NSERC/MPR Teltech Industrial Research Chair
In Radio Frequency Engineering

ACTIVITY REPORT*

Report No. 3 *April 1, 1994 to March 31, 1995*

MESSAGE FROM THE CHAIRHOLDER

This annual report covers the third year of the activities of the Research Chair, from April 1, 1994 to March 30, 1995. The size of the Chair's research group has remained steady at eight permanent members, while two Visiting Professors and three Research Trainees have joined the team for limited periods between one and six months.

As in the previous year, the principal research effort has been directed towards electromagnetic field modeling and simulation, with emphasis on applications to telecommunication technology. However, an important new application of our modeling techniques relevant to British Columbia's Forest Industries has emerged, namely the modeling and design of RF Kilns for drying of softwood lumber. This new application has, in turn, stimulated new research into the modeling of coupled electromagnetic/thermal systems in the time domain. The results of this new endeavour will enable us to model a large variety of situations in which electromagnetic fields are used to deposit energy in arbitrary media. At the same time, we have refined a number of algorithms, accelerated the signal extraction techniques, taylored the computational effort of a simulation to the required bandwidth, and reduced the errors that affect the accuracy of our computations in the presence of field singularities.

While research into novel and improved modeling procedures continues, technology transfer to the industrial users has become a priority. More and more new technologies in the telecommunication, information, processing and sensing areas rely to a great extent on electromagnetic field modeling, ranging from circuit design to electromagnetic compatibility issues. The research program of the Chair addresses these developments by focusing its general expertise in electromagnetic modeling on specific needs of its industrial partners.

We look forward to a rewarding and exciting fourth year of Research and Development at the University of Victoria.

Wolfgang J.R. Hoefer
Victoria, June 1995

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

Department of Electrical & Computer Engineering
University of Victoria, P.O. Box 3055, Victoria, B.C., V8W 3P6, CANADA
Tel: (604) 721-6025 Fax: (604) 721-6230

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.

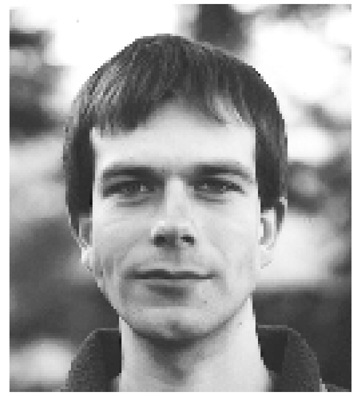
In June 1992, he joined the research team of the NSERC/MPR Teltech Industrial Research Chair in RF Engineering as a Research Engineer. He is also working toward his Ph.D. degree at the University of Victoria.

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.

Currently he is a full-time research assistant working toward his Ph.D. 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.

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 semiconductor material research and microwave semiconductor devices measurement techniques. Since September 1992, she has been working as a Teaching Assistant and is also a full-time graduate student working towards her Ph.D. in the Department of Electrical & Computer Engineering, at the University of Victoria, Victoria, B.C., Canada. Her research interests include numerical techniques for propagation and scattering of electromagnetic fields and waves.

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 analitical 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.

Research Trainee

Jesus Torre was born in Madrid, Spain, on August 26, 1968. He received the "Ingeniero de Telecomunicacion" degree in March 1993 from the "Universidad Politecnica de Madrid". Since September 1993 he is a research assistant of the "Departamento de Electromagnetismo y Teoria de Circuitos" of the same university with a scholarship of the Regional Goverment of Madrid. He is currently working towards his Ph.D. degree. His research interest includes TLM analysis of microwave and millimetre wave passive structures. He joined the NSERC/MPR Teltech Research Chair as a visiting student from May to June, 1994.

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.

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

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

EQUIPMENT

The research group associated with the Chair has recently moved into the new Engineering Laboratory Wingwhere 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.

In addition the research group has network access to a MPP (Massively Parallel Processor) DEC 12000 installed at BC Systems Corporation in downtown Victoria.

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

Hoefer, W.J.R., Sautier, P., "Characteristics of the General Rectangular 2D-TLM Network", Intl. Journal of Numerical Modelling, vol 7, no. 2, pp. 127-139, March/April 1994.

Herring, J.L., Hoefer, W.J.R., "Improved correction for 3-D TLM coarseness error", Electron. Lett., vol. 30, no. 14, pp. 1149-1150, 7 July 1994.

Eswarappa, C., Hoefer, W.J.R., "One-Way Equation Absorbing Boundary Condition for 3-D TLM Analysis of Planar and Quasi-Planar Structures", IEEE Trans. Microwave Theory Techniques, Vol. MTT-42, No. 9, pp. 1669-1677, Sept. 1994 .

Zhang, Q., Hoefer, W.J.R., "Characteristics of New 3D Distributed Node TLM Mesh with Cells of Arbitrary Aspect Ratio", IEEE Trans. Microwave Theory Techniques, Vol. MTT-42, No. 12, pp. 2365-2370, Dec. 1994.

Righi, M., Hoefer, W.J.R., "Efficient 3D-SCN-TLM Diakoptics for Waveguide Components", IEEE Trans. Microwave Theory Techniques, Vol. MTT-42, No. 12, pp. 2381-2385, Dec. 1994.

Eswarappa, C., Hoefer, W.J.R., "Autoregressive (AR) and Autoregressive Moving Average (ARMA) Spectral Estimation Techniques for Faster TLM Analysis of Microwave Structures", IEEE Trans. Microwave Theory Techniques, Vol. MTT-42, No. 12, pp. 2407-2411, Dec. 1994.

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

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.

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.

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. (Submitted)

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

Eswarappa, C. and Hoefer, W.J.R., "Implementation of Berenger Absorbing Boundary Conditions in TLM by Interfacing FDTD Perfectly Matched Layers", Electronics Letters. (Accepted).

Eswarappa, C. and Hoefer, W.J.R., "Bridging the Gap between TLM and FDTD", Microwave and Guided Wave Letters. (Accepted).

PAPERS PRESENTED AT REFEREED CONFERENCES

Russer, J.A., Hoefer, W.J.R., "A TLM Algorithm Simulator for the Visualization of Time Discrete Electromagnetic Processes", in 2nd. Intl. Conference on Computation in Electromagnetics Dig., pp. 120-122, Nottingham, 12-14 Apr. 1994.

Russer, P., Righi, M., Eswarappa, C., Hoefer, W.J.R., "Lumped Element Equivalent Circuit Parameter Extraction of Distributed Microwave Circuits via TLM Simulation", in 1994 IEEE Intl. Microwave Symp. Dig., pp. 887-890, San Diego, Ca, May 23-27, 1994.

Zhang, Q., Hoefer, W.J.R., "Characteristics of New 3D Distributed Node TLM Mesh with Cells of Arbitrary Aspect Ratio", in IEEE Intl. Microwave Symp. Dig., pp. 369-371, San Diego, Ca, May 23-27, 1994.

Krumpholz, M., Russer, P., Zhang, Q., Hoefer, W.J.R., "Field-Theoretic Foundation of Two-Dimensional TLM Based on a Rectangular Mesh", in IEEE Intl. Microwave Symp. Dig., pp. 333-336, San Diego, Ca, May 23-27, 1994.

Eswarappa, C., So, P.P.M., Hoefer, W.J.R., "Efficient Field-Based CAD of Microwave Circuits on Massively Parallel Processor Computers Using TLM and Prony's Methods", in IEEE Intl. Microwave Symp. Dig., pp. 1531-1534, San Diego, Ca, May 23-27, 1994.

Eswarappa, C., Hoefer, W.J.R., "Autoregressive (AR) Spectral Estimation Technique for Faster TLM Analysis of Microwave Structures", in IEEE Intl. Microwave Symp. Dig., pp. 701-704, San Diego, Ca, May 23-27, 1994.

Righi, M., Hoefer, W.J.R., "Efficient 3D-SCN-TLM Diakoptics for Waveguide Components", in IEEE Intl. Microwave Symp. Dig., pp. 27-30, San Diego, Ca, May 23-27, 1994.

Eswarappa, C., Hoefer, W.J.R., "Comparative Study of Spectral Estimation Techniques for Time-Domain Numerical Methods", in 1994 IEEE AP/S Symposium and URSI Meeting Dig., p. 134, Seattle, WA, June 19 - 24, 1994.

Zhang, Q., Hoefer, W.J.R., "Dispersion Characteristics of 3D Distributed Node TLM Mesh with Cells of Arbitrary Aspect Ratio", in 1994 IEEE AP/S Symposium and URSI Meeting Dig., pp. 102-105, Seattle, WA, June 19 - 24, 1994.

So, P.P.M., Hoefer, W.J.R., "3D-TLM Techniques for Field-Based Optimization of Electromagnetic Structures", in 1994 IEEE AP/S Symposium and URSI Meeting Dig., pp. 116-119, Seattle, WA, June 19 - 24, 1994.

Eswarappa, C., Hoefer, W.J.R., "Characterization of Microwave Structures using ARMA System Identification and TLM Method", in 1994 IEEE AP/S Symposium and URSI Meeting Dig., pp. 1124-1127, Seattle, WA, June 19 - 24, 1994.

de Menezes, L.R.A.X., Hoefer, W.J.R., "Modeling Frequency Dependent Dielectrics in TLM", in 1994 IEEE AP/S Symposium and URSI Meeting Dig., pp. 1140-1143, Seattle, WA, June 19 - 24, 1994.

Hoefer, W.J.R., "Parallel and Distributed Computing of Electromagnetic Fields with TLM", Invited Workshop Paper, Workshop W2 at 1994 IEEE AP/S Symposium and URSI Meeting, Seattle, WA, June 19 - 24, 1994.

Hoefer, W.J.R., "Design and Optimization of Microwave Components with Time Domain TLM Electromagnetic Simulator", in 6th Biennial IEEE Conference on Electromagnetic Field Computation Dig., p. 33, Aix-les Bains, July 5-7, 1994.

