NSERC/MPR Teltech Industrial Research Chair
In Radio Frequency Engineering

ACTIVITY REPORT*

Report No. 4 *April 1, 1995 to March 31, 1996*

MESSAGE FROM THE CHAIRHOLDER

This annual report covers the fourth year of the Chair's research activities, from April 1, 1994 to March 30, 1995. Again this year, the size of the research group has remained steady at eight permanent members; one Visiting Professor, Professor Tullio Rozzi, has joined the team for about one month.

While the principal research objectives remained focused on electromagnetic field modeling and simulation with emphasis on applications to information technology, the effort in time domain modeling of moisture content of wood has substantially increased. The early success of our TLM wood model has encouraged us to seek, with considerable success, both industrial and government support for further research in this area. Another new application of our modeling technique, of interest to a Victoria company, is the simulation of soil moisture probes that function by measuring the velocity of an electromagnetic wave traveling through the soil. The modeling and visualization of the probe fields have provided new insight into the functioning of such probes and their design.

Technology transfer to industry has thus been intensified this year. At the same time, a number of theoretical improvements to field modeling have been contributed, all of which are described in this report.

One of the highlights of the past year has been the "First International Workshop on Transmission Line Matrix (TLM) Modeling, Theory and Applications" which was held on August 1 to 3, 1995 at the University of Victoria, and which was financially supported by NSERC, ASI, the French and German governments, and the University of Victoria. Over 50 international participants, among them 14 invited speakers, exchanged latest information on, and expertise in TLM modeling. A summary of the Workshop program and its major conclusions are also attached to this report.

Last, but not least, the first two Ph.Ds from the Chair's research group graduated this year: Drs. Mario Righi and Qi Zhang have convincingly defended their excellent theses. I consider their past and future contributions to be among the most substantial benefits of the Chair to society.

Wolfgang J.R. Hoefer
Victoria, May 1996

*This report can be accessed on the Chair's World-Wide Web Server "http://www-wjrh.ece.uvic.ca".

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THE RESEARCH GROUP

Chairholder and Research Director

Wolfgang J.R. Hoefer received the Dipl.-Ing. degree in Electrical Engineering from the Technische Hochschule Aachen, Germany, in 1965, and the D. Ing. degree from the University of Grenoble, France, in 1968.

During the academic year 1968/69 he was a Lecturer at the Institut Universitaire de Technologie de Grenoble and a Research Fellow at the Institut National Polytechnique de Grenoble, France. In 1969 he joined the Department of Electrical Engineering, the University of Ottawa, Canada where he was a Professor until March 1992. Since April 1992 he holds the NSERC/MPR Teltech Industrial Research Chair in RF Engineering in the Department of Electrical and Computer Engineering, the University of Victoria, Canada.

During sabbatical leaves he spent six months with the Space Division of AEG-Telefunken in Backnang, Germany (now ATN), and six months with the Electromagnetics Laboratory of the Institut National Polytechnique de Grenoble, France, in 1976/77. During 1984/85 he has been a visiting scientist at the Space Electronics Directorate of the Communications Research Centre in Ottawa, Canada. He spent a third sabbatical year in 1990/91 as a visiting professor at the University of Rome "Tor Vergata" in Italy, the University of Nice - Sophia Antipolis in France, and the Technical University of Munich in Germany.

His research interests include numerical techniques for modeling electromagnetic fields and waves, computer aided design of microwave and millimeter wave circuits, microwave measurement techniques, and engineering education. He serves regularly on the Technical Program Committees of IEEE-MTT and AP Symposia, is the co-chairman of the MTT Technical Committee on Field Theory, and the co-founder and managing editor of the International Journal of Numerical Modelling. He serves on the editorial boards of the IEEE-MTT Transactions, Proceedings of the IEE, the International Journal of Microwave and Millimeter-Wave Computer Aided Engineering, and the Microwave and Optical Technology Letters. He was an "Invited Lansdowne Lecturer" of the University of Victoria, B.C., in. 1989, and was awarded the "Peter B. Johns Prize" for the best paper published in the International Journal of Numerical Modelling in 1990. He was elected Fellow of the IEEE for "contributions to the modeling and design of passive microwave and millimeter-wave circuits" in 1991.

Research Engineers

Poman P.M. So received the B.Sc. degree in computer science and physics from the University of Toronto, Toronto, Ontario, Canada, in 1985. He obtained the B.A.Sc. (summa cum laude) and M.A.Sc. degrees in electrical engineering (summa cum laude) from the University of Ottawa, Ottawa, Ontario, Canada, in 1987 and 1989 respectively. He has been engaged in research on the computer-aided design of millimeter and millimeter-wave circuits, TLM techniques for solving electromagnetic problems. He is also the author of the 2D-TLM and 3D-TLM simulators.

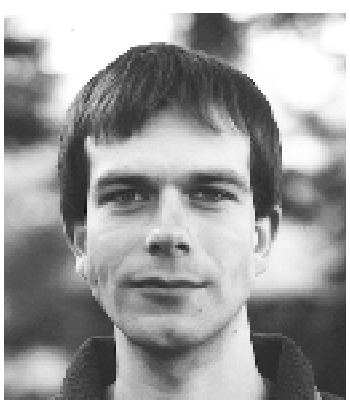
In June 1992, he joined the research team of the NSERC/MPR Teltech Industrial Research Chair in RF Engineering as a Research Engineer. He is also working toward his Ph.D. degree at the University of Victoria.

Channabasappa Eswarappa received the B.E. degree in electronics and communication from Mysore University, India, in 1980, and the M. Tech degree in electrical engineering from the Indian Institute of Technology, Kanpur, in 1982.

He worked as an Assistant Executive Engineer, and later as an Executive Engineer in the Transmission Research Development Laboratory, Indian Telephone Industries, Bangalore, India. He was mainly engaged in the design and development of microwave circuits and the characterization of microstrip discontinuities. Since 1986 he has been engaged in research on numerical techniques for solving electromagnetic problems. He received the Ph.D. degree in electrical engineering from the University of Ottawa, Ottawa, Ontario, Canada, in 1990.

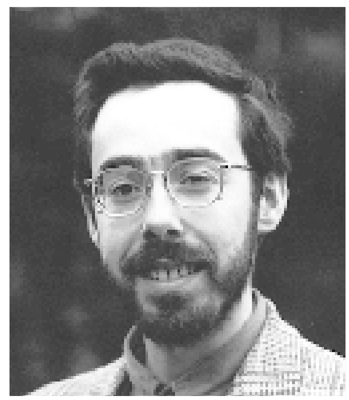
In June 1992, Dr. Eswarappa joined the research team of the NSERC/MPR Teltech Industrial Research Chair in RF Engineering as a Research Engineer.

Postdoctoral Fellow



Jonathan L. Herring was born in Middlesbrough, England, in 1966. He received the M.Eng. degree in Electrical & Electronic Engineering from the University of Nottingham, UK in 1989 and received the Ph.D degree from the same university in 1993. From July 1989 to October 1993 he was employed as a Research Assistant at the University of Nottingham, where he worked on the modelling of EMC problems using the transmission-line matrix (TLM) technique. In November 1993 he joined the Research Chair as a Post-Doctoral Fellow and is continuing work on development of the TLM method. He is a member of the IEEE and an associate member of the Institution of Electrical Engineers (IEE).

Graduate Students



Mario Righi was born in Perugia, Italy, in 1965. He received the degree (summa cum laude) in electronics engineering from the University of Ancona, Ancona, Italy, in 1991. In June 1993 he was awarded the IEEE Graduate Student Fellowship Award from the MTT Society. He successfully defended his Ph.D. thesis in December 1995, and now holds an NSERC Postdoctoral Fellowship in Electrical Engineering, at the University of Victoria, Victoria B.C., Canada. His work is mainly in the area of analytical and numerical modelling of microwave circuits

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Qi Zhang was born in Xiamen, Fujian, China, in 1957. She received the B.S. degree in Physics from Xiamen Unversity, Xiamen, China in 1982 and the M.S. degree in electrical engineering from the University of Regina, Regina, Canada, in 1992.

From 1982 to 1985, she was an Assistant Engineer, and from 1986 to 1989 an Electrical Engineer in Nanjing Electronics Devices Institute, Nanjing, China, where she was involved in III-V seminconductor material research and microwave semiconductor devices measurement techniques. Since September 1992, she has been working as a Teaching Assistant and was a full-time graduate student in the Department of Electrical & Computer Engineering, at the University of Victoria, Victoria, B.C., Canada. She successfully defended her Ph.D. thesis in April 1996. She presently holds a Postdoctoral Fellowship at the Ecole Polytechnique de Montréal.

Leonardo R.A.X de Menezes was born in Brasilia, Brazil, in 1966. He received his B.S. degree in 1990 and his M.Sc. degree in 1993, both from the University of Brasilia (UnB). He is the recipient of a scholarship of the Government of Brasil. He is currently working towards his PhD degree and doing research in TLM modelling of general media, with emphasis in frequency-dependent and nonlinear dielectric material. His interests include numerical modelling in electromagnetics, guided-wave structures and antennas.

Giampaolo Tardioli was born in Foligno, Italy, in 1967. He received the degree (summa cum laude) in electronic engineering from the University of Ancona, Ancona, Italy, in 1993. Currently he is a full-time research assistant, and graduate student, working toward his Ph.D. in Department of Electrical and Computer Engineering, at the University of Victoria, Victoria, B.C., Canada. His work is mainly in the area of analytical and numerical modelling of microwave circuits.

Lucia Cascio was born in Fano, Italy, in 1967. She received the degree (summa cum laude) in electronic engineering from the University of Ancona, Ancona, Italy, in 1993. In 1993 she was awarded a scholarship from the Italian National Research Council for a research program in electro-optic technologies. Currently she is a full-time research assistant, and graduate student, working toward her Ph.D. in the Department of Electrical and Computer Engineering, at the University of Victoria, Victoria, B.C., Canada. Her work is mainly in the area of analitical and numerical modelling of microwave circuits.

Admin. Support

Sherri Cole joined the Research Chair on April 1, 1992, and is providing administrative and clerical support to the NSERC/MPR Teltech Research Chair and its research team.

MISSION OF THE CHAIR

The mission of the Chair comprises three mandates, namely research, education, and technology transfer.

Research:

To advance and generate new knowledge in Radio Frequency Engineering for the benefit of humanity.

Education:

To educate competent RF engineers at both undergraduate and graduate levels, enabling them to become technical leaders of international caliber.

Technology Transfer:

To translate research results into practical tools and procedures for industrial product development, and to transfer technical know-how to industry through seminars, short courses, and exchange of researchers.

RESEARCH OBJECTIVES

Using advanced computer techniques, develop novel methods and procedures for the numerical modeling of guiding and radiating structures for electromagnetic waves,

- Develop analysis and design procedures for structures of arbitrary geometry and electrical composition.
- Create user-friendly CAD tools which link geometry, layout, physical and processing parameters of practical components and circuits with their system specifications and their desired time and frequency performance.

Applications include microwave and millimeter-wave communications, Radar, remote sensing, and, more recently, RF drying of softwood lumber, and soil moisture measurements using electromagnetic waves.

RESEARCH TOPICS

Absorbing Boundary Conditions in TLM

Automatic TLM Mesh Generation

Canonical Problem Solution

Dynamic Field Visualization

Combination of TLM Analysis with Optimization

Modeling of Fields in Regions containing Singularities

Hybrid Modeling Techniques involving two or more Numerical Methods

TLM Modeling of Dispersive Media

TLM Modeling of Nonlinear Media

Johns Matrix Techniques and Diakoptics

Modeling of Moving Boundaries

TLM Modeling of Nonlinear Devices

TLM Modeling of Nonreciprocal Devices

Implementation of TLM on Parallel Computers

RCS Computations with TLM

S-Parameter Extraction from TLM Analysis

Signal Processing of Short Transient Responses

TLM Modeling of Skin Effect

Implementation of Nodes with Special Properties

Modeling of Superconducting Walls with TLM

Modeling of RF Drying of Wood

Modeling of Soil Moisture Probes

EQUIPMENT

The research group associated with the Chair has recently moved into the new Engineering Laboratory Wing where it occupies the **Computational Electromagnetics Research Laboratory**. The following computing equipment is presently installed in this laboratory:

1 HP Series 700 Model 735 Workstation

1 HP Series 700 Model 755 Workstation

1 IBM RISC 6000 Workstation, Model 350;

3 HP X-terminals, Model 19Ca;

1 IBM 486DX2-50 Personal Computer;

2 MacIntosh IIsi computers;

1 MacIntosh IIci computer;

1 Quadra 700 Computer;

1 Powerbook 170 4AB laptop computer;

1 Apple Laserwriter IIg;

2 Apple Personal Laserwriters;

1 HP Deskjet 500C;

1 HP 4Si MX Laserprinter.

The group also has access to the Microwave Laboratory of the Department of Electrical and Computer Engineering, which comprises a complete range of test equipment for frequencies up to 60 GHz.

PAPERS PUBLISHED IN REFEREED JOURNALS

Righi, M., Hoefer, W.J.R., Mongiardo, M., and Sorrentino, R., "Efficient TLM Diakoptics for Separable Structures", IEEE Trans. Microwave Theory Techniques, Vol. MTT-43, No. 4, pp. 854-859, April 1995.

So, P.P.M., Eswarappa, C. and W.J.R. Hoefer, "Parallel and Distributed TLM Computation with Signal Processing for Electromagnetic Field Modelling", Invited Paper, Intl. Journal of Numerical Modelling, Vol. 8, No. 3, pp. 169-185, May/June 1995.

Forest, M., and Hoefer, W.J.R.,"A Novel Synthesis Technique for Conducting Scatterers using TLM Time Reversal," IEEE Trans. Microwave Theory Techniques, Vol. MTT-43, No. 6, pp. 1371-1378, June 1995.

Eswarappa, C. and Hoefer, W.J.R., "Implementation of Berenger Absorbing Boundary Conditions in TLM by Interfacing FDTD Perfectly Matched Layers", Electronics Letters. Vol. 31, No. 15, pp. 1264-1266, July 1995.

