristic properties of the weighted Laguerre polynomials: they are (1) causal, (2) recursively computed, (3) orthogonal, and (4) convergent. What's more, their use allows a complete separation of space and time variables. Thanks to these properties, an unconditional stable scheme is obtained [43]–[50]. An example of weighted Laguerre polynomials of the first four orders is depicted in Figure 3.1.

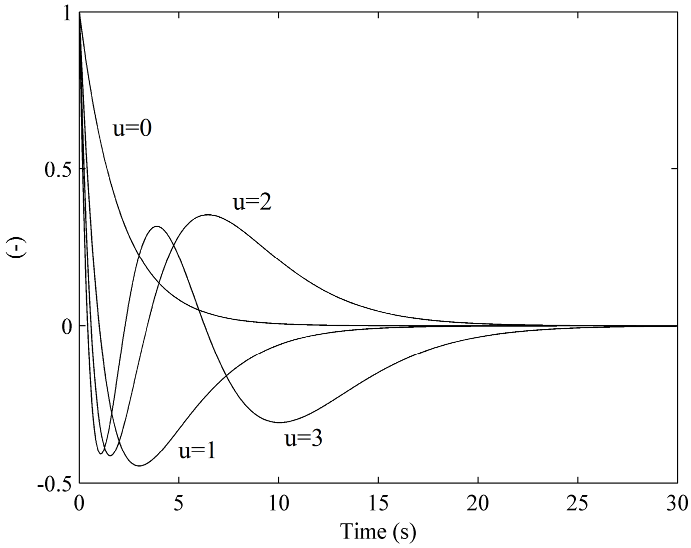

Figure 3.1: Weighted Laguerre polynomials of different order.

Depending on the form of the original TD-EFIE, different MOD schemes have been proposed [43]–[47], [19]. The MOD schemes for TD-MFIE and TD-CFIE have been proposed in [48]–[50]. A common feature of MOD schemes is that the derived matrix equation is solved recursively N_L times (where N_L is the number of temporal basis functions used for expansion of a transient response) to obtain the desired unknown current coefficients. An advantage of the MOD method is that the derivative and integral terms in TDIE with respect to time can be carried out in an analytic fashion.

In order to use the MOD approach, the time scale factor (or time scaling factor) of the time axis and the number of temporal basis functions needed for sufficient approximation of the transient response have to be determined.

Preliminary experience with choosing the time scale factor for the Gaussian pulse used as an excitation signal was described in [19], [47]. In [63], we carried out a deep numerical investigation of the influence of the time scale factor on the efficiency of the MOD approach. The investigation was carried out on the symmetric strip dipole excited as an antenna by a harmonic signal modulated by a Gaussian pulse. During the investigation, the length of the dipole or the parameters of the excitation signal were gradually changed. From the investigation it can be claimed that a chosen time scale factor strongly influences the efficiency of the MOD approach. If this factor is not chosen close to the optimum one (by an optimum scale factor we mean a scale factor which makes the MOD algorithm the most efficient), the MOD approach becomes time consuming. Unfortunately, a simple formula for the prediction of the optimum scale factor could not be given. It seems that the choice of the time scale factor is a weak point of the MOD approach. The example of the described investigation [63] is partly demonstrated in Figure 3.2 where dependence of the number of temporal basis functions on the scale factor for different lengths of the symmetric strip dipole is depicted.

Note that in [63] there is an algorithm for the determination of the number of temporal basis functions. Since this algorithm was included in the author’s Ph.D. thesis [19], this algorithm is excluded from this habilitation thesis.