Hoefer, W.J.R., "Time Domain Modelling of Planar Guiding and Radiating Structures with TLM", Invited Paper, in 1994 Progress in Electromagnetics Research Symposium Dig., p. 266, Noordwijk, The Netherlands, July 11-15, 1994.

de Menezes, L.R.A.X.; Hoefer, W.J.R., "Modeling Nonlinear Dispersive Media in TLM", in 24th European Microwave Conference Dig., Vol. 2, pp. 1739-1744, Cannes, Sept. 5-8, 1994.

Damaschke, J., Hoefer, W.J.R., "Modeling of Regular Conducting and Superconducting Boundaries in TLM", in 24th European Microwave Conference Dig., Vol. 2, pp. 1727-1732, Cannes, Sept. 5-8, 1994.

Hoefer, W.J.R., "Microwave Circuit Design based on Time Domain TLM Field Simulation", Invited Workshop Paper, Workshop W6 at1994 Asia-Pacific Microwave Conference , Tokyo, Dec. 6-9, 1994.

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 Electromag-netics Dig., pp. 13-20, Monterey, Ca, March 20-24, 1995.

CONFERENCE PAPERS ACCEPTED OR SUBMITTED

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., Orlando, Florida, May 15-19, 1995. (Accepted)

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., Orlando, Florida, May 15-19, 1995. (Accepted)

de Menezes, L.R.A.X.; Hoefer, W.J.R., "Modeling General Constitutive Relationships in TLM", in IEEE Intl. Microwave Symp. Dig., Orlando, Florida, May 15-19, 1995. (Accepted)

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., Orlando, Florida, May 15-19, 1995. (Accepted)

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. (Accepted)

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., Newport Beach, CA, June 18 - 23, 1995. (Accepted)

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

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. (Accepted)

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. (Accepted)

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, August 1-3, 1995. (Accepted)

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, August 1-3, 1995. (Accepted)

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, August 1-3, 1995. (Accepted)

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, August 1-3, 1995. (Accepted)

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, August 1-3, 1995. (Accepted)

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, August 1-3, 1995. (Accepted)

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., Univeristy of Victoria, Canada, August 1-3, 1995. (Accepted)

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, August 1-3, 1995. (Accepted)

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, August 1-3, 1995. (Accepted)

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. (Accepted)

VISITORS TO THE CHAIR

May 30, 1994
Professor Roberto Sorrentino, Università degli Studi di Perugia, Perugia, Italy, "Analysis and Optimization of 3D Microwave Structures by the Mode Matching Technique and Adjoint Network Method".

June 17, 1994
Dr. Zhizhang Chen, Technical University of Nova Scotia, Halifax, Nova Scotia, "Modal Analysis of Recursive Time Stepping Numerical Methods".

September 27, 1994
Dr. Eikichi Yamashita, University of Electrocommunications, Tokyo, Japan, "Optimal Design of Printed Antenna Components for Millimeter-wave Imaging Arrays", and "Port Reflection Coefficient Method for Solving Multi-Port Microwave Network Problems".

COURSES TAUGHT AT UVIC

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

ELEC 454 "Microwave and Optical Communication Systems II", Fourth Year Undergraduate Elective Course and Laboratory taught during Spring of 1994 and 1995.

GROUP MEMBER AWARDS

September 1994

Mario Righi and Poman So

Mario Righi and Poman So were both awarded "Quality Presentation Recognition" certificates for their excellent presentations at the 1994 IEEE MTT-S International Symposium, held in San Diego, California, May 23-27. The presented the following papers: "Efficient 3D-SCN-TLM Diakoptics for Waveguide Components", by M. Righi and W.J.R. Hoefer, and "Efficient Field-Based CAD of Microwave Circuits on Massively Parallel Processor Computers Using TLM and Prony's Methods", by C. Eswarappa, P.P.M. So, and W.J.R. Hoefer. Their names have been placed on the 1994 IMS Technical Program Chairman's Honor Roll, and included in the listing as part of an article in the Special IMS MTT-S Transactions, December 1994 issue.

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, 1994 IEEE MTT Intl. Microwave Symposium in San Diego, CA May 23-27, 1994.

Technical Program Committee, 1994 IEEE AP & URSI Symposium in Seattle, WA, June 19 - 24, 1994.

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

Technical Program Committee, 1994 IEEE AP & URSI Symposium in Newport Beach, CA, June 18 - 23, 1995.

International Advisory Committee, 1994 International Conference on Computational Electromagnetics and its Applications (ICCEA'94) in Beijing, China.

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.

An Alternative Way of Computing S-parameters via Impulsive TLM analysis without Using Absorbing Boundary Conditions

(Mario Righi, Eswarappa Channabasappa and Wolfgang J. R. Hoefer, in collaboration with Peter Russer of the Ferdinand Braun Institute, Berlin)

The two major advantages of time domain numerical methods such as the Transmission Line Matrix (TLM) method is the ability to analyze complex structures with arbitrary geometry, and obtain the frequency characteristics over a wide frequency spectrum with a single time domain simulation. One of the major requirements of time domain methods is the availability of good quality broadband matched loads or absorbing boundary conditions in order to truncate the computational domain. Higher-order absorbing boundary operators may be used to increase the bandwidth of absorption, but long time stability may be difficult to achieve. To overcome this problem, we have proposed an attractive alternative to compute the scattering parameters via admittance parameters.

Computation of admittance parameters does not require matched loads (or absorbing boundary conditions). Therefore, unconditional stability is achieved since exact boundary conditions are imposed. Impulsive voltage excitation and short circuit conditions at the ports enable the computation of admittance parameters directly in the time domain. The procedure is particularly suitable for highly dispersive and lossy components, where high quality ABCs are difficult to achieve and natural decay of the impulse response reduces the computational time.

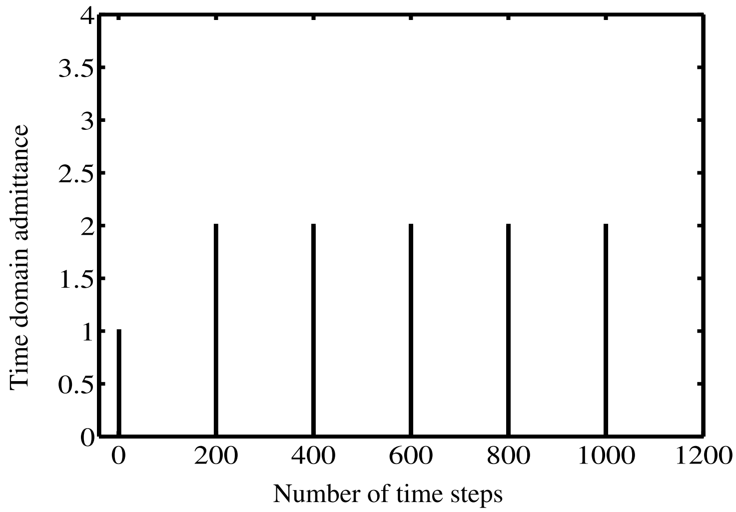
Once a one-port linear circuit is excited with a voltage source v(t), the response current i(t) can be obtained by convolving the voltage source v(t) and the input admittance y(t):

$$i(t) = \int y(t_1 - t)\, v(t_1)\, dt$$

If v(t) is an impulse excitation, the current i(t) at the same port becomes equal to the input admittance of the circuit. This procedure can be easily extended to multiport circuits by applying a multiport version of the previous equation. The frequency domain scattering parameters are then easily obtained by standard transformations.

The above procedure has been implemented for the 3D-symmetrical condensed node (SCN) TLM algorithm and used to analyze one- and two-port waveguide components. First, to validate the procedure, we have analyzed a TEM waveguide stub of length 50 Δl. The simulated time domain admittance can be represented by the series in Fig. 1 (where $\delta(t)$ represents a Dirac delta function and k=100 Δt) so that the Laplace transform can be analytically performed. The admittance obtained, Y(s)=coth(ks), is the analytical input admittance of the stub. Having verified the procedure in case of a plane wave stub, we have applied it to a WR-28 waveguide lossy stub (loss tangent of the medium $\tan\delta = 0.1$). The impulsive excitation was spatially distributed according to the dominant mode field distribution. Because the response current obtained is an infinite series, windowing of the series must be done in order to reduce the truncation error in the Fourier transform performed on a finite number of time steps. The real and the imaginary part of the admittance have been compared with analytical results in Fig. 2. They agree well in the entire operating range of the waveguide. Finally, a two-port circuit has been considered. A thick inductive iris with aperture

$a/2$ and thickness $a/6$ in a WR-28 waveguide has been analyzed. Its S-parameters have been computed with three different methods via admittance parameters (SBC), via direct computation using matched loads (ABC) and via Marcuvitz's equivalent circuit model. A comparison of the S-parameter results is shown in Fig. 3.



$$y(t) = \delta(t) + 2\sum_{n=1}^{\infty}\delta(t-2nk)$$

$$Y(s) = L[y(t)] = 1 + \sum_{n=1}^{\infty} e^{-2kns} =$$

$$= \frac{2e^{2ks}}{e^{2ks}-1} - 1 = \frac{\cosh(ks)}{\sinh(ks)} = \coth(ks)$$

Fig. 1: Time domain admittance and its representation in the time and in the complex frequency domain.

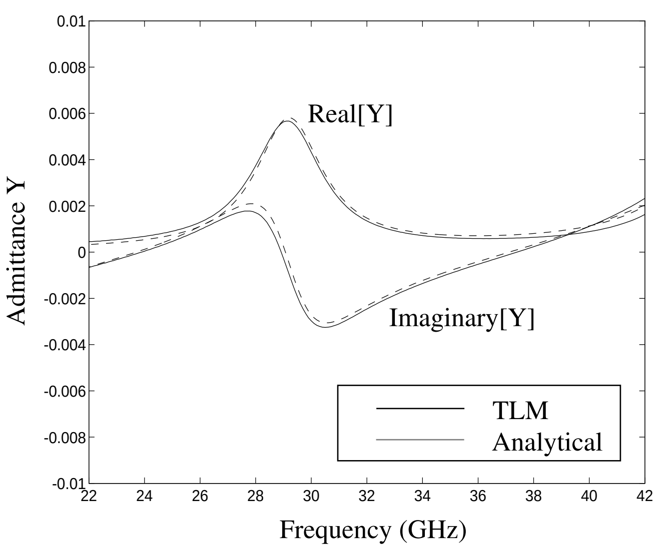


Fig. 2: Comparison of the analytical and TLM input admittance for a lossy waveguide stub.

