Electronic Textbook of Electromagnetic Waves

Zbyněk RAIDA [1], *Dušan ČERNOHORSKÝ* [1], *Kenneth FROEHLING* [2], *Stanislav GOŇA* [1], *Václav MICHÁLEK* [1], *Vlastimil NAVRÁTIL* [1], *Zdeněk NOVÁČEK* [1], *Viktor OTEVŘEL* [1], *Petr POMĚNKA* [1], *Jiří ŠEBESTA* [1], *Zbyněk ŠKVOR* [3], *Tomáš URBANEC* [1], *Geert VANDERSTEGEN* [4], *Bart VANDIJCK* [4]

[1] Dept. of Radio Electronics, Brno University of Technology, Purkyňova 118, 612 00 Brno, Czech Republic
[2] Dept. of Foreign Languages, Brno University of Technology, Purkyňova 118, 612 00 Brno, Czech Republic
[3] Dept. of Electromagnetic Field, Czech Technical University, Technická 2, 166 27 Praha, Czech Republic
[4] Katholieke Hogeschool Limburg, Universitaire Campus, Gebouw B, 3590 Diepenbeek, Belgium

raida@feec.vutbr.cz

Abstract. *Teaching university courses, which deal with the phenomena of the electromagnetic (EM) substantiality and their applications, is rather difficult due to their abstract nature. Therefore, teaching has to be accompanied by clear explanations and by simulations illustrating the examined topics. This is why an electronic textbook (ET) of EM waves and applications was developed.*

The ET presents theoretical descriptions of selected EM phenomena on two levels – on a bachelor's one and a master's one. Descriptive parts of the ET are completed by computer programs, which enable the reader to simulate the studied phenomena. Moreover, the ET explains the practical implementation of simulation routines in MATLAB, which helps students to understand a relationship between rather complicated mathematics and a relatively simple source code of its software implementation.

Since the ET is freely accessible on the web, students can use it whenever as a classical textbook, a handbook or a software package. This fact positively influences the students' knowledge and understanding as proven by our experience.

Keywords

Antennas, computer software, educational methods, electromagnetics, Internet, microwaves, optics, waveguides, teaching methods, computer aided education.

1. Introduction

Increasing demands for a reliable transmission of information causes shifting communication services to use higher and higher frequency bands. Technical universities have to reflect this fact by educating highly qualified specialists who are able to design electronic circuits and antennas working on tens of gigahertz. Since phenomena in this frequency band are of the wave nature, analysis and design have to be based on Maxwell's equations in the integral form or the differential one. Unfortunately, a description of studied phenomena exploiting integral equations or differential ones usually cause problems to students due to the following reasons:

- The phenomena are described by relatively complicated and abstract mathematical expressions, and therefore, imagining the physical meaning of the mathematical description is rather difficult.
- Phenomena of wave nature are relatively abstract, and therefore, properties of studied phenomena can be only investigated indirectly.

In classical education, the above-described problems are solved in the following way:

- During lectures, a basic theoretical description of studied phenomena and systems is presented to students, and their mathematical formulation based on differential or integral equations is explained to them.
- Next, students do computer exercises where they become familiar with basic features of studied structures, typical values of variables describing the structure of interest and with basic consequences. Computer exercises are based on simulation software, which enables one to empirically study the objectives of interest.
- Finally, students equipped with the necessary theoretical knowledge and basic sense for the phenomena, come to the laboratory where they can experimentally test and verify selected phenomena.

In order to accomplish the above-described three steps of education as efficiently as possible, new technologies such as the Internet and multimedia are attractive to be used.

The electronic textbook (ET) can associate theoretical descriptions and practical simulation of examined phenomena. Therefore, the ET can present the basic knowledge in the text form (descriptions, equations, figures), and at

the same time, it enables one to run simulations of studied phenomena directly from the text. Moreover, the ET can enable one to search for additional information via hypertext links.

The ET is conceived as a collection of carefully selected topics, which the electronic processing makes sense to. Specifications of these topics, and the description of their mutual cohesion, are given in Section 2 of the paper.

The ET is of a two-dimensional structure. In the vertical direction, all the processed topics are listed. In the horizontal direction, several layers of the text related to the same topic are at the reader's disposal. The layers differ in the severity of the text (bachelor's textbook and users' guides on one hand, master's textbook and programmer's guide on the other hand). More details are given in Section 3.

