Applied Computational Electromagnetics Society

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APPLIED COMPUTATIONAL ELECTROMAGNETICS SOCIETY (ACES)

NEWSLETTER

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Editor's comment

You will notice one or two new things in this edition of the Newsletter. In the last edition I used a couple of words that seemed to resonate somewhat: "sharing" and "community". Hence, there are some new sections dealing with ACES news and people.

I hope you feel more informed about the two main components of the ACES technical communication – namely the Journal and the Conference. Also, to foster the sense of community, I would like to introduce a little more information about some of the people and their places of work that help make up the ACES community.

I hope you find these additions interesting.

Please let me know what you think and I would like to hear your suggestions for other ways for the Newsletter to help serve the ACES members.

Best wishes

Alistair

apd@dmu.ac.uk

Applied Computational Electromagnetics Society

News

In this issue, welcome the new (and first) class of ACES Fellows, elect new members to the Board of Directors and see the flyer being developed to help promote ACES , the ACES Journal and the ACES Conference.

Election of ACES Fellows

Congratulations to the new ACES Fellows. The following Fellows have all demonstrated exceptional achievements in computational electromagnetics and service to ACES. The first class of ACES Fellows is:

Dick Adler
Atef Elsherbeni
Allen Glisson
Osama Mohammed
Andy Peterson
Doug Werner

Certificates and Plaques will be presented during the 2008 ACES Conference.

The selection committee comprised:

Chair: Randy Haupt, Penn State
Members (in alphabetical order):
Bruce Archambeault, IBM
Steven Best, MITRE
Weng Cho Chew, U of Illinois
Raymond Luebbers, REMCOM, Inc.
Ronald Marhefka, Ohio State
Carey Rappaport, Northeastern University

The Bye-laws state that:

The grade of Fellow is bestowed by the BOD upon a person with exceptional achievements in computational electromagnetics, including ACES publications, and extensive service to ACES. The candidate, the nominator, and the references must be members of ACES in the nomination year and the year this honor is bestowed.

Nominations are submitted to the Awards and Membership Committee by 1 Sep. The Awards and Membership Committee provides a list of recommended candidates to the BOD. At the Fall BOD meeting, the BOD votes to approve the list. ACES Fellows will be officially announced in the March Newsletter and will be recognized at the following ACES conference awards banquet.

If you are interested in finding out more about the ACES Fellow committee and Awards program, please contact Dr. Randy Haupt, rlh45@psu.edu.

Board of Directors Elections

The annual BoD elections are currently 'live' – with a closing date of 20th March. The voting papers can be found by going to http://aces.ee.olemiss.edu/ and clicking on the "BOD Elections" button.

The following reproduces the information of each of the candidates

Alistair Duffy

General Background

Dr Alistair Duffy is Reader in Electromagnetics at De Montfort University (DMU), Leicester, UK and Head of the Engineering Division in the School of Engineering and Technology at DMU. He received his BEng(Hons) and MEng degrees in 1988 and 1989 respectively from University College, Cardiff, University of Wales. He read for his PhD with professors Christopoulos and Benson at Nottingham University, graduating in 1993. He also holds an MBA from the Open University, UK, graduating in 2004. He is a Fellow of the Institution of Engineering and Technology (IET, formerly the IEE) and a Senior Member of the IEEE

He has published approximately 150 papers, mostly on his research interests of validation of computational electromagnetics; physical layer components, particularly communications cabling, and electromagnetic compatibility testing. These are the three areas on which he is lecturing as an IEEE EMC Society Distinguished Lecturer.

Alistair's professional service has seen him contribute to many successful conferences through refereeing functions or organising committee responsibilities (he is currently on the organising committee for the International Wire and Cable Symposium, which attracts approximately 1000 delegates annually). Publication commitments also see him as an Associate Editor for the IEEE Transactions on EMC and as Editor-in-Chief of the Transactions of the IWCS, as well as Editor-in-Chief of the ACES Newsletter. Other professional activities include standards body work in the UK (British Standards Institute) and in the IEEE.
Alistair was Series Editor for a series of undergraduate textbooks published by Butterworth-Heinemann (now part of Elsevier).

He has served in many committee roles in the IET (formally IEE) including Council, International Board and Chair of the Electromagnetics Professional Network.

Past Service to ACES
Alistair has contributed to the ACES newsletter for the last few years providing material for the *Perspectives on CEM* section, raising issues such as the balance of education of students in electromagnetics, how do we know when a simulation is good enough and should journal peer

review be open rather than anonymous. More recently he has been appointed as the Editor-in-Chief, taking over from Dr Bruce Archambeault.

He has organised and presented a special session on validation of computational electromagnetics at the 2006 ACES conference.

Candidate's Platform

I see my main mission, if elected as a member of the ACES BoD, to develop and improve the sense of 'community' that the membership of ACES brings. This is primarily bringing existing and new members together, physically or virtually, to share new knowledge, to ask questions, exchange material, probe each others expertise, and to debate issues of common interest.

I aim to be involved in developments to improve the impact, relevance and penetration of our Journal and Conference. I am supportive of activities to develop products that are relevant and useful to students, educators and practicing engineers. I would like to develop and contribute to initiatives that increase the interaction between ACES and other organisations, where this can be of tangible benefit to our members: both current and future.

Andrew Drozd

GENERAL BACKGROUND

Andrew L. Drozd is President and Chief Scientist of ANDRO Computational Solutions, LLC located at the Beeches Technical Campus in Rome, NY with offices in Bowie, MD. Since its establishment in 1994, his company's focus has been on the development and application of state-of-the-art computational electromagnetics (CEM) integrated toolkits, computational frameworks, hybridized numerical solutions, and dynamic spectrum optimization for large, complex system electromagnetic problems. Currently, the ANDRO Bowie, MD operations and staff report to him on efforts in support of spectrum engineering, spectrum management, and electromagnetic compatibility (EMC) analysis for large platforms and system deployments. Under a contract with ITT Corporation, he and the Bowie Operations staff members support efforts to further modernize and maintain the CEM and electromagnetic environment effects (E3) tools arsenal for the prime customer — the DoD Joint Spectrum Center.

Mr. Drozd received a Bachelor of Science Degree in Physics and Mathematics in 1977 from Syracuse University, and a Masters of Science in Electrical Engineering specializing in RF Communications and Signal Processing in 1982 also from Syracuse University.

Mr. Drozd has been a Member of the ACES Board of Directors since 2006. Additionally, since 2002 he has been the Chair of the Industry Relations Committee for ACES. In this capacity, he acts as liaison between the ACES Board and other industry, government, and academic organizations in order to encourage their participation in various ACES-sponsored activities. For example, he has been involved in arranging for vendor exhibitions and leading efforts to encourage participation in patron sponsorship programs as part of the annual ACES Conference. He has also led initiatives to conduct inter-society workshops and interactive forums for demonstrating the practical application of CEM software tools for solving real-world problems. He has arranged ACES special sessions at other technical conferences, including the Antenna Measurements Techniques Association (AMTA) annual conference. Since 1999, Mr. Drozd has been the Technical Features Article Editor for the ACES Newsletter.

He is the immediate Past President of the IEEE EMC Society (2006-2007) and is an IEEE Fellow "*For the development of knowledge-based codes for modeling and simulation of complex systems for Electromagnetic Compatibility*". He is on the Board of Directors of the IEEE EMC Society and continues in his role on the IEEE Technical Activities Board (TAB). Mr. Drozd is a Member of the IEEE Standards Association (SA). Additionally, he is a member of the IEEE EMC Society Standards Development Committee and is Chair of the P1597.1 and P1597.2 Working Groups for the development of an *IEEE Standard for Validation of CEM Computer Modeling and Simulation (M&S)* and a *Recommended Practice for CEM Computer M&S Applications*, respectively. His efforts along with those of the Working Groups he chairs have culminated in the first-of-its-kind standard and recommended practice for the validation of CEM techniques and computer codes.

Mr. Drozd has authored and co-written over 145 technical papers, reports, and journal articles on topics related to: system-level electromagnetic interference (EMI) analysis, numerical modeling and simulation, dynamic spectrum management, and automated target recognition (ATR). Over the years, he has refereed a number of publications, textbook manuscripts, and study guides devoted to EMC. In 1994 and 1995, he completed peer reviews of a manuscript for the textbook titled, Engineering Electromagnetic Compatibility and a bibliographic compendium on EMC authored by V. Prasad Kodali. He published chapters on *Computer Modeling and Simulation for EMC* in the *EMC/EMI Principles, Measurement & Technologies Study Guide*. He also contributed a chapter on *EMC Modeling and Simulation* for the 1st and 2nd Eds. of the Wiley/IEEE Press book titled *Engineering Electromagnetic Compatibility: Principles, Measurements, Technologies, and Computer Models* by V. P. Kodali. Mr. Drozd also refereed papers on CEM topics for the American Geophysical Union Radio Science Journal in 1997 and 1998. In 1991 he received a best paper award for his publication in the EMC Expo Proceedings titled, "*Analysis of EMI for Shuttle/Space Station Communications Links: An Expert System Approach*".

Additionally, Mr. Drozd organized and chaired well over twenty conference technical sessions, special sessions, and workshops at annual international EMC symposia and ACES conferences. The focus of these various sessions and workshops was on numerical modeling, spectrum management and optimization, EMC and waveform diversity, software standards development, RF communications and sensor systems, and intelligent transportation systems. In addition to ACES, these conferences and other activities have included:

Quality in Electronics Symposium
IEEE EMC Symposium
National Conference on High-Power Microwave Technology for Defense Applications
EMC Expo
International Zurich Symposium and Technical Exhibition on EMC
EMC Roma
EMC Japan/Tokyo
C3I Dual Use Technology and Applications Conference
Society for Computer Simulation (SCS)
Asilomar Conference on Circuits, Systems and Computers
European Cooperation in Science and Technology (COST) 261 Workshop: EMC in Complex and Distributed Systems
DoD E3 Program Review
Euro Electromagnetics (EUROEM/ANEREM) Joint Conference on High Power Electromagnetics, Ultra-Wideband Short Pulse Electromagnetics, and Unexploded Ordnance Detection & Range Remediation
International Wroclaw Symposium and Exhibition on EMC.

He is also an active participant in the Electromagnetic Code Consortium (EMCC) annual meetings. His other professional activities and memberships have included the IEEE MTT Society, Association of Computing Machinery (ACM), American Institute of Physics, and Optics Society of America. He is an iNARTE (International Association of Radio and Telecommunications Engineers) Certified EMC Engineer since the program's inception.

He is a member of the IEEE EMC Society's Technical Committee TC-9 on Computational Electromagnetics and has been a contributor on behalf of TC-6 on Spectrum Management and EMC.

As an active Member and Vice Chair of the IEEE EMC Society Education and Student Activities Committee, Mr. Drozd organizes an annual special workshop session on EMC experiments and modeling and simulation demonstrations held in conjunction with the annual International Symposium on EMC. Mr. Drozd launched and spearheaded this activity starting in 1992 under the auspices of the EMC Society Education and Student Activities Committee. The special session is designed for both the novice and experienced engineer. Important EMC phenomenology and effects are illustrated and demonstrated through physical hardware experiments and computer demonstrations. The session also highlights new or innovative approaches to EMC measurement and simulation. Because of his role as Chair of the Special Session on EMC Experiment Demonstrations, he has been an honorary member of every symposium steering committee since 1992.

Additionally, Mr. Drozd is a Member of the Executive Board of the Armed Forces Communications and Electronics Association (AFCEA) Erie Canal Chapter. In his present AFCEA capacity, he actively supports education, scholarship, scholastic achievement, and science fair award and incentive programs for students and teachers in the local school system.

Mr. Drozd was Chair of the IEEE Mohawk Valley Section's EMC Chapter from 1998 to 2002.

In summary, his fields of interest and expertise include CEM and the development of E3 tools for RF antenna modeling and analysis. Mr. Drozd's responsibilities include: systems engineering; E3 computer modeling, simulation and analysis; novel applications of AI/expert system technologies to CEM analysis; radar cross section (RCS); software development and 3-D visualization tools. Mr. Drozd continues to apply his over 30 years of technical and program experience in electromagnetic technologies primarily in the area of computer modeling. In recent years, he has been involved in applying AI/expert systems to the domain of electromagnetics problem solving. He has developed E3 software products under contracts with the US Air Force Research Laboratory and Naval Air Warfare Center, namely, the *E3Expert* toolkit, which is a progressive computer modeling and simulation capability and a computational framework that provides electromagnetic solutions for complex system using a stepwise multi-fidelity approach.

From 1984 to 1994, Mr. Drozd was a Senior Scientist at Kaman Sciences Corporation (currently ITT) where he managed an EMC Engineering Group. Prior to that he was an EMC Test Engineer for the General Electric Underwater Electronics Programs Department where he led MIL-STD-461/462 and MIL-E-6051 EMC measurement programs. During the 1983 to 1984 period he was an Instructor for Syracuse University teaching courses on Electromagnetics and Physics. From 1978 to 1983, he was the Lead EMC Engineer for the IIT Research Institute Intrasystem Analysis Program Support Center which was responsible for maintaining the inventory of US Air Force EM computer software codes. During the period 1976 to 1978 Mr. Drozd was a Technical Assistant for the US Air Force Rome Air Development Center (RADC) where he provided technical services to government test and computer simulation engineers on behalf of electromagnetic code modification and validation. One of the codes that he performed limited verification and validation (V&V) testing on at the time was the *General Electromagnetic Model for the Analysis of Complex Systems* (*GEMACS*) program. He also conducted laboratory measurements aimed at assessing component high-frequency parasitic effects and nonlinear responses in the HF/VHF regime.