Eswarappa, C. and Hoefer, W.J.R., "Bridging the Gap between TLM and FDTD", Microwave and Guided Wave Letters, Vol. 6, No. 1, pp. 4-6, January 1996.

JOURNAL PAPERS IN PRESS OR SUBMITTED

Eswarappa, C. and W.J.R. Hoefer, "Fast S-parameter Computation of a Microstrip Interdigital Filter using TLM Prony's and Digital Filtering Techniques", Intl. Journal of Numerical Modelling. (In press)

de Menezes, L.R.A.X. and W.J.R. Hoefer, “Modeling of General Constitutive Relationships in SCN TLM”, IEEE Trans. Microwave Theory and Techniques (In press).

PAPERS PRESENTED AT REFEREED CONFERENCES

Eswarappa, C.; Hoefer, W.J.R., "RCS of High Permittivity Cubes Computed with the TLM Method", in 11th Annual Review of Progress in Applied Computational Electromagnetics Dig., pp. 13-20, Monterey, Ca, March 20-24, 1995.

Eswarappa, C.; Hoefer, W.J.R., "Treatment of Instabilities of One-Way Equation Absorbing Boundary Conditions using Digital Filters", in IEEE Intl. Microwave Symp. Dig., pp. 39-42, Orlando, Florida, May 15-19, 1995.

Righi, M., Eswarappa, C., Hoefer, W.J.R., Russer, P., "An Alternative Way of computing S-Parameters via Impulsive TLM Analysis without using

Absorbing Boundary Conditions", in IEEE Intl. Microwave Symp. Dig., pp. 1203-1206, Orlando, Florida, May 15-19, 1995.

de Menezes, L.R.A.X.; Hoefer, W.J.R., "Modelling of General Constitutive Relationships in SCN-TLM", in IEEE Intl. Microwave Symp. Dig., pp. 365-372, Orlando, Florida, May 15-19, 1995.

Herring, J.L.; Hoefer, W.J.R., "Compensation of Coarseness Error in TLM Modelling of Microwave Structures with the Symmetrical Condensed Node", in IEEE Intl. Microwave Symp. Dig., pp. 23-26, Orlando, Florida, May 15-19, 1995.

So, P.P.M., Hoefer, W.J.R., "Recent Advances in Transmission Line Matrix Method Electromagnetic Wave Modelling and Visualization", in IEEE Pacific Rim Conf. on Communications, Computers, Visualization, and Signal Processing Dig., Victoria, BC, May 17-19, 1995

de Menezes, L.R.A.X.; Hoefer, W.J.R., "Dispersion Analysis of State-Variable TLM Symmetrical Condensed Node", in 1995 IEEE AP/S Symposium and URSI Meeting Dig., pp. 778-781, Newport Beach, CA, June 18 - 23, 1995.

Zhang, Q., Hoefer, W.J.R., "Modeling of Inhomogeneous Dielectric Layers using TLM Cuboid Condensed Node", in 1995 IEEE AP/S Symposium and URSI Meeting Dig., pp. 774-777, Newport Beach, CA, June 18 - 23, 1995.

Zwick, R.L., W.J.R. Hoefer, J.L. Herring and S. Avramidis, "Design Considerations of Radio Frequency/Vacuum Dryers", 30th Microwave Symposium, p. 146, Denver, Colorado, July 9-12, 1995.

Eswarappa, C., So, P.P.M., Herring, J.L. and Hoefer, W.J.R., "Progress and Critical Issues in Accurate Time Domain Modeling of Planar Wave Guiding and Radiating Structures with TLM", Invited Paper, in 1995 Progress in Electromagnetics Research Symposium Dig., Seattle, WA, p. 732, July 24-28, 1995.

Eswarappa, C. and Hoefer, W.J.R., "Real Time Interface Between TLM and FDTD Modules and Applications", in First International Workshop on TLM Modeling - Theory and Applications Dig., University of Victoria, Canada, pp. 59-62, August 1-3, 1995.

de Menezes, L. and Hoefer, W.J.R., "Modeling Anisotropic Dispersive Materials in TLM", in First International Workshop on TLM Modeling - Theory and Applications Dig., University of Victoria, Canada, pp. 91-94, August 1-3, 1995.

Eswarappa, C. and Hoefer, W.J.R., "RCS of Metallic and Dielectric Cubes Computed with the TLM Method", in First International Workshop on TLM Modeling - Theory and Applications Dig., University of Victoria, Canada, pp. 165-168, August 1-3, 1995.

So, P.P.M. and Hoefer, W.J.R., "Recent Advances in Transmission Line Matrix Method Electromagnetic Wave Modelling and Visualization", in First International Workshop on TLM Modeling - Theory and Applications Dig., University of Victoria, Canada, pp. 183-186, August 1-3, 1995.

Righi, M. and Hoefer, W.J.R., "Modal Johns Matrices for Waveguide Components", in First International Workshop on TLM Modeling - Theory and Applications Dig., University of Victoria, Canada, pp. 233-236, August 1-3, 1995.

Herring, J.L. and Hoefer, W.J.R., "Accurate Modelling of Zero Thickness Septa with the Symmetrical Condensed Node", in First International Workshop on TLM Modelling - Theory and Applications Dig., University of Victoria, Canada, pp. 237-240, August 1-3, 1995.

Herring, J.L. and Hoefer, W.J.R., "Field Modelling of a RF/Vacuum Wood Drying Kiln with TLM", in First International Workshop on TLM Modeling - Theory and Applications Dig., University of Victoria, Canada, pp. 253-256, August 1-3, 1995.

Zhang, Q. and Hoefer, W.J.R., "Analysis of 3-D Planar Structures by TLM Cuboid Condensed Node Technique, in First International Workshop on TLM Modeling - Theory and Applications Dig., University of Victoria, Canada, pp. 243-247, August 1-3, 1995.

Cascio, L. Tardioli, G. and Hoefer, W.J.R., "Synthesis Procedure via TLM Time Reverse Process", in First International Workshop on TLM Modeling - Theory and Applications Dig., University of Victoria, Canada, pp. 263-266, August 1-3, 1995.

Hoefer, W.J.R., "Progress and Critical Issues in Time Domain Electromagnetic Modeling with TLM", Invited Paper, in LATSIS Symposium 1995 on Computational Electromagnetics Dig., Zürich, Switzerland, Sept. 19-21, 1995.

de Menezes, L. and W.J.R. Hoefer, "Modeling gyromagnetic media in symmetrical condensed node TLM", 12th Annual Review of Progress in Applied Computational Electromagnetics Dig., Vol. 1. pp. 294-301, Monterey, CA, March 18-22. 1996.

Eswarappa, C. and W.J.R. Hoefer, "A Comparative Performance Study of Absorbing Boundary Conditions in TLM and FDTD", 12th Annual Review of Progress in Applied Computational Electromagnetics Dig., Vol. 1. pp. 302-309, Monterey, CA, March 18-22, 1996.

CONFERENCE PAPERS ACCEPTED OR SUBMITTED

Cascio, L., G. Tardioli, T. Rozzi and W.J.R. Hoefer, "Quasi-Static Correction of a Knife Edge Corner in 2D TLM Algorithm", Annual Review of Progress in Applied Computational Electromagnetics Dig., Monterey, CA, March 18-22. 1996. (Accepted)

Zhang, Q. and W.J.R. Hoefer, "Dispersion Analysis of TLM Node for Modeling General Anisotropic and Gyromagnetic Materials", IEEE Intl. Microwave Symp. Dig., San Francisco, CA, June 17-21, 1996. (Accepted)

Herring, J.L. and W.J.R. Hoefer, "Improved Excitation of 3D SCN TLM Based on Voltage Sources", IEEE Intl. Microwave Symp. Dig., San Francisco, CA, June 17-21, 1996. (Accepted)

Eswarappa, C. and W.J.R. Hoefer, "A Hybrid 3D TLM-FDTD Model of Microwave Fields", IEEE Intl. Microwave Symp. Dig., San Francisco, CA, June 17-21, 1996. (Accepted)

Righi, M. and W.J.R. Hoefer, "Efficient Hybrid TLM/Mode Matching Analysis of Packaged Components", Student Paper, IEEE Intl. Microwave Symp. Dig., San Francisco, CA, June 17-21, 1996. (Accepted)

de Menezes, L. and W.J.R. Hoefer, "Accuracy of TLM Solutions of Maxwell's Equations", IEEE Intl. Microwave Symp. Dig., San Francisco, CA, June 17-21, 1996. (Accepted)

Cascio, L., G. Tardioli, T. Rozzi and W.J.R. Hoefer, "A Quasi-Static Modification of TLM at Knife Edge and 90° Wedge Singularities", IEEE Intl. Microwave Symp. Dig., San Francisco, CA, June 17-21, 1996. (Accepted)

Zhang, Q., J. Huang, Ke Wu, W.J.R. Hoefer, “Dispersion Analysis of TLM Node for Modeling Anisotropic and Gyromagnetic Materials”, Symposium on Antenna Techology and Applied Electromagnetics”, Aug. 7-9, 1996 (Accepted).

Hoefer, W.J.R., "Comprehensive Electromagnetic Modelling of Microwave Circuits with TLM", Invited Paper, XXVth URSI General Assembly, Lille, France, Aug. 28 - September 5, 1996. (Accepted).

VISITORS TO THE CHAIR

July 21, 1995
Dr. Amelia Rubio Bretones, Electromagnetics Group, Applied Physics Department, University of Granada, Spain, “Integral Equations in the Time Domain”.

July 21, 1995
Prof. Reinhold Pregla, Fernuniversität Hagen, Germany.

August 15, 1995
Prof. Tullio Rozzi, Department of Electronic Engineering, University of Ancona, “Termination Conditions for the Application of FD-TD Techniques to Planar Structures and Close Homogeneous Waveguides”.

COURSES TAUGHT AT UVIC

The following courses were taught by Professor Hoefer in fulfillment of his teaching mandate.

ELEC 621 “Numerical Techniques in Electromagnetics”, Graduate Course taught during Fall 1995.

ELEC 454 “Microwave Engineering", Fourth Year Undergraduate Elective Course and Laboratory, Undergraduate Course taught during Spring 1996.

SHORT COURSES TAUGHT

The following short courses were taught by Professor Hoefer.

"Theory and Applicatons of TLM", Short Course taught on July 31, 1995, at the University of Victoria in connection with the "First International Workshop on TLM".

"The Transmission Line Matrix (TLM) Technique" Short Course taught on Sept. 12-14, 1995 at the University of Granada, Spain,.

"Introduction to Numerical Modeling of Electromagnetic Fields in Space and Time", 5-Day Short Course taught on April 22-26, 1996, at Gerhard Mercator University Duisburg, Germany.

PROFESSIONAL ACTIVITIES

The Chair is involved in a number of professional activities. It is represented by Professor Hoefer in the following functions:

Technical Program Committee, 1995 IEEE MTT Intl. Microwave Symposium in Orlando, Florida, May 15-19, 1995.

Technical Program Committee, 1996 IEEE MTT Intl. Microwave Symposium in San Francisco, California, June 17-21, 1996

Director and Chair of Technical Program Committee, 1st International Workshop on TLM Modeling, Univ. of Victoria, B.C., August 1995

Member of International Scientific Advisory Committee, Electrosoft 1996, San Miniato, Italy, June 1996..

Co-Chairman of IEEE-MTT Technical Committee on Field Theory. (MTT-15).

Editorial Boards of IEEE Transactions on Microwave Theory and Techniques, IEEE Transactions on Antennas and Propagation, IEE Proceedings on Microwaves, Optics, and Acoustics, International Journal of Microwave and MM-Wave Computer Aided Design.

Managing Editor, International Journal of Numerical Modelling, (Electronic Networks, Devices and Fields).

Guest Editor, Special Issue on Time Domain Techniques, International Journal of Microwave and MM-Wave Computer Aided Design.

Scientific Advisory Board, Ferdinand Braun Institut, Berlin, Germany.

Invited Professor, Gerhard Mercator University Duisburg, April 15 to May 15, 1996.

RESEARCH REPORTS

A Quasi-Static Modification of TLM at Knife Edge and 90° Wedge Singularities

(Lucia Cascio, Giampaolo Tardioli, and Wolfgang J.R. Hoefer, in collaboration with Tullio E. Rozzi from the University of Ancona, Ancona, Italy)

The TLM method is widely regarded as an efficient and flexible technique for the analysis of a large class of electromagnetic problems. One of the main limitations of this and other numerical techniques is that the spatial discretization fails to accurately describe the singularities of the electromagnetic field, which occur for example close to sharp edges. Unless a very fine discretization is used, the singular behavior around the corner is poorly represented and the frequency domain characteristics of the structure will typically be shifted. This error is very often unacceptable when we are dealing with narrowband structures such as filters.

The accuracy of the discretized model can be improved by introducing a better description of the field singularity, through local modification of the algorithm. We have taken a new approach based on the quasi-static approximation of the Green's functions for an infinite conductive wedge. The field distribution around a corner is represented in terms of an equivalent circuit, expressed by a Z matrix, which can be implemented easily and efficiently in TLM.

Due to the quasi-static approximation, the voltages at the ports of the equivalent circuit depend only linearly on the frequency. Therefore, using a bilinear discretization scheme to approximate the frequency dependance, we obtain a recursive formulation to describe the corner condition in the TLM process:

$$\bar{V}_k^r = \left(\frac{2}{\Delta t}Y_0[Z] - [I]\right)\left(\frac{2}{\Delta t}Y_0[Z] + [I]\right)^{-1}\left(\bar{V}_k^i + \bar{V}_{k-1}^r\right) - \bar{V}_{k-1}^i$$

In this expression Y_0 is the TLM link line admittance, $\bar{V}_k^r$ and $\bar{V}_k^i$ are the vectors of the voltages incident and reflected at the terminals of the equivalent circuit at the time step k.