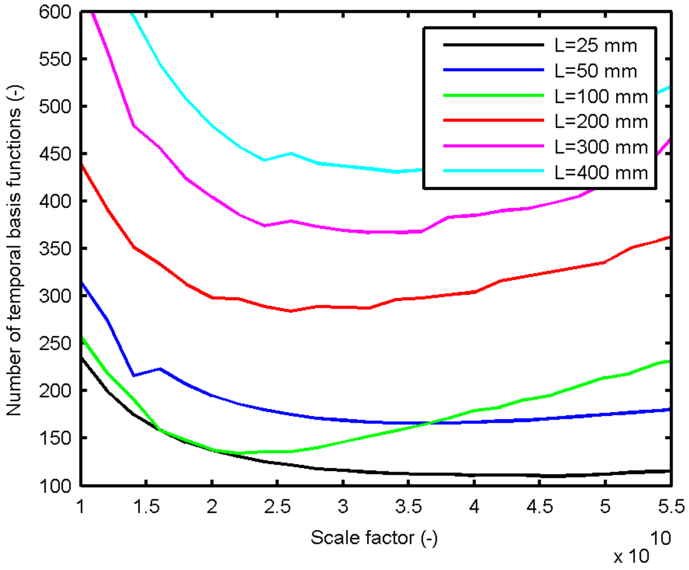

Figure 3.2: Dependence of the number of temporal basis functions on the scale factor for different lengths of the symmetric strip dipole. The width of the dipole is 2 mm.

In [44] and [45], the expression for the determination of the minimum number of temporal basis functions was published. This one depends on the width of the frequency band of the excitation signal, and the length of the response. Since the length of the response is usually unknown (in the case we are interested in the steady state), and that expression does not take into account the scale factor of the time axis, the expression in [44], [45] is almost inapplicable. The number of temporal basis functions can be determined by the algorithm proposed in [19].

Although the MOD method is unconditionally stable and more accurate than the MOT one, the MOD approach suffers from low computational efficiency in comparison to the MOT method. Thus, recently, there have been several attempts to decrease the computational complexity of the MOD approach by a discrete fast Fourier transform (FFT) based algorithm expediting the recursive spatial convolution [51]-[53], using a new form of the temporal basis functions and a modified computational form of the Green’s function [54], or using a near-orthogonal higher order hierarchical Legendre basis functions as spatial basis functions [55].

3.2 Scheme with Hermite Polynomials

Using the scheme with Hermite polynomials, the weighted Hermite polynomials are used as temporal basis and testing functions [56], [64]. The weighted Hermite polynomials are orthogonal, convergent and can be recursively computed, however, they are non causal [42]. Thanks to these properties, an unconditionally stable scheme with Hermite polynomials can be obtained (the derivation is carried out in the same way as the MOD scheme with Laguerre polynomials, and the derivative terms in TDIE with respect to time are carried out in an analytic fashion) where a temporal response is approximated by a set of weighted Hermite polynomials. The first four weighted Hermite polynomials are depicted in Figure 3.3.

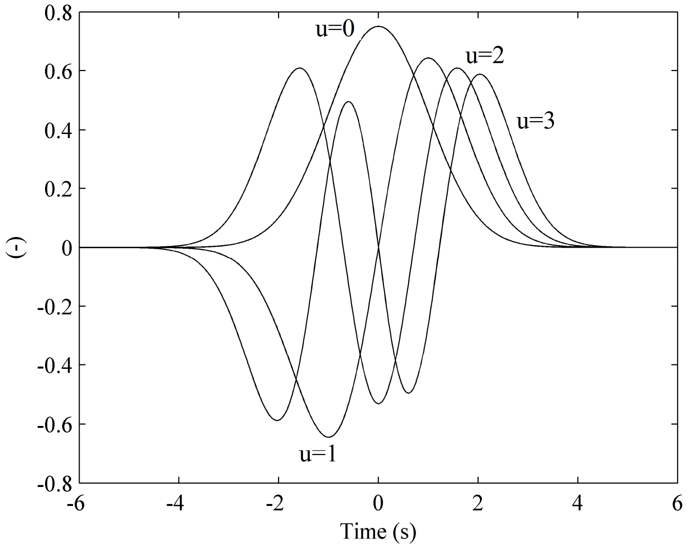

Figure 3.3: Weighted Hermite polynomials of different order.

In [64], we compared the MOD scheme with Laguerre polynomials and the scheme with Hermite polynomials. The most important difference of these schemes is that unknown current coefficients with the MOD scheme is obtained by solving a matrix equation recursively, whereas those coefficients using the scheme with Hermite polynomials are obtained by solving a large matrix equation. Further, since the Hermite polynomial are non causal, apart from a scale factor and a number of temporal basis functions, an expansion position of these polynomials at a desired time instant should be chosen since this choice influences the efficiency of the scheme.