PAST SERVICE to ACES

Mr. Drozd has been a Member of ACES for well over 15 years. He has been a Member of the ACES Board of Directors since 2006 and Chair of the Industry Relations Committee since 2002. He has concentrated on developing stronger ties to other agencies and institutions to broaden awareness of ACES and what it has to offer to its members internationally. He has further organized sessions and presented papers at many of the ACES conferences. He has been a long-time active member of ACES and its journal editorial board primarily as Technical Feature Article Editor for the ACES Newsletter. He has twice been a recipient of ACES service/recognition awards in 2002 and 2003 for contributions to the ACES community for his efforts as Technical Feature Article Editor and for his efforts on behalf of supporting industry relations.

CANDIDATE's PLATFORM

As an ACES Board Member, I will continue to strive towards the goal of bringing together various technical and industry/academic communities that have not necessarily been traditionally part of the mainstream of ACES. My hope to is help diversify the ACES technological forefronts, while keeping within our traditional vision and mission, and to help expand our membership base in the process. I firmly believe that ACES, like any established technical organization, must continually keep pace with upcoming as well as current developments in the relevant fields of interest, ours of course being CEM and its practical application. It must be more than just a theoretical exercise. My ongoing involvements in ACES along with my positions in the IEEE, EMC Society and other key organizations that foster new advancements in CEM and numerical tools, can only help this cause and achieve the goals of diversity and growth as I envision it. This will be accomplished in concert with other Board members and ACES colleagues. I have achieved some modest success over the past several years through my industry relations efforts and would like to further these accomplishments as a Board member. We are on the verge of a new age for numerical tools and CEM technologies. There is a new thrust afoot within government and academic CEM communities which is leading to resurgence in the advancement of CEM tools. Research is underway to develop the next generation of CEM tools and numerical approaches that will lead to a major broadening of our perspectives on CEM as we know it today and pave the way towards the collaborative, interdisciplinary realm of CEM in the coming few years. I would like to see the ACES community and its members be a major player in leading this advancement. My role as an ACES Board Member will be directed at achieving this goal and setting the stage for the future.

Erdem Topsakal

Erdem Topsakal was born in Istanbul, Turkey in 1971. He received his BSc. degree in 1991, M.Sc. degree in 1993 and PhD degree in 1996 all in Electronics and Communication Engineering from Istanbul Technical University. He worked as an Assistant Professor in Electrical and Electronics Engineering Department at Istanbul Technical University between 1997 and 1998. He was a post doctoral fellow from 1998 to 2001 and an assistant research scientist from 2001 to July 2003 in Electrical Engineering and Computer Science Department of the University of Michigan. In August 2003, he joined the Electrical and Computer Engineering Department of James Worth Bagley College of Engineering at Mississippi State University as an Assistant Professor. His research areas include implantable antennas, numerical methods, fast methods, antenna analysis and design, frequency selective surfaces/volumes, electromagnetic coupling and interference, direct and inverse scattering. He has published over 80 journal and conference papers in these areas. He received the URSI young scientist award in 1996 and NATO fellowship in 1997. He is the recipient of 2004- 2005 Mississippi State

University Department of Electrical and Computer Engineering outstanding educator award. He is a senior member of IEEE and an elected member of the URSI commissions B and K. He currently serves as the Chair for the Mississippi Academy of Sciences Engineering and Physics Division, Associate Editor-in-Chief for the Applied Computational Electromagnetics Society (ACES) journal, Associate Editor for IEEE Antennas and Wireless Propagation Letters (AWPL), and Secretary for URSI-USNC Commission K, Electromagnetics in Biology and Medicine. He is also a member of the IEEE United States Committee on Communications and Information Policy as a representative of IEEE Engineering in Medicine and Biology Society. He is a member of electrical engineering honor society, eta kappa nu.

Yashushi Kanai

GENERAL BACKGROUND

Dr. Yasushi Kanai is a current Associate Editor of *ACES*. He is a Professor of the Information and Electronics Engineering Department at Niigata Institute of Technology, Kashiwazaki, Japan. He received his Bachelor's Degree, Masters of Engineering Degree, and Doctorate Degree in Information Engineering from Niigata University, Japan, respectively in 1982, 1984, and 1989. He worked as a research engineer at Alps Electric Co., Ltd., from 1984 to 1992, where his responsibility was developing magnetic recording heads using numerical methods. During 1992–1995, he was an Associate Professor at the Department of Information Engineering, Niigata University. In 1995, he joined the Niigata Institute of Technology at its establishment. He has many years of teaching, research, and industry consulting experience. He has authored and co-authored more than 70 peer-reviewed journal papers, more than 90 international conference records, and more than 100 national conference records. Furthermore, he has contributed several chapters to books. He specializes in micromagnetic analysis, both in perpendicular magnetic recording heads and media, and electromagnetic field – heat transfer coupled computations of hyperthermic treatment. He is also interested in wave propagation using non-standard finite-difference time-domain (NS-FDTD) analysis. Professor Kanai was an Exhibit Co-chair of the Twelfth Biennial Conference on Electromagnetic Field Computation (IEEE CEFC Miami) during Apr. – May, 2006 and a Treasurer of the Eighth Perpendicular Magnetic Recording Conference (PMRC Tokyo) in Oct. 2007. He was also on the Advisory Boards of the 1st, 2nd, and 3rd IEEE North American Perpendicular Magnetic Recording Conference (2002, 2003, and 2004), the Programme Committees of the XII-th, XIII-th XIV-th, and XV-th International Symposia on Electrical Apparatus and Technologies, Bulgaria (2001, 2003, 2005 and 2007), and the Advisory Boards of the 1st and 2nd Nanoscale Devices & System Integration Conferences (2003 and 2005). He also has experience reviewing many journal papers and conference record digests, including IEEE Transactions on Magnetics, Journal of Applied Physics, and national journals in Japan.

PAST SERVICE to *ACES*

Currently an Associate Editor of *ACES*, Dr. Kanai has presented many papers at *ACES* Conferences since 1995. In 2003, he organized the special session related to "Japanese

Research in Electromagnetic Field Computations." It was the first attempt to organize a session exclusively related to Japanese research. For his contribution to organizing that session, he received The Valued Service Award. He also surveyed Japanese researchers and found that it was difficult to join and submit papers unless the journal has an Impact Factor listed on the ISI citation index. He conveyed that opinion to the then President. Eventually, the President accepted the opinion and now *ACES* has an Impact Factor listed on the ISI citation index. He was also a co-organizer of "Low frequency Applications 1" and "Low frequency Applications 2" at the *ACES 2006 Conference*. This attempt was based on his wish to invite many researchers of low-frequency applications to *ACES* to participate along with the high-frequency researchers. In cooperation with another co-organizer, he invited many Asian researchers to the *ACES* conference in Miami.

CANDIDATE's PLATFORM

I would like work with particular emphasis on several subjects, all of which are important to *ACES*. First, I would like to encourage many foreign researchers to join *ACES* conferences and submit many papers to the *ACES* journals. Because the *ACES Journal* now has an Impact Factor listed on the ISI citation index, increased participation of foreign researchers is expected. Second, I would like to encourage organization of "low-frequency" sessions as well as high-frequency sessions and welcome the involvement of low-frequency issue researchers to *ACES* conferences. In addition, I am currently co-organizing a special session "Non-standard FD-TD methods" at the *ACES 2008 Conference* at Niagara Falls, Canada. I will work hard to succeed this session.

Dr. Atef Z. Elsherbeni

GENERAL BACKGROUND

Atef Z. Elsherbeni received an honor B.Sc. degree in Electronics and Communications, an honor B.Sc. degree in Applied Physics, and a M.Eng. degree in Electrical Engineering, all from Cairo University, Cairo, Egypt, in 1976, 1979, and 1982, respectively, and a Ph.D. degree in Electrical Engineering from Manitoba University, Winnipeg, Manitoba, Canada, in 1987. He was a part time Software and System Design Engineer from March 1980 to December 1982 at the Automated Data System Center, Cairo, Egypt. From January to August 1987, he was a Post Doctoral Fellow at Manitoba University. Dr. Elsherbeni joined the faculty at the University of Mississippi in August 1987 as an Assistant Professor of Electrical Engineering. He advanced to the rank of Associate Professor on July 1991, and to the rank of Professor on July 1997. On August 2002 he became the director of The School of Engineering CAD Lab, and the associate director of The Center for Applied Electromagnetic Systems Research (CAESR) at The University of Mississippi. He was appointed as Adjunct Professor, at The Department of Electrical Engineering and Computer Science of the L.C. Smith College of Engineering and Computer Science at Syracuse University on January 2004. He spent a sabbatical term in

1996 at the Electrical Engineering Department, University of California at Los Angeles (UCLA) and was a visiting Professor at Magdeburg University during the summer of 2005.

Dr. Elsherbeni received the 2006 School of Engineering Senior Faculty Research Award for Outstanding Performance in research, the 2005 School of Engineering Faculty Service Award for Outstanding Performance in Service, The 2004 Valued Service Award from the Applied Computational Electromagnetics Society (ACES) for Outstanding Service as 2003 ACES Symposium Chair, the Mississippi Academy of Science 2003 Outstanding Contribution to Science Award, the 2002 IEEE Region 3 Outstanding Engineering Educator Award, the 2002 School of Engineering Outstanding Engineering Faculty Member of the Year Award, the 2001 ACES Exemplary Service Award for leadership and contributions as Electronic Publishing Managing Editor 1999-2001, the 2001 Researcher/Scholar of the year award in the Department of Electrical Engineering, The University of Mississippi, and the 1996 Outstanding Engineering Educator of the IEEE Memphis Section.

Dr. Elsherbeni has conducted research dealing with scattering and diffraction by dielectric and metal objects, finite difference time domain analysis of passive and active microwave devices including planar transmission lines, field visualization and software development for EM education, interactions of electromagnetic waves with human body, sensors development for monitoring soil moisture, airports noise levels, air quality including haze and humidity, reflector and printed antennas and antenna arrays for radars, UAV, and personal communication systems, antennas for wideband applications, and antenna and material properties measurements. He has co-authored 94 technical journal articles, 24 book chapters, and contributed to 266 professional presentations, offered 17 short courses and 18 invited seminars. He is the coauthor of the book entitled "*Antenna Design and Visualization Using Matlab*", Scitech, 2006, the book entitled "*MATLAB Simulations for Radar Systems Design*", CRC Press, 2003, the book entitled *"Electromagnetic Scattering Using the Iterative Multiregion Technique"*, Morgan & Claypool, 2007, the book entitled *"Electromagnetics and Antenna Optimization using Taguchi's Method"*, Morgan & Claypool, 2007, and the main author of the chapters "*Handheld Antennas"* and "*The Finite Difference Time Domain Technique for Microstrip Antennas"* in Handbook of Antennas in Wireless Communications, CRC Press, 2001. He was the main advisor for 31 MS and 8 PhD students.

Dr. Elsherbeni is a Fellow member of the Institute of Electrical and Electronics Engineers (IEEE) and a fellow member of The Applied Computational Electromagnetic Society (ACES). He is the Editor-in-Chief for ACES Journal, and an Associate Editor to the Radio Science Journal. He serves on the editorial board of the Book Series on Progress in Electromagnetic Research, the Electromagnetic Waves and Applications Journal, and the Computer Applications in Engineering Education Journal. He was the Chair of the Engineering and Physics Division of the Mississippi Academy of Science and was the Chair of the Educational Activity Committee for the IEEE Region 3 Section. Dr. Elsherbeni's home page can be found at http://www.ee.olemiss.edu/atef and his email address is Elsherbeni@ieee.org.

PAST AND CURRENT SERVICE TO ACES

Technical Program Chair of ACES 2006, 2007, and 2008 conferences
Co-chair of ACES 2005 conference
Chair of ACES 2003 conference
Co-chair of ACES 2004 conference
ACES electronic publication manager editor, 2000-present
ACES Journal Editor-in-Chief, 2002-present
ACES pilot electronic publication project and website developer, 1999-present
Presented papers at many ACES conferences
Chaired and co-chaired, and organized sessions at ACES conferences
Offered short courses at the last 6 ACES conferences
ACES publications committee chair, 2004-present
Member of ACES conference committee, 2003-present

CANDIDATE'S PLATFORM

For the coming few years, my continued service to ACES society will be focused on

- Enhancing the quality of the published journal articles and increasing the frequency of publications of the Journal,
- Expanding the scope of the Journal to include up to date applications addressing emerging technology,
- Expanding the annual conference activity and encouraging the participation from other electromagnetic communities in holding joint conferences in US and abroad,
- Continuing the development and enhancement of the on-line service provided by ACES web site, and
- Increasing the membership of the society

The ACES Flyer

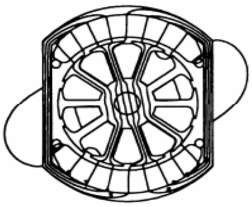
Although the title may sound like the name of an old steam locomotive, it actually refers to the development of a two page leaflet to be used (typically) at conferences and other meetings to raise awareness of ACES and of the Journal and Conference.