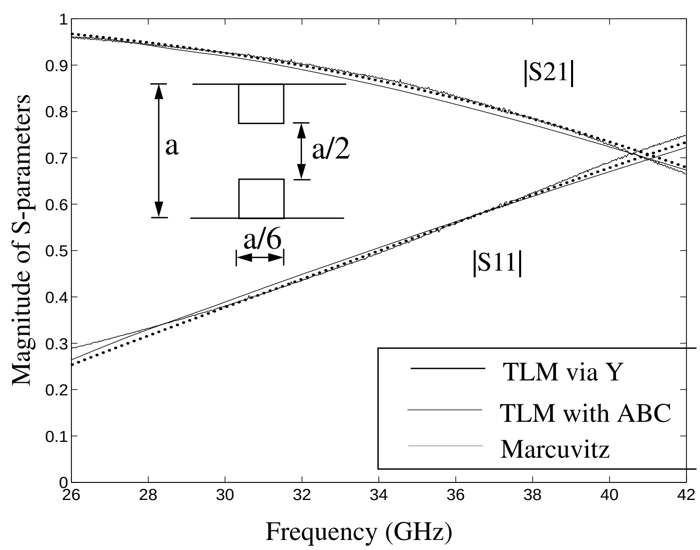


Fig. 3: Comparison of S-parameters for a thick inductive iris in a WR 28 waveguide computed via admittance parameters, with ABC and Marcuvitz equivalent circuit.

Further details can be found in:

M. Righi, C. Eswarappa, W. J. R. Hoefer, P. Russer, "An Alternative Way of Computing S-parameters via Impulsive TLM analysis without Using Absorbing Boundary Conditions" to be presented at the 1995 Intl. Microwave Symposium MTT-S, Orlando Florida.

Extraction of Equivalent Circuit of MMIC components via TLM Simulation

(Mario Righi and Wolfgang J. R. Hoefer, in collaboration with Bernhard Bader, Ralf Doerner and Peter Russer, of the Ferdinand Braun Institut, Berlin, Germany)

The analysis of complex microwave circuits can be efficiently accomplished by a segmentation procedure. The circuit is first decomposed into subsections analyzed individually, and the results are recombined to obtain the overall behaviour of the structure under investigation. For some of the subsections a simple equivalent circuit can suffice while for others a full wave analysis is required. In order to create a link between these different techniques one can perform a full wave analysis of complex components and extract an equivalent lumped element circuit from such analysis. This work deals with the extraction of equivalent circuits from a complex component pre-simulated with the TLM method. The equivalent circuit is extracted with a rigorous procedure leading to the topology and the value of its elements. The procedure can be applied to link time domain field solvers with SPICE type simulators and to create a library of microwave components simulated with TLM for later use. In addition the procedure is extended to include losses for two-port components by including appropriate resistors in the equivalent circuit.

As an example the extraction of the equivalent circuit of a MMIC spiral inductor realized in coplanar technology (Fig. 1) is demonstrated.

From the time domain simulation of the coplanar spiral inductor, the frequency domain admittance Y(p) is computed via Laplace transform.

$$Y(p) = L[Y(t)]$$

In case of low-loss components the Fourier transform can also be adopted since the real part of the poles is relatively small as compared to their imaginary part, and it can be determined solely from their dependance on frequency. The complex admittance matrix is then expanded in a series of poles α_n and their residues A_n. By restricting the analysis to a finite range of frequencies the sum can be terminated after a finite number, N, of poles.

$$Y(p) = A^{(0)} + \sum_{n=1}^{N} \frac{A^{(n)}}{p - \alpha^{(n)}} + A^{(\infty)} p$$

The frequency domain Prony's method is used to locate the poles and the corresponding residues. From the pole location and residue values, a canonical Foster realization follows.

The coplanar inductor has been discretized with a uniform mesh of size 2 µm, and the mesh has been excited with a Gaussian pulse covering the frequency range of interest. The S-parameters computed are shown in Fig. 1 and compared with measured results. The agreement between simulated and measured results is excellent in this frequency range, and wideband lumped element extraction can then be performed based on the simulated results.

The final equivalent circuit for the coplanar inductor, after simplifying and neglecting the non-relevant elements, is shown in Fig. 2. Poles for Y_{11} and Y_{12} in the frequency range dc-80 GHz and the corresponding lumped element values are shown in Table 1.

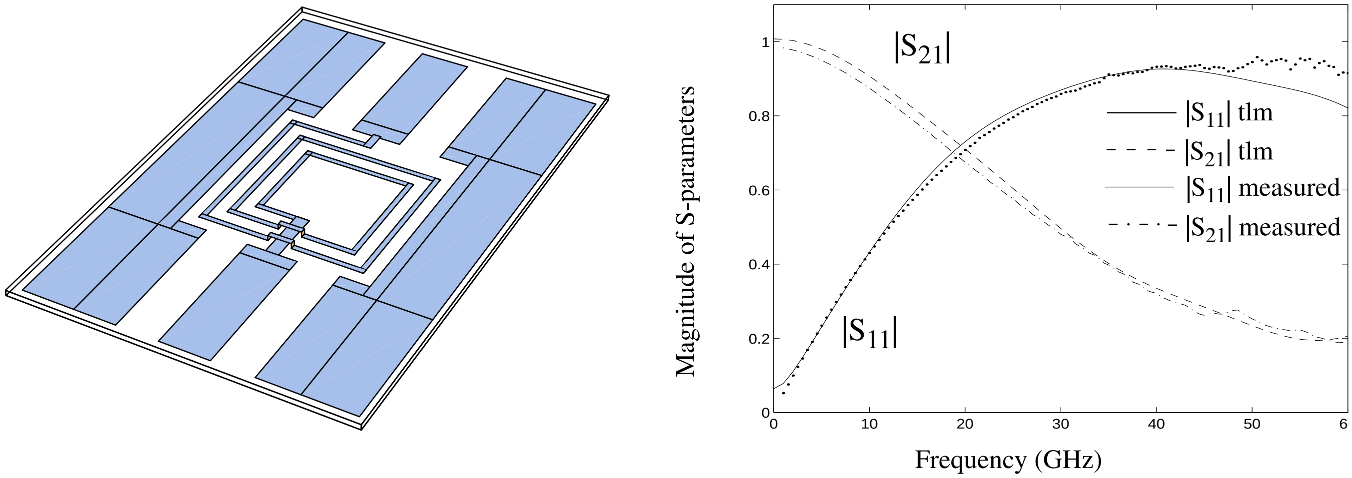


Fig. 1: Magnitude of S-parameters of the open coplanar spiral inductor

Geometry of the coplanar spiral inductor: central conductor width: 38µm, ground to ground width: 102 µm, air bridge height: 2 µm, spiral line width: 4µm, substrate permittivity: ε_r=12.9.

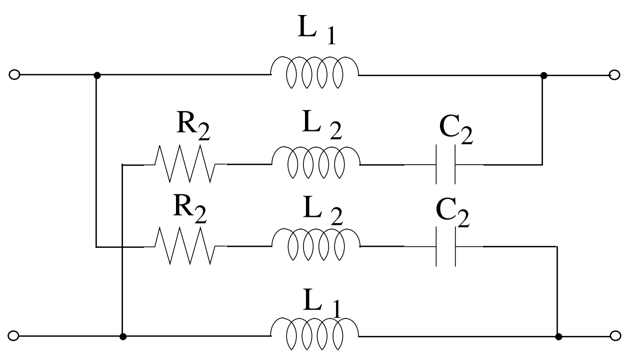


Fig. 2: Equivalent circuit of the coplanar spiral inductor

Table 1: Poles and lumped element parameters for the coplanar spiral inductor

Pole no.	Freq. (GHz)	Damping factor	L_i (pH)	R_i (Ω)	C_i (pF)
1	0.0	-3.16	9.2		
2	70.73	-24.16	7.9	0.38	0.644

Further details can be found in:

M. Righi, W. J. R. Hoefer, B. Bader, R. Doerner and P. Russer, “Extraction of Equivalent Circuit of MMIC components via TLM Simulation” to be presented at the 1995 MIOP conference Germany.

Wood Drying

(Jon Herring and Wolfgang J. R. Hoefer)

The TLM method has been used to model the field distribution within a full-scale pilot plant for a wood drying kiln developed by the Council of Forest Industries, Vancouver, B.C., for drying softwood lumber. The kiln exploits a combination of radio-frequency heating and vacuum drying technologies and offers improvements in drying time and in wood quality over conventional gas-fired kilns. The RF generator oscillates between frequencies of 5 and 10 MHz with a maximum power output of 350 kW and the vacuum chamber has a lumber-holding capacity of 55 m^3. By coupling the field simulation with a drying model, the variation in the moisture content of the lumber packages throughout the drying process has been obtained. This has enabled improvements to the existing kiln design to be made so that more uniform drying in the package cross-section could be achieved.

In the original electrode configuration, a stack of three lumber packages was placed between a hot and a ground electrode with air gaps on either side to facilitate material handling and to reduce the change in total load impedance as the wood dried. The moisture content at four stages in the drying cycle obtained by simulation is shown in fig. 1, over the cross-section of the packages. The hot electrode is on the left side and the darker areas indicate drier wood. It is apparent that the drying is non-uniform and the lumber remains wet on the ground electrode side. A set of simulations were performed to investigate how this difference could be minimized within the confines of the existing kiln. Once the recommended improvements had been made to the electrodes a much more satisfactory drying uniformity was achieved, as shown in fig. 2. The experimental results verified the predictions made by the model and this has greatly improved confidence in using the model for future RF/vacuum drying applications.

