Electromagnetic waves play an increasingly important role in communication, remote sensing, multi-sensor integrated systems, detection and identification (signal processing), microwave hardware design, compatibility, bio-electromagnetics, and many other applications in extremely complex natural and/or man-made environments. Although extremely valuable as reference and physical insights, analytical methods are mostly incapable of handling these challenging real-world problems. Luckily, most of these problems can be attacked by various numerical methods, which become extremely powerful with today's computer technology and intelligent parallel processing approaches. No single method, either analytic or numerical, is best suited for handling all possible cases in these problems; instead, a combination of methods is required to attain greatest flexibility and efficiency. Therefore, the trend is definitely toward "hybridization."

Electromagnetic problems are represented by Maxwell's equations. Mathematically, Maxwell's equations and problem-dependent boundary conditions establish the solution. Postulating the problem, writing it down in terms of integro-differential equations, and showing uniqueness and existence of the solutions may be enough for mathematicians. However, for engineers, observable-based parameterization as well as numerically computable (with rapid convergent properties if in series) forms are essential. Numerical modeling of observable-based numerically computable parameterized complex electromagnetic problems is covered in this book.

The phrases "numerical electromagnetics," "electromagnetic simulation," "computational electromagnetics," etc., have become popular in the last few decades. I have been experiencing difficulty in the conceptualization of computational electromagnetics not only for the candidates of internet-oriented, computer-weaned young researchers, but also for experienced engineers and researchers in the electromagnetic community. Some think that computers do everything and they usually neglect to look for the physical explanation behind the numbers. Others believe that computing numbers and drawing a graph from a simple equation with a computer is the substance of computational electromagnetics. Establishing an intelligent balance between these two extremes requires a new perspective in engineering education, which is also one of the aims of this book.

Doing numerical simulation in electromagnetics is as easy (as well as difficult) as doing measurements. It is easy, because you can obtain commercial codes that do almost everything for you, like you can supply computer-controlled devices for measurements. The simulation packages include almost everything, all are user-
friendly, all have self-checking routines for control, and all are calibrated, like most of high-tech measurement devices. On the other hand, we are in real trouble if we do not know what to do with the results (the numbers we obtain), or if we have no idea what to expect from the simulation or measurement. Unlike common opinion, we have to understand the physics of the problem, since we may frequently be puzzled even with the simplest mathematical relations.

This book is intended mainly for engineers, software developers, academia, and students. It is an attempt to present challenging electromagnetic problems and numerical simulation approaches. Although I have been working with a broad range of numerical simulation techniques both in time and frequency domains, they form only a subset of all numerical methods. It is intended that the book will be of use to a wide range of readers: to the professional electromagnetic engineers, who are already familiar with many of the problems but require a consolidated overview of the subject; to the students, both graduate and undergraduate levels, as a supplementary text as well as educational and project developing tools; to academia, who wish to use powerful simulators as either educational or research purposes.

A few clarifying notes may be of value, particularly with regard to what this book does not include. First, it does not say that the methods presented here are the only or the most efficient ones. They are solely the methods that the author has been using and has had expertise on. No single method can be the "only one" in electemagnetics. Moreover, efficiency depends not only on the problem at hand, but also on the structure and parameter regimes. Second, the book does not include mathematical details of the problems chosen and assumes that the reader has already some kind of electromagnetic background (the IEEE Electromagnetic Wave Theory Series is an excellent collection of classical books). With this assumption, the majority of the theoretical content is reserved for physical aspects behind electromagnetic problems mentioned here. Finally, the book does not include details of the computation, computer languages (such as Fortran, Matlab, etc), and signal processing techniques (such as discrete and fast Fourier transformations, windowing, zero padding, interpolation, etc.). Therefore, the reader is strongly advised to go over these matters, if he or she is interested in using the simulation packages included, making additions/changes on the source codes supplied, or developing better codes. For example, the reader will be more comfortable if he or she knows the details of the differences between theoretical (mathematical) Fourier transform and discrete (numerical) Fourier transform (DFT) and fast Fourier transform (FFT) (e.g., periodicity, aliasing and spectral leakage effects, etc.).