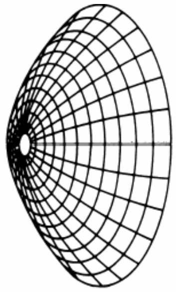
What is presented on the next couple of pages is the latest draft of the flyer. It will be finalised for the Conference.

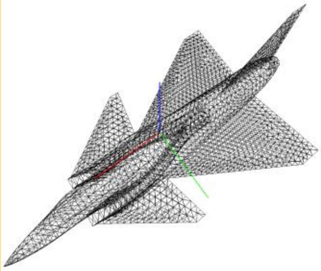
If you are holding a meeting or attending a conference and think that you may be able to distribute some of these to anyone who is (or is potentially) interested in the Society, then please get in touch with the Newsletter editor in the first instance.

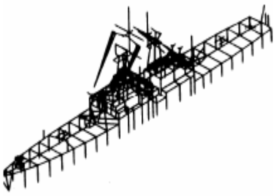
Applied Computational Electromagnetics Society Journal

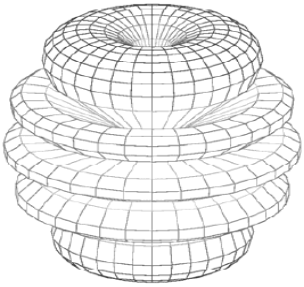
http://aces.ee.olemiss.edu











The Applied Computational Electromagnetics Society (ACES) Journal is devoted to the exchange of information in computational electromagnetics, to the advancement of the state of the art, and to the promotion of related technical activities.

The ACES Journal welcomes original previously unpublished papers, relating to applied computational electromagnetics. All papers are refereed.

The scope of the Journal includes, but is not limited to:

- Numerical solution techniques, optimization, and innovation;
- Technological innovation in Electromagnetics;
- Identification of new applications for electromagnetics modeling codes and techniques;
- New materials;
- Biomedical effects of EM fields;
- Integration of computational electromagnetics techniques with new computer architectures;
- Code validation.

Some recent papers that have appeared in the journal are:

➢ *A. Taflove, "A Perspective 40–year history of FDTD Computational Electromagnetics," vol. 22, no. 1, pp: 1-21, March 2007.*

➢ *J. L. Volakis, K. Sertel, and C. Chen, "Miniature Antennas and Arrays Embedded within Magnetic Photonic Crystals and Other Novel Materials," vol. 22, no. 1, pp: 22-30, March 2007.*

➢ *S. M. Ali, N. K. Nikolova M. H. Bakr, "Semi-analytical Approach to Sensitivity Analysis of Lossy Inhomogeneous Structures," vol. 22, no. 2, pp. 219-227, July 2007.*

The ACES Journal is published four times annually (in March, June, September and December). The electronic copy of the journal is available at no charge to ACES members.

Editor-in-Chief: **Atef Elsherbeni (atef@olemiss.edu)**

Applied Computational Electromagnetics Society

Around ACES

Many of us readily recognise the name Andy Drozd from his previous work with ACES, his work with other organizations and in his professional capacity with his company. In "Meet the ACESians", we find out a little more about what makes Andy who he is. Giulio Antonini is also a name that regular readers of this Newsletter will recognise. Giulio works hard as an associate editor for this Newsletter and, in "Members Laboratories", we find out a little more about where he works and what he works on.

Meet the ACESians

ANDY DROZD

Your Newsletter editor caught up with Andy Drozd and asked a few questions to find out a little more about the man.

Where were you born and brought up, where do you live now and what circumstances brought you there?

I was born in Vucht, Belgium at a very early age. I currently live in the Upstate New York Area (a.k.a. Central New York State, about 260 miles NW of New York City/Manhattan). My family and I emigrated from Europe (by way of Le Havre, France) to New York City in 1956. My family was displaced by WWII events and that's what brought us to America. My father had relatives who immigrated from Germany and Poland to the US prior to WWII. They took up residence in New York City, Buffalo and Rome, NY (Rome is currently where I reside and work with other family and friends).

What did you read at university, which university(ies) and why this (these) subjects?

I took up reading and studies at Syracuse University in Syracuse, New York in areas related to Physics and Mathematics. Prior to that while in High School, I was intrigued by the sciences, namely electrical science and themes related to advanced electromagnetics. That focused my interests on the four basic forces in nature (gravity, electromagnetic, weak and strong) and the attempts by pre-eminent scientists to unify them. My true area of interest early on in the university was on Einstein's Special and General Theory of Relativity and how it related to matter, energy, speed of light (ah ha! The electromagnetic part!!) and time-space relationships. As I got more involved and engrossed in EM waves, I developed a better appreciation for the EM aspects of this branch of science and that's what formed my foundation in my career and to a large extent, my personal side interests in reading up on this topic (string theory, etc.). As I conducted more in-depth research during the years that followed, I began to see how EM forces played a major role in our day-to-day lives and how it was so pervasive starting that the basic theoretical level on up through our computational EM work when we talk about *quadrature* mapping of Maxwell's equations for infinite space to a bounded, finite space problem. These processes have always intrigued me.

What is your current job and what does it entail? What are you most proud of achieving?

I am President and Chief Scientist for ANDRO Computational Solutions, LLC located at the Beeches Technical campus in Rome, NY with offices in Bowie, Maryland. Our focus has been on the development and application of state-of-the-art computational electromagnetics (CEM) integrated toolkits, computational frameworks, hybridized numerical solutions, and dynamic spectrum optimization for large, complex system EM problems. I manage as well as contribute technically to our R&D work which is largely sponsored by the US Department of Defense (DoD) to develop new tools and techniques for modelling and simulating system-level EM problems. I am most proud of my achievements in developing the *E^3Expert* toolkit which is an integrated suite of tools that employ artificial intelligence/expert systems to solve, in a progressive manner, various electromagnetic environment effects (E^3) problems and applications. Expert system techniques are used to guide the analyst in the model generation process and how/when to apply certain numerical solutions based on time, frequency, and fidelity (accuracy) requirements. I am also proud to have been elevated to IEEE Fellow "*For the development of knowledge-based codes for the modelling and simulation of complex system Electromagnetic Compatibility (EMC)*".

If you weren't doing this job what would your ideal occupation be? What are your abiding passions?

I still have strong interests in research work related to EM wave theory and particle physics as applied to unifying the four fundamental forces. I have always been fascinated by the time-space relationships that Einstein and his contemporaries wrote about and how time and space can be warped to allow for forward and backward movement within these dimensions. Astronomy, cosmology, and subjects dealing with the meaning of life are collectively an abiding passion. If I had to do it all over again, I might consider doctoral work in these or related areas. I think many of the answers of life will be discovered in pursuing these topics. I think that time travel will one day be realized, not in our lifetime though!

If you were abandoned in an underground laboratory with no immediate chance of release and with the opportunity of only using one numerical technique, which technique would you want to use and why? What 'big problem' would you want to spend your time trying to solve with your modelling?

This is indeed an insane question, but a probing one. I'll provide a lunatic fringe sort of answer. I would like to be able to take a finite-difference time-domain solution to a new level and perhaps marry it with a multilevel fast multipole algorithm to study the effects of fields on and from the human body in near real time. I would like to analyze the effects of EM energy surrounding the human body and its interaction with surrounding media and other incident forces to see if medical/healing effects can be derived. In other words, use a *feng shui* approach to study how to exploit EM energy for humanitarian/medical purposes.

If you had a 'one shot' time machine to bring someone from any period of history to keep you company in the underground laboratory, who would you choose and why?

Well, Einstein would be an obvious choice, but I would also would like to bring Jesus Christ, Socrates, Newton and Descartes into the mix, in that order.

Any interesting stories or anecdotes?

I believe that our dreams are opportunities for our inner selves (say the soul) to migrate in time and space and explore or experience the possibilities of past and future lives. I think we are not here by accident but we are being constantly tested and challenged. In the long run, I think that makes us better beings. I find that dreams can come true if you believe and read the signs. However, I am also a firm believer in the power of probability and chance (Einstein would have disagreed with that!). I think that we can shape the future based on our past and our present experiences, but chance and fate play big roles in helping or hurting our attempts. We can all be prophets of one kind or another, but some are better at it than others.

Members Laboratories

The University of L'Aquila EMC Laboratory

The UAq EMC Laboratory is part of the Department of Electrical Engineering of the University of L'Aquila (L'Aquila, Italy). It is directed by Prof. Antonio Orlandi and coordinated by Prof. Giulio Antonini (ACES Member) and has more than 10 members including Faculty members, PhD and Masters students. The taught courses that are taught specifically by academics from the laboratory are Electromagnetic Compatibility (EMC) and Signal Integrity, these are taught in the School of Engineering.

The Laboratory has a long term research cooperation agreement with the EMC Laboratory at the Missouri University of Science and Technology (MS&T, Prof. J. Drewniak) formerly University of Missouri at Rolla (UMR) in the field of EMC and Signal/Power Integrity for high-speed digital boards.

The laboratory has received the IBM Shared University Research (SUR) grant for three years in a row and is the only laboratory in Italy to achieve this.

The main focus of the research activity of the UAq EMC Laboratory is numerical modelling and simulations. The aims are twofold: firstly, to develop advanced numerical techniques for the solution of challenging issues in EMC and Signal Integrity subjects and, secondly, to apply these techniques and strategies to support industry in the solution of real-world problems. In doing achieving this, it is considered that developing a detailed understanding of physical mechanisms using numerical modelling is fundamental to offering qualitative and quantitative design guidelines with scientific bases.

Some of the areas where this has been applied include:

- Systems level strategies to understand interaction of large systems with impulsive electromagnetic sources such as LEMP or EMP. In these cases parts of the systems are represented by three dimensional full wave models and parts are represented by 1- or 2D models. The connection between these models is the critical part. Ad hoc procedures have been developed but also research efforts are given over to devising approaches for commercial software (widely used in Industry) to perform these tasks.

- In the field of board design the goal is the quantification of the impact that passive structures such as vias, and materials have on digital signal and power quality. An on going project on large backplanes for 10 to 40 Gb/s data stream is used to steer the modelling research efforts. This is particularly challenging due to the combination of high frequencies and large geometrical dimensions involved.

- The power integrity issues related to digital boards focus on the cavity model approach that conjugates accuracy with light CPU and memory requirements. The use of this approach for multilayer structures and with a wide frequency range; from low frequencies, where the skin effect it is not well developed, to high frequencies are current research topic of the Laboratory's Researchers.

Among the projects in which the Laboratory is involved in cooperation with other international research institutions there is the development of the Feature Selective Validation (FSV) technique with Dr Alistair Duffy at the De Montfort University (Leicester, UK) the FSV technique is continuously improved and appropriate software tools are developed and made available for download at http://ing.univaq.it/uaqemc/ . The FSV technique is used to compare different datasets (such us those coming from numerical simulations, measurements, etc.) and aims to mimic the judgement of a group of experts when they perform the same comparison by visual inspection of the data. FSV has been identified as the preferred technique for data comparison by the IEEE Standard P1597.

The UAq EMC Laboratory has established a fruitful cooperation with Dr. A. Ruehli, the father of Partial Element Equivalent Circuit (PEEC) and Modified Nodal Analysis (MNA), at the IBM T. J. Watson Research Center (NY, USA). Over the years, the Laboratory has made significant contributions to the advancements of the PEEC method in the field of dielectric and magnetic material modelling, broadband PEEC models, non-orthogonal PEEC formulation. An on going project aims to develop a fast time-domain solver based on the waveform relaxation technique.

The rapid increase in operating speed and density of modern integrated circuits is a challenging problem for the transmission line modelling method. Its difficulty comes from the requirement to properly capture physical effects like reflection, dispersion, delay and attenuation which cannot be neglected when broadband signals propagate along the interconnect. The use of time-domain macromodels is mandatory when non-linear drivers and receivers are to be incorporated. The necessity to properly model lossy and dispersive effects, such as skin-effect and dielectric losses, makes the macromodeling a challenging task. Recently a new spectral formulation has been proposed for transmission line macromodeling. The open-end impedance matrix is expressed in a series form as an infinite sum of matrices of rational functions, The rational form of the open-end impedance matrix allows an easy identification of poles and residues and, thus, the development of a reduced-order system of the interconnect. The pole-residue representation can be synthesized in an equivalent circuit or converted into a state space model which can be easily embedded into conventional non-linear circuit SPICE-like solvers. Such a technique has been successfully applied to printed circuit board and on-chip interconnects. The same technique has also been adopted to model nano-interconnects.

The Laboratory has well established research collaborations with leading research institutions such as the Packaging Research Center of the Georgia Institute of Technology (Atlanta, GA, USA, Prof. M. Swaminathan), the EISLAB of the Lulea University of Technology (Lulea, Sweden, Prof. J. Delsing), the University of Ghent (Ghent, Belgium, Prof. T. Dhaene), IBM T. J. Watson Research Center (NY, USA, Dr. A. Ruehli), University of Washington (Seattle, USA, Prof. V. Jandhyala), the EMC Laboratory at the Katholieke Hogeschool Brugge-Ostende (Bruge, Belgium, Prof. J. Catrysse), IBM Research Triangle Park (NC, USA, Dr. B. Archambeault).