Each topic is accompanied by MATLAB programs, which can be used both for simulating studied phenomena and for observing the parallelism between the mathematical description of a phenomenon and its software implementation. The detailed information is given in Section 4.

In the conclusion, a subjective experience with the development of the ET is generalized, and students' approach to the ET is described.

The ET was developed in two versions.

The first version of the ET is written in Czech with a few chapters translated into English, which should help Czech students to improve their knowledge of specialized English. The Czech version of ET is accessible via

http://www.feec.vutbr.cz/~raida/multimedia

The second version of the ET is written in English with a few chapters composed in Dutch. The English version of the ET is accessible via

http://www.feec.vutbr.cz/~raida/multimedia_en

The paper concentrates on the English-Dutch version.

2. Contents of the Textbook

The contents of the ET is at the reader's disposal in the left-hand frame of the screen during the whole time of reading. As shown in Fig. 1, the ET consists of six chapters covering selected topics of EM theory and techniques.

The first chapter, "Introduction", is devoted to the unification of readers' knowledge, to the introduction of notation used in the ET, and to the definition of the basic terminology.

The second chapter, "Propagation of EM Waves", discusses selected topics from the field of wave propagation in inhomogeneous media (dielectric layers, diffraction on a half-plane or on a cylinder). The described phenomena are simulated using geometric theory of diffraction in order to illustrate the investigated phenomena [1], [2].

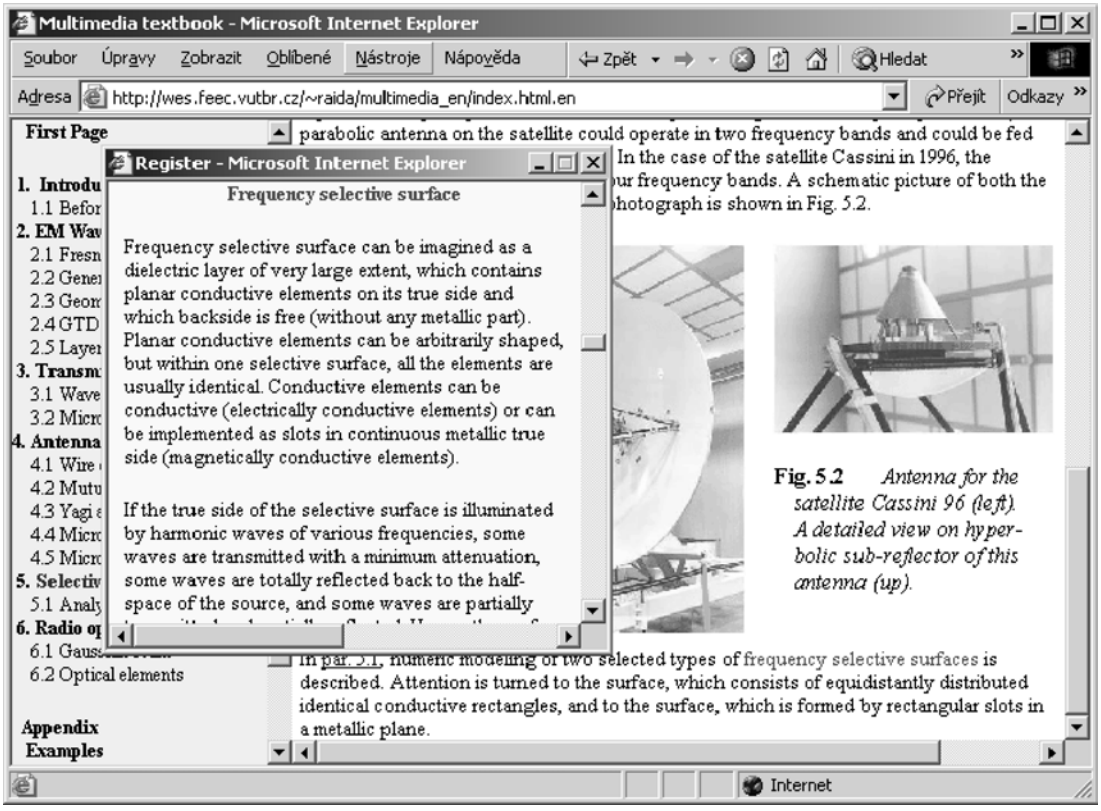

Fig. 1. A brief explanation of the indexed term "frequency selective surface" in the explanatory window in the foreground. The contents of the textbook is perpetually visible in the left-hand frame.

