A NEW ELECTROMAGNETIC ENGINEERING PROGRAM AND TEACHING VIA VIRTUAL TOOLS

L. Sevgi

Electronics and Communications Engineering Department
Doğuş University
Zeamet Sokak, No. 21, Acıbadem-Kadıköy, İstanbul, Turkey

Abstract—The societal and technological priorities of the world have been continuously changing because of complex computer and technology-driven developments in everywhere like communications, health, defense, economy, etc. Electromagnetic (EM) systems have become more and more complex however the explosive growth of computer capabilities has revolutionized the design and analysis of such complex systems. This has made interdisciplinary exposure necessary in modern EM engineering, also has brought up discussions of educational challenges and novel teaching approaches that confront wave-oriented EM engineering in the 21st century. This paper reviews EM computer simulation strategies and summarizes novel virtual tools that may be used in connection with classical EM lectures as well as with a newly proposed EM Engineering Program.

1. INTRODUCTION

Electromagnetics (EM) is everywhere! We have been witnessing the transformation from engineering EM to EM engineering for some time. Electromagnetic engineering community must be prepared to adapt to frequent shifts in technological priorities and rapid scientific advances, followed by rapid advances in technologies. Today, addressing the technical challenges posed by system complexities requires a broad range of innovative, multi-disciplinary analytical and computational skills that are not adequately covered in conventional EM engineering curricula. Universities and educational institutions have been actively engaged in efforts to design curricula for teaching the necessary skills to a computer-weaned generation of students, with access to the internet and consequent globalization of information. Physics-based modeling, observation-based parameterization, and computer-based simulations

are the key issues of these challenges. These issues have been discussed in detail and powerful EM simulators were given in [1].

Experimentation and hands-on training are the fundamentals of EM engineering education however strong theoretical background is also a must. With the development of new computer technologies, interactive multimedia programming languages, and the internet it is now possible to simulate complex EM problems and laboratory projects of all sorts on a computer all around the world. Experiment-oriented problems can be offered without the overhead incurred when maintaining a full laboratory. At this point the question arises: should an intelligent balance be established between real and virtual experimentations and how? Another similar problem is the balance to be maintained between teaching essentials (theory) and cranking the gear (blind computer applications) [2].

Triggered by these facts, discussions and thoughts we have developed and introduced multipurpose EM virtual tools [3–18] that can be used in most of the classical EM lectures as well as in novel *EM Engineering Programs* (EMEP), and have been discussing them internationally [19–24]. We have always looked for something which would be useful, give physical insight, and effective so that the young EM researchers and students can use intelligently. This paper tutorially reviews these simple, easy-to-use but effective virtual tools, and, in connection, proposes a novel EMEP.

2. MODELING AND SIMULATION STRATEGIES IN EM

Computational EM is a novel area that includes research in high-performance computing, applied mathematics and physics, intelligent systems and information technologies [1]. It is a new and cost-effective way of solving complex EM problems beyond the reach of analytical methods, and the outcome is powerful software packages and virtual tools for the students, lecturers, researchers, and scientists.

Computational EM require basic understanding of fundamental concepts like modeling, analytical solution, numerical solution, analytical- and numerical-based modeling, simulation, model validation, code verification through canonical tests/comparisons, accreditation, etc. *Analytical solution* is the solution based on a mathematical model (usually in differential and/or integral forms) of the physical problem in terms of known, easily computable mathematical functions, such as, sine, cosine, Bessel, Hankel functions, etc. *Numerical solution* is the solution based on direct discretization of the mathematical representations by using numerical differentiation, integration, etc. Semi *analytical-numerical solution* is in between these two and is the solu-

tion based on partially derived mathematical forms that are computed numerically.

Modeling and simulation is extremely valuable in engineering if based on physics-based modeling and observable-based parameterization. It starts with the definition of the real-life problem. Its conceptual model is the basic theory behind the real-world problem. Some disciplines have already been in their *mature* stage in establishing theories. For example, Maxwell equations establish the mathematical model of *field and circuit theories* in EM engineering, define the interaction of EM waves with matter, and form the basis for a real understanding of electrical problems and their solutions. All of the frequency and time domain methods use either differential or integral form of Maxwell equations. The well-known and widely used numerical methods are FEM, MoM, SSPE, FDTD and TLM (see [1] and its references).

Finite element model (FEM) analysis of a problem includes discretization of the solution region into a finite number of sub-regions or elements, derivation of the governing equations for a typical element, assembling all elements in the solution region, and solving the system of equations obtained. A major difficulty encountered in FEM analysis is data preparation, which is essentially element generation; therefore special mesh generators have been developed for this purpose. Method of Moments (MoM) is based on solving (via discretization) complex integral equations by reducing them to a system of linear equations. The equation solved by MoM generally has the form of an *electric field integral equation* (EFIE) or a *magnetic field integral equation* (MFIE). Although MoM can be applied also in the time domain, the majority of these equations are set in the frequency domain. The Fast Multipole Method (FMM) and the Multilevel Fast Multipole method (MFMA) are the modified MoM approaches which reduce the number of unknowns in matrix form solutions of integral representations for the fields. The split-step parabolic equation (SSPE) technique, widely used in propagation scenarios, implements the solution of the one-way parabolic type wave equation. It neglects back-scatter effects and is valid in regions close to near-axial propagation. It is an initial value problem, mostly used in 2D, where transverse and/or longitudinal characteristics can be included. The finite-difference time-domain (FDTD) method discretizes Maxwell equations by replacing derivatives with their finite-difference approximations directly in the time domain. The transmission line matrix (TLM) method uses Huygen's principle, i.e., it is based on circuit theory, and the discretization of fields in an array of three-dimensional (3D) lumped elements.

3. NOVEL EM VIRTUAL TOOLS

The virtual tools we have developed and their capabilities are listed in Tables 1 and 2. These tools can be used as teaching aids in labs and projects of various EM lectures. Some virtual tools are general and useful for major engineering disciplines. For example, D-FFT [9] is LabView-based virtual tool where the user may train themselves via applications of Fourier transform (FT), discrete Fourier transforms (DFT) and fast Fourier transforms (FFT). It should be remembered that DFT and FFT are synthetic operations so the user should well-understood under what conditions DFT and FFT correspond to mathematical FT. If not satisfied, these conditions cause numerical effects such as aliasing, spectral leakage, scalloping loss, etc., which may all be investigated via D-FFT virtual tool.