The new method has been applied to analyze discontinuities in the transverse section of a WR(28) rectangular waveguide (a=7.112 mm). To validate the model of a knife edge, a symmetrical inductive iris with aperture $d=a/2$ has been analyzed both with the corner modification and the regular TLM algorithm, and the results have been compared with Marcuvitz's formulae. The scattering parameters obtained for different discretizations are shown in Fig. 1-a. Note that the corner modification improves considerably the accuracy of the TLM algorithm (Fig. 1-b) even when a very coarse mesh is used. To further test the efficiency of the proposed method, an iris-coupled waveguide bandpass filter, with center frequency of 33.18 GHz and bandwidth of 0.94 GHz, has been analyzed. Also in this case the corner correction results in a much faster convergence to Marcuvitz's curves as compared with the standard TLM algorithm (Fig. 2).

To verify the model of the 90° wedge, a symmetrical iris, of thickness $t=a/6$ and aperture $d=a/2$ has been examined. Comparison with the uncorrected TLM algorithm and other techniques has shown that in this case the correction is less effective since, for this kind of discontinuities, the standard TLM method provides good accuracy even with relatively coarse discretizations (Fig. 3).

Further details can be found in:

L Cascio, G. Tardioli, T. E. Rozzi, and W. J. R. Hoefer, "A Quasi-Static Modification of TLM at Knife Edge and 90 Wedge Singularities" to be presented at the 1996 IEEE MTT Symposium, S. Francisco, CA.

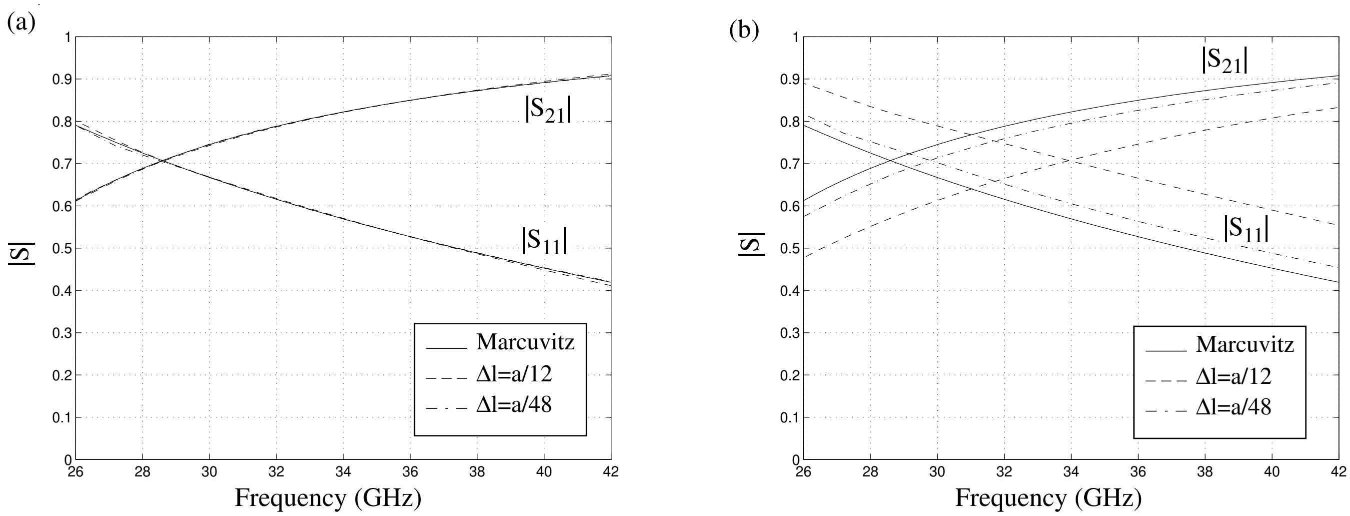


Fig. 1: S-parameters for the thin iris in WR(28) waveguide: a) TLM with corner correction, b) TLM without corner correction

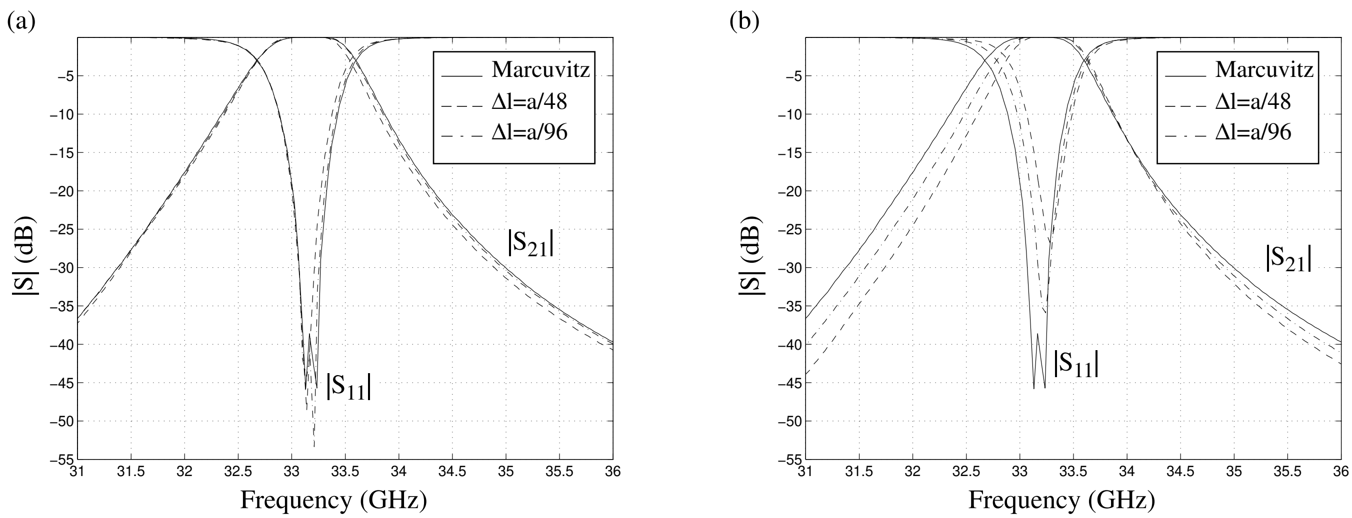


Fig. 2: Iris coupled bandpass filter in WR(28) waveguide: a) TLM with corner correction, b) TLM without corner correction

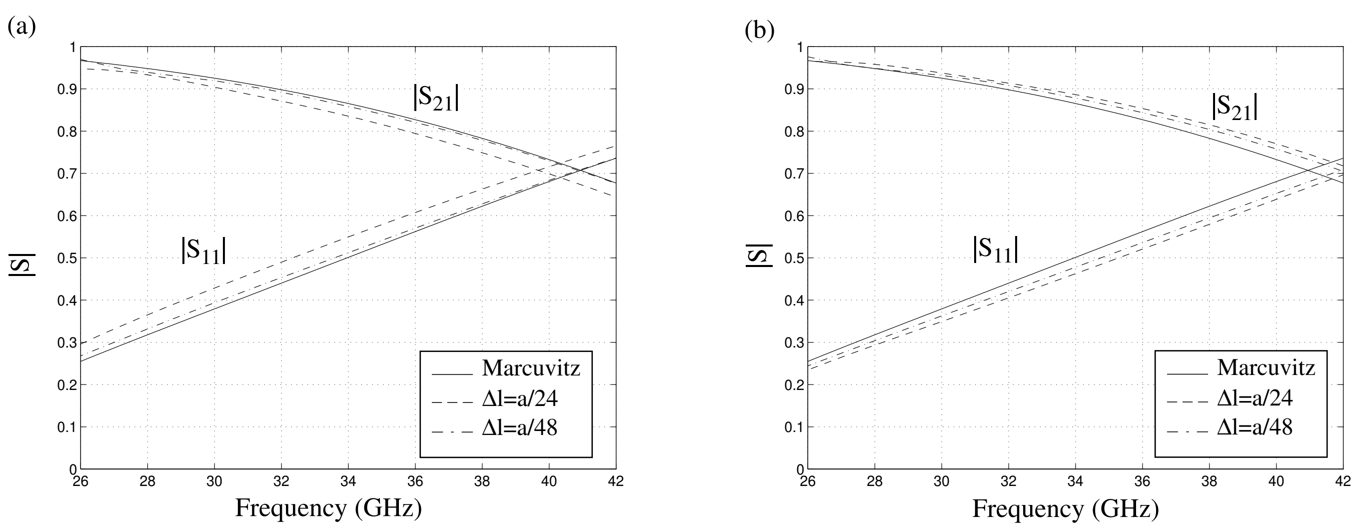


Fig. 3: S-parameters for the thick iris in WR(28) waveguide: a) TLM with corner correction, b) TLM without corner correction

Synthesis Procedure via TLM Time Reverse Process

(Lucia Cascio, Giampaolo Tardioli, and Wolfgang J.R. Hoefer)

The analysis of microwave structures with time domain methods (such as TLM and FDTD) is a well established technique which offers extreme flexibility in the geometry of the structure to be analyzed. An entirely new application of these methods is based on their possibility to treat time reversed Maxwell's equations. In this way it is feasible to perform an inverse analysis of a scattered field in order to reconstruct the original source distribution and, therefore, the shape of the scatterer. This procedure has been introduced in [1] to reconstruct sources in closed structures. A further step is the utilization of the reverse method for synthesis procedures. The goal is to synthesize the geometry of a passive structure from its desired frequency or time domain response using alternate forward and backward simulations.

This work presents a new approach to the synthesis of thin scatterers in waveguides based on the TLM time reverse process. The procedure begins by establishing a relation between the properties of the reconstructed field (in particular of its dominant mode) and the geometry of the scatterer. For simple geometries, such as a thin inductive iris in parallel plate, this can be accomplished with a single reconstruction. Once the fundamental mode of the scattered field is modified according to the synthesis specifications and then reinjected into the empty waveguide, a modal analysis of the reconstructed field at the section of the scatterer will contain the information about the desired dimensions of the obstacle.

The proposed synthesis method has been tested for a parallel plate waveguide of width a=62 Δl and length l=98 Δl (Δl=1mm). The fundamental mode has been extracted from a *target* structure having w/a= 0.2258. A *guess* structure with w/a = 0.8065 has been used as starting point for the synthesis. The synthesized mean value after only one synthesis step is 0.3025, which corresponds to the exact value of the desired scatterer w/a = 0.2258, as it can be seen in Fig. 1 (TR-TLM).

Further details can be found in:

L Cascio, G. Tardioli and W. J. R. Hoefer, "Synthesis Procedure via TLM Time Reverse Process" Proceedings of the 1st Int. Workshop on TLM Modeling, pp. 263-266, Victoria, Canada, August 1995.

References

[1] R. Sorrentino, P. P. M. So, W. J. R. Hoefer, "Numerical Microwave Synthesis by Inversion of the TLM Process", *21st European Microwave Conference Digest*, pp. 1273-1277, Stuttgart, Germany, Sept. 1991

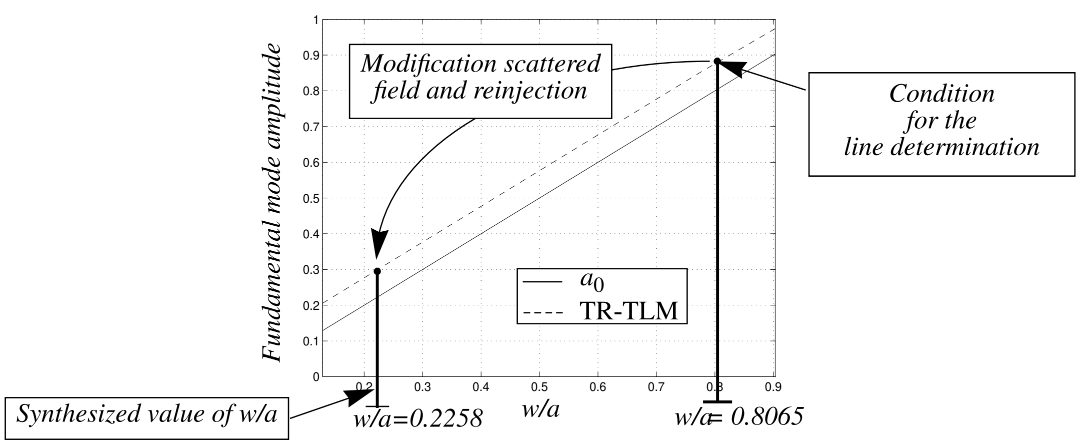


Fig. 1: Fundamental mode amplitude of the reconstructed field for a parallel plate waveguide and synthesis example

Modeling gyromagnetic media in symmetrical condensed node TLM

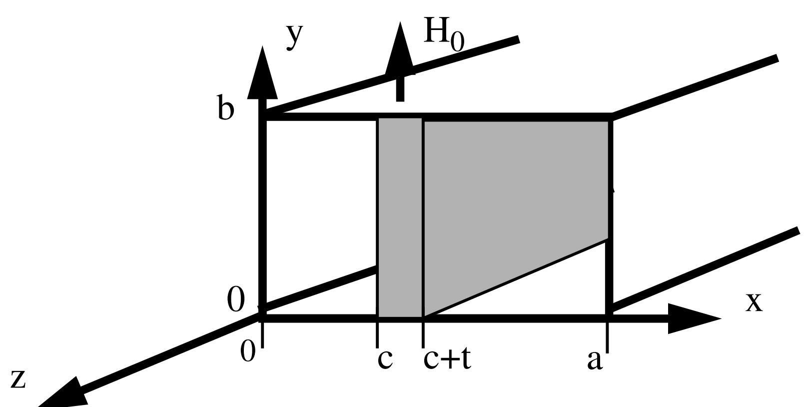
(*L. de Menezes, W.J.R. Hoefer*)

A major research effort in TLM is devoted to modeling of electromagnetic constitutive relationships, which describe the interaction of electric and magnetic fields with the medium. This work shows a simple procedure to represent the behavior of gyromagnetic media in the TLM algorithm.