Members of the UAq EMC laboratory. Giulio Antonini (4th from right, front row) and Antonio Orlandi (4th from left, front row)

Applied Computational Electromagnetics Society

Publications update

With the conference about upon us, the following pages give an outline of the veritable feast of computational electromagnetics in Niagara Falls. The contents of the most recent couple of issues of the Journal are presented: remember, you can access the papers through the ACES website.

ACES Conference, Niagara Falls March 30 – April 4 2008

This section gives an outline of what to expect in the technical sessions at the ACES conference.

More information can be found at http://aces.ee.olemiss.edu

ACES 2008 Short Courses

The FDTD Technique for EM Applications -
Atef Elsherbeni
Advanced FDTD Methodologies –
James B. Cole
Transmission-Line Metamaterials and Their Applications -
George Eleftheriades
Progress in Applied Electromagnetics: Theory and Numerical Implementation –
Geyi Wen
Advanced Strategies for Solving Problems with FDTD –
James B. Cole
ACA, Adaptive Cross Approximation -
John Shaeffer
Printed RF Electronics, RFIDs and Wireless Sensors: State and Challenges -
Manos Tentzeris

ACES 2008 Invited Plenary Talks

"Smart Antennas and their Impact on Network and Communication Systems Performance" -
Constantine A. Balanis,
"Antennas for Wireless Communications: Recent advances using Dielectric Resonators"
Yahia Antar,
"3D Anisotropic Periodic Media: from Concepts to Printed Antenna Realizations"
John L. Volakis ,
"Negative-Refraction Metamaterials and their Applications",
George V. Eleftheriades,
"Microwave Antennas for Medical Applications"
Koichi Ito
"Industrial Trend and Design Challenges in Wireless Handheld Development"
Nagula Sangary,

ACES 2008 Technical Program

PLENARY SESSION
"Smart Antennas and their Impact on Network and Communication Systems Performance"
Constantine A. Balanis

PLENARY SESSION
"Antennas for Wireless Communications: Recent advances using Dielectric Resonators"
Yahia Antar

STUDENT PAPER COMPETITION
Session Chairs:
Mohamed Bakr and Amir Zaghloul
"Modeling of Volumetric Negative-Refractive-Index Media Using Multiconductor Transmission-Line Analysis"
Scott Rudolph and Anthony Grbic
"Numerical Models of the Volume Response Function of Conductance Catheters: the Effect of Multiple Unused Electrodes"
John E. Porterfield and John A. Pearce
"Comparison of the Distorted Born Iterative and Multiplicative-Regularized Contrast Source Inversion methods: the 2D TM case"
Colin Gilmore, Puyan Mojabi, and Joe LoVetri
"Modeling of Vertical Displacement CMOS-MEMS Capacitive Sensors"
Greg McFeetors and Michal Okoniewski
"Breast Skin Effect on Scattered Electromagnetic Fields"
Douglas A. Woten, Shruti Pandalraju, and Magda El-Shenawee
"Computation of the Impulse Response and Coding Gain of a Digital Interconnection Bus"
Hristomir Yordanov, Michel T. Ivrlac, Amine Mezghani, Josef A. Nossek, and Peter Russer
"An hp-Adaptive Discontinuous Galerkin Method in Time Domain Applied to the Simulation of Highly Localized Current Sources"
Sascha Schnepp, Erion Gjonaj, and Thomas Weiland
"Application of the Radial Point Interpolation Method as Meshless Time-Domain Technique in Electromagnetics"
T. Kaufmann, C. Fumeaux, and R. Vahldieck
"A Method for Introducing Nonuniform Grids into the FDTD Solution of the Transmission-Line Equations Based on the Renormalization of the Per-Unit-Length Parameters"
Roberto B. Armenta and Costas D. Sarris
"Improved Forward Backward Method Applied to 2D Scattering Problems"
Marie Mullen, Conor Brennan, and Turlough Downes

MICROWAVE IMAGING AND INVERSE PROBLEMS
Session Organizer:
Magda El-Shenawee
Session Chair:
Magda El-Shenawee
"Modelling 3D mm-Wave Scattering from Human Body Under Gaussian Beam Illumination with a 2.5D VIE Solver"
Sara Van den Bulcke and A. Franchois

"Photogrammetry-based Surface Reconstruction for Improving Microwave Breast Tumor Detection"
Aastha Trehan, Reza K. Amineh, Mihail S. Georgiev, and Natalia K. Nikolova
"Microwave Imaging Exploiting AdjointBased Surrogate Models"
Mohamed H. Bakr, Peipei Zhao, and Natalia K. Nikolova
"Breast Skin Effect on Scattered Electromagnetic Fields"
Douglas A. Woten, Shruti Pandalraju, and Magda El-Shenawee
"Mathematical Modeling of Breast Lesion Growth"
Ahmed Hassan and Magda El-Shenawee
"Impact of an Antenna Scan Pattern on Surface Estimation for Radar-Based Breast Cancer Detection"
Trevor C. Williams, Jeff M. Sill, and Elise C. Fear
"Breast Shape Reconstruction using Microwave Techniques and the Level Set Method"
Mohammad Reza Hajihashemi and Magda El-Shenawee
"A Swarm-based Multi-Scaling Inverse Strategy for Three-Dimensional Microwave Imaging"
Andrea Massa, Massimo Donelli, Davide Franceschini, Manuel Benedetti, and Renzo Azaro
"Towards the Synthesis of Plasmonic Nanostructures by Means of Stochastic Optimization"
Demetrio Macias, Alexandre Vial, Dominique Barchiesi, Gilles Lerondel, Marianne Derouard, and Jerome Hazart
"Hybrid Binary-Real Genetic Algorithms for Microwave Image Reconstruction"
A. Ashtari, S. Noghanian, A. Sabouni, and G. Thomas
"Comparison of the Distorted Born Iterative and Multiplicative-Regularized Contrast Source Inversion Methods: the 2D TM case"
Colin Gilmore, Puyan Mojabi, and Joe LoVetri
"Water Content and Tissue Composition Effects on Microwave Tomography Results"
Abas Sabouni, Sima Noghanian, and Stephen Pistorius
"Data derived generalized SEA applied to MPV TD data"
Fridon Shubitidze

ANTENNA MODELING AND SMALL ANTENNAS

Session Organizers:
Qinjiang Rao and Dong Wang
Session Chairs:
Qinjiang Rao and Dong Wang

"Wideband Printed CPW-fed Binomial Curved Slot Antennas"
Xian-Ling Liang and Tayeb A. Denidni
"User's Hand Effects on Built-in L-shaped Folded Monopole Antenna for Mobile Handsets"
Yongho Kim, Toshiteru Hayashi, Yoshio Koyanagi, and Hisashi Morishita
"Realization of a compact Patch Antenna over an Artificial Magneto-Dielectric Substrate"
W. Abdouni, A-C Tarot, A. Sharaiha
"A Design Method for Pattern/Polarization Diversity Antenna"
George Shaker, Gholamreza Rafi, Safieddin Safavi-Naeini, and Nagula Sangary
"A New UWB Microstrip-Fed Planar Elliptical Patch Antenna for Wireless Communications"
Abdallah A. Alshehri and A. R. Sebak
"Q-factor Investigation of Antennas over Magneto-Dielectric Substrates"
Sylvain Collardey, Ala Sharaiha, and Kouroch Mahdjoubi
"Investigation of Signal Integrity in On-Chip Antennas"
K asra Payandehjoo and Ramesh Abhari
"A Multiple Folded Strip Antenna for Handset Devices"
Qinjiang Rao, Wen Geyi, and Dong Wang
"The Advantages of BICGStab(l) Algorithm in the Design of Implantable Antennas"
K. B. Grantham and E. Topsakal

BOUNDARY ELEMENT METHOD AND ALLIED TOPICS IN COMPUTATIONAL ELECTROMAGNETICS

Session Organizer:
Alireza Baghai-Wadji
Session Chair:
Alireza Baghai-Wadji
"Approximating the Scattering Coefficients for a Non-Rayleigh Obstacle by Boundary Defect Minimization"
Giovanni F. Crosta
"A Parallel CBFM-MLFMA Implementation for the Analysis of Complex Problems"
Eliseo García, Carlos Delgado, Iván González, and Felipe Cátedra
"An inherently Well-Conditioned Integral Equation to Solve the Scattering Problems by Partially Coated Objects"
Florence Millot and Sebastien Pernet
"Improved Forward Backward Method Applied to 2D Scattering Problems"
Marie Mullen, Conor Brennan, and Turlough Downes

COMPUTATIONAL ELECTROMAGNETICS FOR NONDESTRUCTIVE EVALUATION AND MATERIALS CHARACTERIZATION

Session Organizers:
Jeremy Knopp and Michael J. Havrilla
Session Chairs:
Jeremy Knopp and Michael J. Havrilla
"Characteristics of a Current Wire Near a Conductor Surface"
Farzad Tavakkol Hamedani

"The Joy of Computing with Volume-Integrals" Harold A. Sabbagh, R. Kim Murphy, and Elias H. Sabbagh

"Fast Multipole Algorithm for the Evaluation of Magnetostatic Fields in 3D Ferromagnetic Samples"
Ben Van de Wiele, Femke Olyslager, and Luc Dupre

"Model based Inversion Technique of GMR signals using Element-Free Galerkin Method"
Xin Liu, Yiming Deng, Zhiwei Zeng, Lalita Udpa, and Jeremy S. Knopp

"Finite Formulation for Modeling Complex Half - Space Problems"
Maryam Heshmatzadeh and Greg E. Bridge

"Numerical Simulation of the 3-D Temperature Distribution"
C Meng, J. T. Tang, J. P. Cheng, Q. Sh Xia, and Y. N. Liu

FINITE-VOLUME AND DISCONTINUOUS GALERKIN TIME-DOMAIN TECHNIQUES

Session Organizers:
Joe LoVetri and Christophe Fumeaux
Session Chairs: J
Joe LoVetri and Christophe Fumeaux

"Introduction of Composite Material and Thin Wire Formalisms in a Discontinuous Galerkin Time Domain Method" - . Volpert, X. Ferrieres, B. Pecqueux, and G. Cohen T

"Efficient Time Integration Strategies for High Order Discontinuous Galerkin Time Domain Methods" - Adrien Catella, Victorita Dolean, Loula Fezoui, and Stephane Lanteri

"An hp-Adaptive Discontinuous Galerkin Method in Time Domain Applied to the Simulation of Highly Localized Current Sources" - Sascha Schnepp, Erion Gjonaj, and Thomas Weiland

"The Complex Frequency-Shifted PML Discontinuous Galerkin Time-Domain Method on Unstructured Meshes" - Harald Songoro and Zoltan Cendes

"FVTD Thin-Wire Modelling of a Microwave Tomography System" - Dmitry Firsov, Cam Kaye, and Joe LoVetri

"Spherical Domain Truncation for the FVTD Method" - C. Fumeaux, D. Baumann, K. Sankaran, T. Kaufmann, R. Vahldieck, and E.-P. Li

OPTIMIZATION TECHNIQUES FOR ELECTROMAGNETIC APPLICATIONS

Session Organizer:
Ozlem Kilic
Session Chairs:
Ozlem Kilic and Randy Haupt

"Optimized Aperiodic Concentric Ring Arrays" - Randy L. Haupt

"FEKO Optimization Capabilities: Simplex, Particle Swarm, Genetic Algorithm" - Marlize Schoeman, Ulrich Jakobus, and Brian Woods

"Comparison of Nature Based Optimization Methods for Multi-beam Satellite Antennas" - Ozlem Kilic

"Nature-Inspired Optimization of Metamaterials" - Do-Hoon Kwon, Zikri Bayraktar, Jeremy A. Bossard, Douglas H. Werner, and Pingjuan L. Werner

"Direction Finding Applications in Numerical Electromagnetic Optimization" - Keith A. Lysiak and Jason Polendo

"Design of an Ultra-Wideband Antenna Using Taguchi's Optimization Method" - Wei-Chung Weng, Fan Yang, and Atef Z. Elsherbeni

"A Particle Swam Optimization Algorithm with Hybridized Real and Binary Parameters" - Nanbo Jin and Yahya Rahmat-Samii

PLENARY SESSION

3D Anisotropic Periodic Media: from Concepts to Printed Antenna Realizations" - John L. Volakis

PLENARY SESSION

"Negative-Refraction Metamaterials and their Applications"
George V. Eleftheriades

ELECTROMAGNETIC MODELING USING FEKO – I

Session Organizer:
C. J. Reddy
Session Chairs:
C. J. Reddy and Ulrich Jakobus

"Space Mapping Optimization of Microwave Structures with FEKO"
lawomir Koziel and John W. Bandler

"The Application of FEKO Software to Ground Electronic Warfare Scenarios"
Jason P. Dauby

"Design and Analysis of a Waveguide Modal-Spectrometer"
Wolfgang K. J. Mahler and Thomas F. Eibert