Table 1. Basic-level virtual EM tools developed in our group.

| EM Virtual Tool	Purpose
D-FFT	A virtual FFT instrument prepared with the LabVIEW. It can generate and display time and frequency domain behaviors of sinusoids, a rectangular pulse, a pulse train, a Gaussian function, a sine modulated Gaussian function.
1DFDTD	A Matlab-based FDTD simulation of plane wave propagation in time domain through single, double or three-layer media. EM parameters are supplied by the user.
TDRMETER	A virtual time-domain reflectometer virtual tool. It is used to locate and identify faults in all types of metallic paired cable. Fourier and Laplace analyzes are also possible.
RAY / MODE HYBRID	Ray/mode representations inside a parallel plate non-penetrable waveguide. RAY serves as a tool to compute and display eigenray trajectories between specified source/observer locations and to analyze their contributions to wave fields individually. HYBRID may be used to display range and/or height variations of the wave fields comparatively, calculated via ray summation, mode field summation, and hybrid ray-mode synthesis.
DiSLAB	A Matlab package designed to investigate wave propagation through a 2D dielectric waveguide. Both analytical formulations and the SSPE propagator are used for comparisons.
ARRAY	A simple Matlab antenna array package of isotropic radiators accommodated with beam forming and beam steering capabilities. It plots 2D and 3D radiation patterns of a number of selected and user-located isotropic radiators.
MGL-2D	A general purpose 2D FDTD package for both TE and TM type problems. Any 2D scenario may be created by the user by just using the PC mouse.
SNELL	A simple Matlab package for the visualization of ray contributions between a source/receiver pair above a 2D ground using the ray shooting technique. A number of rays, whose angles of departures are specified by the user, are shot through a propagation medium characterized by various linear vertical refractivity profiles.

The packages 1DFDTD and TDRMeter simulates pulsed plane wave propagation and pulsed voltage/current propagation along a

Table 2. Advanced-level virtual EM tools developed in our group.

EM Virtual Tool	Purpose
WEDGE	A Matlab package for the exploration of wave propagation inside a 2D non-penetrable, homogeneously filled wedge-waveguide. It is designed to investigate line-source-excited wave fields in terms of normal, adiabatic and intrinsic mode solutions.
DRMIX	A Matlab-based Millington package prepared for the mixed-path path loss predictions. The effects of the number of multi-mixed paths, path-lengths, electrical parameters of each propagation section, and the frequency can be investigated.
GrSSPE	A simple Matlab groundwave propagation package for the visualization of EM propagation over non-flat terrain through non-homogeneous atmosphere, for waves radiated by a horizontally oriented antenna over the ground.
GrMoMPE	A Matlab package which modifies MoM method by the application of forward backward spectral acceleration (FBSA) technique and integrate it with the SSPE method. Precise SSPE vs. MoM comparisons are possible.
MSTRIP	An FDTD-based EM simulator for the broadband investigation of microstrip circuits. The user only needs to picture the microstrip circuit via computer mouse on a rectangular grid, to specify basic dimensions and operational needs such as the frequency band, simulation length.
MGL-RCS	An FDTD-based EM simulator for RCS prediction. The user only needs to locate a 3D image file of the target in 3DS graphics format, specify dimensions and supply other user parameters. The simulator predicts RCS vs angle and/or RCS vs. frequency.

transmission line, respectively. These tools are important for the visualization of 1D pulse scattering. They can also be used to show the analogy between plane waves and transmission lines. They both are based on FDTD modeling of first order coupled differential equations of the same form. For the plane waves, the coupled equations relate spatial variations of the electric fields to the time variations of the magnetic fields (or vice versa) in terms of medium EM parameters conductivity, permittivity and permeability. The same equations relate pulsed voltage variations along the transmission line to the pulsed current variations in time via the line parameters modeled by the lumped elements RLC. These virtual tools are also very effective in showing the time and the frequency domain characteristics of plane waves and transmission lines using DFT or FFT. The Laplace transform is also used in the TDRMeter to show the transient effects along the line [12]. Figs. 1 to 4 show some examples obtained using the TDRMeter tool.

As shown in Fig. 3(a), the standard *Fourier Transformation procedure* includes (i) discrimination of the incident and reflected pulse in the time domain, (ii) moving to the frequency domain via FFT, and (iii) taking the ratio of the reflected and incident pulses within the band of the pulse. Similarly, the shape of the echo may be used to
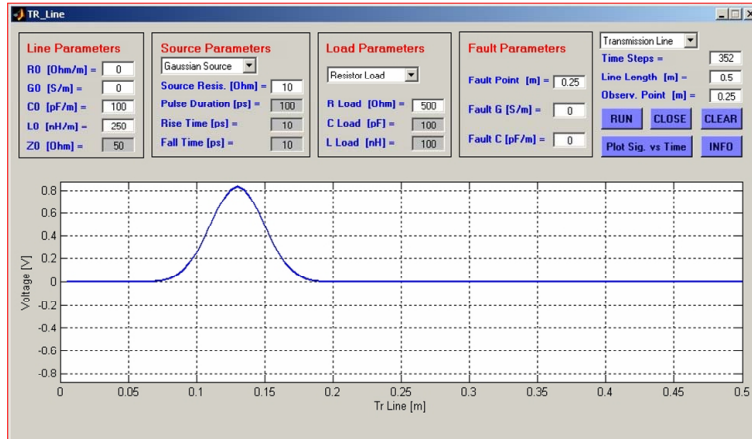
Figure 1. The front panel of the TDRMeter package, resistive termination, a Gaussian pulse traveling towards the load (a $50\,\Omega$ transmission line, $R_s = 10\,\Omega$, $R_L = 100\,\Omega$).
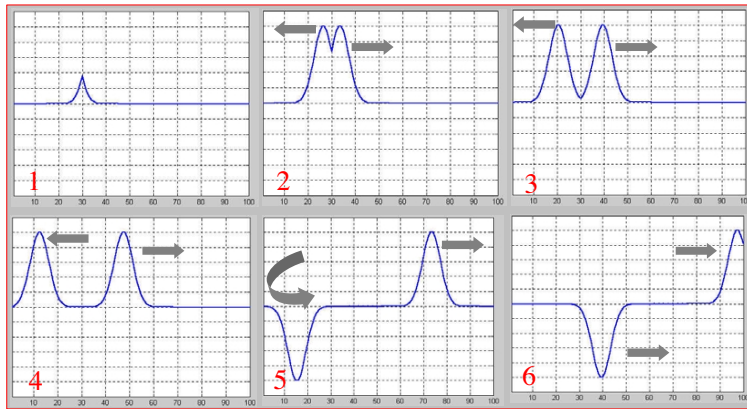