The medium behavior is represented by equivalent sources connected to the node. The sources are determined by the constitutive equations and the total voltages and currents at the node. The differential equations describing these relationships are solved using state-variable techniques with suitable discretization schemes . The resulting system of difference equations is solved at each TLM timestep.

This technique has several advantages over conventional dielectric and magnetic models used in TLM. While the use of the stub-loaded approach is more efficient for frequency independent media, the proposed technique can model several kinds of constitutive equations with few modifications to the TLM algorithm. The technique is robust, can be used with several discretization schemes, results in a scattering matrix independent of the medium behavior, and can be integrated with conventional circuit analysis programs, if the equivalent circuit of the medium behavior is available.

The method presented in this work has been used to simulate an E-plane resonance isolator in a WR90 waveguide. The device was designed to have a 30 dB reverse attenuation at 10 GHz. The ferrite slab was 0.5 mm wide, 24 mm long, and placed at 2.54 mm from one of the inner waveguide walls, with a saturation magnetization of 1700 Gauss and a bias magnetic field of 2840 Oersteds. We used the backwards Euler scheme, because of stability problems encountered with the trapezoidal discretization approach. Since the backwards Euler scheme introduces numerical losses, it avoided the instability problems obtained using energy conservative schemes.



RESONANCE ISOLATOR

Accuracy of TLM solutions of Maxwell's equations

(L. de Menezes and W.J.R. Hoefer)

In most practical cases, the solution of electromagnetic problems has to rely on the use of numerical methods. Some of these techniques use the approximation of differential operators by difference ones. This represents the substitution of the continuous problem by the discrete one. In all consistent numerical methods, the solution of the difference equations tends to the differential counterpart as the discretization step tends to zero.

However, the discrete solution can converge slower to the continuous one in the vicinity of discontinuities. The reason is the finite number of modes propagating in the mesh that represents the continuous space. Moreover, the propagation constant of each of these modes can differ considerably from the continuous counterparts,. The overall effect is a reduction of the accuracy of the representation of modes near discontinuities.

Some of these effects cannot be predicted by the dispersion analysis of the difference equation, which expresses the relationship between modes and frequency warping of the solutions. This work advances further in this direction by solving analytically the difference equation of the numerical scheme, subjected to the actual boundary conditions of the problem. The closed-form solution can be only obtained in certain cases, which allows some conclusions about the propagation behavior of the modes present in a general case.

In this work, the analytical solution of the two dimensional shunt node TLM method is obtained for the special case of a capacitive diaphragm in a TEM waveguide. The solution provides the behavior of the susceptance of the discrete structure, which is compared to the actual continuous solution. It is shown that the accuracy of the field is reduced from second to first order with the introduction of the discontinuity.

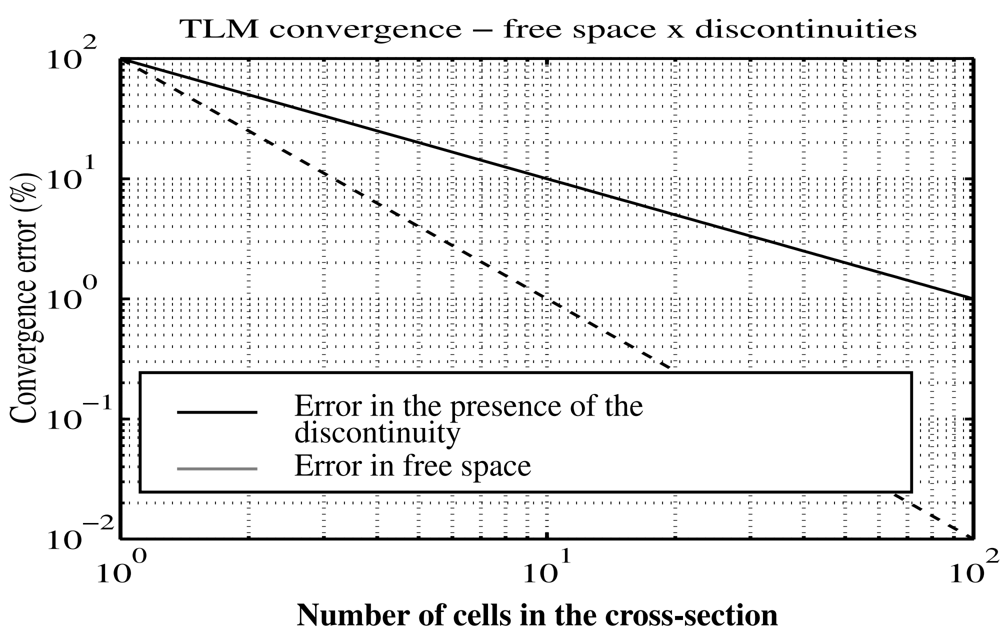


Fig.1 Convergence of the susceptance on the capacitive diaphragm

Efficient Hybrid TLM/Mode Matching Analysis of Packaged Components

(Mario Righi, Wolfgang J.R. Hoefer)

A combination of Transmission Line Matrix (TLM) method and time domain mode matching is proposed. The resulting hybrid algorithm allows to take full advantage of the characteristics of time domain methods for regions with highly complex geometries while exploiting the efficiency of analytical formulations for the more regular regions. The approach is demonstrated for a packaged microstrip line containing a via-hole. While the planar circuit is discretized by a TLM mesh, the field in the package is decomposed into modal fields. The two sub-domains are joined by modal diakoptics. We thus obtain not only a significant reduction in computer time and memory, but also gain new insight into the physics of package resonance.

In time domain modal diakoptics the field is decomposed into a series of modes. The number of modes depends on the distance of the reference planes from the closest discontinuity, and on the spectrum of the excitation. All modal transmission lines are uncoupled and are terminated in the time domain by the convolution of the incident mode amplitude with its modal impulse response. The reflected mode amplitudes are then superimposed, sampled, and re-injected into the TLM mesh. The whole process can be described in compact form as follows:

$$[V^r(k)] = [C] \quad [J(k')] \quad * \quad [C]^T \quad [V^i(k-k')]$$

where $[V^{i,r}(k)]$ represent the incident and reflected voltage waves, [C] is the matrix that couples modes to TLM impulses, [J(k)] is a diagonal matrix containing the modal Green's functions, and * denotes numerical convolution.

By using the modal Green's function of a waveguide stub rather than the Green's function for a matched load it is possible to represent the upper part of the package in Figure 1. Note that the modal Short-circuit Boundary Conditions (SBCs) applied along the plane AA' have the following properties:

- The boundary is not absorbing, but purely reactive.
- The boundary is placed parallel to the propagation direction in the microstrip rather than perpendicularly to it.

The packaged microstrip via-hole (Figure 1) has been discretized with a uniform TLM mesh of size Δl=0.2 mm. A simulation has been performed for the full and for the segmented structure terminated with modal short-circuit boundary conditions. The SBCs have been placed at one third of the box depth, confining the standard TLM mesh to the complex region comprising the coax-to-microstrip transitions and the planar circuit. The TLM computational volume is therefore reduced by a factor three. This is confirmed by the comparison of mesh size and CPU time for the two TLM analyses is summarized in Table 1. Both memory and CPU time are reduced by 70% when diakoptics are used.

The S-parameters of the packaged microstrip line containing a via-hole obtained with the full and the reduced domain simulations using the above time domain waveforms are shown in Figure 2. The curves are overlapping. To further test the stability of the SBC, the number of modes included in the SBCs has been reduced to just the first three modes excited in the package (TM^y_{01}, TE^y_{11} and TM^y_{11}). The corresponding S-parameters are shown in Figure 3. Note that the resonance due to the modes with order '21' has been lost. This resonance has been numerically suppressed by eliminating the corresponding Green's function.

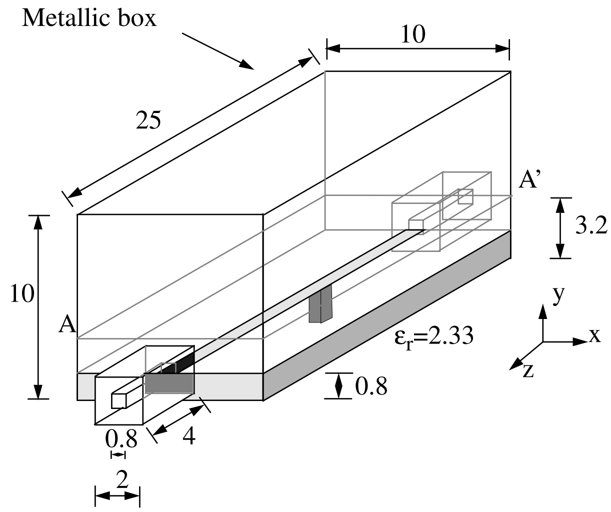


Figure 1: Geometry of a packaged microstrip via-hole (including coax-to-microstrip transitions). Strip width: 2 mm, via-hole size: 0.8 by 0.8 mm. All other dimensions in the figure are in mm.

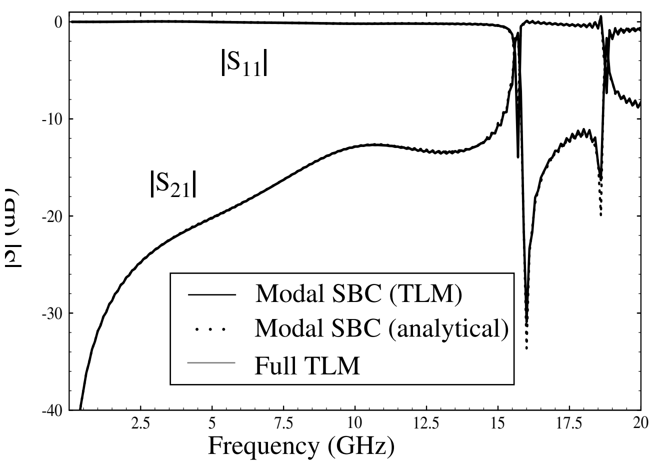


Figure 2: Magnitude of the S-parameters for the packaged microstrip via-hole (including coax-to-microstrip transitions).

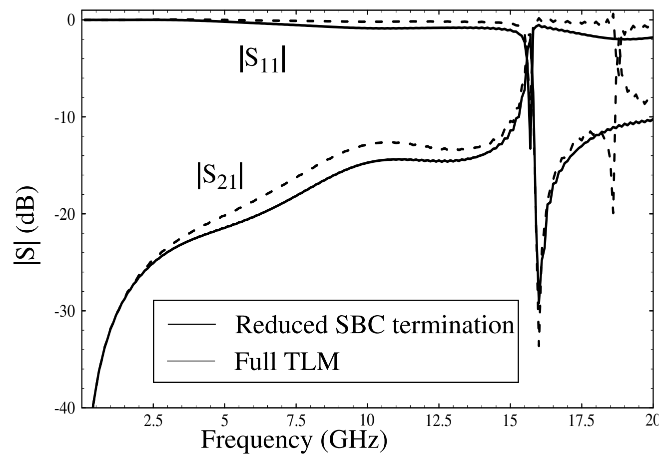


Figure 3: Magnitude of the S-parameters for the packaged microstrip via-hole (including coax-to-microstrip transitions). Modes up to the ‘11’ order are included.

Package	**Mesh Size**	**CPU Time**
Full TLM simulation	50 by 50 by 165	~ 100 hr.
Segmented domain	50 by 15 by 165	~ 30 hr.

Table 1: Comparison of mesh size and CPU time for the analysis of the packaged microstrip via-hole. Simulation performed for 16000 time steps.

Further details can be found in:

M. Righi, W. J. R. Hoefer, “Efficient Hybrid TLM/Mode Matching Analysis of Packaged Components” to be presented at the 1996 MTT-S International Microwave Symposium, San Francisco, CA, June 1996.

Excitation of 3D SCN TLM with Voltage Sources

(Jonathan Herring and Wolfgang J.R. Hoefer)

In TLM, voltage pulses are introduced into the system and the time evolution of the fields is observed at appropriate output points. An impulse excitation can be used to obtain information at all frequencies within the working frequency range of the mesh. However, it is often necessary to use a band-limited excitation, for example, to avoid instabilities with certain kinds of absorbing boundary conditions, or to reduce signal processing problems. For such a continuous waveform, the usual approach is to assume that the voltage pulses that must be added to the pre-existing pulses are simply proportional to the desired incident field at each instant in time. In structure such as waveguides, this introduces transients due to the highly dispersive impedance. Alternatively, hard voltage sources may be placed in a reference structure to obtain the correct pulses that must be injected to produce the desired waveform. When these pulses are introduced into the structure under study, the advantages of rapidly decaying transients and absorption of reflected waves are combined.