"New FEKO Modeling Capabilities: Waveguide Ports with Dielectrics, Fast MLFMM based Near-Field Calculations, Integrated Network Modeling, and Dielectric GO"
Ulrich Jakobus, Marianne Bingle, Marlize Schoeman, Johann J. van Tonder, and Frank Illenseer

"Comparison of Three Major MOM Codes for a Large Wire-Grid Ship Model"
Keith A. Lysiak

"Low Sidelobe Polarization Tapers for Planar Arrays"
Daniel W. Aten and Randy L. Haupt

"Aircraft Antenna Modeling, Analysis and Testing Ground Plane Effects and Considerations"
David W. Estlick

"Uniform Circular Array Active Element Radiation Patterns, FEKO Predictions Versus Measurements"
Craig Birtcher and Constantine A. Balanis
"Patch Antenna Modeling Issues Using Commercial Software"
William O. Coburn, Steven Weiss, and Canh Ly
"A Study of Large Cylindrical Arrays of UHF Patch Dipole Antenna Elements"
James D. Krieger, Alan J. Fen
"VHF Antenna Modeling for Rocket Application"
César De La Jara
"Simulations of a Shaped Dielectric Lens Antenna by FEKO"
Yosuke Tajima and Yoshihide Yamada
"Numerical Radar Cross Section Simulation and Analysis of Complex Targets in FEKO"
Ryan C. Solomon, Hank Leong and Yahia M. Antar

RECENT DEVELOPMENTS AND APPLICATIONS WITH TIME-DOMAIN MODELING TECHNIQUES

Session Organizers:
Zhizhang Chen and Michel Ney
Session Chairs:
Zhizhang Chen and Michel Ney

"A Method for Introducing Nonuniform Grids into the FDTDSolution of the Transmission-Line Equations Based on the Renormalization of the Per-Unit-Length Parameters" - Roberto B. Armenta and Costas D. Sarris
"Development of the Unconditionally Stable Error Reduced LOD FDTD Method" - Iftikhar Ahmed, Erping Li, and Zhizhang Chen
"Statistical Model of Induced Ground Voltage Using the TLM Method" - Leonardo R. A. X. de Menezes, João Batista J. Pereira, and Geovany A. Borges
"FDTD Full-Maxwell's Equations Modeling from Near-DC to Light" - Jamesina J. Simpson
"The Numerical Thickness of the Wire Medium Slabs in the Spatially Dispersive Finite Difference Time-Domain Simulations" - Yan Zhao, Pavel Belov, and Yang Hao
"A Comprehensive Study of SS-TLM Numerical Dispersion – Comparison with ADI-FDTD" - Sandrick Le Maguer, Jeremy Lanoë, and Michel M. Ney
"Application of the Radial Point Interpolation Method as Meshless Time-Domain Technique in Electromagnetics" - T. Kaufmann, C. Fumeaux, and R. Vahl 1
"Comparison of Measured and Predicted Electromagnetic Propagation in Arrays of Sub-Wavelength Holes in Metal Films" - N. Cinosi, S.P. Walker, M. J. B
"Archimedean Spiral Antenna Assessment for GPR: Comparison of Simulated and Measured Results" - Naomi R. Schwartz and Amir I. Zaghloul

"Adaptive Mixed-Order FDTD Techniques on a Non-uniform Mesh" - Profy Fernandes and Zhizhang (David) Chen
"Stochastic electromagnetic modeling with uncertain dielectric properties using FDTD" - Man-Faï Wong, Jessica Carette, Abdelhamid Hadjem, and Joe Wiart
"Coalescing Tetrahedral TLM cells into Higher Order Elements for Improved Efficiency" - P. Sewell, T. M. Benson, C. Christopoulos, D. W. P. Thomas, A. Vukovic, and J. G. Wykes

INVERSE SCATTERING IN MEDICINE AND BIOLOGY - STATE OF THE ART, RECENT ADVANCES AND FUTURE TRENDS

Session Organizers:
Andrea Massa, Paul Meaney, and Renzo Azaro
Session Chairs:
Andrea Massa, Paul Meaney, and Renzo Azaro

"Microwave Imaging for Bone Fracture Risk Assessment" - Paul M. Meaney, Tian Zhou, Margaret W. Fanning, Shireen A. Geimer, and Keith D. Pau
"3D Quantitative Microwave Imaging with a Regularized Gauss-Newton Method for Breast Cancer Detection" - J¨urgen De Zaeytijd and Ann Franchois
"Wavefront Reconstruction Using a Dispersive Propagation Model"
Daniel Flores-Tapia, Gabriel Thomas, and Stephen Pistorius
"A Multi-Resolution Three-dimensional Approach based on SVM for Breast Cancer Detection"
F. Viani, M. Donelli, P. Rocca, R. Azaro, and A. Massa
"Computational Model of Ductal Carcinoma In-Situ"
Seth Shumate and Magda El-Shenawee

ADVANCED TRANSMISSION LINES MODELING, MACROMODELING AND SIGNAL INTEGRITY

Session Organizer:
Sami Barmada
Session Chairs:
Sami Barmada and Robert Flake

"Signal Transmission Immune to Dispersion in Lossy Metal Transmission"
Robert H. Flake
"Computation of the Impulse Response and Coding Gain of a Digital Interconnection Bus"
Hristomir Yordanov, Michel T. Ivrlac, Amine Mezghani, Josef A. Nossek, and Peter Russer
"Crosstalk Analysis of Micromachined Rectangular Coaxial Lines"
Yuya Saito and Dejan S. Filipović
"Electromagnetic PCB Pattern Modeling Techniques for the Efficient RF Hardware Simulation for Mobile Phones"
Yongsup Kim, Kwangmo Yang, and Austin S. Kim

"Parameters Update Integration in EM Analysis of ATL and PTL in the FDM"
S. Cookey Ekpo, Armstrong Sunday, and Edidiong-Obong Ekpo
"Modeling of UIC cables in railway systems for their use as PLC channels"
S. Barmada, A. Gaggelli, P. Masini, A. Musolino, R. Rizzo, and M. Tucci

ELECTROMAGNETIC MODELING WITH QUICKWAVE / CONCERTO
Session Organizer:
Malgorzata Celuch
Session Chair:
Malgorzata Celuch and Luca Roselli
"Wideband Self-adjoint Jacobian Computation with Time-domain Field Solutions"
Yunpeng Song and Natalia K. Nikolova
"Neural Network Technique Simultaneously Optimizing Antenna Return Loss and Radiation Pattern"
Ethan K. Murphy and Vadim V. Yakovlev
"Utilizing Hybrid Dielectric-Metal and Mesh Refinement Techniques When Modeling a MMIC in Concerto Quickwave"
David M. Perry
"Comparison of Two Approaches to Modeling of Microwave Heating with Load Rotation"
Pawel Kopyt
"Modeling-Based Synthesis of a Microwave Heating Process Producing Homogeneous Temperature Field" - Brian G. Cordes, E. Eugene Eves, and Vadim V. Yakovlev
"Full-wave Modelling of Large Axisymmetric Antennas" -Michael P. Hook

MODELING TECHNIQUES FOR PERIODIC STRUCTURES AND METAMATERIAL APPLICATIONS - I
Session Organizer:
Costas D. Sarris
Session Chairs:
Costas D. Sarris and Alexander B. Yakovlev
"Analysis of Periodic Strips of Gold using FDTD" - Rodney Gomez, Katherine Lugo, Nader Farahat, and Raj Mittra
"Review of Complex Looped FDTD and its new applications" - Bartlomiej W. Salski, Malgorzata Celuch, and Wojciech K. Gwarek
"FVTD Simulations of Nano-structured Plasmonic Metamaterials" - L. J. Prokopeva, A. S. Lebedev, M. P. Fedoruk, and A. V. Kildishev
"Dielectric Resonator Antenna Design using Dispersion Engineered Materials" - Salih Yarga, Kubilay Sertel, and John L. Volakis
"Accurate and Rapid Analysis of High Impedance Surfaces: Plane-Wave and Surface-Wave Analytical Models" - Alexander B. Yakovlev, Constantin R. Simovski, Sergei A. Tretyakov, and George W. Hanson

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Technical Features

This issue presents a paper on the use of the Partial Element Equivalent Circuit in automotive applications and a paper looking at dielectric modelling.

PEEC modeling of automotive electromagnetic problems

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Abstract

This paper presents the combination of the nonorthogonal Partial Element Equivalent Circuit (PEEC) models and interconnect structures through a macromodel approach for the analysis of automotive electromagnetic problems. The applications are within automotive computational electromagnetics due to the typical combination of cable harnesses and chassis structures. It is shown that PEEC-based solvers are capable of handling electrically large problems with high geometrical complexity for detailed analysis in both the time- and frequency- domain with attached multi-conductor transmission lines.

Index Terms

Electromagnetic modeling, equivalent circuit, electromagnetic compatibility, macromodels

I. Introduction

The need for three-dimensional (3-D) electromagnetic (EM) modeling is increasing due to multi-gigahertz signal bandwidths at all levels of integration and packaging, mixed-signal functionality, and larger wiring densities in complex 3-D environments [1]. In the 2005 International Technology Roadmap for Semiconductors (ITRS) [2], the use of high frequency 3-D EM modeling is designated as an emerging area. Solving combined electromagnetic and circuit analysis problems is required for printed circuit board (PCB), subsystem-PCB modeling, and electrical interconnect and package (EIP) problems. Two-dimensional (2-D) multiconductor transmission line (MTL) analysis is used for problems which can be solved in this way. However, where 2-D modeling is inadequate, 3-D modeling techniques must be used. The partial element equivalent circuit (PEEC) method [3], [4], [5] is a 3-D full-wave

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modeling method suitable for combined EM and circuit analysis. Unlike the method of moments (MoM), PEEC is a full spectrum method valid from dc to the maximum frequency determined by the meshing. In the PEEC method, the integral equation is interpreted as Kirchoff's voltage law applied to a basic PEEC cell, which results in a complete circuit solution for 3-D geometries. The equivalent circuit formulation allows for additional SPICE type circuit elements to be easily included. Further, the models and the analysis apply to both the time-and the frequency-domain. With a general purpose SPICE type solver, different analysis such as quasi-static, LR or RC, and multi-conductor transmission line model analysis can be performed.

The PEEC method has recently been extended to include nonorthogonal geometries [6]. This model extension, which is consistent with the classical orthogonal formulation, includes the Manhattan representation of the geometries in addition to the more general quadrilateral and hexahedral elements. This helps in keeping the number of unknowns at a minimum and thus reduces computational time for nonorthogonal geometries.

Electronic components and systems are widely used in modern vehicles for safety, control, and entertainment systems for example. While this revolution was going on, the electronics industry developed issues and concepts that were addressed to allow inter-operation of the systems in the presence of each other and with the external environment. For this reason electromagnetic compatibility (EMC) has gained an increasing importance as systems and components started to have influence on each other just due to their operation. The advent of electric and hybrid vehicles and the increasingly wide range of systems and frequencies which are used in vehicles, are expected to make automotive EMC an increasingly troublesome burden to vehicle manufacturers in the future. It is considered that the adoption of numerical modeling techniques will provide the most cost effective approach for future automotive EMC engineering. The PEEC method has shown to be particularly suitable for the solution of EMC and electrical interconnect and package (EIP) problems in combination with SPICE type circuit models since the entire problem is solved in the circuit domain. The advantage with the method is the systematic development of equivalent circuits which offers a good insight in the physics of the original problem and a deep understanding of the interaction mechanisms (conduction and radiation).

To efficiently handle the combination of complex PEEC models and interconnect structures (signal transmission in cable harnesses), the cables can not be meshed and treated as PEEC models. This would create an extremely large PEEC model which would result in excessive calculation times. Therefore, cable harnesses could be treated using multi-conductor transmission line (MTL) theory and integrated with the PEEC model. For example, work in this direction has been presented for transmission lines in [7]. In this work, the combination of PEEC models with MTL:s is conducted through a macromodel description. The MTL port voltages/current are related to PEEC model node potentials/currents and the two models are solved simultaneously. This gives a very efficient solution of the problem in both the time and frequency domain.

II. PEEC BASIC THEORY

The PEEC formulation uses an integral equation solution of Maxwell's equations based on the total electric field.