Figure 2. Gaussian pulse injection along a transmission line short-circuited at both ends. Graphs show different time instants (1: pulse injection, 2: detachment of the right- and left-traveling pulses, 3, 4: pulses propagating towards left and right, 5, 6: right-propagating pulses, one from the source, the other reflected from the left boundary with the opposite phase).

predict the nature of the mismatch along the transmission line and/or at the load. This is achieved (as in Fig. 4) by the application of *Laplace Transformation procedure* [12].
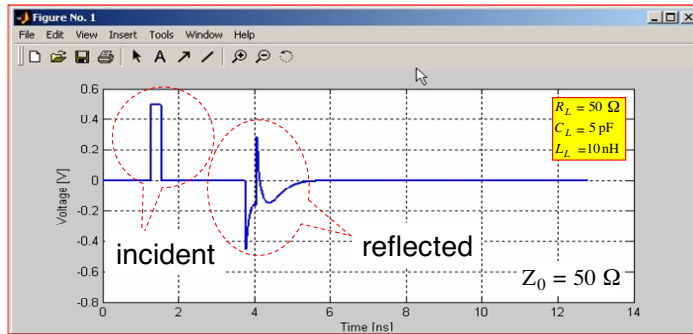
(a)
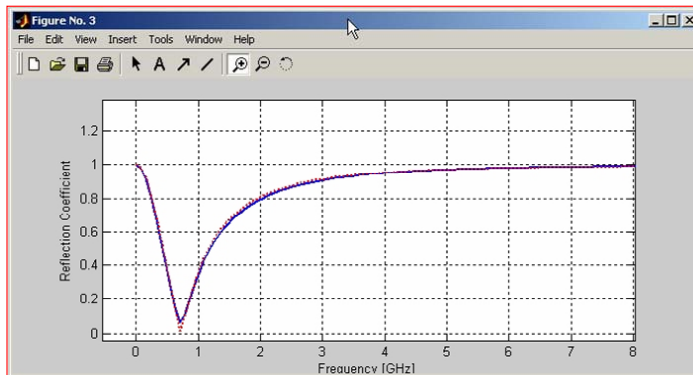
(b)

Figure 3. (a) Signal vs. time at mid point of a $50\,\Omega$, $0.5\,\text{m}$ TL under parallel RLC termination ($R_L = 50\,\Omega$, $C_L = 5\,\text{pF}$, $L_L = 10\,\text{nH}$). Matched termination is used at the source ($R_s = 50\,\Omega$). Pulse length $= 400\,\text{ps}$, (b) Voltage reflection coefficient vs. frequency obtained with the FFT procedure; Solid: TD simulation result, Dashed: Analytical exact solution.

The TDRMeter virtual tool can be used to teach, understand, test and visualize the TD TL characteristics; echoes from various discontinuities and terminations. Inversely, the types and locations of fault can be predicted from the recorded data. Any electronic device and/or circuit include TL lines (i.e., coaxial, two-wire cables, parallel plate lines, microstrip lines, etc. therefore have transient EM characteristics. A wide range of EMC problems may be simulated with the TDRMeter virtual tool, such as, conducted emissions, common and differential mode effects, etc., both in time and frequency domains.
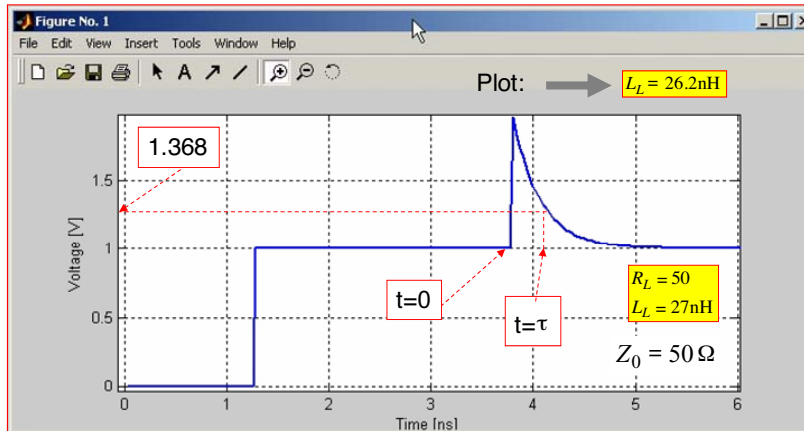
Figure 4. Signal vs. time (step response) at mid point of a $50\,\Omega$, $0.5\,\mathrm{m}$ TL under serial RL termination ($R_L = 50\,\Omega$, $L_L = 27\,\mathrm{nH}$). Matched termination is used at the source ($R_s = 50\,\Omega$). The value of the inductor calculated from the plot is $26.2\,\mathrm{nH}$.

Also, reflections due to various types of transmission structures, impedance effects of vias, signal and power line couplings, etc., on printed circuits with smaller and smaller dimensions make signal integrity one of the most important and complex EMC problems. Therefore, the virtual tool may be particularly helpful for a student or circuit designer in the evaluation of signal integrity.

ANTEN [14] is a Matlab package to visualize beam forming and beam steering capabilities of various linear, circular, and planar arrays of isotropic radiators. The user may form any kind of an array and observe radiation patterns in 2D or 3D (for vertical or horizontal polarizations). An interesting feature is added in designing planar arrays. The user may design an arbitrary array by just locating arbitrary number of isotropic radiators using the PC mouse. Inter-element phasing is done automatically to steer the beam of the designed array to the specified beam pointing direction. An example produced via ANTEN is given in Fig. 5.