Further details can be found in:

J. L. Herring, W. J. R. Hoefer and R. Zwick, “TLM Modeling of a RF/Vacuum Wood Drying Kiln”, *Progress in Electromagnetics Research Symposium*, Seattle, Washington, USA, July 24-28, 1995.

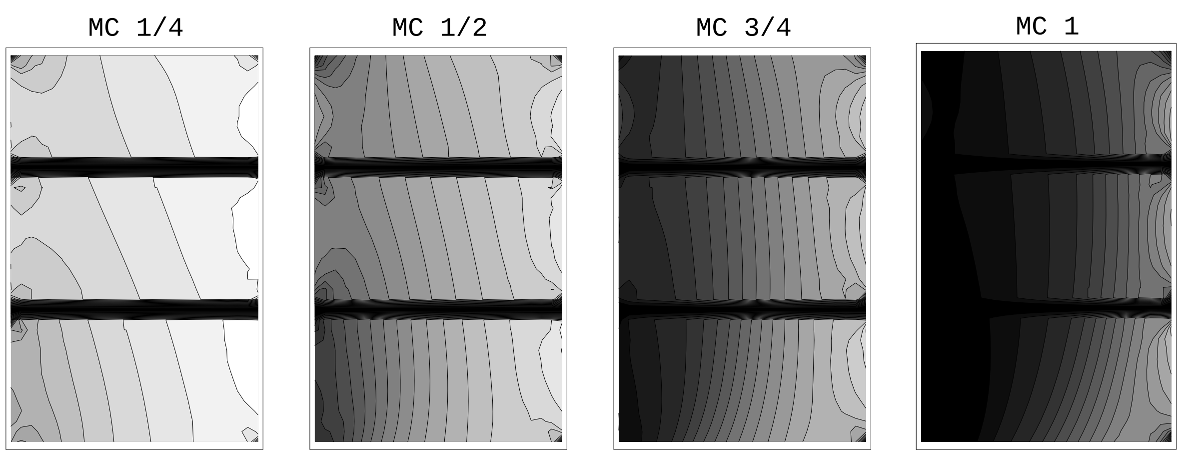


Fig. 1 Moisture content in three packages with the original electrode configuration

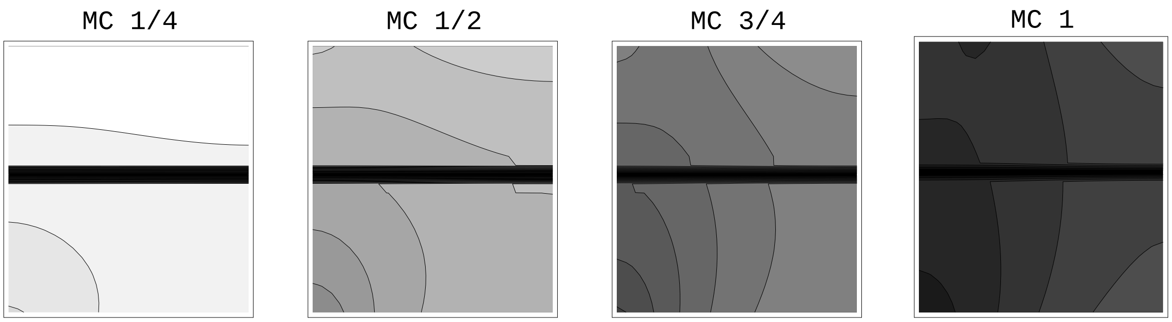


Fig. 2 Moisture content in two packages with the revised electrode configuration

Coarseness Error Correction

(Jon Herring and Wolfgang J. R. Hoefer)

When modelling edges or corners in TLM it is often found that frequency domain characteristics are shifted towards lower frequencies. For example, consider a non-touching axial strip placed in a waveguide, as shown in fig. 1. If this is modelled with a standard symmetrical condensed node (SCN) mesh, with a spatial resolution of $\Delta l = a/60$, the minimum in S21 occurs at a frequency of 35.5GHz, almost 3GHz lower than the expected result. Increasing the mesh resolution produces an approximately linear increase in frequency towards the correct result, as shown by the middle line in fig. 3, but finite computer resources impose limits on this approach (8 times the storage and 16 times the run-time for a doubling of resolution). It is possible to get improved results by reducing the timestep only provided that a node with good dispersion characteristics is selected. This is shown by the bottom line for the hybrid SCN. The increase in frequency is not as great as for the first case and any improvement appears to be very problem dependant. In any case, the problem of an increase in run-time remains.

A method has been developed in which a modification is made to the nodes immediately surrounding the edges of the strip, with a standard coarse mesh used in the rest of the problem space. This is illustrated in fig. 2 for the bottom left corner of a strip in the plane of the page, where the grey squares represent the short-circuit boundaries from which the strip is constructed, and the outline cubes represent the nodes. Along the edges, groups of four nodes are connected to produce “supernodes” in which the delay associated with the internal link-lines is eliminated. Six nodes are connected together at the corners. Results are shown by the top line in fig. 3. The frequency is much less dependant on the mesh resolution and is close to the expected result. Good results have also been obtained for an E-plane filter, which shows the generality of the method.

Further details can be found in:

J. L. Herring and W. J. R. Hoefer, “Improved correction for 3-D TLM coarseness error”, *Electronics Letters*, vol. 30, no. 14, pp 1149-1150, 7 Jul 1994.

J. L. Herring and W. J. R. Hoefer, “Compensation of Coarseness Error in TLM Modeling of Microwave Structures with the Symmetrical Condensed Node”, *IEEE Intl. Microwave Symp. Dig.*, Orlando, Florida, USA, May 15-19, 1995.

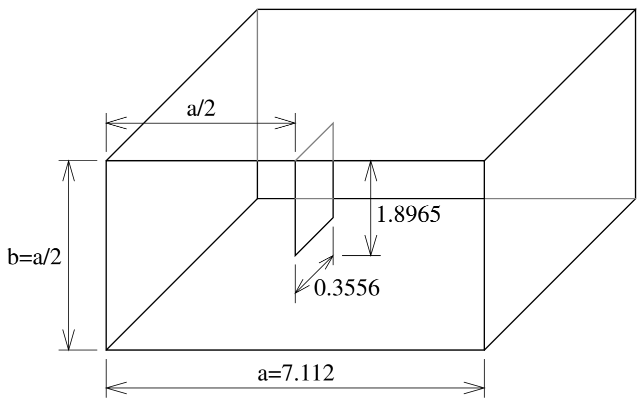


Fig. 1 Non-touching axial strip in a rectangular waveguide (dimensions in mm)

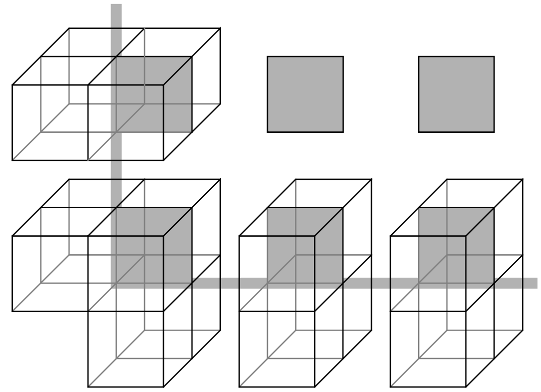


Fig. 2 Correction applied around a corner of the strip

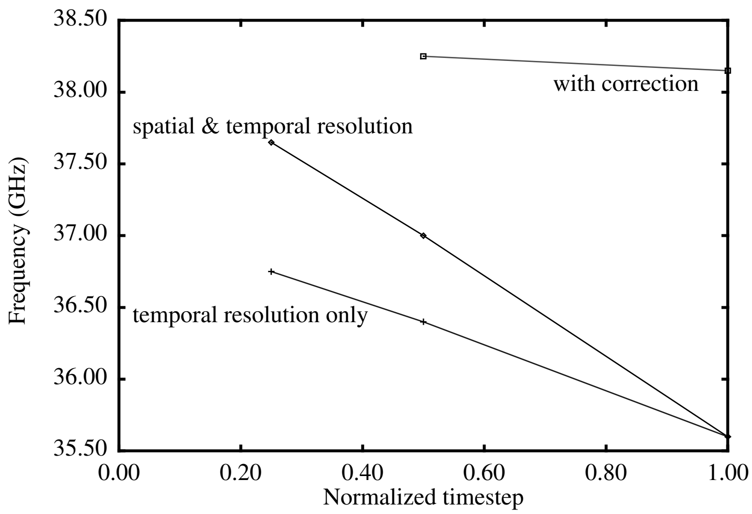


Fig. 3 Effect of resolution on the frequency at which S21 has a minimum

Modelling of General Constitutive Relationships in SCN TLM

(Leonardo de Menezes and Wolfgang J.R. Hoefer)

The basic TLM formulation requires that the constitutive parameters of the medium be specified as constants. Therefore, an appropriate wide-band modelling of general (dispersive, nonlinear, etc...) media cannot be performed without major modification of the algorithm. The TLM algorithm can be modified to represent general constitutive relationships. This can be done by using previously decoupled 2-D scattering matrices. The constitutive relationships are solved with equivalent node sources and state-variables.

The technique was validated by comparing SCN TLM results with calculations of the cutoff frequency of a waveguide filled with anisotropic material. The example simulated a WR-28 (7.112 mm by 3.556 mm) waveguide using regular mesh with a discretization of 24 x 12 x 4. A sapphire substrate was used as a dielectric ($\varepsilon_u = 9.34$ and $\varepsilon_v = 11.49$). The optical axis lies on the xy plane, rotated by an angle φ with respect to the x axis.The problem was calculated for φ of 0^o, 45^o and 90^o using backwards Euler discretization

Table 1 - Comparison of results for the sapphire example.