The starting point is the total electric field at or in the material which is:

$$\boldsymbol{E}^i(\boldsymbol{r},t) = \frac{\boldsymbol{J}(\boldsymbol{r},t)}{\sigma} + \frac{\partial \boldsymbol{A}(\boldsymbol{r},t)}{\partial t} + \nabla\phi(\boldsymbol{r},t) \tag{1}$$

where $\boldsymbol{E}^i$ is the incident electric field, $\boldsymbol{J}$ is the current density in a conductor and $\boldsymbol{A}$ and ϕ are vector and scalar potentials respectively. The vector potential $\boldsymbol{A}$ is for a single conductor at the field point $\boldsymbol{r}$ given by:

$$\boldsymbol{A}(\boldsymbol{r},t) = \mu \int_{v'} G(\boldsymbol{r},\boldsymbol{r}')\boldsymbol{J}(\boldsymbol{r}',t_d)dv' \tag{2}$$

The scalar potential is similarly

$$\phi(\boldsymbol{r},t) = \frac{1}{\epsilon_0}\int_{v'} G(\boldsymbol{r},\boldsymbol{r}')\varrho(\boldsymbol{r}',\tau)dv' \tag{3}$$

where the free space Green's function is

$$G(\boldsymbol{r},\boldsymbol{r}') = \frac{1}{4\pi}\frac{1}{\mid \boldsymbol{r}-\boldsymbol{r}' \mid} \tag{4}$$

and the retardation time is given by $\tau = t - \frac{|\boldsymbol{r}-\boldsymbol{r}'|}{c}$ which simply is the free space travel time between the points $\boldsymbol{r}$ and $\boldsymbol{r}'$. The conservation of charge is enforced by the continuity equation:

$$\nabla \cdot \boldsymbol{J}\left(\boldsymbol{r},t\right) = -\frac{\partial\varrho\left(\boldsymbol{r},t\right)}{\partial t} \tag{5}$$

The most popular method for the discretization of integral equations was called by Harrington the *method of moments* (MoM) [8] with different implementation [9]-[12]. In PEEC, in the first step the unknown quantities $\boldsymbol{J}\left(\boldsymbol{r},t\right)$ and $\varrho\left(\boldsymbol{r},t\right)$ are expanded as a weighted sum of finite set of basis functions. Next, the so-called Galerkin's testing or weighting process ([13]) is used to generate a system of equations for the unknowns weights by enforcing the residuals of equations (1)-(5) to be orthogonal to a set of weighting functions which are chosen to be coincident with the basis functions. It is evident that this procedure transforms equations (1)-(5) into the Kirchoff Voltage and Current Laws (KVL and KCL) respectively.

A. Improved PEEC models for accuracy and stability

In the PEEC framework, the magnetic field coupling between two elementary volumes α and β is described by partial inductances defined, in the Laplace domain, as:

$$L_{p,\alpha\beta}(s) = \frac{\mu_0}{4\pi a_\alpha a_\beta}\int_{v_\alpha}\int_{v_\beta}\frac{e^{-s\tau}}{|\boldsymbol{r}_\alpha - \boldsymbol{r}_\beta|}\boldsymbol{u}_\alpha\cdot\boldsymbol{u}_\beta \; dv_\alpha dv_\beta \tag{6}$$

where $\tau = |\boldsymbol{r}_\alpha - \boldsymbol{r}_\beta|/c_0$ and c_0 is the speed of light in vacuum. In the past such coefficient was approximated taking the exponential term out of the integral. More recently [14] it has been pointed out that such choice may prevent the model to capture the damping which occurs at high frequency, causing inaccuracies and late-time instability. For this reason a macromodel for the partial element has been evaluated, providing accuracy and better stability properties at the same time [15]. These targets are achieved by means of different techniques based on: (1) subdivision schemes [16], (2) *split-cap filter* [15], (3) *R-ind filter* [15], and (4) macromodels generated by orthogonal vector fitting techniques [17] which will be described in detail in the references.

B. Non-orthogonal formulation

Three dimensional electromagnetic modeling of car chassis requires handling non-orthogonal geometries. The PEEC formulation for non-orthogonal geometry utilizes a *global* as well as a *local* coordinate system. The key *global* coordinate system uses conventional orthogonal coordinates x, y, z. Hence, a global vector $\boldsymbol{F}$ is of the form $\boldsymbol{F} = F_x\hat{\boldsymbol{x}} + F_y\hat{\boldsymbol{y}} + F_z\hat{\boldsymbol{z}}$. Therefore, the global unit vectors $\hat{\boldsymbol{x}}$, $\hat{\boldsymbol{y}}$ and $\hat{\boldsymbol{z}}$ are position independent. A vector in the global coordinates is denoted as $\boldsymbol{r}$. All local coordinates have to relate back to the global x, y, z coordinates. Therefore, a unique representation is needed for the mapping from a local point a, b, c on an object to the global point $\boldsymbol{r_g}$. Mapping a point in the above hexahedron from a local coordinate point a, b, c into a global coordinate point x, y, z is described by $x = \sum_{k=0}^{7} N_k(a, b, c)x_k$, which is applied for $x = x, y, z$ with coefficients given by

$$\begin{aligned} N_0 &= 1/8(1-a)(1-b)(1-c) \qquad & N_1 &= 1/8(1-a)(1-b)(1+c) \\ N_2 &= 1/8(1-a)(1+b)(1-c) \qquad & N_3 &= 1/8(1-a)(1+b)(1+c) \\ N_4 &= 1/8(1+a)(1-b)(1-c) \qquad & N_5 &= 1/8(1+a)(1-b)(1+c) \\ N_6 &= 1/8(1+a)(1+b)(1-c) \qquad & N_7 &= 1/8(1+a)(1+b)(1+c) \end{aligned} \tag{7}$$

where $a \in [-1, +1]$ and again $a = a, b, c$.

Fig. 1 (a) details the (Lp,P,τ)PEEC model for the nonorthogonal metal patch in Fig. 1 (b) when discretized using four edge nodes (dark full circles). The model in Fig. 1 (a) consists of:

- partial inductances (Lp) which are calculated from the volume cell discretization using a double volume integral.
- coefficients of potentials which are calculated from the surface cell discretization using a double surface integral.
- retarded current controlled current sources, to account for the electric field couplings, given by $I_p^i = \frac{pij}{pii} I_C^j(t - t_{d_{ij}})$ where $t_{d_{ij}}$ is the free space travel time (delay time) between surface cells i and j,
- retarded current controlled voltage sources, to account for the magnetic field couplings, given by $V_L^n = Lp_{nm}\frac{\partial I_m(t-t_{d_{nm}})}{\partial t}$, where $t_{d_{nm}}$ is the free space travel time (delay time) between volume cells n and m.

III. PEEC-based electromagnetic solver

A program for electromagnetic analysis, based on the theory and references outlined in the previous section, has been developed [18]. The solver can handle both the traditional orthogonal PEEC model and the newly introduced nonorthogonal formulation which is needed for the analysis of automotive problems. The solver creates an equivalent circuit containing resistances, inductances, capacitances, and coupled voltage and current sources (to account for electromagnetic couplings) for the given geometrical layout (CAD-data as specified in an input file). The user adds external electronic (sub-)systems and analysis mode as described by the SPICE syntax. For example, the solver performs transient analysis by the use of the `.tran`-command. The actual solution of the resulting circuit equations, in either the time- or frequency- domain, is performed in the solver and results are given as current- and voltage-distributions in the geometrical layout.

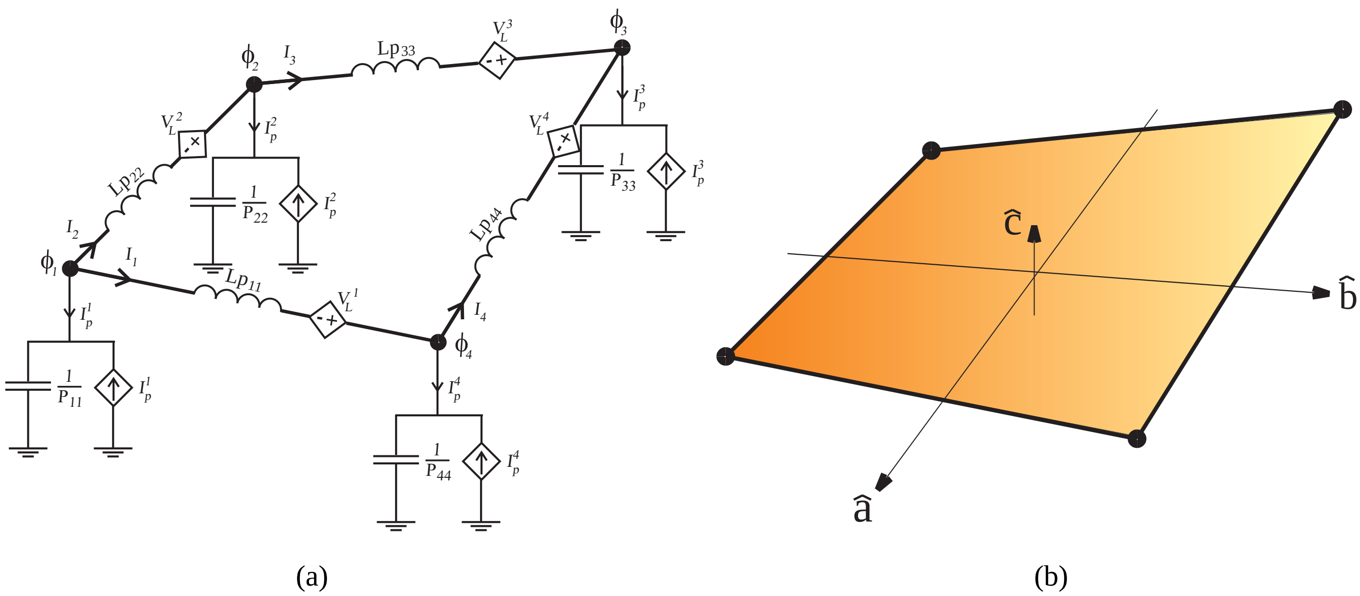


Fig. 1. Nonorthogonal metal patch (a) and PEEC model (b).

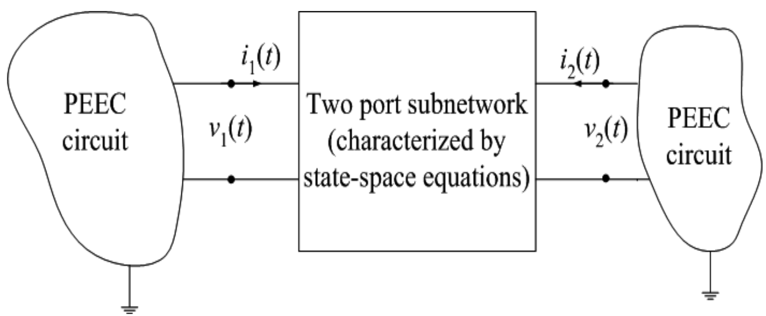


Fig. 2. PEEC model connected to a multiport system.

IV. INCORPORATION OF MACROMODELS

Automotive computational electromagnetic problems can be extremely complex to be modeled entirely in the PEEC framework. Therefore, it can be useful to incorporate a macromodel describing an electromagnetic system into PEEC models. This can be accomplished by starting from a linear electromagnetic system described by a state-space model

$$\begin{cases} \dot{\boldsymbol{x}}(t) = \boldsymbol{A}\boldsymbol{x}(t) + \boldsymbol{B}\boldsymbol{v}(t) \\ \boldsymbol{i}(t) = \boldsymbol{C}\boldsymbol{x}(t) + \boldsymbol{D}\boldsymbol{v}(t) \end{cases} \tag{8}$$

where $\boldsymbol{A} \in \mathbf{R}^{p\times p}$, $\boldsymbol{B} \in \mathbf{R}^{p\times q}$, $\boldsymbol{C} \in \mathbf{R}^{q\times p}$, $\boldsymbol{D} \in \mathbf{R}^{q\times q}$, p is the number of states, q is the number of ports, $\boldsymbol{x}(t)$ is the state of the macromodel, and inputs and outputs are represented by the port voltages $\boldsymbol{v}(t)$ and the port currents $\boldsymbol{i}(t)$, respectively. Fig. 2 shows an example of the incorporation of a multiport system into the PEEC environment.

The discretization process of the EFIE (1) and the successive Galerkin's weighting leads to generate an equivalent circuit as seen in Fig. 1 (a). When Kirchhoff's voltage and current laws are enforced to the N_i independent loops and N_ϕ independent nodes of the PEEC equivalent circuit we obtain:

$$-\boldsymbol{A}\boldsymbol{\Phi}(t) - \boldsymbol{R}\boldsymbol{i}_L(t) - \boldsymbol{L}_p\dot{\boldsymbol{i}}(t) = \boldsymbol{v}_s(t) \tag{9a}$$

$$\boldsymbol{P}^{-1}\dot{\boldsymbol{\Phi}}(t) + \boldsymbol{i}_{macro} - \boldsymbol{A}^t\boldsymbol{i}_L(t) = \boldsymbol{i}_s(t) \tag{9b}$$

where

- $\boldsymbol{\Phi}(t) \in \mathbf{R}^{N_\phi}$ is the vector of node potentials to infinity; $\mathbf{R}^{N_\phi}$ is the node space of the equivalent network;
- $\boldsymbol{i}_L(t) \in \mathbf{R}^{N_i}$ is the vector of currents including both conduction and displacement currents; $\mathbf{R}^{N_i}$ is the current space of the equivalent network;
- $\boldsymbol{i}_{macro}(t) \in \mathbf{R}^{N_\phi}$ is the vector of currents of macromodels;
- $\boldsymbol{L}_p$ is the matrix of partial inductances describing the magnetic field coupling;
- $\boldsymbol{P}$ is the matrix of coefficients of potential describing the electric field coupling;
- $\boldsymbol{R}$ is the matrix of resistances;
- $\boldsymbol{A}$ is the connectivity matrix;
- $\boldsymbol{v}_s(t)$ is the vector of distributed voltage sources due to external electromagnetic fields or lumped voltage sources;
- $\boldsymbol{i}_s(t)$ is the vector of lumped current sources.