The packages RAY/HYBRID [15], WEDGE [16] and DiSLAB are designed in Matlab using mathematical solutions, therefore are very important to teach ray-mode representations in 2D parallel plate, wedge-type and slab waveguides, respectively. TM characteristics of these three structures are almost canonical and covered in most of the classical EM lectures. To teach and show mode solution, ray solutions and their hybrid usage inside a 2D parallel plate waveguide RAY and

(a)   (b)
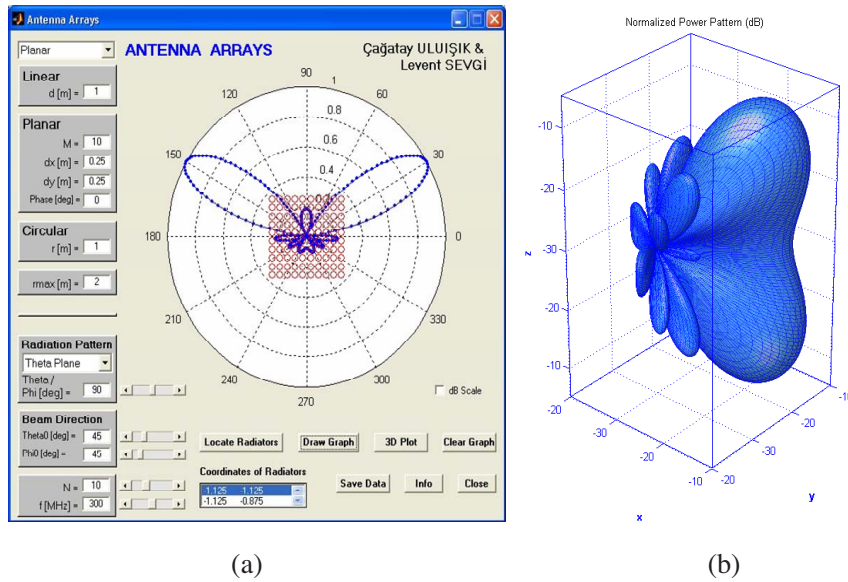
Figure 5. A 10×10 planar array, (a) horizontal plane 2D pattern, (b) 3D radiation pattern ($f = 300$ MHz, inter-element distances are 0.25 m in both x- and y-directions, the beam angles are $\theta_0 = 45°$ and $\varphi_0 = 45°$.

HYBRID virtual tools are very useful. Two examples are presented in Figs. 6 and 7. As shown, the user may visualize individual or collective contributions of the rays and/or the modes. The same is true for the WEDGE and DiSLAB virtual tools. The 2D parallel plate waveguide with penetrable and non-penetrable boundaries are canonical structures in teaching rays representation, eigenvalue (source-free) and Green's function (source-driven) problems [15, 16].

SNELL [17], MGL-2D [11], GrSSPE [13], GrMoMPE [5] and DrMIX [6] are 2D propagators based on different frequency or time domain methods. One- and/or two-way propagation problems, either in the time or in the frequency domains, can be simulated. SNELL is a ray shooting virtual tool which uses only a simple equation. The user specifies refractivity variations of the medium, may locate non-penetrable obstacles on the ground along the propagation direction, vertical beam of the source. The 2D propagation environment is divided into a number of horizontal slices and a number of rays are shot and Snell law is applied at each range/height point. An example is given in Fig. 8.
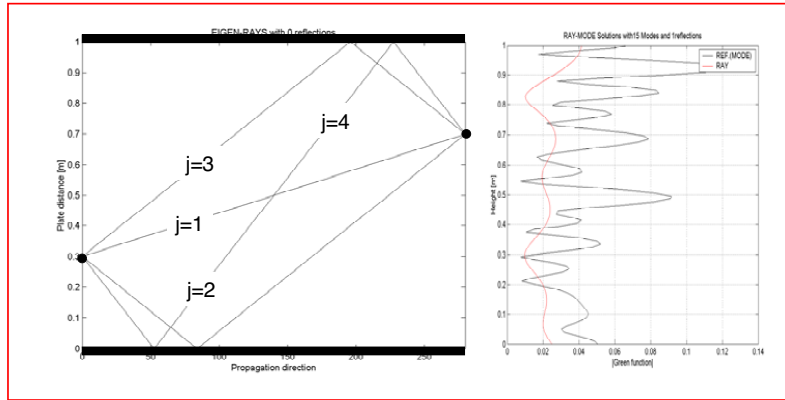
Figure 6. (Left) first four eigenarray inside a 1 m-wide parallel plate waveguide for a set of parameter (distance = 5.6 m, source height = 0.3 m, observer height = 0.7 m, f = 2387 MHz, ka = 50, n = 1). The number of propagating modes for these parameters is 15. (Right) Wave field vs. height calculated via both mode and ray summations (mode summation is the reference solution).
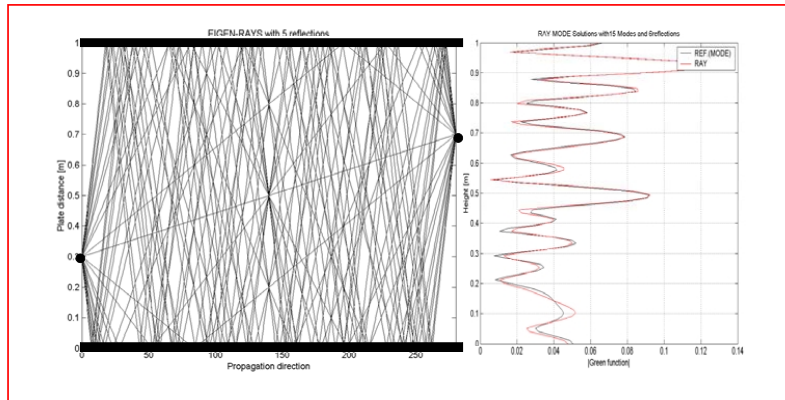
Figure 7. Same with the Fig. 6 but for $n = 1$ to 5. As observed, ray solution approaches to the reference (mode) solution as the rays stuff the waveguide.