Analytical Cutoff Frequency	Axis Angle	SCN - TLM	Error (%)
6.2221 GHz	0^o	6.21 GHz	0.19
6.5354 GHz	45^o	6.57 GHz	-0.53
6.9012 GHz	90^os	6.90 GHz	0.02

Further details can be found in:

W.J.R. Hoefer, “The transmission line matrix method - theory and applications”, IEEE Trans. Microwave Theory and Tech., vol. 33, Oct. 1985.

L. de Menezes, W.J.R. Hoefer, “Modelling frequency dependent dielectrics in TLM”, IEEE AP-S Symposium Digest, pp. 1140-1143, Jun. 1994.

L. de Menezes, W.J.R. Hoefer, “Modelling nonlinear dispersive media in 2D-TLM”, 24th European Microwave Conference Proceedings, pp.1739-1744, Sept. 1994.

P. Naylor and R. Ait-Sadi, “Simple method for determining 3-D TLM nodal scattering in nonscalar problems,” Electronic Letters, vol. 28, pp. 2353-2354, Dec. 3, 1992.

Dispersion Analysis of State-Variable TLM Symmetrical Condensed Node

(Leonardo de Menezes and Wolfgang J.R. Hoefer)

The study of the numerical dispersion effects in discretization schemes is very important for time-domain simulation of Maxwell’s equations. The generalized dispersion analysis of 2D and 3D TLM formulations was presented in 1993, by Nielsen and Hoefer. However, only recently, closed-form solutions for the 3-D SCN TLM have been obtained.

We have performed a comparative dispersion analysis of the inhomogeneous 2-D and 3-D SC nodes using state-variable and stub-loaded models. Both analyses were performed with matrix-order reduction using frequency-domain techniques. The use of the state-variable model is more flexible than the stub-loaded approach and yields identical results for the approximate trapezoidal discretization scheme.

The results are presented in Fig.1.

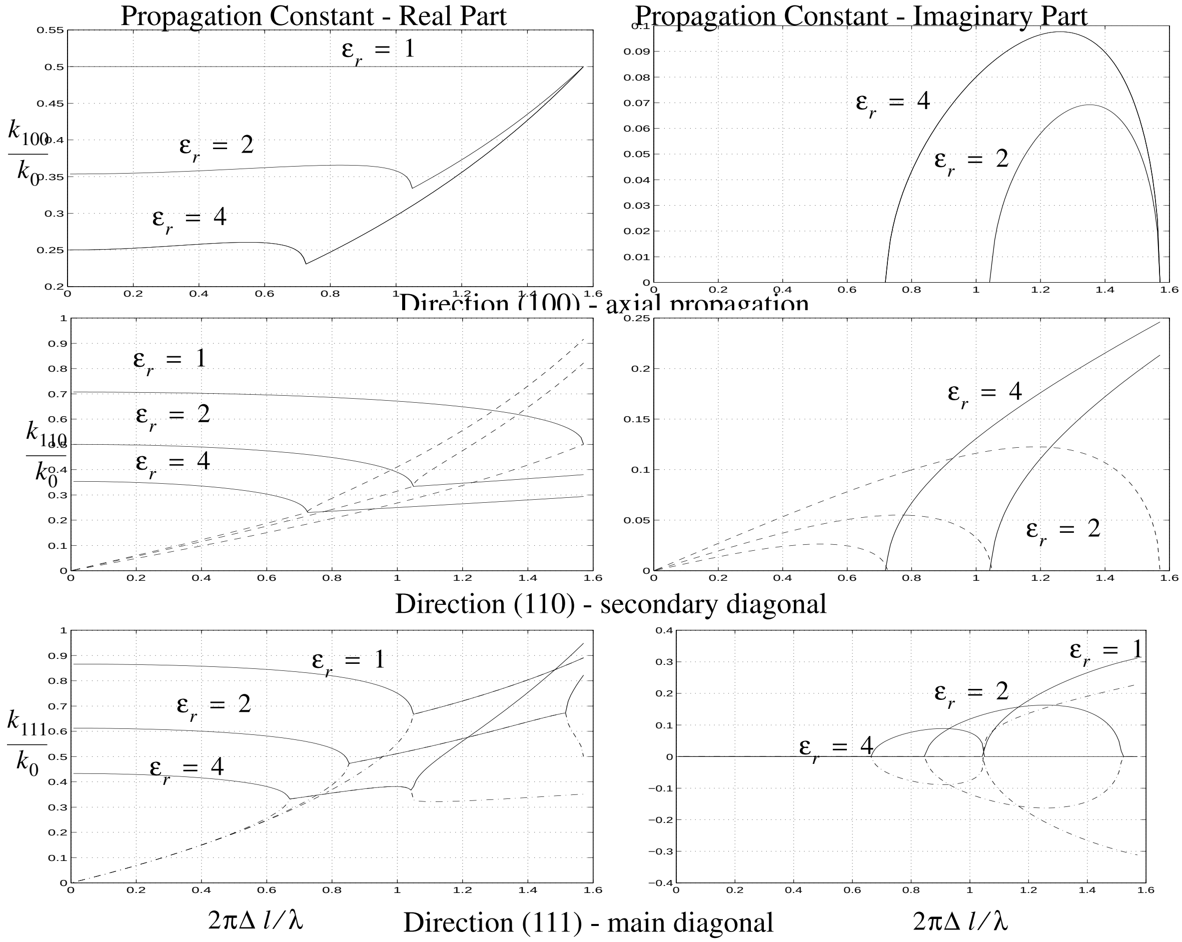


Fig.1 - Dispersion results for the 3D SCN TLM. Solid lines: lossless propagating modes, dashed lines: lossy modes, dash-dotted lines: spurious mode.

Further details can be found in:

J.S. Nielsen and W.J.R Hoefer, “Generalized dispersion analysis and spurious modes of 2-D and 3-D TLM formulations”, IEEE Trans. on Microwave Theory and Techniques, vol. 41, pp-1375-1384, Aug. 1993.

M. Krumpholz and P.Russer, “On the dispersion of TLM and FDTD”, IEEE Trans. on Microwave Theory and Techniques, vol. 42, pp. 1275-1279, Jul. 1994.

M. Celuch-Marcysiak and W.K Gwarek, “On the effect of bilateral dispersion in inhomogeneous symmetrical condensed node modelling”, IEEE Trans. on Microwave Theory and Techniques., vol. 42, pp. 1069-1073, Jun. 1994.

V. Trenkic, T.M.Benson and C.Christopoulos, “Dispersion analysis of a TLM mesh using a new scattering matrix formulation”, to be published on IEEE Microwave and Guided Wave Letters in Mar. 1995.

P. Naylor and R. Ait-Sadi, “Simple method for determining 3-D TLM nodal scattering in nonscalar problems,” Electronic Letters, vol. 28, pp. 2353-2354, Dec. 3, 1992

Recent Advances in Transmission Line Matrix Method Electromagnetic Wave Modelling and Visualization

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

A state-of-the-art electromagnetic wave simulator based on this method has been implemented. This simulator incorporates all the advanced TLM concepts and procedures described in [1] and [2] using the object-oriented programming paradigm [3]. 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 (FD-TD), finite difference (FD) and finite elements (FE) methods can be easily integrated into this simulator. The TLM simulator contains both shunt and series node algorithms.

This simulator is based on a *document-view* programming model [4]. The *document* part of the model contains C++ objects which encapsulate the data and procedures of the shunt and series two-dimensional TLM methods. 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, hence into this simulator, by simply deriving new methods from a common base method. This idea is depicted in Figure 1.

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 2 depicts the main control window together with the editor and its associated tool boxes. The main window 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 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, allows 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

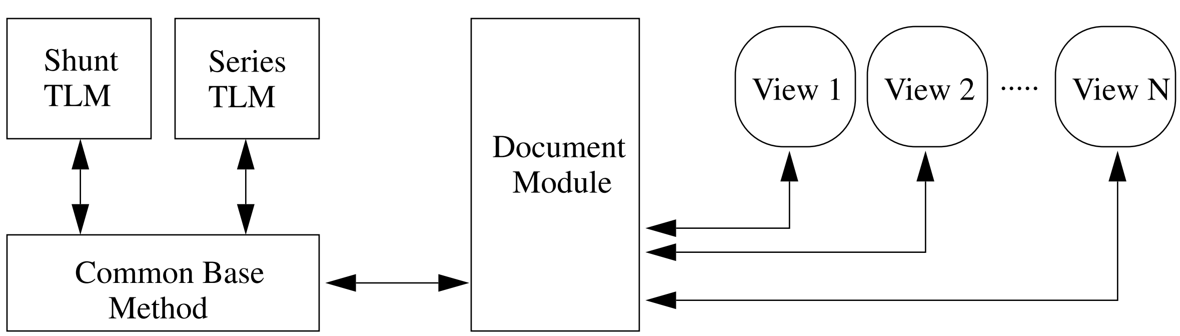


Figure 1: The *document-view* programming model used to implement this simulator. The *document* module isolates the base numerical method from the various graphical *view* modules. Therefore, compatible numerical methods can be easily incorporated into the simulator.