In [64], we carried out a numerical investigation on an analysis of straight wire of different lengths. The wire was excited as an antenna by a Gaussian pulse at its center. The expansion of the weighted Hermite polynomial was carried out roughly around half of the time support of the transient response. From the investigation it can be concluded that the scheme with Hermite polynomials required a lower number of temporal basis functions for short responses than the scheme with Laguerre polynomials, and vice versa. Further, it seems that the choice of the time scale factor and the expansion position of the polynomials at a desired time instant are weak points of the scheme with Hermite polynomials. These two weak points with the fact that the unknown current coefficients are found by solving a large matrix equation probably prevent further development or exploitation of this scheme.

3.3 Conclusions

This chapter summarizes the author's work in the field of exploiting orthogonal weighted Laguerre and Hermite polynomials as entire-domain temporal basis functions for transient analysis based on solving TDIEs carried out at the Department of Radio Electronics from 2008 to 2009. The author's investigation [63], [64] results into the following conclusions:

- A time scale factor of the MOD method strongly influences the efficiency of the MOD approach. If its value is not close to the optimum one, the MOD method is very time-consuming. Unfortunately, a simple rule or formula for the optimum scale factor prediction could not be given. It seems that the choice of the time scale factor is a weak point of the MOD method with Laguerre polynomials [63].
- The scheme with Hermite polynomials [64] does not seem promising for time-domain analysis.

Future work in the field presented in this chapter could be focused on the development of a methodology for choosing an appropriate time scale factor for the MOD method.

4 OPTIMIZATION OF ANTENNAS IN TIME DOMAIN

Due to the frequency domain nature of antenna parameters, transient responses obtained by time domain analysis have to be converted by Fourier transformation into the frequency domain to evaluate antenna properties. Such an approach can be cumbersome if a broadband or pulse radiation antenna [57] is designed with the help of the optimization procedure. In this case, it is more convenient to define the objective function directly in the time-domain. Following this principle, the objective function in [58] is formulated in the time-domain. However, only matching an antenna to the desired excitation pulse is taken into account. Other important phenomena such as the influence of a feeding line of an antenna or the antenna radiation are not considered.

In [59], a better approach for a direct time domain design of antennas for Ultra-Wideband (UWB) communication was proposed. The objective function considers antenna efficiency, a distortion of transmitted pulse at a receiver, and a desired (omnidirectional) radiation of an antenna. For computing the antenna efficiency, a reflected component of the input antenna signal has to be known. Unfortunately, this component can be difficult to obtain if the antenna is analyzed without a transmission line.

In [65], we proposed the time-domain objective function which for a given excitation pulse takes into account the "time-domain impedance matching", a distortion of responses at the feeding point and in a desired radiating direction (with respect to the excitation pulse), and the radiated energy in the desired direction. The proposed objective function was verified on the optimization of a bow-tie antenna using a combination of the MOD approach and the particle swarm optimization algorithm in its conventional form. The transient responses of the current at the feeding point of the optimized bow-tie antenna and the radiated pulse in the desired direction, both normalized to the square root of their auto-correlation functions at t=0 s, are shown in Figures 4.1 and 4.2, respectively. For comparison, the excitation pulse is normalized in the same way as the responses. The computed reflection coefficient for the excitation pulse and the current response is depicted in Figure 4.3 (denoted by TD) after mapping the results to the frequency-domain. Apparently, the optimized antenna is very well matched to the feeding line. For the verification of the antenna radiation in the desired direction, the magnitude of the transfer function (the ratio of the spectrum of the radiated pulse and the excitation pulse) normalized to its maximum is depicted

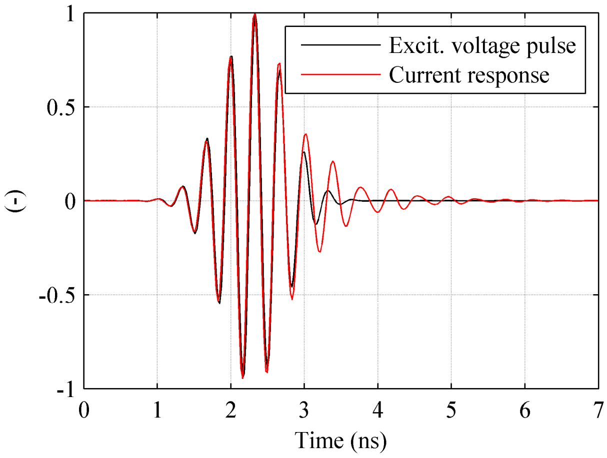

Figure 4.1: Normalized excitation voltage pulse and current response of the optimized bow-tie antenna.