GrSSPE and GrMoMPE are MoM- and SSPE-based propagators where the user may design arbitrary non-flat terrain profiles and calculates signal strength and path loss variations along the range up to a specified receiver point. The user may also import longitudinal
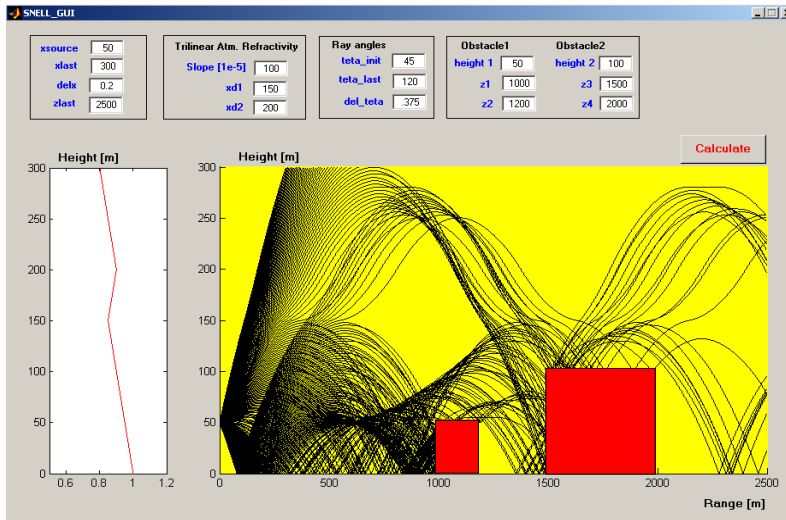
Figure 8. The front panel of the Matlab package SNELL and ray shooting through an environment with a vertical tri-linear refractivity profile having two obstacles along the propagation path (source height $= 50$ m, maximum height $= 300$ m, layer height $= 0.2$ m, maximum range $= 2500$ m, first ray angle $= 45°$, last ray angle $= 120°$, ray increment $= 0.375°$, Refractivity slope $= 0.001$, the heights of ducting and anti-ducting are 80 m and 150 m, respectively, 1. obstacle: height $= 50$ m, base length $= 200$ m, range $= 1000$ m; 2. obstacle: height $= 100$ m, base length $= 500$ m, range $= 1500$ m).

terrain profiles and run the simulations over these profiles and obtain path loss vs. range curves. This is really important, since it gives a possibility of comparing a real-life measurement data against simulation data obtained via the SSPE and/or MoM propagators. Finally, MGL-2D is an FDTD based 2D propagator which can be used for broad range of EM problem simulations. Some examples are presented in Figs. 9–11.

Finally, MSTRIP [10] and MGL-RCS [4] are 3D FDTD codes designed specifically to investigate single- or double-layer microstrip circuits and EM reflectivity of objects, respectively. MSTRIP is a FDTD-based EM simulator accommodated with the powerful perfectly matched layer (PML) routine, specifically designed for microstrip circuit investigations. The user only needs to picture the microstrip circuit via computer mouse on a rectangular grid, to specify basic dimensions and operational needs such as the frequency band,
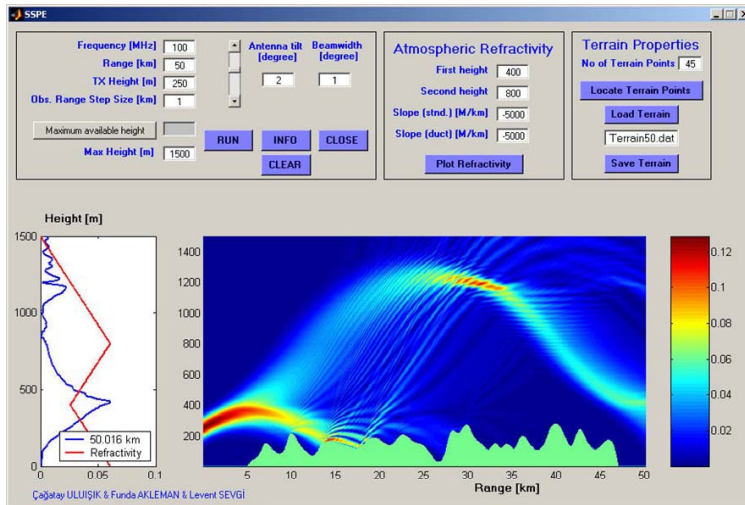
Figure 9. The SSPE virtual tool and propagation through tri-linear atmosphere over an irregular terrain; frequency 100 MHz, maximum range 50 km, maximum height 1500 m, transmitter height 250 m, antenna tilt 2 degrees upwards, and beamwidth 1 degrees. Linearly increasing and decreasing refractivity segments have slopes of 5000 M/km.
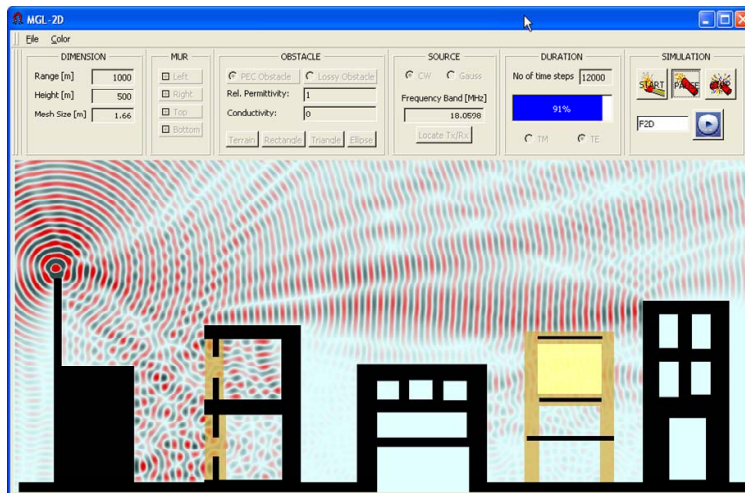