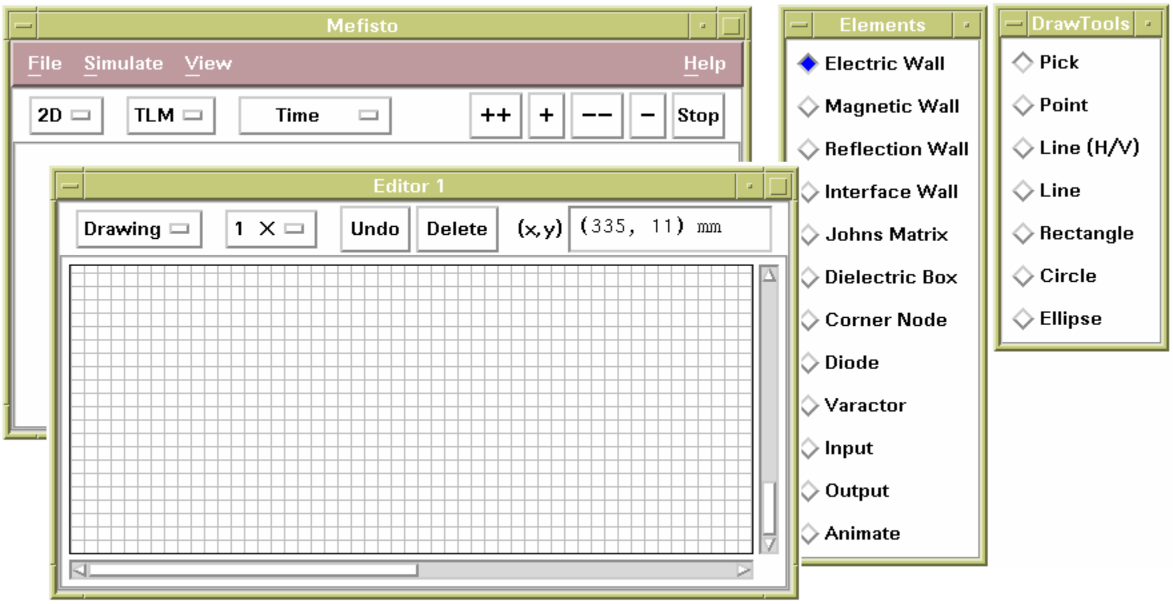


Figure 2: The graphical front end of the simulator. The tool boxes on the right of the Editor window allows the user to select the desired drawing element.

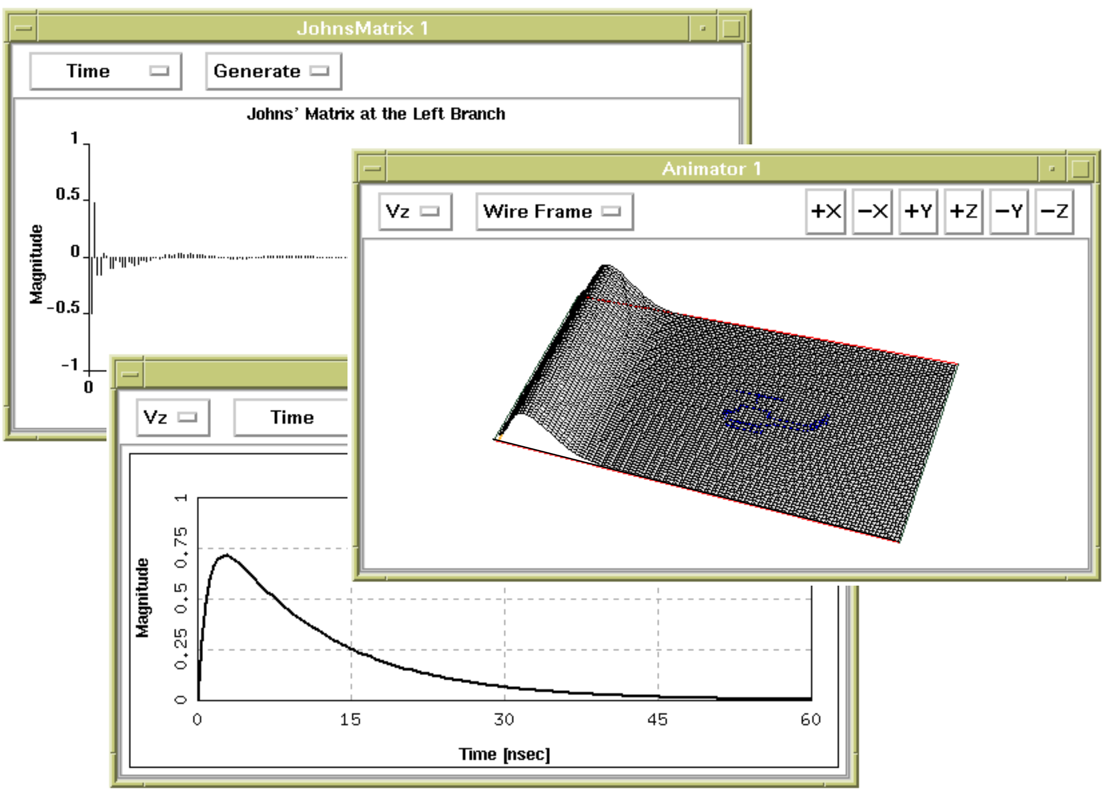


Figure 3: The Animator, Generator and Johns-Matrix windows of the simulator. These windows allow users to interactively control the input and output characteristics.

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

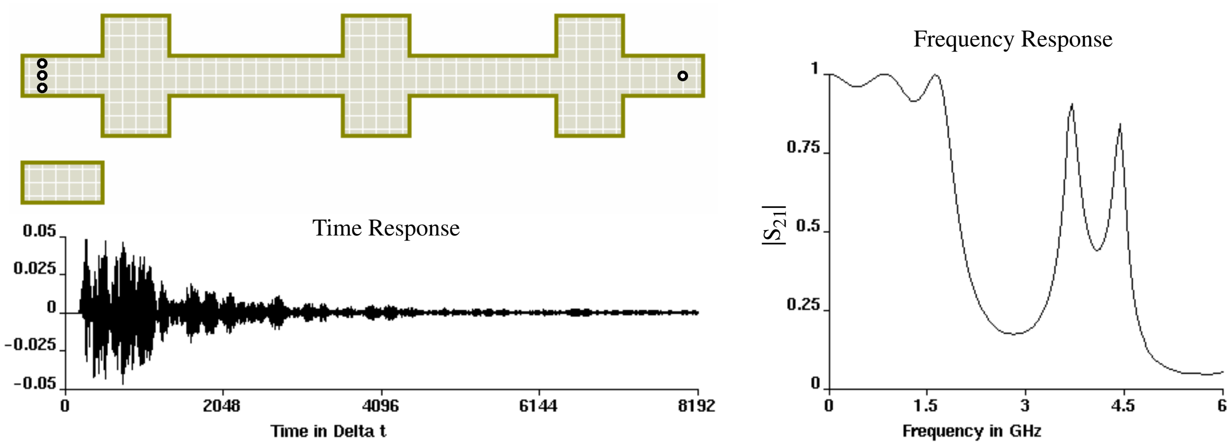


Figure 4: The equivalent two-dimensional TLM model of a microstrip low-pass filter, ($\varepsilon_r = 9.60$, $\varepsilon_{eff} = 8.22$, $\Delta l = 1$ mm)[1]. The input and output ports are at the left and right sides of the filter, respectively.

Richardson extrapolation procedure [5] 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 3.

Figure 4 depicts the topology of a microstrip low-pass filter modelled by its equivalent parallel plate waveguide model with non-dispersive effective permittivity. This model is, of course, quite limited but works well at "low" frequencies, in this case several GHz. The input and output ends of the filter are matched. A small reference section with the same electrical properties as the input end is needed for the direct extraction of the S-parameters of the filter, [1] and [2]. The time and frequency domain responses due to an impulse excitation are shown in the same figure as well.

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Modeling of Inhomogeneous Dielectric Layers Using TLM Cuboid Condensed Node

(Qi Zhang and Wolfgang J.R. Hoefer)

Traditional TLM models require stubs to model structures filled with dielectric layers, such as microstrip, finline, etc. Usually, when cubic cells are used to discretize inhomogeneous dielectrics, all cells are of equal size, but those in the dielectric other than air are loaded with stubs to slow down the network velocity and reduce the wave impedance. Since the wavelength is shorter in the dielectric regions, the discretization per wavelength is coarser. That, in turn, causes increased dispersion and coarseness errors. Hoefer and Sautier [1] have proposed a general 2D-TLM algorithm which removes the stubs in dielectric layers. In this project that concept has been extended to the 3D cuboid condensed node.

A 3D cuboid condensed node[2] with arbitrary aspect ratios is shown in Fig. 1. This is a unit cell of the generalized three-dimensional TLM network. As discussed in [1] the requirements of impulse synchronism and proper network velocities naturally impose a higher cell density in the dielectric regions. For example, a guiding structure may be uniform in the x-y plane, but consist of two or more dielectric layers in the z direction (see Fig 3.). In this structure, the propagation vectors are the same tangential to the dielectric interface, but different in the normal direction. The discretization in the x-y plane remains the same in both regions, while the discretization in z-direction must be finer in the higher permittivity region. Now we need to determine the aspect ratios of the cells in media 1 and 2. The network velocity is isotropic in both media. One is $c/(2\sqrt{\varepsilon_{r1}})$ and the other is $c/(2\sqrt{\varepsilon_{r2}})$. In addition to satisfying the phase condition at the interface we must also properly represent the impedance step across the interface. The voltage impulses crossing the interface will be scattered as shown in Fig. 2. Based on the above we can simulate inhomogeneous structures without the need for stubs. Since the mesh size in z direction is reduced in the higher permittivity region, dispersion error is reduced accordingly.

To verify the validity and accuracy of the algorithm for the cuboid cell, a parallel plate resonator has been chosen. A TLM implementation has been used to find the resonant frequency. The parallel plate resonator modeled on the computer is shown in Fig. 3. In order to compare the new with the traditional scheme, the resonator has been discretized into cuboid cells of aspect ratios $\alpha_1 = \beta_1 = \gamma_1 = 1$ in the air layer, yielding $\alpha_2 = 1$, $\beta_2 = 4$ as well as $\gamma_2 = 1/4$ in the dielectric layer (Fig. 4), and into cubic cells with stubs in the dielectric layer. The resonator was excited with a narrow Gaussian impulse, and its response was picked up at two observation points, one in the air region and the other in the dielectric region. Both output points give the same frequency response after Fourier Transform. The numerical results obtained from this simulation are summarized in the following Table 1:

Theoretical resonant frequency	TLM			
	Cuboid node w/o stubs		Cubic node with stubs	
f_r (GHz)	f_r (GHz)	error (%)	f_r (GHz)	error (%)
5.8355	5.8345	-0.017	5.8306	-0.084
13.5735	13.5622	-0.083	13.5911	+0.130
20.0084	20.0234	+0.075	20.7177	+3.545
25.3538	25.2308	-0.485	25.4839	+0.513
32.9191	32.7659	-0.465	31.6613	-3.821

We thus observe that the cuboid discretization gives better results than the cubic discretization. Based on this comparison, we demonstrate that the cuboid scheme maximizes the flexibility of the TLM method, agrees well with theoretical results, and has better accuracy than the traditional stub-loaded scheme.