There is considerable flexibility in the choice of where elements such as sources are introduced, for example, they may be placed at a node or at the mid-point of the link-lines connecting adjacent nodes. Simple circuit theory can be used to place voltage or current sources on the link-lines. Here, sources are placed at a node. Sources can be implemented by substituting a new scattering procedure. Alternatively, the same effect can be achieved by modifying the incident pulses so that the correct scattered pulses are obtained after a standard scattering event. It can be shown that to impose a voltage V_s, a quantity ΔV must be added to the link-lines and stubs contributing to the corresponding electric field component, where

$$\Delta V = V_s - V^i_{tot}$$

V^i_{tot} is the total voltage calculated from the incident pulses. For the hybrid node

$$V^i_{tot} = \frac{2}{2(\hat{Y}_a + \hat{Y}_b) + \hat{Y}_s}(\hat{Y}_a(V^i_1 + V^i_2) + \hat{Y}_b(V^i_3 + V^i_4) + \hat{Y}_s V^i_5)$$

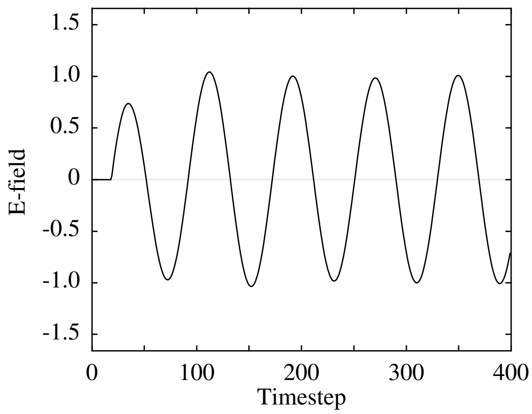
$\hat{Y}_a$, $\hat{Y}_b$ are the normalized link-line admittances, $\hat{Y}_s$ is the normalized open-circuit stub admittance and V^i_1, V^i_2, V^i_3, V^i_4 and V^i_5 are the incident voltage pulses. Similarly, to impose a current, I_s, ΔV is given by

$$\Delta V = Z_{tot} I_s$$

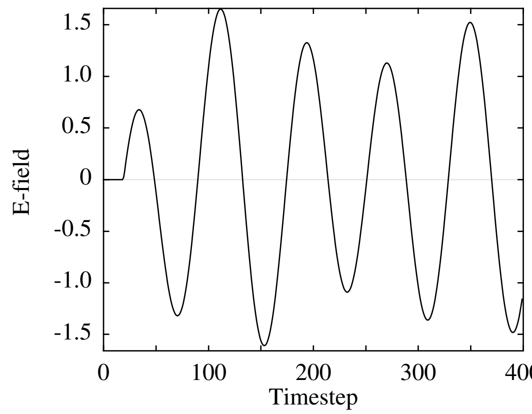
Z_{tot} is the combined impedance of the link-lines and stubs. For the hybrid node

$$Z_{tot} = \frac{Z_0}{2(\hat{Y}_a + \hat{Y}_b) + \hat{Y}_s}$$

The difference between applying a hard voltage source and the conventional additive excitation is shown in fig. 1 for a waveguide structure. The excitation is sinusoidal in time and is applied over the cross-section with the spatial distribution of the dominant mode. In the second case, the amplitude is somewhat indeterminate and steady-state is not achieved quickly. The pulses that are introduced by the hard voltage source are shown in fig. 2. It is apparent that in order to produce a sinusoidal electric field in a waveguide with additive excitation, it would be better to introduce an offset cosine wave rather than a sinusoidal one. A hard source cannot be used directly to obtain S-parameters since it will not absorb the wave reflected from the input port. However, hard sources can be placed in a reference structure and, for each node in the cross-section, the pulses injected by the source can be obtained and then added in to the structure under study. This reference structure need only be a single node thick if Johns matrix boundaries are used. The advantages of this are that a field of known amplitude is introduced in which the transients decay more rapidly than for the conventional approach. This is important for visualization purposes and is essential if the amplitude must be known in advance, for example, when modelling non-linear systems.



(a) hard voltage source



(b) additive excitation

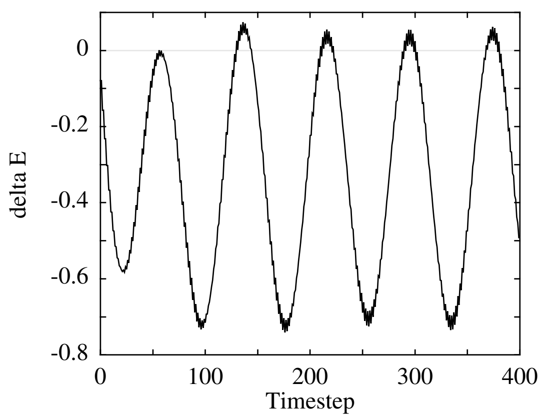


Fig. 2 – Pulses injected by the source to maintain a sinusoidal waveform

Further details can be found in:

J. L. Herring and W. J. R. Hoefer, "Improved Excitation of 3D SCN TLM Based on Voltage Sources", IEEE Intl. Microwave Symp. Dig., San Francisco, CA USA, June 16–21, 1996.

The Design of a Multi-Purpose Electromagnetic Field Simulation Tool

(Poman P.M. So and Wolfgang J.R. Hoefer)

Abstract

A general design framework for a multi-purpose electromagnetic field simulation tool is presented in this report. This framework allows stand-alone programs to be executed independently of each other as well as in collaboration with each other via a master program to form a simulation tool. A prototype simulator based on this framework is presented at the end of this report.

A General Framework

Figure 1 depicts a collection of programs and shows how they can work together in a sequential manner. The graphical editor produces a high level structure description file for the structure to be analysed. The mesh generator translates that file to a lower level structure description syntax which can be used by the field solver directly. With the data stored in a file provided by the signal generator, the field solver can then perform the required computation and store the result in an output file. This output file can then be used by the signal processor.

The four description languages (SDL, LLSDL, EDL and RDL) depicted in Figure 1 are provisions to incorporate third party software into the simulation tool. These languages must be very high level and easy to understand so that the user of the tool can either produce these files with the provided programs or with other professional third party programs.

The programs in Figure 1 can also work together concurrently; if the intermediate data files are replaced by pipes[1], then the interactions among these programs can be controlled by a master program. The gray circle in Figure 1 represents such a master program.

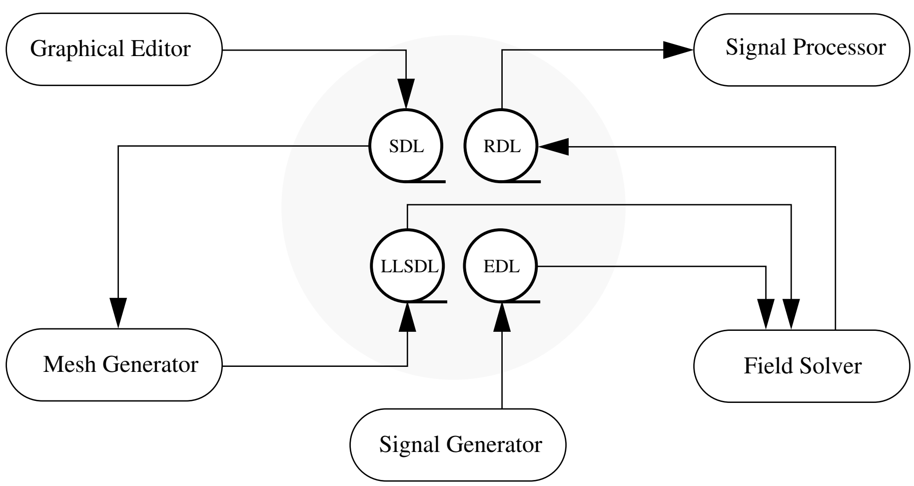


Figure 1: The graphical editor, mesh generator, field solver, signal generator and signal processor are separated programs which can work independently of each other as well as in collaboration with each other via a controlling program. The above abbreviations stand for:

SDL	Structure Description Language.
LLSDL	Low Level Structure Description Language.
EDL	Excitation Description Language.
RDL	Response Description Language.

The Graphical Editor

The graphical editor takes human input via the mouse and keyboard and produces an SDL output file in either the ASCII or a binary format. It must be user friendly and powerful enough to handle highly complex three-dimensional structures.

Figure 2. depicts such a graphical editor with it various components. The event processor responds interactively to human input via the input devices attached to the computer. The processor also directs other components of the graphical editor to perform element editing, storing as well as displaying the elements stored in the element stacks on the drawing windows.

The Mesh Generator

The mesh generator of this simulator must be powerful enough to handle structures of highly irregular three-dimensional geometry. Figure 3 depicts such a mesh generator with some of its components.

After reading in the SDL input, the mesh generator must extract and discretize the geometrical data in order to produce an input data file for the field solver. Because the SDL file can be produced by using an external ASCII editor or other third party programs, the mesh generator must verify the correctness of this file. The grayed path in Figure 3 is an error handling mechanism; instead of creating incorrect output data, the mesh generator invokes an external error handling module. This module can be provided by a third party package so that its SDL data producing program can be notified if error is detected.

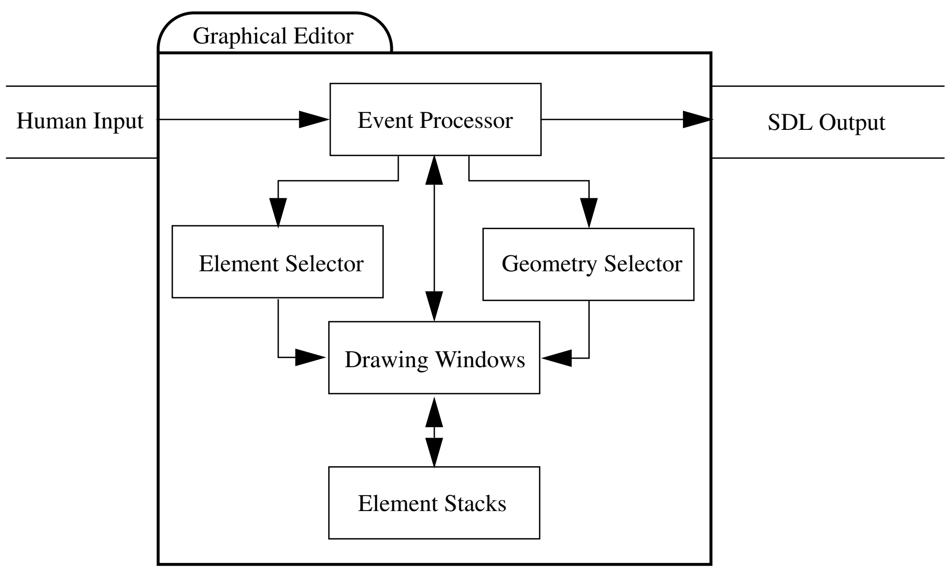


Figure 2: A graphical editor with its various components. The event processor is the heart of the editor, it responds interactively to human input and directs other components of the editor to perform various functions.

1. P.P.M. So, C. Eswarappa and W.J.R. Hoefer, *Distributed Parallel TLM Computation and Digital Signal Processing for Electromagnetic Field Modelling*, an invited paper, International Journal of Numerical Modelling — Electronic Networks, Devices and Fields, vol. 8, no. 3/4, May-August 1995, pp 169-185, John Wiley & Sons. Ltd.

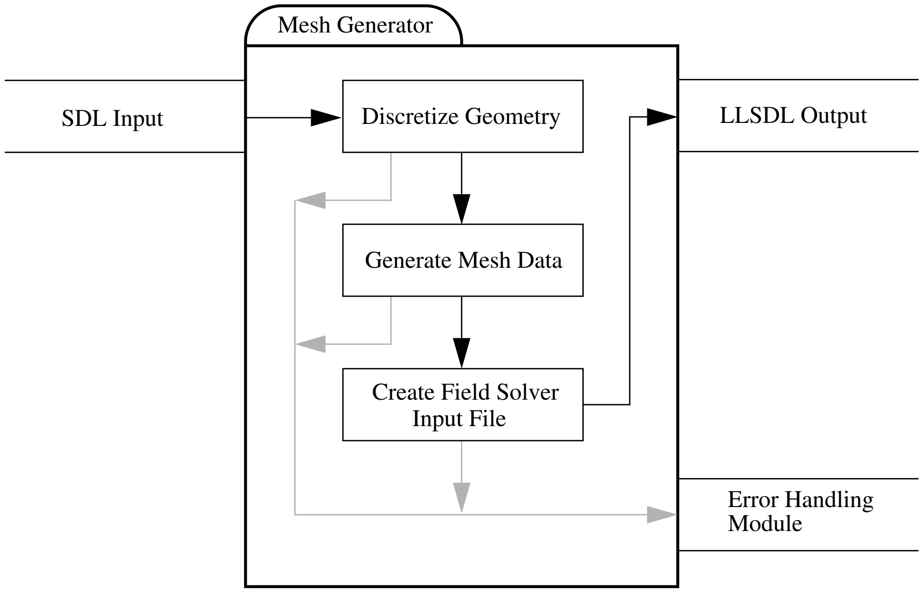


Figure 3: A mesh generator with some of its components. The grayed path is an error handling mechanism; instead of creating incorrect output data, the mesh generator invokes an external error handling module.

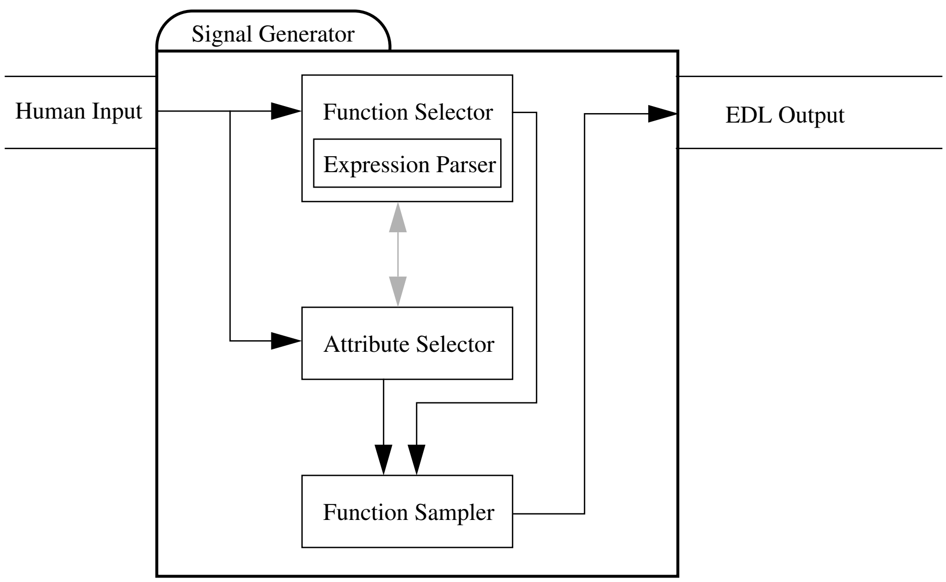


Figure 4: A signal generator with its various components. In the event that the built-in options do not include the function that is needed, the function selector should invoke the expression parser to compute the desired function.

In general, it is quite impossible to recover from errors without causing problems down the simulation path. Therefore, a simple way to handle error is to report it to the user and then terminate the execution of the mesh generator and/or the simulator.

The Signal Generator

The signal generator accepts human input from the mouse and keyboard then produces EDL output data in either the ASCII or a binary format. Once the EDL output is produced, execution of the signal generator can be terminated. Figure 4 shows some of the components of this signal generator.