Figure 10. The MGL-2D virtual tool and outdoor propagation modeling along a horizontally-projected user-specified street after some time.
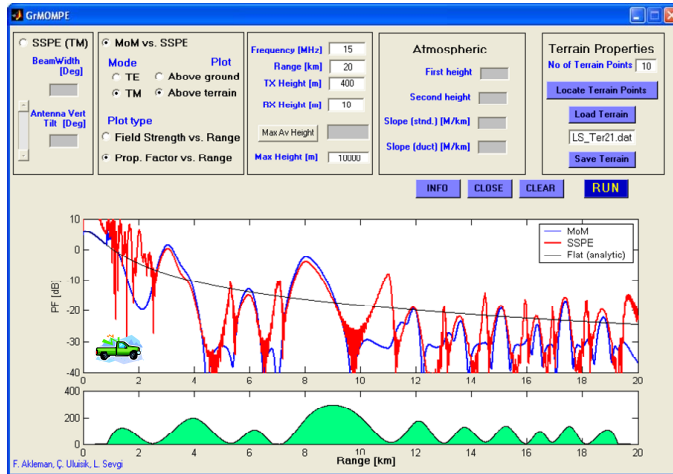
Figure 11. A typical non-flat terrain scenario (a surface with many smooth irregularities; with range in [km] and height in [m]) and propagation factor in dB vs. range in [km] for the TM-type problem ($f = 15$ MHz, maximum range $= 20$ km, transmitter height $= 400$ m, receiver height $= 10$ m).
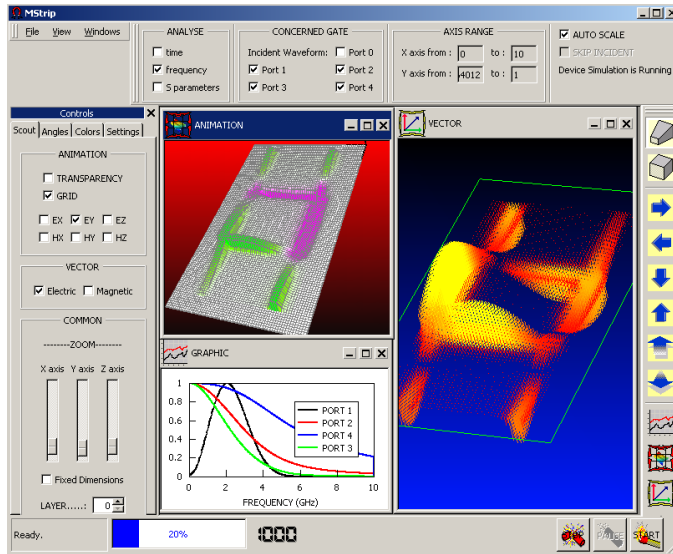

Figure 12. The MSTRIP virtual tool; a typical 4-port coupler, a snapshot during its FDTD simulation and the frequency responses at four ports.
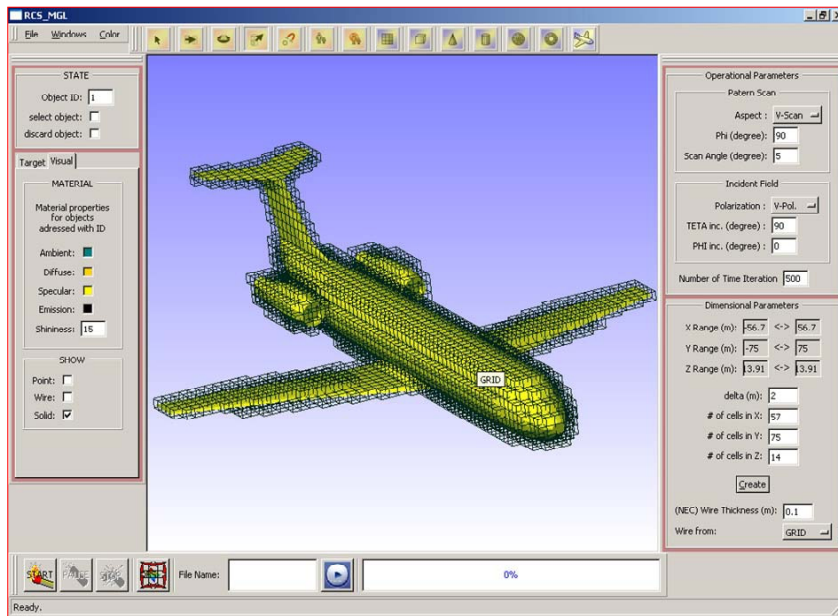
Figure 13. The front panel of the MGL-RCS package and the 3D discrete model of an air target (a 50 m-long DC-10 jet) imported from a 3DS file.

simulation length. The rest is handled by the virtual tool and output such as signal vs. time signal vs. frequency, etc., can be displayed on-line during the simulation. Moreover, three dimensional visualizations are possible where the user may record any length of films for further illustrations. MGL-RCS is an RCS prediction tool which can be used to create 3D targets from canonical blocks such as rectangular prism, cone, cylinder, sphere, and torus; or 3D models of surface and/or air vehicles saved in different graphics files (e.g., 3DS format) can be used as radar targets. Near EM scattered fields around the target, caused by an incident Gaussian plane wave hitting the target from a specified direction, can be simulated using a 3D numerical FDTD model. EM transient scattering may also be recorded in a specified file as a video clip. Far fields can be extrapolated and stored via the application of equivalence principle and bi-static RCS patterns can be plotted using discrete Fourier transformation (DFT) onto the stored time-domain EM scattered data. Figs. 12 to 14 are reserved for the examples of MSTRIP and MGL-RCS.
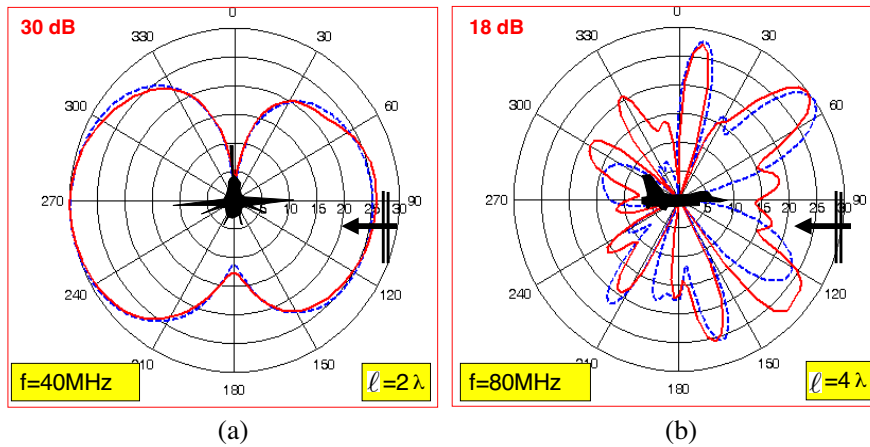
Figure 14. FDTD vs. NEC for angular bi-static RCS predictions at two different cases; (a) $f = 40\,\text{MHz}$, $\theta_i = 90°$, $\varphi_i = 0°$, $\varphi_s = 0°$, $0° \leq \theta_s \leq 360°$ with angular resolution of $\Delta\theta = 3°$, Vertical scan, $\sigma_{\varphi\varphi}$-case. (b) $f = 80\,\text{MHz}$, $\theta_i = 90°$, $\varphi_i = 90°$, $\varphi_s = 90°$, $0° \leq \theta_s \leq 360°$ with angular resolution of $\Delta\theta = 3°$, Vertical scan, $\sigma_{\varphi\varphi}$-case. Solid (red): FDTD, Dashed (blue): NEC2. Maximum plot values are given on top right.