The port voltages $\boldsymbol{v}(t)$ can be related to node potentials $\Phi(t)$ through the relation:

$$\boldsymbol{v}(t) = \boldsymbol{S}\Phi(t) \tag{10}$$

where $\boldsymbol{S} \in \mathbf{R}^{p\times N_\phi}$; it is easy to verify that, between macromodel currents $\boldsymbol{i}_{macro}(t)$ and port currents $\boldsymbol{i}(t)$ the following relation holds:

$$\boldsymbol{i}_{macro}(t) = \boldsymbol{S}^T\boldsymbol{i}(t) \tag{11}$$

that allows to map port currents into the N_ϕ PEEC nodes (dark circles in Fig. 1 (a) and (b)). Equations (9a)-(9b), (8), along with (10)-(11), represent a set of $N_i + N_\Phi + p + q$ equations to be solved for the same number of unknowns, namely $\boldsymbol{i}_L(t), \boldsymbol{\Phi}(t), \boldsymbol{x}(t), \boldsymbol{i}(t)$.

It is to be pointed out that the proposed approach allows to link multi-conductors transmission lines to PEEC models as well as any kind of macromodel of linear electromagnetic systems.

V. Numerical results for chassis structure

In the first test the developed PEEC solver has been used to analyze the voltage distribution on a car chassis in both the time- and frequency domain. The sequential PEEC-solver is written in C++, uses the GMM++ template library for matrix computation, and all the test are performed on a standard Linux server (Intel Xeon, duel core with 4 Gb RAM).

The discretization process, mesh seen in Fig. 4 (a), of the overall chassis structure into quadrilateral patches led to 3 816 inductive cells, 2 862 capacitive cells, and 1 355 nodes. This results in 14 558 040 mutual inductances, 8 188 182 mutual coefficients of potential (capacitances) which results in an $N \times N$ dense linear system $Ax = b$ with N = 5 171. This system is complex in the frequency domain due to the phase shift in the electromagnetic couplings while the time domain solver requires the use of history files for potentials and currents.

The majority of the computation time (4 hours), for both the tests, is the calculation of the nonorthogonal partial elements (inductances and coefficients of potential). The subsequent solution of the circuit equations is performed in 10 minutes in the time domain (1 500 time steps) and in 3 hours in the frequency domain (100 frequencies).

A. *Time domain analysis*

The first test is carried out in the time domain with the chassis excited by a fast current pulse. The current source is a pulse waveform of Gaussian-type, $I(t) = e^{-x \cdot x}$ where $x = \frac{t-(150e-9)}{(50e-9)}$, injected in the front bumper. The back bumper is terminated with a 50 Ω resistor to infinity in order to have a current path through the chassis. This results in the terminal voltages, at the front bumper (V_{FRONT}) and back bumper (V_{BACK}), as seen in Fig. 3 (a). The results, current and voltage distribution, can be visualized in the analyzed structure instead at single ports. This results in the potential distribution, in the chassis, as seen in Fig. 3 (b) for time $t = 180$ ns.

B. *Frequency domain analysis*

The only addition for the frequency domain test is a resistor (100 Ω) in parallel with the input current source (unitary for AC analysis). The result is given as the potential distribution in the chassis at 22 MHz in Fig. 4.

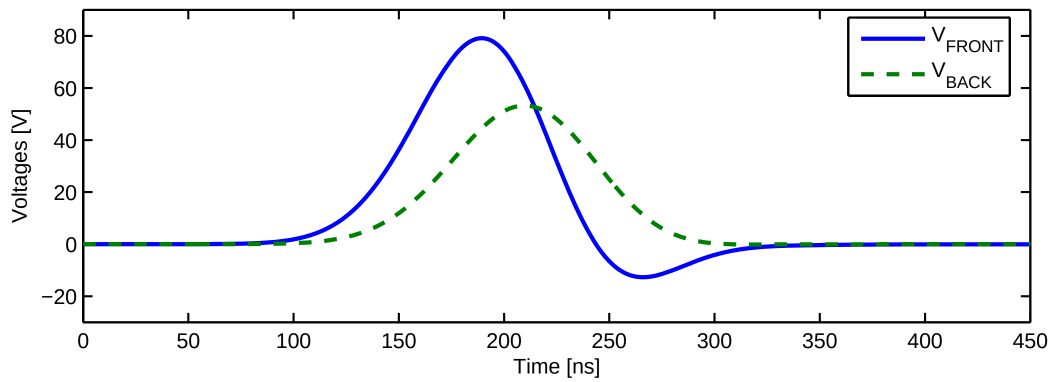
C. *Chassis with and an interconnect structure*

The second test adds a multi-conductor transmission line (MTL) to the chassis analysis in the previous section. The inclusion of the MTL is through the macromodel formulation detailed in Sec. IV. The interconnect structure consists of two signal lines with a common reference conductor, driving circuitry, and a PEEC model for two square loops as schematically shown in Fig. 5. The interconnect structure is positioned near the back window of the chassis, Fig. 6 (b).

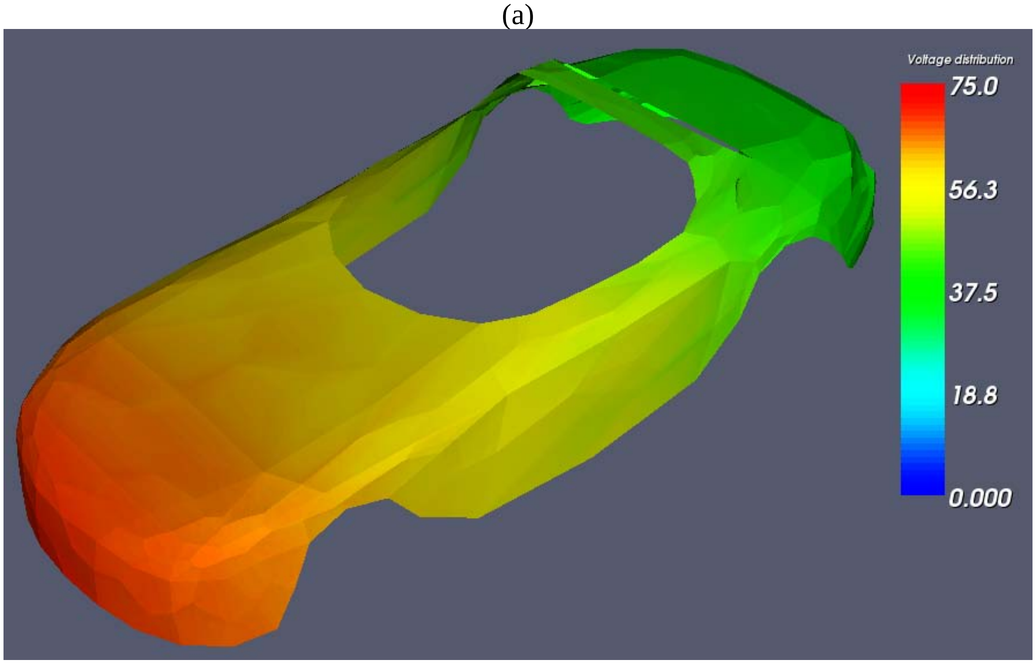
For testing, one signal conductor is excited using a unitary Gaussian pulse function with a 5 ns rise time. The port voltages for the MTL is observed as well as the induced voltages and currents in the chassis.

The port voltages, near and far end, are shown in Fig. 6 (a). The induced voltages in the chassis, as seen in Fig. 6 (b), are close to 0.4 V near the small loop structures.

Since the proposed approach works well for frequency domain analysis, the last example shows a situation where a current- and voltage- distribution in the chassis impact on interconnect port voltages through the loop structures. The chassis is excited as described in Sec. 4.1.2 while observing the interconnect port voltages, seen in Fig. 7. Port voltages well over 1.5 V are observed around 85 MHz. Further, since the loop attached to signal conductor 2 is closer to the chassis, the induced voltages are slightly higher (Vin T2 and Vout T2 in Fig. 7) in that one than in signal conductor 1.



(a)



(b)

Fig. 3. Time domain voltages at front and back bumper of chassis for the current injection (a). Potential distribution in chassis at a specific time point (180 ns) after excitation with the Gaussian pulse.

The overall computation time, compared to single chassis analysis, is not impacted due to the addition of the macromodel and the loop circuits. This is due to the minimal inclusion of unknowns compared to the chassis structure. However, the creation of the macromodels require some effort in post-processing to create the $\boldsymbol{A}$, $\boldsymbol{B}$, $\boldsymbol{C}$, and $\boldsymbol{D}$ matrices in (8).

VI. Conclusions and Discussion

This paper shows the first application of nonorthogonal PEEC to an electrically large structure in both the time- and frequency domain. The developed solver is utilizing standard C++ libraries and requires only a Linux server to perform the analysis. Within the PEEC framework, additional active and passive circuit elements are easily included which enable the analysis if complete automotive systems with the effects of the chassis geometry in the same solver.

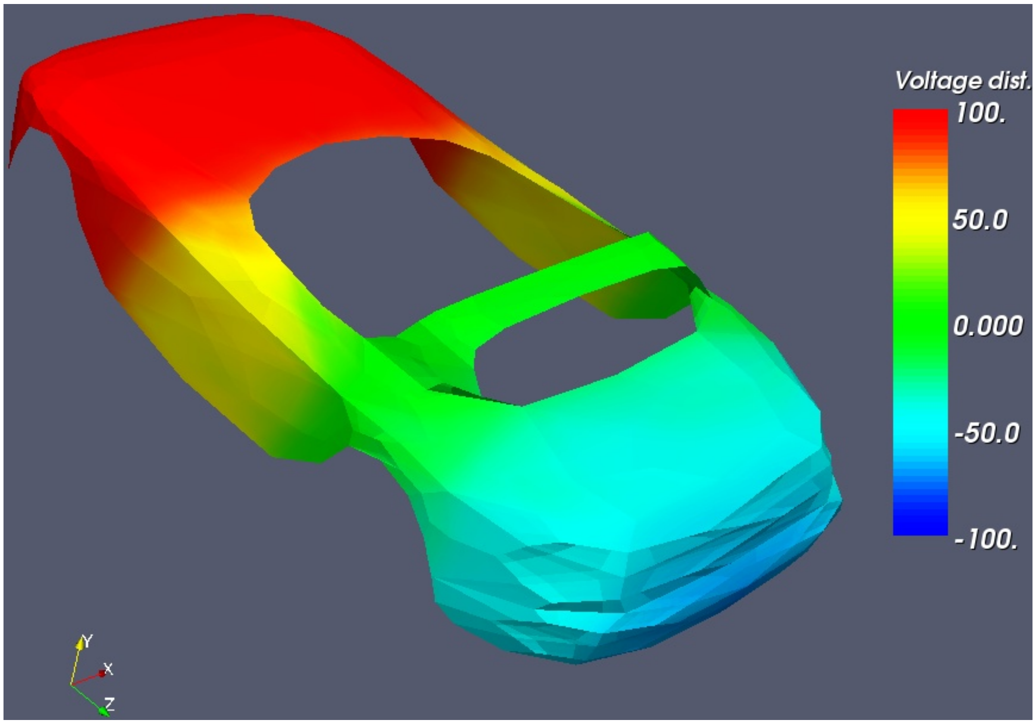


Fig. 4. Potential distribution in chassis analyzed with the PEEC solver at 22 MHz.

This paper also outlines the combination of PEEC models and interconnect structures through a macromodel approach. The applications are within automotive computational electromagnetics and involve nonorthogonal PEEC models for electrically large structures. With the electrically large structures, multi-conductor transmission lines are included through a macromodel approach resulting in an computationally efficient method.