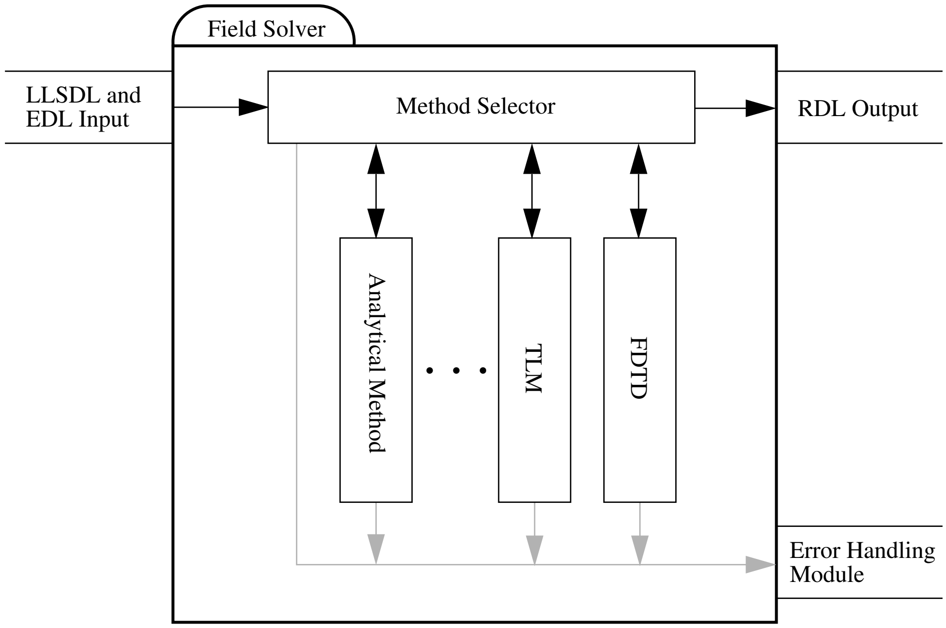


Figure 5: A field solver with its various analytical and numerical methods. Because the LLSDL and EDL input can be provided by external programs, an error handling path is provided in case those files contain erroneous data.

The function selector and attribute selector behave like the event processor of the graphical editor; they respond interactively to human input to determine the appropriate function and its attributes (such as magnitude, frequency, etc.) the user has selected. The information is passed on to the function sampler which generates a discrete version of the function based on the time step of simulation provided internally by the simulation tool and produces the appropriate EDL output file.

The signal generator should provide as many functions as possible, but there is no way to determine and implement all the functions one would like to use to excite the structure under study. Therefore, the function selector should provide a mathematical expression parser option to allow the user to specify some uncommon expressions.

The Field Solver

The field solver must take advantages of the existing well proven time domain methods such as TLM and FDTD as well as analytical methods, so that the best of these methods can be combined whenever and wherever possible. Figure 5 depicts such a field solver with its various analytical and numerical methods. These methods should be able to work independently as well as seamlessly together with each other.

A method selection mechanism must be implemented to select the appropriate method whenever possible. It must also provide an option to the user to override its selection.

Because the SDL and EDL input can be produced by third party software, the field solver must verify the correctness of these inputs. The grayed path in Figure 5 is an error handling mechanism; instead of creating incorrect output data, the field solver invokes an external error handling module. This module can be provided by a third party package so that its LLSDL and EDL data producing program can be notified if error is detected. However, a simple way to handle error is to terminate the execution of the field solver.

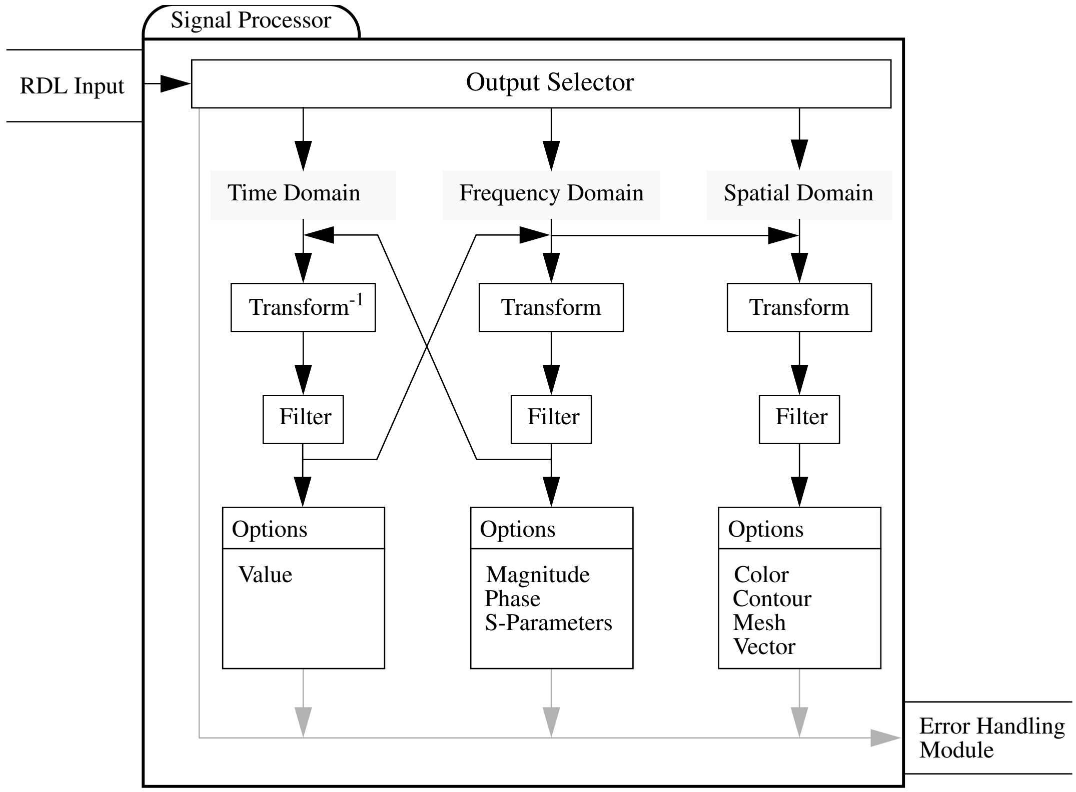


Figure 6: A signal processor with its various internal components. The grayed blocks are not physical modules, they are used as logical tags to group the functionalities of the three different domains together.

The Signal Processor

The signal processor of this simulator must be able to show the computed responses in the time, frequency as well as spatial domains. It must also have some advanced filtering capabilities in these domains so that unwanted signals can be eliminated from the responses. Figure 6 shows such a processor with its various internal components.

The output selector in Figure 6 allows the user to select the type or types of outputs to be displayed. Once a complete set of RDL input is received, this signal processor should be able to function independently of the field solver. In the other words, the signal processor should perform all the required computations with the current RDL input and store the computed result in its internal buffer for interactive viewing and processing. The signal transformation blocks in the figure should contain a null (i.e. no operation, just let the signal pass through with no transformation) and a Fourier transform function. Whereas, the signal filtering blocks should contain a null as well as some practical filtering functions.

A Prototype Multi-Purpose Electromagnetic Field Simulator

This simulator incorporates a lot of the advanced concepts and procedures for the TLM method using the object-oriented programming paradigm. The connections between the graphical interface and the numerical computation modules are carefully designed so that other compatible numerical methods such as finite difference time domain (FDTD), finite difference (FD) and finite elements (FE) methods can be easily integrated into this simulator.

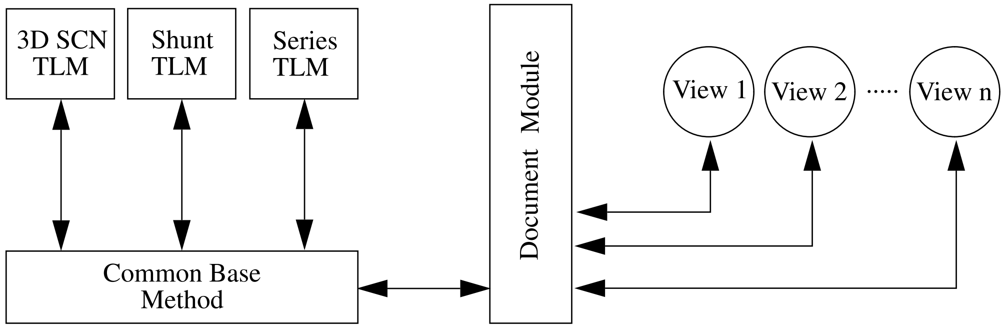


Figure 7: The *document-view* programming model used to implement this simulator. The *document* module isolates the base numerical method from the various graphical *view* modules. Therefore, compatible numerical methods can be easily incorporated into the simulator.

This simulator is based on a d*ocument-view* programming model. The *document* part of the model contains C++ objects which encapsulate the data and procedures of the TLM method. The *view* part of the model contains various C++ graphical interface objects to display the geometry of the structure under study as well as its responses to the applied electromagnetic excitations. Because of this clean separation between the document and its associated views, compatible numerical methods can be easily integrated into the document object by simply deriving new methods from a common base method. This idea is depicted in Figure 7.

The graphical interface front end of this simulator consists of a main window and five types of subwindows (each subwindow has an associated view object): Editor, Generator, Analyzer, Animator and Johns-Matrix, Figure 8 depicts the main control window together with the editor and its associated tool boxes.

The main window of the simulator has a menu system and a button bar which allow users to enter commonly used commands. The other subwindows mimic various kinds of instruments that microwave

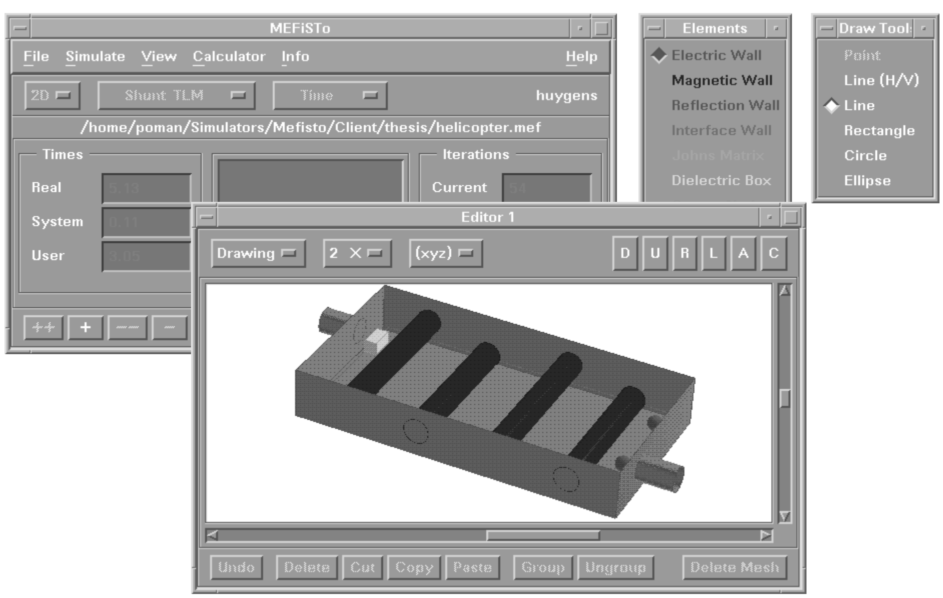


Figure 8: The graphical front end of the simulator. The tool boxes on the right of the Editor window allows the user to select the desired drawing element.

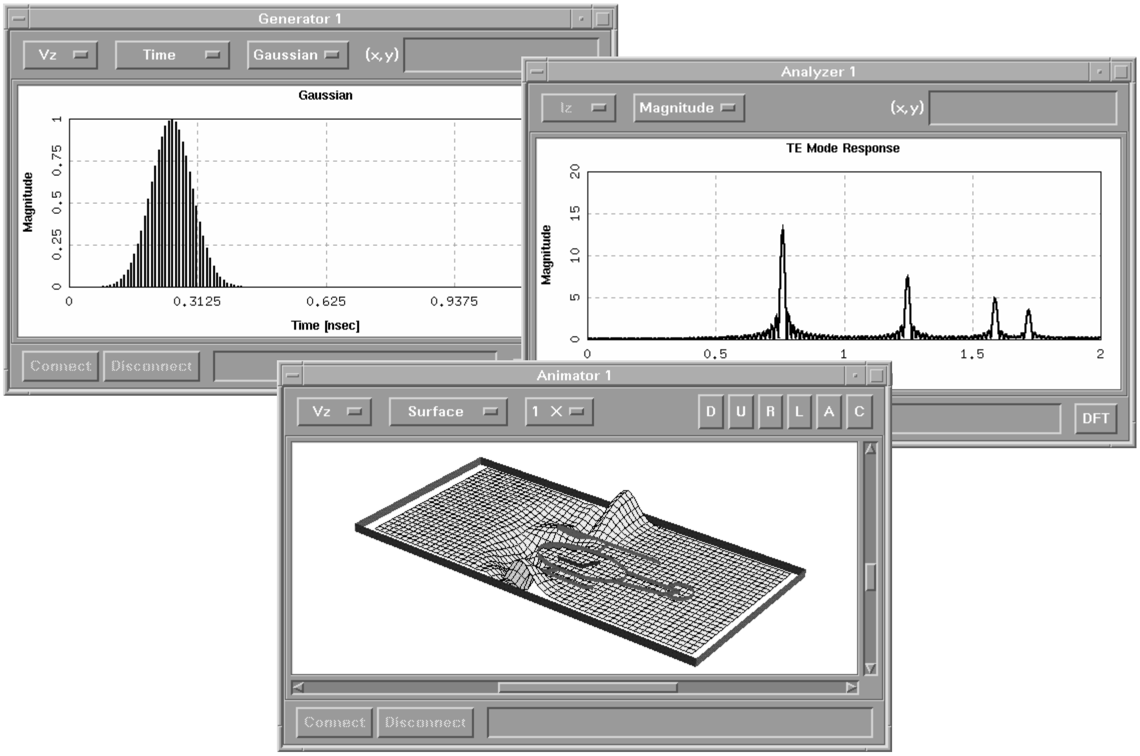


Figure 9: The Generator, Analyzer and Animator windows of the simulator. These windows allow users to interactively control the input and output characteristics.

engineers would normally find in their laboratories, such as drafting table, generator, scope and network analyzer, as well as a hard-to-find instrument — the field animator.