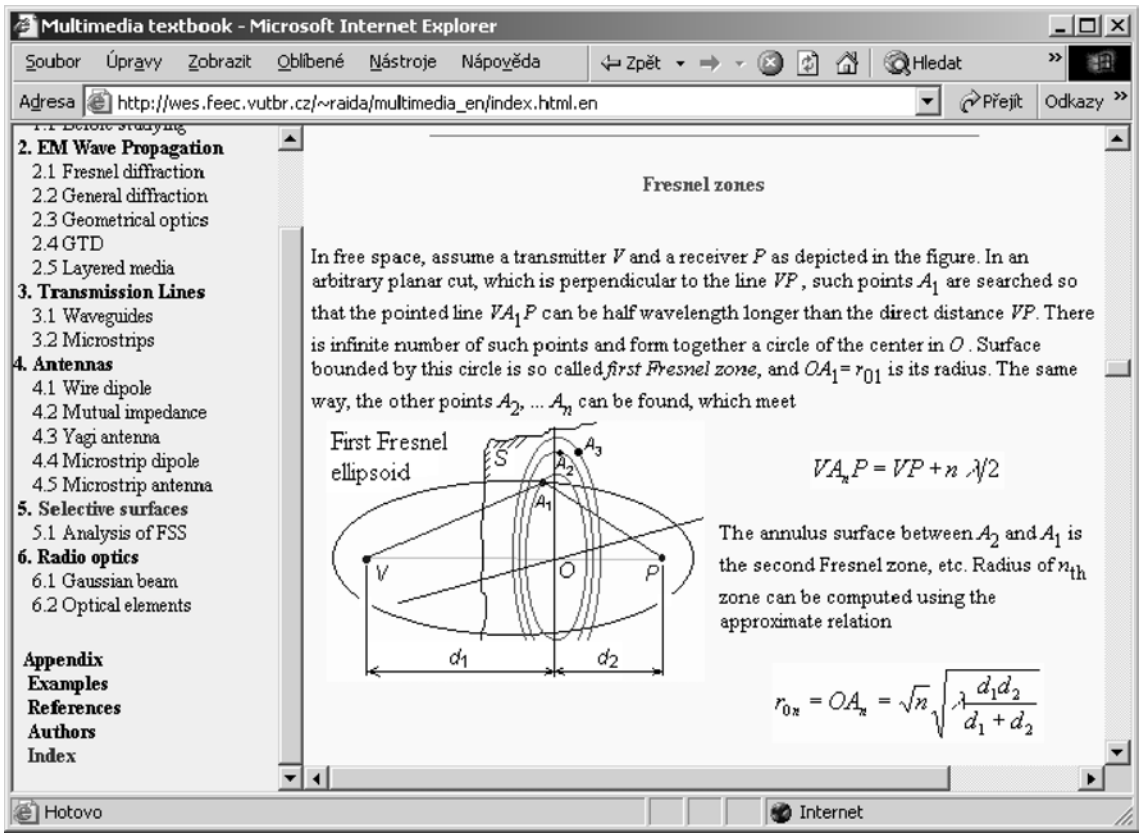

Fig. 2. A window of an indexed term sorted alphabetically. Each indexed term is completed by a brief explanatory text (and graphics if needed).

The third chapter, "EM Waves on Transmission Lines", is oriented towards investigating wave propagation along selected types of transmission lines. Waveguides and shielded microstrip lines are modeled using the finite-element method [3], [4].

The fourth chapter, "Antennas", deals with wire antennas (a symmetric dipole, a Yagi antenna, a mutual impedance of parallel wires) and microstrip antennas (microstrip dipoles, patch antennas). All the antennas are modeled using the method of moments in order to demonstrate their basic properties [5], [6].

The fifth chapter, "Frequency-Selective Surfaces", describes basic types of those reflectors and discusses the way of modeling their behavior by the frequency-domain method of moments [7].

The sixth chapter, "Radio-optics", introduces the Gaussian beam and its exploitation for the basic modeling in the area of paraxial optics [8].