References

[1] W.J.R. Hoefer and P. Sautier: ‘Characteristics of the general rectangular 2D-TLM network’ International Journal of Numerical Modelling Electronic Networks, Devices and Fields, vol.7, no.2,pp.127-139, March/April 1994.

[2] V. Trenkic, C. Christopoulos and T. M. Benson, ‘A graded symmetrical super-condensed node for the TLM method’, in IEEE-APS Symposium 1994 Digest, pp. 1106-1109.

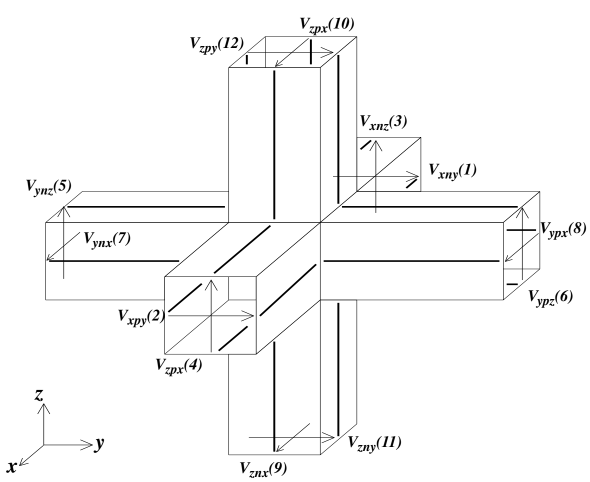

Fig 1. 3D cuboid condensed node

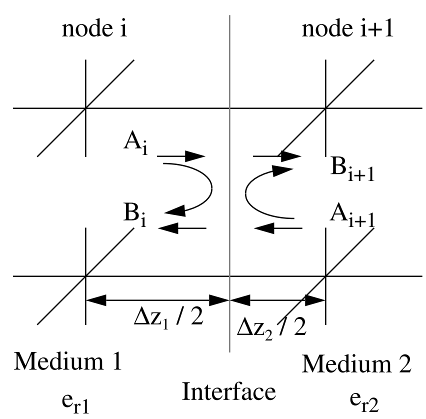

Fig 2. Impulse scattering at the interface between two dielectric media.

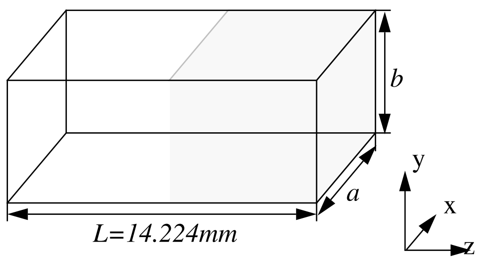

Fig 3. Parallel plate resonator

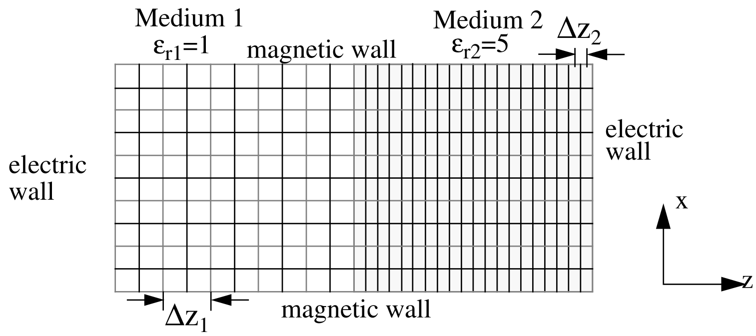

Fig 4. Discretization of parallel plate resonator (x-z plane)

Dispersion Characteristics of 3D Distributed Node and Condensed Node TLM Mesh with Cells of Arbitrary Aspect Ratio

(Qi Zhang and Wolfgang J.R. Hoefer)

It is well known that the dispersion error affects the accuracy of the TLM method due to the spatial discretization. In order to evaluate the accuracy of the TLM method and quantify the dispersion error, the dispersion relation of the discrete mesh has to be known. Recently the general three-dimensional distributed node and cuboid condensed node TLM mesh with cells of arbitrary aspect ratio have been proposed. The nodes remove the restriction that the cell shape must be cubic. Both nodes are stub-free. In this project we investigate the dispersion characteristics of both nodes. The dispersion analysis of a TLM mesh is based on the application of the Floquet theorem to an infinite three- dimensional mesh. The application can be described by an eigenmatrix equation, and its characteristic is the dispersion relation.

The cuboid distributed node contains a rectangular shunt node and a series node which are in an interlaced arrangement. The dispersion relation is shown in Fig. 1, where $\alpha = \Delta x/\Delta z = 0.5$ and $\Delta z/\lambda = 0.15$. For a coarse discretization $\Delta z/\lambda = 0.15$ the wavelength in the TLM network can no more be considered large compared with the network parameter Δz, and the velocity becomes dispersive and depends on the direction of propagation. The maximum dispersion occurs in the axial directions. For the above example Δz is larger than Δx, and the propagation vector becomes larger along the longer mesh (z-direction) than along the shorter mesh dimension (x-direction). For comparison, the dispersion characteristic of the equivalent cubic mesh has been plotted in Fig. 1. According to the above discussion, we can choose a wave propagation direction for our validation test and thus minimize the dispersion error in the numerical results. Similar work has been done for the cuboid condensed node. Fig. 2 shows its dispersion relation. Comparing with that of the cubic condensed node, the maximum dispersion error does not occur in diagonal direction, and the minimum error can be found at an angle different from 45^{o} and depending on the cell aspect ratios. In an arbitrary direction the dispersion surface is plotted for the 3D cuboid distributed node and condensed node in Fig. 3 and 4, respectively.

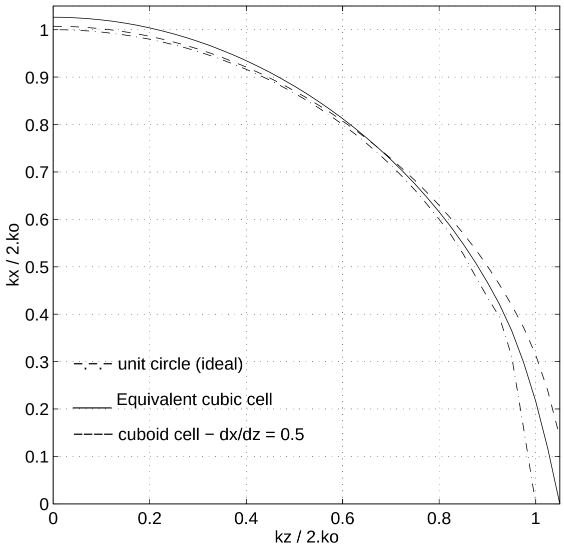

Fig. 1 The dispersion characteristics for a 3D cuboid distributed node in the x-z plane. Δx=0.3, Δy=Δz=0.6

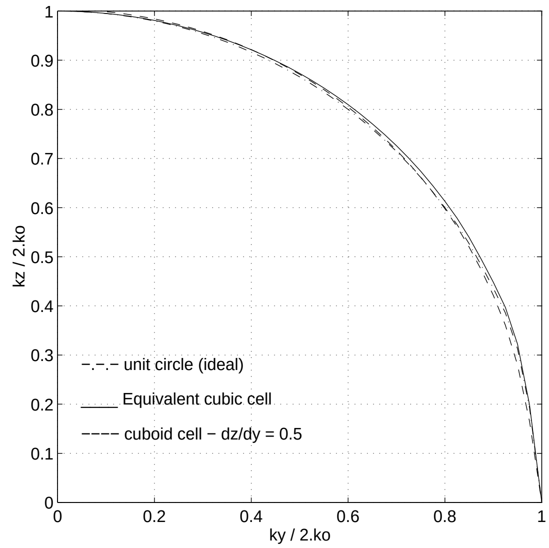

Fig. 2 The dispersion characteristic for a 3D cuboid condensed node in the x-y plane. Δx = Δy = 0.6, Δz = 0.3.

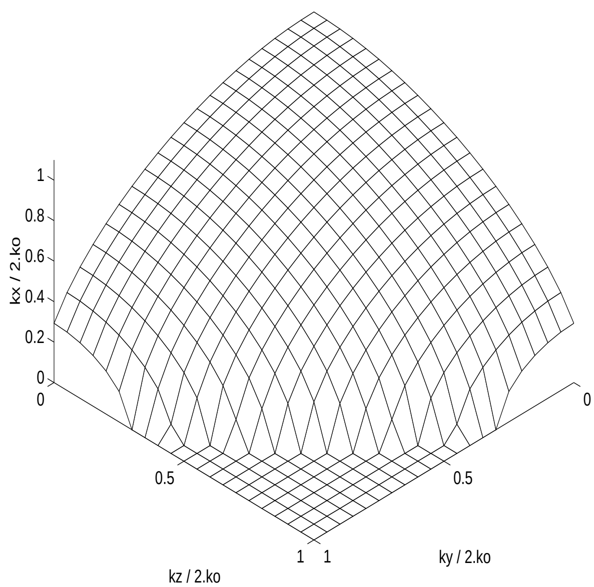

Fig. 3 Plot of the dispersion surface for the cuboid distributed node (Δx = 0.3, Δy = Δz = 0.6)