The Editor window, mimics the drafting table, allowing users to input the geometry of the structure to be studied via a mouse-based user-friendly drawing mechanism. The tool boxes on the right of the Editor window allow users to select the desired drawing element. Once the geometry is entered, the Editor can discretize the structure to various degrees of coarseness as specified by users. This feature allows problems to be solved with successively finer meshes, and the results can be used in the Richardson extrapolation procedure to estimate the result one would obtain from an infinitely fine mesh.

The Generator window models the signal generator one would find in the microwave laboratory. It allows users to specify the characteristics of the excitation waveform. The Analyzer window models the oscilloscope. It lets users measure the electrical response of the structure. The Animator window (there is nothing like it in the microwave laboratory) allows users to visualize the field evolution in the structure to be studied; it thus enriches the user's perception of electromagnetic wave propagation to an extent rarely achieved by any other tool in the microwave laboratory. The Johns-Matrix window models a high quality matched load. It lets users terminate the structure to be studied with a minimum reflection at the input and output planes. These windows are shown in Figure 9.

Conclusion

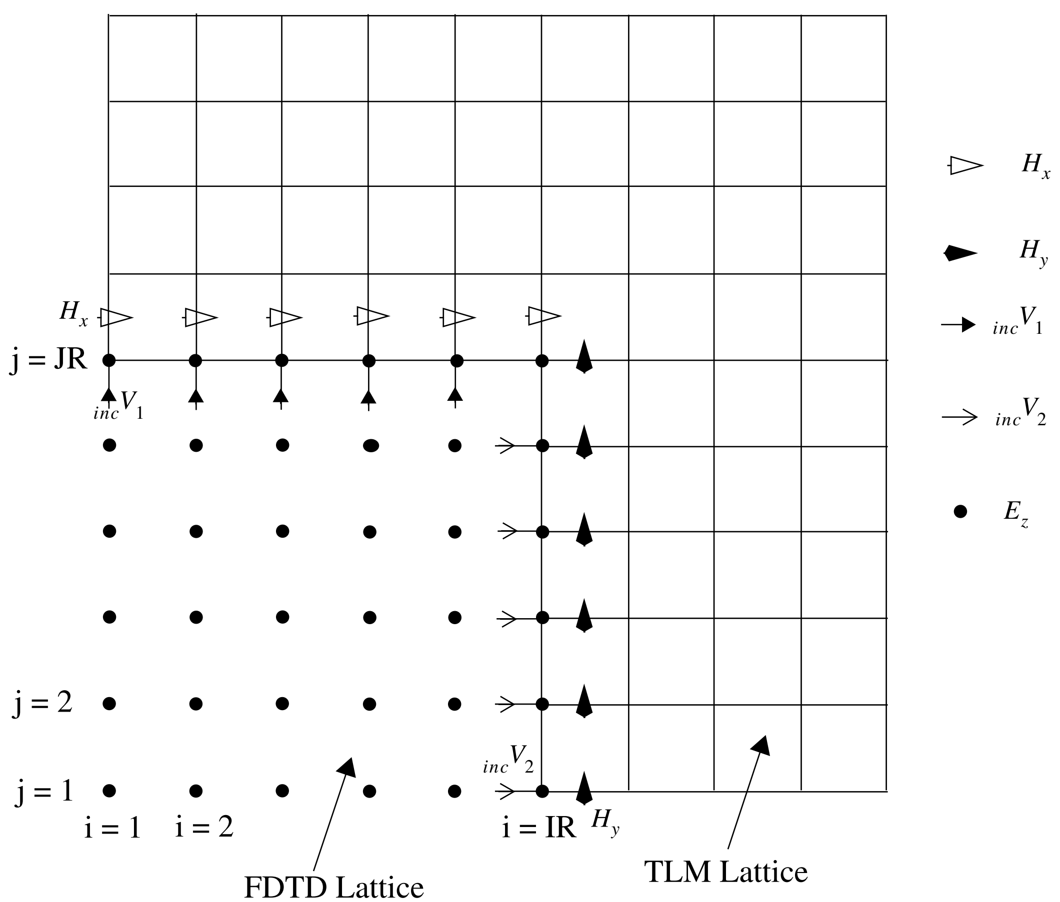
A design framework for a multi-purpose electromagnetic simulation tool as well as a prototype simulator based on the framework have been presented in this report. The framework and the prototype simulator demonstrated that advanced TLM features and techniques can be easily integrated into a well designed tool.

Bridging the Gap between TLM and FDTD

(Channabasappa Eswarappa and Wolfgang J.R. Hoefer)

A real-time interface between Transmission Line Modelling (TLM) and Finite Difference Time Domain (FDTD) algorithms has been developed and validated. A structure can be subdivided in an arbitrary manner into connected TLM and FDTD subdomains which are updated simultaneously. In this way the specific advantages of both methods can be exploited when solving a given problem. The interface procedure has been validated by solving identical structures first with TLM, then FDTD, and finally with a combination of both. All three methods yield identical numerical results for equal excitation, space and time resolution. Further details can be found in

C. Eswarappa and W.J.R. Hoefer, "Bridging the Gap between TLM and FDTD" *IEEE Microwave and Guided Wave Lette*rs, vol. 6, no. 1, pp. 4-6, January 1996.



Discretization of space with interconnected TLM and FDTD lattices.

Implementation of Berenger Absorbing Boundary Conditions in TLM by Interfacing FDTD Perfectly Matched Layers

(Channabasappa Eswarappa and Wolfgang J.R. Hoefer)

Berenger's perfectly matched layer (PML) absorbing boundary condition is implemented for the first time in a TLM mesh. This is achieved through a special interface (explained in the previous page) between the FDTD-PMLs and the TLM lattice . Application to rectangular waveguides yields reflections less than -50 dB at frequencies up to six times the cutoff frequency. These absorbing boundary conditions are compared with one-way equation absorbing boundary conditions and with matched layers having only electric losses. Further details can be found in

C. Eswarappa and W.J.R. Hoefer, "Implementation of Berenger Absorbing Boundary Conditions in TLM by interfacing FDTD Perfectly Matched Layers", *Electronics Letters,* vol. 31, no. 15, pp. 1264-1266, 20th July 1995

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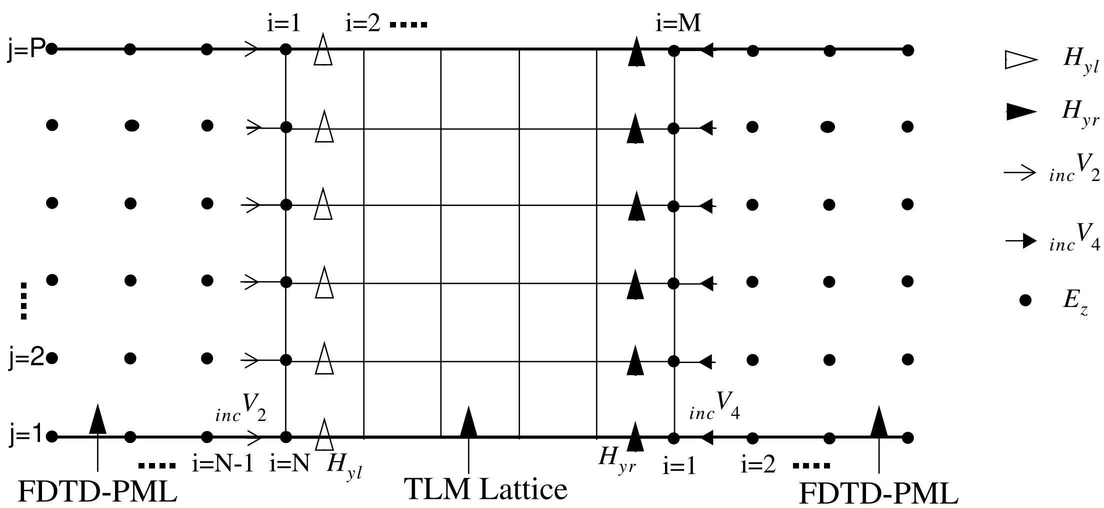
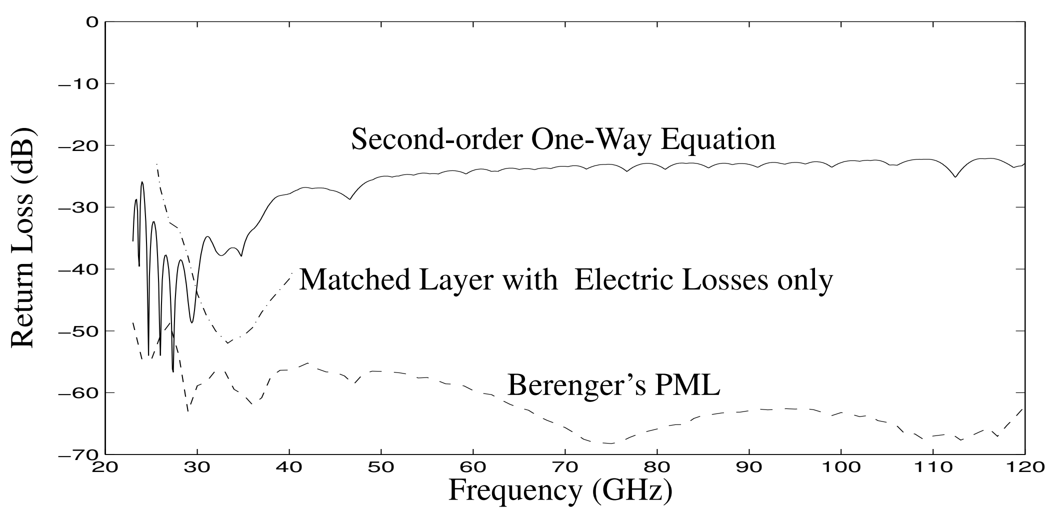


Discretization of a rectangular waveguide section with a shunt TLM mesh and two FDTD-PML meshes.



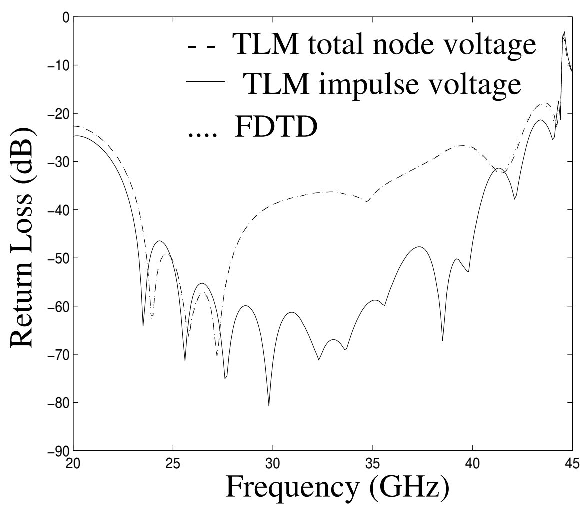
Comparison of return loss in the WR 28 waveguide for different Absorbing boundary conditions.

Comparative Performance Study of One-way Equation Absorbing Boundary Conditions in TLM and FDTD

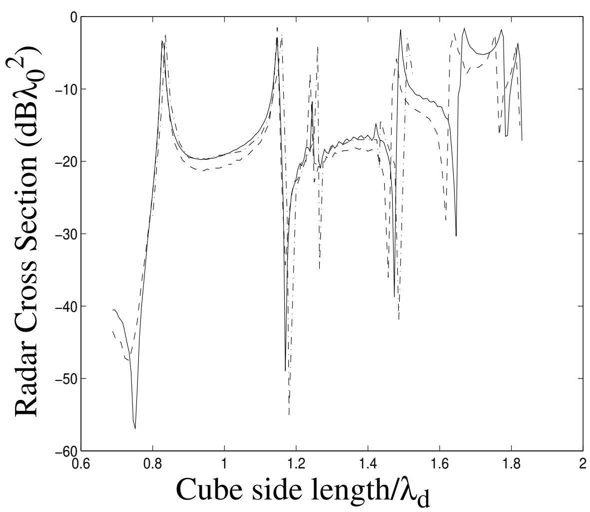
(Channabasappa Eswarappa and Wolfgang J. R. Hoefer)

A comparative performance study of Higdon's absorbing boundary conditions (ABCs) in TLM and FDTD under identical conditions (such as same time step, excitation, etc.) has been done. It has been observed that an ABC applied directly to the TLM voltage impulses absorbs better than the same ABC applied to the TLM total node voltages or FDTD field values. It has also been found that in a FDTD analysis, the damping factors have a greater influence on the stability than the way in which the absorbing boundary operators are discretized, while in a TLM analysis the opposite is true. Also, in a TLM analysis, the absorbing boundaries can be placed closer to a scatterer than in a FDTD analysis without affecting the accuracy. These observations have been demonstrated by applying them to examples such as waveguides and dielectric cubes. Further details can be found in

C. Eswarappa and W.J.R. Hoefer, "A comparative performance study of absorbing boundary conditions in TLM and FDTD" *12th Annual Review of Progress in Applied Computational Electromagnetics* (ACES) 1996 Digest, pp. 302-309, March 18-22, 1996, Monterey, CA.