Since the ET consists of selected topics, and the basics of EM theory are not included in it, a special indexing mechanism has been developed in order to explain the basics to the reader. The basic indexed terms are printed in red in the text. Clicking the red basic term, a special explanatory window is opened, whose contents provides a brief explanatory text and graphics (see Fig. 1). Clicking elsewhere, the explanatory window is automatically closed.

An alphabetical list of indexed terms completed by the explanatory text (and even graphics when needed) is accessible via the menu item "Index" at the bottom of the contents frame (see Fig. 2).

3. Structure of the Textbook

The two-dimensional structure of the ET can be seen in Fig. 3. The vertical dimension of the ET is identical with the contents, and the five-item menu at the top of the page gives the horizontal dimension.

The level (A) is a basic level of the ET. The level (A) is written as a clear explanatory text, which brings all the information in a very simple form free of any mathematical derivation. The mathematical description is limited to the initial mathematical formulation of the problem and to its final solution. The results can be simulated using a respective MATLAB program.

The level (A) can be used as a textbook for students of the bachelor study programs, where students are interested in practical results with the basic notion of the theoretical background. Further, the basic level can serve as a manual concentrating the most important formulae.

The second level (B) of the ET can be read as a continuous text, which contains all the detailed mathematical derivations presented as results in the level (A). Moreover,

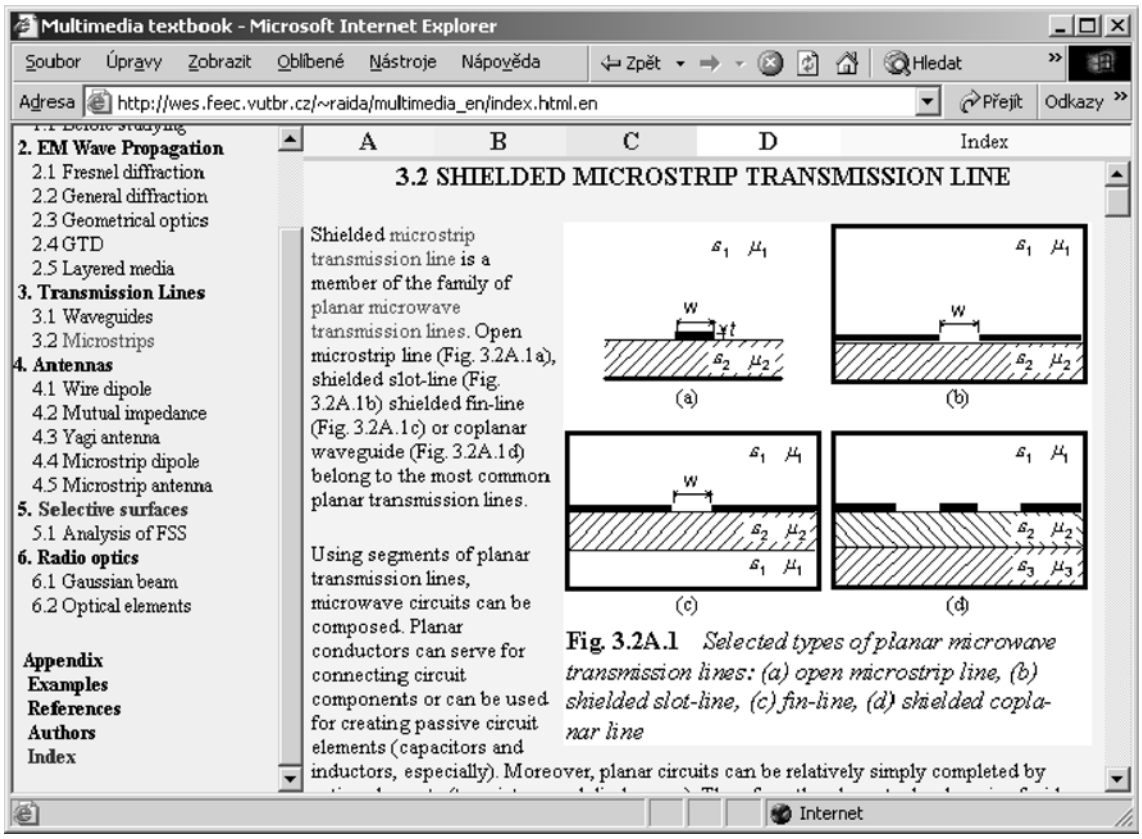

Fig. 3. Two-dimensional structure of the textbook. The vertical dimension is given by the contents of the MT (left-hand frame). The horizontal dimension consists of layers A, B, C, D, and "Index".

mathematical parts, which were omitted in the level (A), can be accessed by links from the basic level. Mathematical passages are joined together by a brief text expecting a more experienced reader.