4. A NOVEL EM ENGINEERING PROGRAM — EMEP

Most of ECE engineering program have EM lectures such as *EM Fields*, *EM Waves*, *Antennas and Propagation*, *Introduction to Microstrip Circuits*, *Wireless Communication*, *EMC Engineering*, *Filter Theory*, *Radar and Sensing Systems*, etc. However, current complexity of most of the EM problems necessitates revisit of the number and contents of these lectures. A novel EMEP program, partially based on the presented virtual tools can be designed with a reduced number of lectures and credits. Essential topics can be covered in four different lectures; *EM Engineering* I, II, and III, *Microwave Engineering*. Other related engineering topics may be covered in the lecture *EM Special Topics*. Fundamentals topics to be covered inside the first four lectures are listed in Tables 3 and 4.

Junior-level EM courses basically covers EM topics in one- and two-dimension. After summarizing current challenging EM problems, and reviewing Fourier and discrete Fourier fundamentals, the first quarter (nearly three weeks) of the first lecture *EM Eng-I* is reserved for Maxwell equations, fundamental representations and basic derivations. Then, EM fields/waves are discussed in 1D in the

Table 3. Junior-level EM lectures and topics to be covered in the proposed EMEP.

EM Engineering - I	
•EM Engineering & Challenging Problems	•Spherical waves, Cylindrical waves
•Fourier transforms, DFT & FFT	•Poynting theorem & EM Power
•LabView-based **FFT VT**	•Wave/matter interaction
•Maxwell Equations	•Plane Waves & 1D FDTD Solutions
•Time & Frequency Representations	•Matlab-based **1D FDTD VT**
•Electrostatics and Magnetostatics	•Plane waves −Tran smission Line Analogy
•Electrodynamics	•Transmission Line Theory
•Scattering, Radiation & Diffraction	•Matlab-based **TDRMeter VT**

EM Engineering - II	
• Complex 2D EM Problems	• FDTD-based **MGL-2D VT**
• 2D Parallel Plate Waveguide & Ray/Mode	• EM (Hertz & ring) Dipoles
• Solutions (**HYBRID VT**)	• Antenna Fundamentals
• 1D Sturm-Liouville Prolem (**STURM VT**)	• EMC & Communication Antennas
• Ray tracing, Ray Shooting & **SNELL VT**	• Arrays, Beam Forming& Steering
• Friis Formulae & Path Loss Definiton	• Matlab-based **ARRAY VT**
• Propagation Through Atmosphere,	• Wire Antennas & NEC Modeling
• Refractivity Effects & **SSPE VT**	• 3D Rectangular waveguides
• Dielectric Slab Waveguide & **DiSLAB**	• Resonators

Table 4. Senior-level EM lectures and topics to be covered in the proposed EMEP.

EM Enginering - III	
• Fundamentals of EMC, EMI & BEM	• N-port devices & S-parameters
• Signals and Noise in Electromagnetics	• LC −TL Equivalence
• Non-Linearity Effects & Harmonics	• Microstrip Lines & Microstrip Circuits
• EMC Standards, Tests & Measurements	• Broadband Filter Design
• EMC & Shielding Effectiveness (**SE VT**)	• Chebychev and Butterworth Filters
• Specific Absorption Rate (**SAR VT**)	• FDTD-based 3D **MSTRIP VT**

EM Engineering - IV (Special Topics)	
• Computational Electromagnetics	• Detection & Tracking Algorithms
• Finite Difference Time Domain Method	• RCS Modeling & Simulation
• Finite Element Method	• **MGL-RCS VT**
• Method of Moments	• Multi-Sensor Surveillance systems
• Radars and Sensing Systems	• Opical Fibers, Wireless Communication

second quarter; which focuses on the plane waves. The transmission line theory is summarized in the third quarter starting with the discussion of plane wave — transmission line analogy. The last quarter is reserved for the virtual lab experimentations using the two virtual tools, 1DFDTD and TDRMeter [12]. Resonance effects of the plane wave propagation in a 1D finite region and/or along a finite length short/open circuited transmission line can be presented using the discrete Fourier transformation tools DFT or FFT. Also, transients along a transmission line can be presented using the Laplace transformation and the TDRMeter data. Numerical experimentations of the excitation and/or observation of the resonances (i.e., modes) in 1D can be performed easily.

Fundamental EM problems in 2D are included in the second lecture, *EM Eng–II*. Classical 2D parallel plate waveguide with penetrable as well as non-penetrable boundaries are discussed in this course. Ray, mode and hybrid solutions are presented together with the visual capabilities of the RAY, HYBRID [15] and DiSLAB virtual tools. Ray-mode representations and ray shooting methods are covered in this lecture. The relation between eigenvalue and Green's function problems are related via the Sturm-Liouville problem. The FDTD-based virtual tool MGL-2D [11] can be used to create many realistic EM scenarios, from indoor-outdoor propagation to tunneling, waveguides to resonators, etc. Antennas and radiation topics are also covered in this lecture.

The first advanced level EMEP lecture *EM Eng-III* is basically reserved for EM compatibility, bio-EM engineering, and microstrip circuit design and analysis. Signal processing aspects in EM are also covered in this lecture. Finally, the last lecture *Special EM Topics* is reserved for modeling and numerical simulations, and may include radar and sensing systems, problems related to Multi Sensor Surveillance, fundamentals of Wireless Systems, and Fiber Optics. All lectures are 3-credit (2 hr course +2 hr applications with virtual tools). The total number of credits of this EMEP with these 4 lectures is 12 and replaces those classical EM lectures mentioned above with the total number of credits of more than 21. This gives students a plenty of space to work with engineering projects. It should be noted that, the new EMEP necessitates revision of two more junior-level courses; *Numerical Analysis* and *Probability, Statistics, and Stochastic Modeling*.

5. CONCLUSIONS

A new EM Engineering Program is introduced to cope with current challenges in engineering education. The program is based on two junior and two-senior level EM Engineering courses. Various powerful virtual tools which play essential roles in teaching in this new EMEP are also discussed. It should be noted that, an intelligence balance between EM theory and numerical simulations must be established when using this EMEP.