Return loss of Higdon's second-order absorbing boundary condition in a WR28 waveguide (a = 0.5, b = 0.5, $\theta_1 = 30^0$, $\theta_2 = 45^0$, $\varepsilon_1 = 0.0$, $\varepsilon_2 = 0.0$)



RCS computed with TLM, FDTD and comparison with measurements

— TLM with 20 Δl white space

--- FDTD with 30 Δl white space

-.- Measurements [Trueman, et al]

Dispersion Analysis of TLM Node for Modeling General Anisotropic and Gyromagnetic Materials

(Qi Zhang, Jifu Huang, Ke Wu and Wolfgang J.R. Hoefer)

Among the critical issues regarding the accuracy of TLM results are the errors due to frequency and directional dispersion in the discrete spatial TLM network. It is well known that the TLM method has a cutoff frequency and deviations from the linear dispersion relation for frequencies approaching the cutoff frequency. This error is produced by the space discretization. In order to evaluate the accuracy of the TLM method and quantify the dispersion error, the dispersion relation of the discrete mesh must be known. The generalized dispersion analysis of two- and three-dimensional TLM schemes was first proposed by Nielsen and Hoefer in 1993 [1]. The usual approach for the derivation of the TLM dispersion relation is based on Floquet's theorem [2] and the network structure. Further work on the dispersion behavior of isotropic media modeled by condensed nodes has been reported by Krumpholz and Russer [3] and Trenkic et al. [4]. The dispersion in anisotropic media has been studied by Huber et al. [5] and Trenkic [6], but the investigations are restricted to wave propagation along the mesh axes and the mesh diagonals in symmetric anisotropic media.

Recently, Huang and Wu have proposed a unified TLM model for wave propagation in electrical and optical structures considering permittivity and permeability tensors [7]. Using this model a TLM algorithm has been derived to address various computational issues in non-diagonal tensor problems encountered in practical situations. However, the wave properties of the node employed in this model have not been systematically investigated yet. The study of the dispersion characteristics of this node remains a great challenge because of the complexity and size of calculations involved. In the project the dispersion analysis is based on the numerical solution of an eigenvalue equation to overcome this difficulty. The dispersion relation for the three-dimensional TLM condensed node modeling arbitrary permittivity and permeability tensors is obtained (Fig.3 - Fig.8). In the analysis, the dispersive behavior of the TLM node modeling m-cut sapphire (Fig.1), r-cut sapphire substrates (Fig.2) and gyromagnetic material is investigated with the same spatial discretization. It is verified that a relatively fine mesh is required to obtain good accuracy in the simulation of the m-cut sapphire material. This analysis shows that it is possible to minimize the numerical dispersion error when modeling anisotropic and gyromagnetic media.

References

[1] J. Nielsen, W.J.R. Hoefer, "Generalized dispersion analysis and spurious modes of 2D and 3D TLM formulations", IEEE Trans. on MTT, vol. 41, No. 8, pp. 1375-1384, Aug. 1993.

[2] J. Nielsen, W.J.R. Hoefer, "A complete dispersion analysis of the condensed node TLM mesh", IEEE Trans. on MTT. Vol.27, No 5, pp3982-3985, Sept. 1991.

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[7] J. Huang and Ke Wu, “A unified TLM model for wave propagation of electrical and optical structures considering permittivity and permeability tensors”, IEEE Trans. on MTT, vol. 43, No. 10, pp. 2472-2477, Oct. 1995.

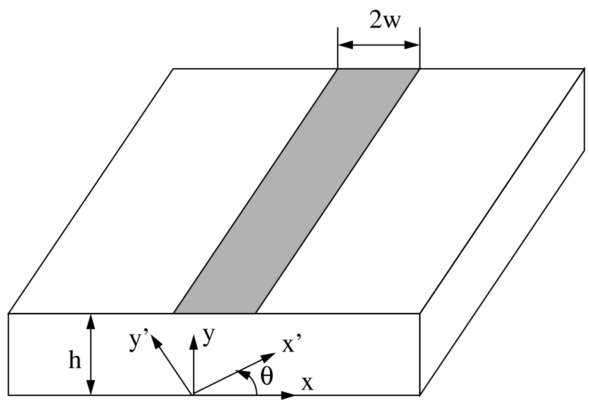

Fig.1 Microstrip geometry showing the crystal (x’,y’) and microstrip (x,y) axes. (m-cut sapphire)

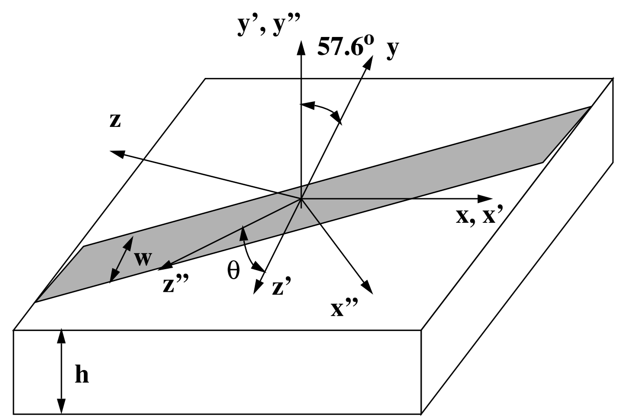

Fig.2 Arbitrarily oriented r-cut sapphire-based microstrip.

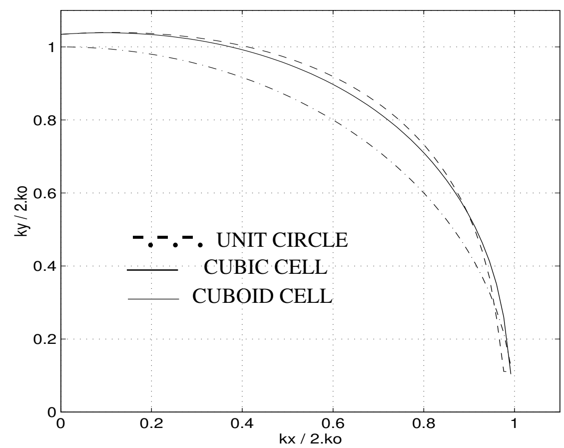

Fig. 3 The dispersion characteristics for a 3D condensed node in x-y plane. $\Delta x = 0.2$, $\Delta y = \Delta z=0.1$ (sapphire-m-cut, θ=60°)

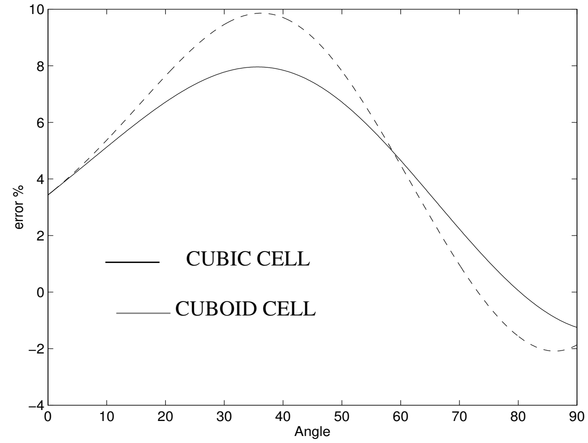

Fig.4 The dispersion error for a 3D condensed node in x-y plane. $\Delta x = 0.2$, $\Delta y = \Delta z = 0.1$ (sapphire-m-cut, θ=60°)

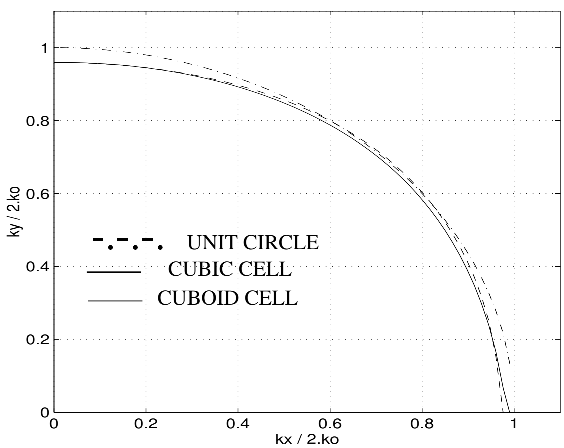

Fig.5 The dispersion characteristics for a 3D condensed node in x-y plane. $\Delta x = 0.2$, $\Delta y = \Delta z = 0.1$ (sapphire-r-cut)

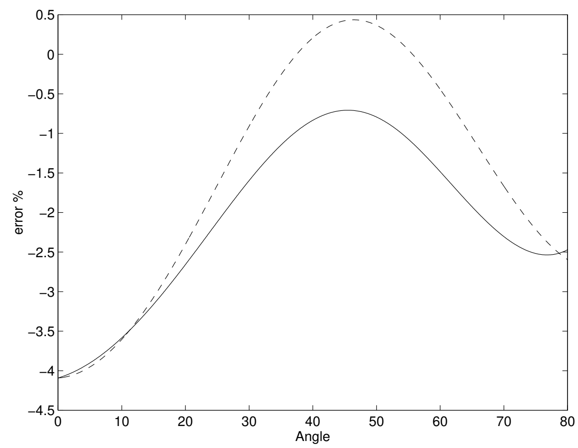

Fig. 6 The dispersion error for a 3D condensed node in x-y plane. $\Delta x = 0.2$, $\Delta y = \Delta z = 0.1$ (sapphire-r-cut, θ=57.6°)

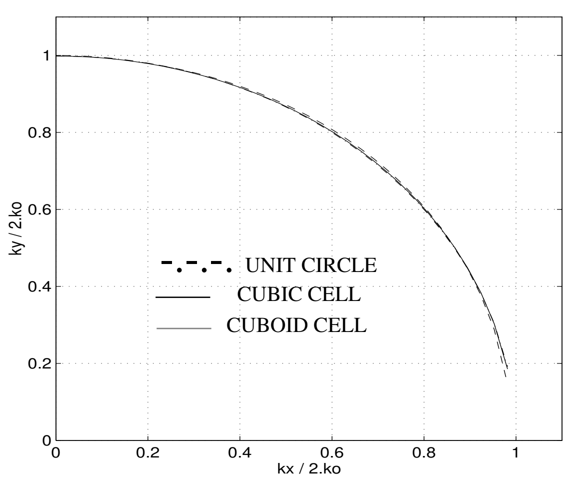

Fig.7 The dispersion characteristics for a 3D condensed node in x-y plane. $\Delta x = 0.2$, $\Delta y = \Delta z = 0.1$ (gyromagnetic material)

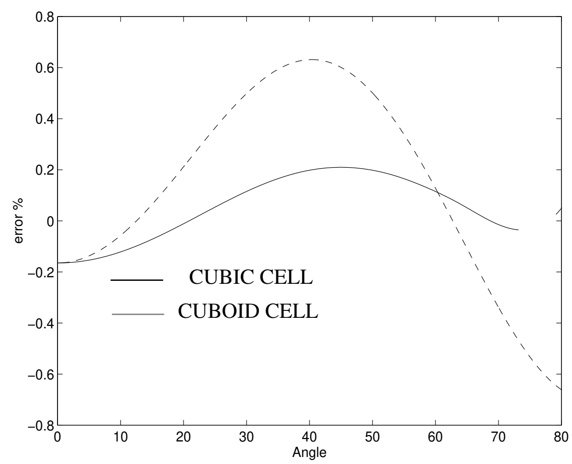

Fig. 8 The dispersion error for a 3D condensed node in x-y plane. $\Delta x = 0.2$, $\Delta y = \Delta z = 0.1$ (gyromagnetic material)

COLLABORATION WITH LOCAL COMPANIES AND UNIVERSITIES

RF drying of softwood lumber in collaboration with the Faculty of Wood Science in UBC

(Mario Righi, Jonathan Herring, Wolfgang J.R. Hoefer and UBC team)

A time domain model for the RF drying of wood in a vacuum kiln is being developed. The model includes the following physical phenomena involved in the drying of wood:

- Electromagnetic field distribution in the wood and the surrounding kiln
- Energy deposition which increases the mobility of moisture in the lumber
- Heat transfer and
- Mass transfer which in turn changes the dielectric properties of the wood.

The project aims at coupling all these phenomena in a self-consistent numerical model in space and time. Validation of the simulated results will be performed through the vacuum kiln available at UBC.

Modelling of a soil moisture probe in collaboration with Gabel Corporation, Victoria

(Jonathan Herring, Channabasappa Eswarappa and Wolfgang J.R. Hoefer)

Gabel Corporation design and manufacture soil moisture probes which operate by measuring the time taken for pulses to travel along a fixed length of the probe. An increase in the level of moisture around the probe slows down the pulses. The TLM method has been used to directly model the operation of various probe configurations in the time domain for soils of different properties. By visualizing the fields, the effect of non-homogeneities (air gaps, water pockets, etc.) in the soil surrounding the probe can be seen. A typical result is shown in fig. 1, in which the electric field at a point in the soil is shown against time and distance along the probe, for the case of an open-circuit termination.

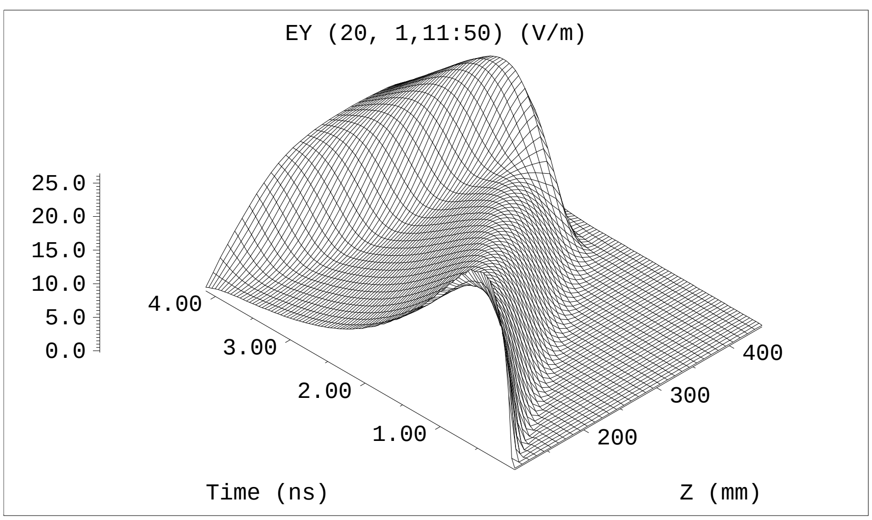

Fig. 1 – Electric field at a point in the soil along the length of the probe against time