The Internet broadens our environment and brings people closer. This is an excellent source for everybody as long as we know where to look and how to search. I have many inquiries from all around the world, from India to Brazil, Germany to United States, regarding to assistance on computational electromagnetics. This may be a graduate student who has a term project on RCS modeling, or a young university professor who newly overtakes an undergraduate or graduate course, or a practicing engineer who is hired to design a new antenna system, etc. I try to respond to all of these inquiries step by step, starting from
sharing my computer codes (if available) to the end (if possible) until I see them successfully get along with the work by their own. It is astonishing to see how they pass through major steps: self-confident at the beginning, puzzled a lot while making progress, and finally getting experienced at the end. It is these steps that make them good in computational electromagnetics:

- First, they are very excited to have a source code of a powerful simulator, with which they can do "real" engineering job (MODEL AVAILABILITY).
- Then, they soon realize that having a powerful code does not solve their problem. They, themselves, should understand the physics, mathematics, the model, approximations (if any), validity ranges, and parameter optimization (MODEL VALIDITY).
- Finally, they feel strange and confused when they satisfy all pre-requisite, run the simulator and get the results. They all ask similar questions, like:
  - Now, what?
  - What am I going to do with these data?
  - Are they meaningful?
  - What do the numbers mean to me?
  - What should I have expected before the simulation?
  - How do I check my results? (JUDGING and VALIDATION)

It is these relations, interactions, steps, and questions that inspired me a lot in writing this book.

The book is organized into two parts. Introduction, concepts, and approaches and numerical simulation techniques used in the examples are given in Part I. Part II is application-oriented. Characteristic applications, which occupy by far the largest part, are collected in six chapters in Part II. The goal was to make the chapters relatively self-contained, augmented by user-friendly powerful software, enabling the reader to find specific problem solutions in the relevant chapters with minimal interference to other chapters. Each chapter contains sample simulators. The simulators are aimed to include as much different scenarios with maximum flexibility as possible. Although restricted and simulations may be performed with a certain range of parameters, the reader may develop and/or modify the source codes (available on the ftp site at the following address: ftp://ftp.wiley.com/public/sci_tech_med/complex_electromagnetic) to simulate almost any kind of electromagnetic problems.

Chapter 1 describes ground-wave propagation. The problem is to find out propagation characteristics and path loss between two points on or above the lossy surface of the spherical earth including rough surface and non-flat terrain, above which exists radial as well as longitudinal refractive index variations. Observable based, analytical, full-wave (3D) solution has not appeared yet. Instead, analytical approximate reduced formulations have been in use for a couple of decades. Moreover, time- and frequency-domain numerical models have been introduced in the last decade or two and have been applied to 2D problems successfully. This chapter first states the problem in general and outlines spectral solutions in terms of rays and modes. Then, a frequency-domain effective and easy-to-use technique, the split-step parabolic equation (SSPE), is discussed in detail. Finally, the new
time domain wave propagator (TDWP) is presented. Sample propagators, namely, GRWAVE, HFMIX, KNIFE, SSPE, and TDWP, are given with characteristic scenarios and canonical examples. The propagators include a variety of test cases, in which the reader may exercise complex electromagnetic interactions and may do simulations to better understand ground-wave propagation phenomena.

Chapter 2 is an exposition of antenna systems. After giving explanations for some of the fundamental antenna parameters that are frequently used, wire antennas and arrays are discussed together with electronic beam steering concepts. MH, HF, and VHF monopoles on and above the ground are analyzed with NEC2 code (with MoM technique). Horizontal and vertical radiation patterns are simulated. Various ground screens are also designed, and their effects in improving antenna gain and array pattern is also demonstrated. Then, an FDTD-based antenna simulator FDANT is presented, where time-domain antenna and array analyses are possible. Canonical comparisons between MoM and FDANT are also included. The simulator FDANT includes linear and planar arrays of wire antennas in free space. The reader may enjoy doing simulations with small-size (maximum two by five) vertical linear arrays with beam steering-capabilities and may obtain radiation patterns at vertical and/or horizontal planes. In order to do that, one only needs to apply off-line discrete DFT by using the output files of FDANT. The routine ANDFT is also enclosed for this purpose.