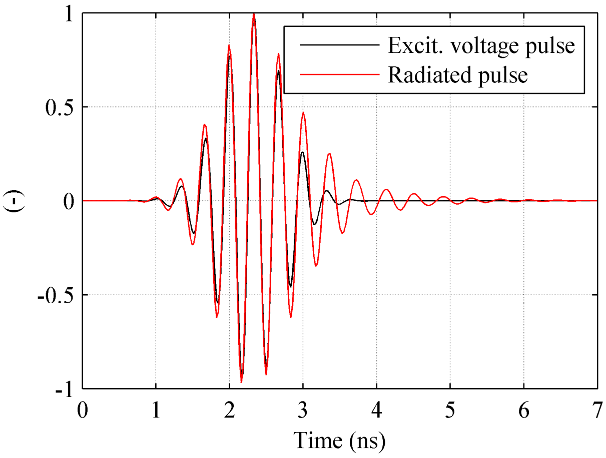

Figure 4.2: Normalized excitation and radiated pulses of the optimized bow-tie antenna.

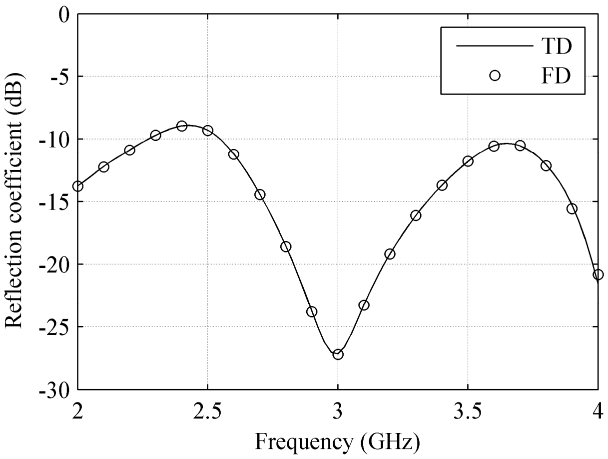

Figure 4.3: Reflection coefficient of optimized bow-tie antenna.

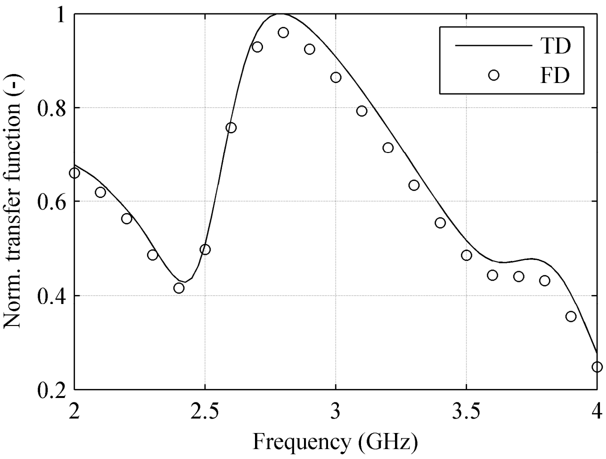

Figure 4.4: Normalized transfer function of optimized bow-tie antenna.

in Figure 4.4. The minimum radiation corresponds to the frequency 4 GHz. The optimized bow-tie antenna was also analyzed by the method of moments in the frequency domain (denoted in Figures 4.3 and 4.4 by FD). The agreement of both solutions is good. Obviously, the optimized antenna exhibits favorable characteristics.

Apart from using the proposed approach for the optimization of conventional wideband antennas, our approach [65] can be used after small modification for the design of antennas for UWB communication where it is necessary to optimize the antenna not only from the viewpoint of conventional antenna parameters, but also from the viewpoint of the ability to transmit/receive a pulse of a desired shape.

4.1 Conclusions

This chapter summarizes the author’s work in the field of optimization of antennas in the time domain carried out at the Department of Radio Electronics from 2008 to 2009. The most important result is a proposal of the time domain objective function for optimization of broadband and pulse radiation antennas in the time domain [65].