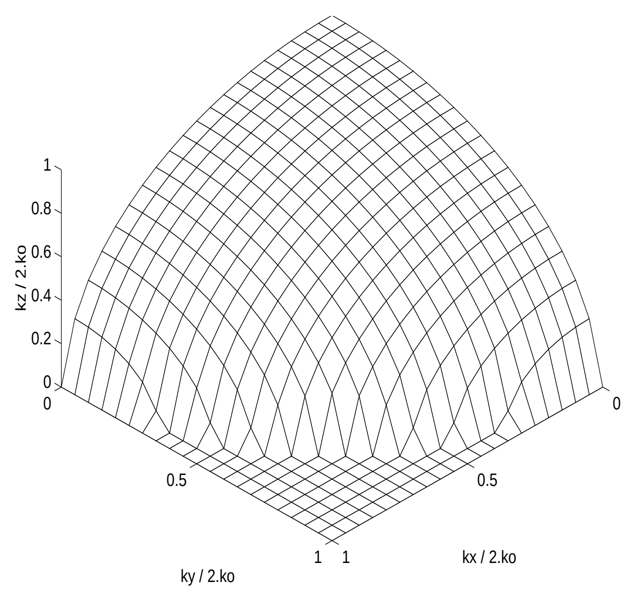

Fig. 4 Plot of the dispersion surface for the cuboid condensed

RCS of High Permittivity Cubes Computed with the TLM Method

(Channabasappa Eswarappa and Wolfgang J. R. Hoefer)

The three-dimensional time domain Transmission Line Matrix (TLM) method has been applied to compute the RCS of dielectric cubes of relative permittivity 37.84 and 79.46, and comparison has been made with published measurements [1]. Since the high permittivity cubes ring for a very long time, very good quality absorbing boundary conditions having long term stability are required. We have achieved these by modifying Higdon's absorbing boundary conditions. Long term stability has been obtained by using proper discretization of the boundary operators (derivatives), and very low reflections have been obtained by concatenating two first-order boundary operators. We have obtained stability beyond 60,000 time steps by placing the absorbing boundaries just 20 cells away from the cube surfaces (cube size is 15 cells). The near-field to far-field transformation technique based on the well known equivalence principle is applied to compute the far electromagnetic field components from the near tangential electric and magnetic fields on a closed fictitious surface surrounding the scatterer. The RCS data computed with the TLM method agree very well with the measurements published in [1], and are plotted in Figs. 1a and 1b. The frequency shift between the TLM results and the measurements is negligible, while a considerable frequency shift has been reported between results obtained with FDTD and measurement [1]. Further details can be found in [2].

References

[1] C.W. Trueman, S.J. Kubina, R.J. Luebbers, S.R. Mishra, and C. Larose, "RCS of High Permittivity Cubes by FDTD and by Measurement", *9th Annual Review of Progress in Applied Computational Electromagnetics* Digest, pp. 2-10, March 22-26, 1993, Monterey, CA.

[2] C. Eswarappa and W.J.R. Hoefer, "RCS of High Permittivity Cubes computed with the TLM Method", *11th Annual Review of Progress in Applied Computational Electromagnetics Digest*, pp. 13-20, March 20-25, 1995, Monterey, CA.

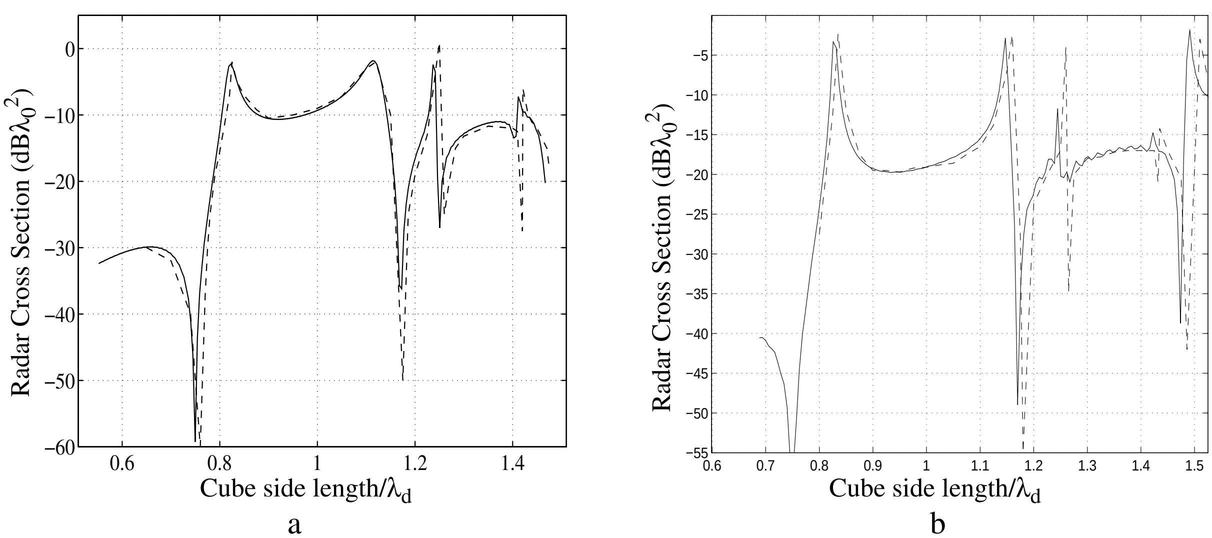

Fig. 1 : RCS computed with 60,000 TLM time steps:— TLM, -- Measurements by Trueman, et al. [1]

a) cube side length = 8.97 mm, ε_r = 37.84, bistatic angle = 8 degrees

b) cube side length = 7.72 mm, ε_r = 79.46, bistatic angle = 8 degrees

Treatment of Instabilities of One-way Equation Absorbing Boundary Conditions Using Digital Filters

(Channabasappa Eswarappa and Wolfgang J. R. Hoefer)

A very general solution has been proposed to the difficult problem of treating instabilities of one-way equation (local) absorbing boundary conditions in time domain electromagnetic simulations. Digital filters have been inserted between the mesh and the absorbing boundaries (as shown in Fig. 1) to filter out the high frequency numerical noise generated by the absorbing boundary interpolation equations. The problem arising out of the finite delay of the digital filters has been solved my making the filter delay equal to the time delay in the longer link lines of the graded mesh. By adopting this technique, instabilities have been eliminated as demonstrated in Figs. 2a and 2b.

Further details can be found in:

C. Eswarappa and W.J.R. Hoefer, "Treatment of instabilities of one-way equation absorbing boundary conditions using digital filters" accepted for presentation at 1995 *MTTS Symposium*.

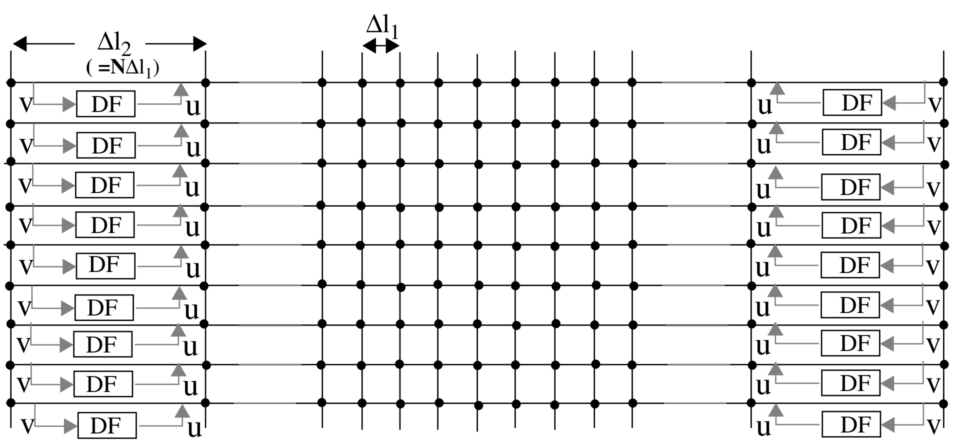

Fig. 1: Two-dimensional graded TLM mesh and digital filters (DF) to filter out the high frequency noise generated by the absorbing boundary interpolation equations. *v* is computed using absorbing boundary interpolation equations. *u* is the output of the digital filters.

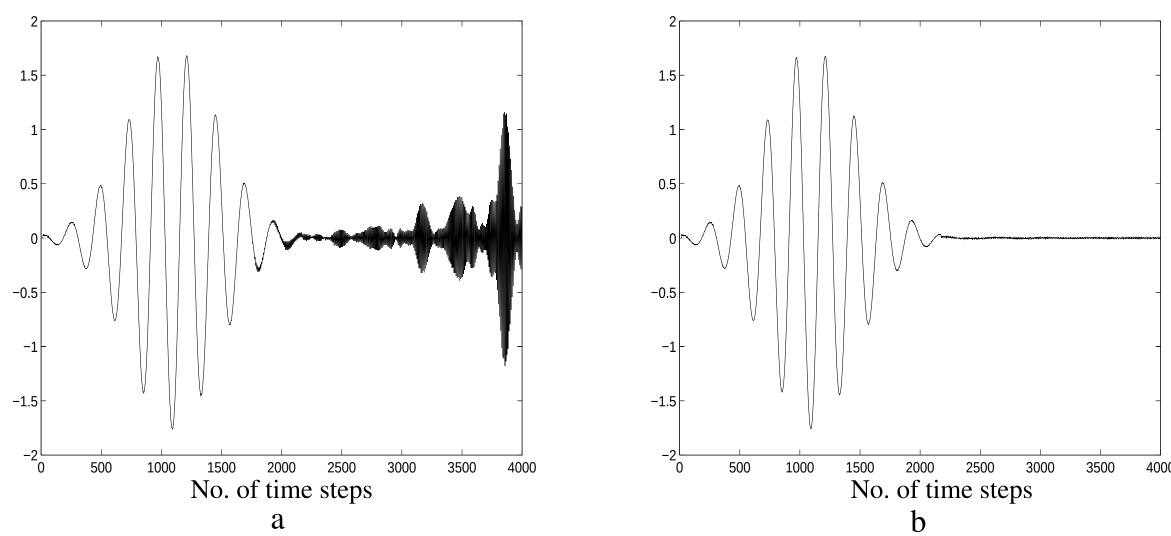

Fig. 2: Time domain responses of the waveguide (WR28) discretized with a variable mesh:

a) without digital filters, b) with digital filters inserted between mesh and absorbing boundaries.