Chapter 3 deals with radar cross-section (RCS) modeling. First, RCS fundamentals are outlined and RCS reduction techniques are discussed briefly. Then, MoM-, FDTD-, and TLM-based RCS simulators are given as sample simulators, with which the reader may do RCS calculations of complex targets in free space. Two types of sample simulators are designed in a way to handle both mono-static and bi-static RCS problems. Different scenarios are also included to let the reader to do his or her own simulations both in time and frequency domains. The simulators F-SNRCS and T-SNRCS (FDTD-, and TLM-based simulators, respectively) simulate single direction mono- and bi-static RCS problems. For a chosen target, angle of illumination, and polarization, scattered near fields are simulated inside 3D FDTD or TLM volumes and time-domain far fields are extrapolated along the chosen direction. RCS vs. frequency variations may be obtained off-line via DFT by using the routine SNDFT, which is prepared for this purpose. The simulator F-BIRCS performs the same simulations except for a number of observation directions on a chosen scattering (horizontal or vertical) plane. The DFT routine prepared for this purpose is BIDFT. The reader runs BIRCS, obtains time-domain results and then produces RCS patterns at different planes at different frequencies by applying BIDFT separately at each frequency. The parameters are fixed to yield RCS patterns for maximum $l = 6 - 8 \lambda_{\text{min}}$, where $l$ is the longest dimension of the target and $\lambda_{\text{min}}$ is the minimum wavelength.

Chapter 4 is reserved for microstrip network design with FDTD and TLM techniques. After giving fundamental explanations of microstrip lines and networks, FDTD-based sample simulator FDSTRIP is taken into account, where pre-prepared different microstrip networks can be simulated. The reader may choose one of the pre-prepared microstrip networks and calculate short pulse (broadband) $S$ parameters. The thickness and relative permittivity of the substrate are fixed to be
Chapter 5 discusses electromagnetic compatibility (EMC) and bio-electromagnetics (BEM) modeling. EMC and BEM have become two major areas in electromagnetic engineering. In this chapter, two canonical problems, which are characteristic problems of EMC and BEM, are discussed: the shielding effectiveness (SE) modeling and the specific absorption rate (SAR) calculations. The FDSE and TLMSE packages, which are FDTD- and TLM-based SE simulators, respectively, are presented. Both of them simulate aperture leakage of a perfectly electrical conductor (PEC) enclosure, which may be assumed, for example, a personal computer (PC) case or a PEC screen of an electronic device, etc. The enclosure size, computation volume, cell sizes, and excitation pulse bandwidth are fixed. The reader may locate different apertures on different planes of the enclosure, and SE simulations may be performed. Electromagnetic leakage is a complex problem and one cannot predict what will happen by looking at the structure, aperture size, polarization, etc. Moreover, high (low)-frequency behaviors can also not be predicted by just calculating or measuring low (high)-frequency variations. SE must be obtained at each case (aperture location, size, and frequency) separately. I think the reader will enjoy to see how electromagnetic leakage varies with frequency for variety of aperture and observation locations. For SAR calculations, FDSAR and TLMSAR packages are presented. Multi-rectangular blocks with different relative permittivity and conductivity are used to eliminate discretization errors, so that FDTD and TLM comparisons may show the difference between their behaviors against numerical dispersion. The reader will also find results and comparisons done via these simulators.

Finally, Chapter 6 presents radar simulation. Radar simulation is a complex problem that includes all aspects of electromagnetics; signal generation and propagation, RCS, antenna effects, noise and clutter elimination, detection, tracking, etc. The answer regarding the need for a radar simulation depends on the mission: For example, it may be to understand radar signal environment; to optimize radar parameters, such as transmitter power, receiver gain, path loss, radar cross section (RCS), noise and clutter, etc.; to find out under what conditions the radar equation is satisfied for a given set of parameters; to evaluate algorithms, such as detection, tracking, sensor fusion, etc.; to use the radar simulator in a multi-sensor surveillance system simulation, to play different scenarios and try to find out the answers to “What if .."-type questions; and, finally, to use it as a system design tool. In this chapter an emerging radar, high-frequency surface-wave radar (HFSWR) and integrated surveillance concepts are presented.