5 CONCLUSIONS

This habilitation thesis summarizes the author’s work in the field of modeling microwave structures by TDIE based methods and optimization of antennas in the time domain. The work was carried out at the Department of Radio Electronics from 2007 to 2011. The following most important results have been achieved:

- Improvement of the filtering technique to be accurate and efficient approach for the stabilization of the MOT method [60].
- Considering the investigation of the influence of different temporal basis functions on the stability of the MOT method [61], it can be claimed that a temporal basis function with poor high frequency content doesn’t have to guarantee a more stable MOT method than the one with rich high frequency content.
- Acceleration of the MOT method for TD-EFIE by an equivalent dipole moment method [62].
- Considering the investigation of the MOD method with Laguerre polynomials [63], it can be claimed that a time scale factor of the MOD method strongly influences the efficiency of the MOD approach. It seems that the choice of the time scale factor is a weak point of the MOD method with Laguerre polynomials.
- Considering the properties and investigation of the scheme with Hermite polynomials [64], it can be claimed that this scheme does not seem promising for time-domain analysis.
- A proposal of the time domain objective function for optimization of broadband and pulse radiation antennas in the time domain [65].

Although lots of effort has been carried out in the area of the TDIE based methods development and interest in these methods has increased, it is evident that these methods are not still ready for widespread exploitation in computational electromagnetics.

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7 SELECTED PUBLICATIONS OF THE AUTHOR

7.1 Marching on in Time Method

[60] LACIK, J., Filtering technique for stabilization of marching-on-in-time method, *Radioengineering*, 2010, vol.19, no. 2, p. 290–298.

[61] LACIK, J., LUKES, Z., RAIDA, Z. Analysis of stability of MOT scheme with different temporal basis functions. *38th European Microwave Conference*, 2008, p. 1370–1373.

[62] LACIK, J., Acceleration of marching on in time method for TD-EFIE by equivalent dipole moment method and its analysis, *Radioengineering*, 2011, vol. 20, no. 3, p. 569–574.

7.2 Use of Orthogonal Polynomials as Entire-Domain Temporal Basis Functions

[63] LACIK, J., Laguerre polynomials' scheme of transient analysis: scale factor and number of temporal basis functions, *Radioengineering*, 2009, vol. 18, no. 1, p. 23–28.

[64] LACIK, J., RAIDA, Z., On using orthogonal polynomials for transient analysis of wire antennas, *14th Conference on Microwave Techniques*, 2008, p. 1–4.

Note that a part of the publication [63] devoted to the determination of the number of temporal basis functions was included in authors Ph.D. thesis [19], so it is excluded from this habilitation thesis.

7.3 Optimization of Antennas in Time Domain

[65] LACIK, J., LAGER, I. E., RAIDA, Z., Multicriteria optimization of antennas in time-domain, *Radioengineering*, 2010, vol.19, no. 1, p. 105–110.

ABSTRACT

This habilitation thesis deals with modeling microwave structures using TDIE based methods and optimization of antennas in the time domain. The thesis is divided into three main parts where the author's contributions are shortly described and given in context with results of other researchers.

The first part is focused on the stability and efficiency improvement of the marching on in time method. The second part deals with exploiting orthogonal weighted Laguerre and Hermite polynomials as entire-domain temporal basis functions for transient analysis based on solving TDIEs. The attention is mainly focused on the choice of the time scale factor and efficiency of schemes with orthogonal polynomials. The third part of this thesis is focused on the definition of the time domain multicriteria objective function for optimization of broadband and pulse radiation antennas.

This habilitation consists of six selected publications of the author.

ABSTRAKT

Tato habilitační práce se zabývá modelováním mikrovlnných struktur pomocí metod pro řešení integrálních rovnic v časové oblasti a optimalizací antén v časové oblasti. Práce je rozdělena do tří hlavních částí, kde jsou autorovy příspěvky krátce popsány a dány do kontextu s výsledky ostatních výzkumných pracovníků.

První část práce je zaměřena na zlepšení stability a efektivnosti metody postupného výpočtu v čase. Druhá část práce se zabývá využitím ortogonálních váhovaných Laguerrových a Hermitových polynomů jako časových bázových funkcí pro analýzu v časové oblasti založenou na řešení integrálních rovnic. Hlavní pozornost je zaměřena na volbu měřítka časové osy a efektivnost schémat s ortogonálními polynomy. Třetí část předložené práce je zaměřena na definici multikriteriální funkce přímo v časové oblasti pro optimalizaci širokopásmových antén a antén pro pulsní vyzařování.

Tato habilitační práce je složena z šesti vybraných publikací autora.