REFERENCES

1. Sevgi, L., *Complex Electromagnetic Problems and Numerical Simulation Approaches*, IEEE Press & John Wiley and Sons Inc., NJ, June 2003.

2. Sevgi, L. and I. C. Göknar, "An intelligent balance in engineering education," *IEEE Potentials Magazine*, Vol. 23, No. 4, 40–41, Oct./Nov. 2004.

3. Uluışık, Ç., G. Çakır, M. Çakır, and L. Sevgi, "Radar Cross Section (RCS) modeling and simulation: Part I — Definitions, strategies, and canonical examples," *IEEE Antennas and Propagation Magazine*, Vol. 50, No. 1, Feb. 2008.

4. Çakır, G., M. Çakır, and L. Sevgi, "Radar Cross Section (RCS) modeling and simulation: Part II — A novel FDTD-based RCS prediction virtual tool," *IEEE Antennas and Propagation Magazine*, Vol. 50, No. 2, Apr. 2008.

5. Akleman, F. and L. Sevgi, "A novel MoM- and SSPE-based groundwave propagation field strength prediction simulator," *IEEE Antennas and Propagation Magazine*, Vol. 49, No. 5, 69–82, Oct. 2007.

6. Sevgi, L., "A mixed-path groundwave field strength prediction virtual tool for digital radio broadcast systems in medium and short wave bands," *IEEE Antennas and Propagation Magazine*, Vol. 48, No. 4, 19–27, Aug. 2006.

7. Gündüz, S., G. Çakır, and L. Sevgi, "A generic microstrip structure for the realization of all-type broadband filters," *Microwave and Optical Technology Letters*, Vol. 48, No. 12, 2390–2393, Dec. 2006.

8. Sevgi, L., "Virtual tools/labs in electrical engineering education," *ELEKTRIK, Turkish J. of Electrical Engineering and Computer Sciences*, Vol. 14, No. 1, 113–127, Special issue on Electrical and

Computer Engineering Education in the 21st Century: Issues, Perspectives and Challenges, 2006.

9. Sevgi, L. and Ç. Uluışık, "A labview-based virtual instrument for engineering education: A numerical fourier transform tool," *ELEKTRIK, Turkish J. of Electrical Engineering and Computer Sciences*, Vol. 14, No. 1, 129–152, Special issue on Electrical and Computer Engineering Education in the 21st Century: Issues, Perspectives and Challenges, 2006.

10. Çakır, G., M. Çakır, and L. Sevgi, "A novel virtual FDTD-based microstrip circuit design and analysis tool," *IEEE Antennas and Propagation Magazine*, Vol. 48, No. 6, 161–173, Dec. 2006.

11. Çakır, G., M. Çakır, and L. Sevgi, "A multipurpose FDTD-based two dimensional electromagnetic virtual tool," *IEEE Antennas and Propagation Magazine*, Vol. 48, No. 4, 142–151, Aug. 2006.

12. Sevgi, L. and Ç. Uluışık, "A matlab-based transmission line virtual tool: Finite-difference time-domain reflectometer," *IEEE Antennas and Propagation Magazine*, Vol. 48, No. 1, 141–145, Feb. 2006.

13. Sevgi, L., Ç. Uluışık, and F. Akleman, "A matlab-based two-dimensional parabolic equation radiowave propagation package," *IEEE Antennas and Propagation Magazine*, Vol. 47, No. 4, 184–195, Aug. 2005.

14. Sevgi, L. and Ç. Uluışık, "A matlab-based visualization package for planar arrays of isotropic radiators," *IEEE Antennas and Propagation Magazine*, Vol. 47, No. 1, 156–163, Feb. 2005.

15. Felsen, L. B., F. Akleman, and L. Sevgi, "Wave propagation inside a two-dimensional perfectly conducting parallel plate waveguide: Hybrid ray-mode techniques and their visualisations," *IEEE Antennas and Propagation Magazine*, Vol. 46, No. 6, 69–89, Dec. 2004.

16. Sevgi, L., F. Akleman, and L. B. Felsen, "Visualizations of wave dynamics in a wedge-waveguide with non-penetrable boundaries: Normal, adiabatic, and intrinsic mode representations," *IEEE Antennas and Propagation Magazine*, Vol. 49, No. 3, 76–94, Jun. 2007.

17. Sevgi, L., "A ray shooting visualization matlab package for 2D ground wave propagation simulations," *IEEE Antennas and Propagation Magazine*, Vol. 46, No. 4, 140–145, Aug. 2004.

18. Sevgi, L., "Modeling and simulation strategies for electromagnetic wave propagation in complex environments: Groundwave path loss prediction virtual tools," *IEEE Transactions on Antennas and Propagation*, Vol. 55, No. 6, 1591–1598, Special issue on

Electromagnetic Wave Propagation in Complex Environments: A Tribute to Leopold Benno Felsen, Jun. 2007.

19. Uluışık, Ç. and L. Sevgi, "Numerical modeling and simulation studies of 2D radiowave propagation over non-flat terrain and through inhomogeneous atmosphere," *Springer Proceedings in Physics Series*, Vol. 104, 45–54, Complex Computing Networks, Jan. 2006.

20. Sevgi, L., "From engineering electromagnetics towards electromagnetic engineering," *ELECO 2007, 5th International Conference on Electrical and Electronics Engineering*, Bursa, Turkey, Dec. 5–9, 2007.

21. Sevgi, L., "Electromagnetic engineering and teaching via virtual computer tools," *EUROCON 2007 the International Conference on Computer as a Tool*, a half-day short course, Warsaw, Poland, Sept. 9–12, 2007.

22. Sevgi, L., "Modeling and simulation strategies in antennas and propagation: Novel virtual tools," *EuCAP 2006, the First ESA European Conference on Antennas and Propagation*, a half-day short course, Nice-France, Nov. 6–10, 2006.

23. Sevgi, L., "Modeling and simulation strategies in electromagnetics: Teaching via virtual tools," *IEEE AP-S International Symposium & USNC/URSI National Radio Science AMEREM Meeting*, a half-day short course, Albuquerque, New Mexico, USA, Jul. 9–14, 2006.

24. Sevgi, L., "Modeling and simulation strategies in EMC engineering: Problems and challenges," *EMC 2005 6th International Symposium on EMC and EM Ecology*, two-hour tutorial, St Petersburg, Russia, Jun. 21–24, 2005.