When the book was planned nearly a year ago, I thought that a collection of computer codes, effective and valid in a broad range of electromagnetic problems
including (but not limited to) antennas and propagation, radars and radar cross section, microstrip network design and EMC / BEM, would serve EE students and engineers as educational as well as engineering design and research tools. I also thought that it would be better if the codes were tailored with user friendly graphical user interfaces (GUIs). Since then, I have had many discussions with my colleagues and students on the characteristics and the presentation styles of the codes. During these discussions I have changed my mind frequently about structures of the codes until I thought that I found the most appropriate ones.

The codes are organized as follows:

- Each simulator is prepared for a certain class of electromagnetic problems.
- The simulators are coded in Fortran and compiled with Linux G77.
- Canonical scenarios are prepared for each code, where the reader may test different cases to gain physical insight.
- Some of the parameters are specified and some are left to the reader. The aim here is to present to the reader a simulator that is user-friendly, with as many different scenarios as possible.
- The simulators are included as stand-alone executable (i.e., *.EXE) packages, and Fortran source codes are also included. The philosophy here is to let the reader first use the code to understand and practice and, subsequently, make modifications if he or she is interested in doing so and has a desire to go further.
- The sample simulators have almost identical structures. The reader supplies requested input parameters from an input file (e.g., SSPE.INP or TDWP.INP, etc.). The simulator runs with these parameters and yields output parameters as output files. If, for example, path loss vs. range is simulated for ground-wave propagation, then the output file RANGE.DAT will have two columns; the first column is the range (in meters or kilometers) and the second column is the path loss in (dB). Number of rows depend on the user supplied first range, last range and range increment values. Therefore, the reader may have path loss vs. range graphics with any graphics tool he or she has. For time-domain simulators, frequency-domain results are obtained off-line via discrete Fourier transform (DFT) by using output files of the simulator as input file of the DFT tool.
- Not all sample simulators are prepared in a way to warn or restrict the reader from entering some invalid parameters. For example, the 2D propagation simulator SSPE can handle the effects of an obstacle along the propagation path between transmitter and receiver. The heights and base widths of these obstacles are supplied by the reader. Valid parameter regions are given for each simulator. Although any value may be supplied, SSPE is valid within paraxial region (i.e., for small longitudinal variations), which means that results for sharp and high obstacles are invalid. The reader may observe this invalidity from the output of the SSPE simulator. The contour plots may be used to observe smooth EM wave interaction, cylindrical wave spread, edge and tip diffraction, etc.
- This structure is effective and suitable for GUI preparation. Although supplied one or two samples, preparation of GUIs are left to the interested reader.
Most of the materials used in this book have come from or have been derived from studies carried out under my direction at the Electrical-Electronics Engineering Faculty of Istanbul Technical University and Center for Defense Studies of Istanbul Technical University Foundation. Propagation tools based on ray-mode and parabolic equation approaches were initially prepared by myself. SSPE was written by myself and augmented by Dr. Funda Akleman so that it deals with the impedance boundary condition or varying terrain heights, and TDWP was prepared by Dr. Funda Akleman, during her Ph.D. studies. FDTD-based codes are prepared by myself and my students. Many people have made contributions to them. We follow similar structures in our FDTD-based codes with Dr. K. S. Kuns and Dr. R. J. Luebbers (as they present in their book The Finite-Difference Time-Domain Method for Electromagnetics, CRC Press, Boca Raton, FL, 1993). The near to far-field transformation algorithm YAKUZ was prepared by myself during undergraduate studies of my student Erdem Başeğmez. All TLM-based codes were developed by Dr. M. Orhan Özyalçın while he was working on his Ph.D. thesis, and they were augmented by him and Dr. Funda Akleman. I express my gratitude to those of my students who had worked in preparation of these computer codes during their undergraduate and graduate theses. Especially, I would like to mention Dr. Funda Akleman and Dr. M. Orhan Özyalçın, who are also co-authors of Chapters 1 and 5, respectively, for their valuable contributions.

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Levent Sevgi
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