The second level (B) can be used as a textbook for students of the master study programs where students are expected to obtain a good theoretical background. Students who feel the text too demanding can access simpler explanations in the layer (A) via links.

In contrast to the layers (A) and (B), the layer C is built in the form of a collection of text fragments, which do not create any continuous unit in their entirely. Separate segments contain user's guides of modeling programs.

The fourth layer of the ET (D) contains text segments, which describe the proper software implementation of simulation programs in MATLAB.

The last horizontal layer, "Index", contains the list of indexed words completed by the explanatory text, which are related to the studied chapter only.

4. Simulation Programs

All of the simulation programs accompanying the ET are written in MATLAB 5.3. This concept has got its advantages and disadvantages.

The main advantage in using MATLAB programs consists of the fact that students can simply observe the way of software implementation of differential equations or integral ones, which are described in the ET. Therefore, students can better understand a rather abstract mathematical description of studied phenomena.

Furthermore, students can modify the source code and examine changes in the simulation process caused by these modifications. Therefore, students can get a better notion of consequences of the matter of those changes.

Moreover, the MATLAB source code is platform-independent, and therefore, the simulation programs can run on a PC under Windows, or on a workstation under Unix.

On the other hand, the use of the ET is conditioned by having MATLAB installed on the computer. Furthermore, the reader of the ET should have open one window for the book and another independent window for the simulation program.

Therefore, we plan to rewrite selected programs to Java in order to have the programs in the platform-independent binary form at one's disposal, which might be run directly from the text. The programs can be used by readers who are not interested in MATLAB implementation of routines described in the ET.

In order to make the programs user friendly, the shell creating the standard Windows users' interface completed

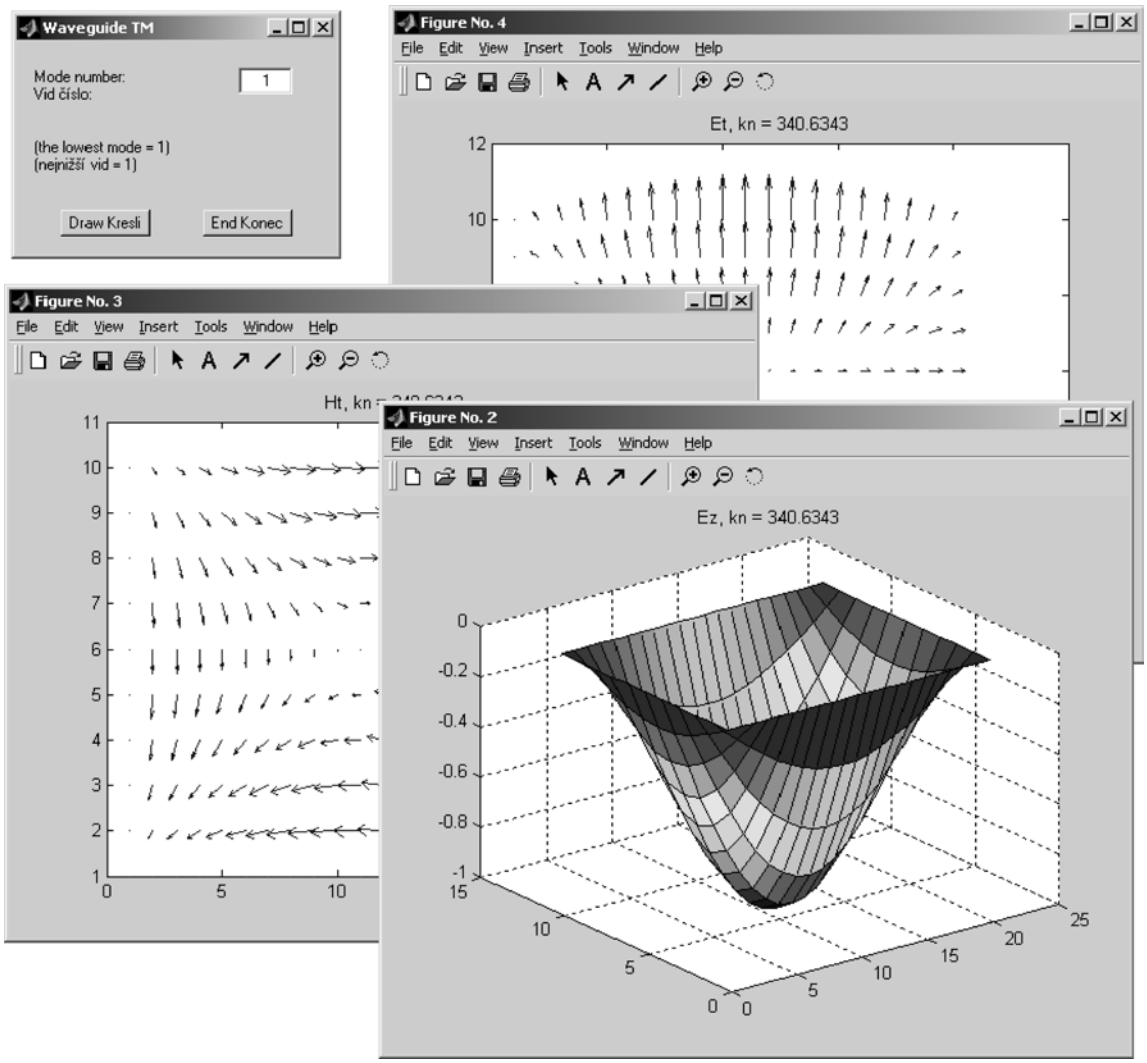

Fig. 4. A standard Windows user's interface of Matlab programs accompanying the multimedia textbook.

the m-files. Readers, who are not interested in MATLAB, can run the programs as classical Windows applications. The typical users' interface of programs, which are incorporated into the ET, is depicted in Fig. 4.

5. Conclusions

The ET was developed in order to make reading and studying easier and more efficient compared with standard textbooks. Students can follow the thread of the problem, simply skipping already known things and investigating more intensely problems they are not familiar with. The described personal selection of the way of study can be done simply by clicking the desired link.

Searching in the ET is also easier than in the classical textbook. A full-text search machine can find every appearance of the term in the whole book almost immediately. The result of the search makes clear all the dependencies of the word with the possibility of going to the chapter where the word is found.

Posting examples and pictures to the ET supports the theoretical explanation of a phenomenon. Compared to the standard textbook, the pictures are of a higher resolution, colorful and not only static. Using sequences of a picture, the time dependencies of an examined phenomenon can be easily shown (i.e., the time course of an EM field in the waveguide can be illustrated exploiting animations). The examples can be much more extensive. If necessary, source code of simple programs for testing and further developing can be posted on the page and downloaded anytime.

The fact that the updating cycle of the ET can be significantly shorter than in the case of the printed book is another advantage. It is quite simple to update the text, an example or just add an extra chapter to the ET and upload it to the web or release a new CD in comparison to the same process with the printed textbook.

Moreover, the ET can be conceived as an open publication. Authors from universities and companies all over the world can contribute new chapters of the ET in an electronic form (written in a proper word processor). Editors of

the ET convert the text into HTML taking care for the proper structure; incorporate new indexed terms into the existing indexing mechanism; connect new pages by links with the existing parts of the ET; and build a unified users' interface of simulation programs.

The described version of the ET was developed by the above-described way. Chapters of the ET were created by Ph.D. students of the Czech Technical University in Prague and the Brno University of Technology in Microsoft Word. The chapters were reviewed by professors, were improved and were translated into HTML. Authors verified the result.

Only those students who can buy it in the bookstore can read the standard textbook. The described ET can be accessed via Internet, which simplifies the way for students to obtain the desired knowledge.

Even from the authors' point of view, electronic publishing brings some extra possibilities. The feedback from readers can be faster and closer. Obviously and commonly, when a reader finds a problem (or even a mistake) while reading a text on the Internet, he then can send an email to the authors' team, asking for an explanation or just pointing their attention to the disputable topic.

The Czech version of the ET was tested at the Brno University of Technology in teaching regular courses of master's program *Electronics and Communication*:

- The course *EM Waves and Transmission Lines* (3rd year of the study, obligatory) brings the basics of antennas, wave propagation, and microwave transmission lines. Students attending this course used primarily the layer A (bachelor's level) of the textbook and exploited MATLAB programs as simple applications, which helpem them to solve individual projects.
- The course *CAD in Microwaves* (5th year of the study, optional) introduces students to the basics of numerical modeling of microwave circuits and antennas. Since the students have to become familiar with the details of the mathematical description of EM structures, they were primarily interested in the matter published in the layer B (master's layer). Moreover, students learned to implement numerical models of EM structures in MATLAB, and therefore, they were interested even in the layer D (programmer's guide).

A free, instant access to the ET and to the accompanying software increased the interest of students in their study of electromagnetics and numerical methods, which can be understood as the most important benefit of the ET.

The students are even highly interested in the ET itself. They bring their own proposals for the extension of the contents (chapters on antennas for mobile communication systems, chapters on time-domain modeling of EM structures, etc.). They even ask for new functions, which should be incorporated into the ET:

- Each chapter should be completed by a set of questions and tasks, which solution could be submitted and verified directly on the web page.
- The ET should be completed by as much animations as possible because they are very useful for better understanding and better notion of studied EM phenomena and functionality of described EM structures.

Implementation of the system of questions and tasks, and their verification is now intensively developed so that the textbook can be used for the purposes of e-learning.

New animations for the textbook are developed by students in the frame of individual projects in the optional course *CAD in Microwaves*.

The electronic textbook, which is described in the paper, is under continuous development. Therefore, the authors are grateful to opinion on ET conception and ET contents so that the ET can be further developed.

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About Authors...

Zbyněk RAIDA is with the Faculty of Electrical Engineering and Communication (FEEC), Brno University of Technology (BUT). He is interested in exploitation of numerical methods to the analysis of microwave systems, and to the application of genetic algorithms and artificial neural networks to the design of microwave structures.

Dušan ČERNOHORSKÝ is with FEEC, BUT. His research activities are oriented to antenna techniques and to the application of EM field. His development is focused in short-wave and mobile antennas, in adaptive antennas, and in temporal-spatial signal processing.

Kenneth FROEHLING is with FEEC, BUT. He is an expert on English of electrical engineering, communication technologies and computer science.

Stanislav GOŇA is with RAMET, Kunovice. His research activities are oriented to the numerical modeling of antennas and other microwave structures by the method of moments. He is also interested in modeling of microwave structures by the finite-element method in ANSYS.

Václav MICHÁLEK is with FEEC, BUT. He has been engaged in several projects oriented to the computer-aided education and to the exploitation of new technologies in educational process.

Vlastimil NAVRÁTIL is with SIEMENS Corporate Technology, Erlangen. He is interested in electromagnetic compatibility (measurement of EM interference, and testing EM resistance, modeling GTEM cells).

Zdeněk NOVÁČEK is with FEEC, BUT. His research is focused in the design of special-purpose radiating systems, to near-field antenna measurements, and to temporal-spatial signal processing.

Viktor OTEVŘEL is with FEEC, BUT. He is interested in time-domain numerical modeling of microwave structures and in the development of novel algorithms for global optimization of microwave structures.

Petr POMĚNKA is with TheNet, Brno. He is interested in the numerical analysis of microwave structures. He participated in projects oriented to the computer-aided education and to the exploitation of new technologies in education.

Jiří ŠEBESTA is with FEEC, BUT. His research is focused in radar technology, satellite communication and related topics.

Zbyněk ŠKVOR is with the Faculty of Electrical Engineering, Czech Technical University in Prague. His research is oriented to numerical methods for the analysis of EM fields, to measurement and design techniques for HF and microwave circuits.

Tomáš URBANEC is with FEEC, BUT. His research is focused in analytical modeling and numerical analysis of special microwave transmission structures. He is engaged in measurement of microwave circuits and antennas.

Geert VANDERSTEGEN graduated at the Katholieke Hogeschool Limburg in Belgium in 2002. In 2002, he spent 3 months at the Dept. of Radio Electronics, Brno University of Technology, where he was engaged in the design of the presented textbook.

Bart VANDIJCK graduated at the Katholieke Hogeschool Limburg in Belgium in 2002. In 2002, he spent 3 months at the Dept. of Radio Electronics, Brno University of Technology, where he was engaged in the design of the presented textbook.