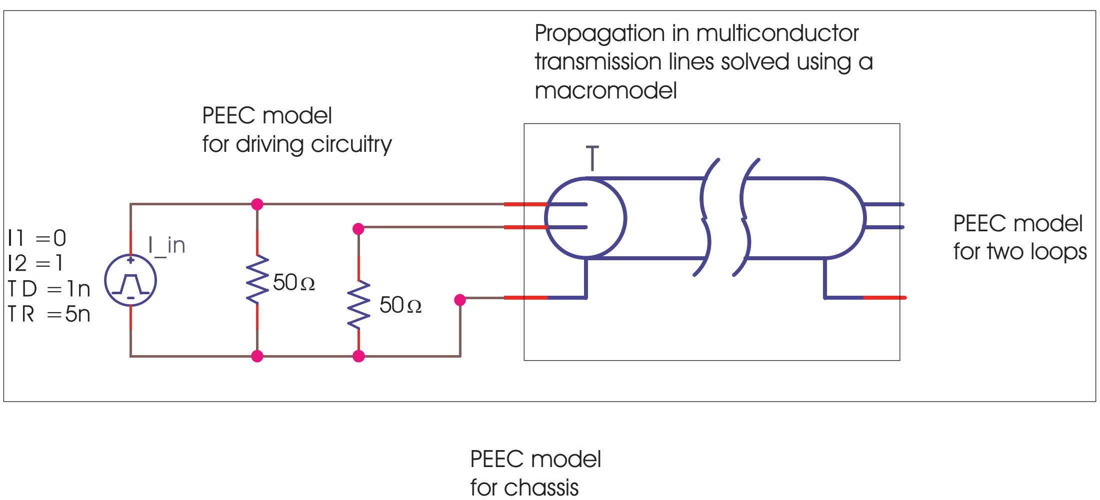
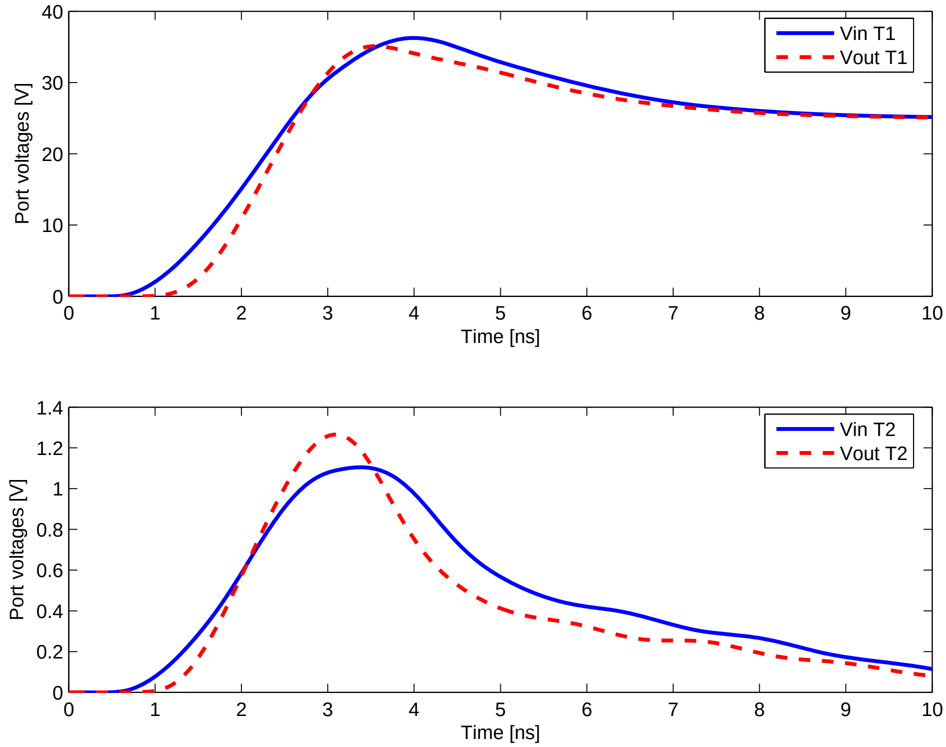
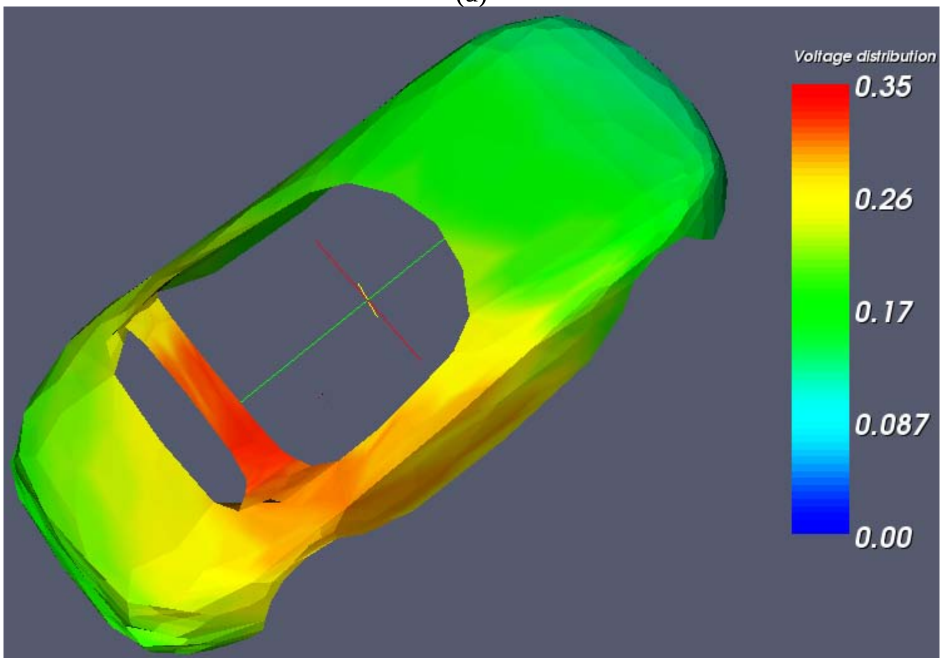


Fig. 5. Test configuration for chassis and interconnect structure.



(a)



(b)

Fig. 6. MTL port voltages, near and far end, for the chassis and interconnect structure in (a) and induced voltages in the chassis structure (b).

VII. Acknowledgements

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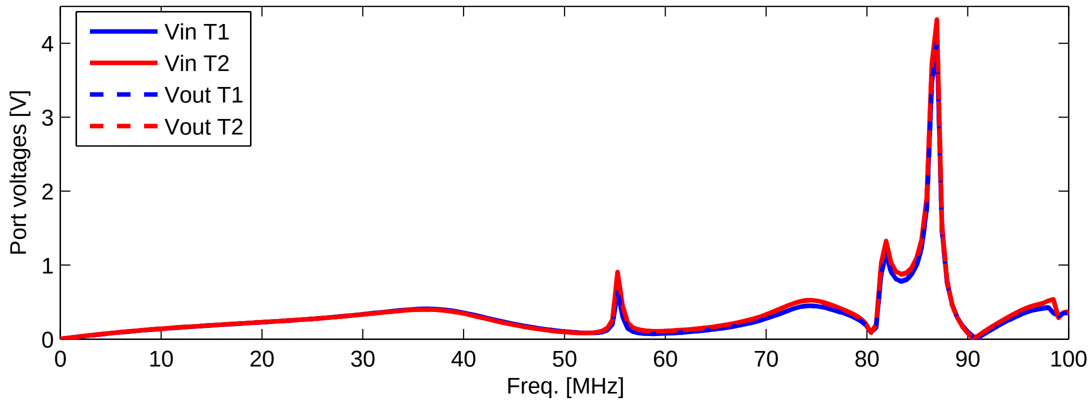

Fig. 7. Induced voltages at interconnect ports from the interaction between the loops and the chassis structure.

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Modeling of Field Distribution and Energy Storage in Diphasic Dielectrics

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Modeling of electrostatic field distribution and energy storage in diphasic dielectrics containing high-permittivity $BaTiO_3$ in a glass host has been carried out analytically and numerically. An analytical formulation employs the Maxwell Garnett (MG) mixing rule, and numerical simulation uses software based on the boundary element method (BEM). The field distribution was studied as a function of a dielectric contrast and a volume fraction of phases. For a high-permittivity sphere enclosed in a low-permittivity glass cube it was found that the dielectric contrast of 75 and volume fraction of 46.8% led to the increased energy storage density. For composites with lower volume fractions of high-permittivity inclusions, the field enhancement factor of 2.6 was observed, whereas for the higher volume-fraction composites, field enhancement up to 10 was noticed. The higher field enhancement factors are expected to lead to dielectric breakdown at the lower applied fields, limiting energy density. The upper limit of applicability of the MG formulation in terms of the inclusion volume fraction was also established, and it is a function of the dielectric contrast. The host material permittivity causes a substantial variation in the applicability limit of the MG mixing rule, while the permittivity of inclusion phase does not affect the limit.

Keywords: Dielectric composites, electric field distribution, energy storage

I. INTRODUCTION

The properties of dielectric mixtures have been investigated for more than 100 years.[1-5] One of the objectives of the research in this area has been the development of dielectric bodies with enhanced energy storage capabilities, for example, crystallization of a phase with higher permittivity, like $BaTiO_3$, in a glass matrix.[6] The general goal is to take advantages of both high energy storage capacity of the $BaTiO_3$ inclusions and high breakdown strength of the glass phase. This approach may eliminate the porosity that causes field concentration (enhancement) adversely impacting breakdown.[7] Other ways of solving this problem are based on the dispersing materials with high permittivities, such as $BaTiO_3$, into polymeric hosts to assure high energy density, high breakdown strength, low dielectric loss, fast speed, low cost, and graceful failure leading to higher reliability.[8-9] Recent studies of these composites have resulted in effective permittivities between 20 and 115,[10-11] depending on the volume fraction of a filler and attributes of the synthesis process.

The dielectric response of such composites has been modeled using different effective medium theories.[12-16] Description of the dielectric behavior of these materials is based on formulations that include the dielectric properties of two constituent phases and their volume fractions. The geometry of inclusions is also important, and typically, ellipsoidal inclusions are assumed.[17-18] Energy storage characteristics of a composite material may be found knowing effective permittivity retrieved using a quasistatic approximation. This means that the size of the inclusions is much smaller than the wavelength in the medium. Also, the materials are assumed to be linear.

It has been reported that Maxwell Garnett (MG) formulation for diphasic dielectrics can be applied up to 30 % volume fraction of inclusions, that is, for comparatively dilute mixtures.[19] Most known mixing rules assume that the lines of electric flux are *not distorted* by the particles, and hence, there are inherent limitations in accurately predicting the energy storage capabilities of composites.[20] For heterogeneous composite the electric lines of flux will tend distribute them according the permittivity ratios of the host and the inclusion phase.[21] Local inhomogenities in electric field distribution, *i.e.*, field enhancement in the low permittivity phase and field penetration in the high permittivity (ε) phase, are not taken into account by classical mixing theories.

Numerical simulation results demonstrate that the electric field distribution in composites may be of three different types. The first type is the field enhancement in the low-permittivity phase at the boundary separating two phases in the direction of the applied field. The second type is the field in high permittivity phase – this is a low-intensity field. The third type is the intermediate-intensity field in the low permittivity phase. An insightful study to understand field distribution in such composites was carried out, but it is limited only by two-dimensional cases.[22]

The present study is aimed at a comprehensive analysis of the impact of the field distribution on the energy storage and breakdown strength. To do this, it is necessary to quantify electric field distribution and gain a profound understanding of the parameters that determine this distribution. For solving this problem, the dielectric properties of constituent phases and their volume fractions should be determined. This specifically involves identifying an ideal *dielectric contrast.* The dielectric contrast is defined as the ratio of the permittivity of the inclusion phase to the permittivity of the host phase:

$$c = \frac{\varepsilon_{incl}}{\varepsilon_{host}}, \qquad (1)$$

The three-dimensional (3D) numerical simulation software (*Coulomb*) is used in the present study to comprehensively analyze an impact of the field distribution on the energy storage and breakdown strength. This software is based on the solution of the Laplace's electrostatic equation and allows for taking into account local inhomogenities in the field distribution. The results of simulations are interpreted from the perspectives of field enhancement and field penetration into the high permittivity phase. One of the important questions to be answered is how these properties are related to the dielectric breakdown.

Another goal of this work is to determine the limits of applicability of the Maxwell Garnett formulation in terms of the inclusion volume fraction. Maxwell Garnett theory has been accepted as a satisfactory approximation, when inter-particle interactions and multiple scattering are not significant, *i.e.*, when there are dilute mixtures.[23] Though scientific community has been cognizant of this limitation, the minimum limit on the inclusion volume fraction (or inter-inclusion separation distance) has not been established yet.

Herein, the results for diphasic dielectric bodies with different permittivities and volume fractions are reported. A three-dimensional model of a composite is based on a sphere enclosed in a cube (SEC), with the cube representing a low-permittivity (*e.g.*, glass) phase, and a spherical inclusion representing a high-permittivity (*e.g.*, barium titanate) phase. It needs to be mentioned here that the assumption of a sphere enclosed in a cube matrix is a special "non-random" case. V. Myroshnychenko *et. al* have rightfully acknowledged the fact that inspite of earnest computational advances and ability to model randomly dispersed inclusions, as well as non-random structures, it has been difficult to find experimental systems that bear close resemblance to the idealized models.[24] V. Myroshnychenko *et. al.* have developed an algorithm for 2D case with random inclusions for two cases of surface fractions: percolating systems and non-percolating systems, and compared their results with other traditional EMT theories. However, local electric field distribution as a function of inclusion volume fraction and dielectric contrast has not explored. Herein, the electric field increase has been quantified as a function of the properties of the inclusion and the host phase. The MG formulation was also applied to calculating effective permittivity of this system, and the results of the two approaches are compared.

II. SIMULATIONS

A. METHOD AND SOFTWARE FOR NUMERICAL SIMULATIONS

Simulations were carried out using the commercially available software *Coulomb* from Integrated Engineering Software (Winnipeg, Manitoba, Canada). *Coulomb* is a 3D code that uses a boundary element method to solve Laplace's equation for electrostatic potential inside the geometry of interest.[26,27] Laplace's equation

$$\nabla^2 V = 0 \qquad (2)$$

is a particular case of the Poisson's equation,

$$\nabla^2 V = -\frac{q_{vol}}{\varepsilon}, \qquad (3)$$

where q_{vol} is the free charge volume density, V is the electric potential, and $\varepsilon = \varepsilon_0 \varepsilon_r$ is the permittivity of the medium.

Compared to finite element methods (FEM) and finite difference methods (FDM), the boundary element method reduces the number of calculations that must be performed for the solution of electrostatic potential problems. Automatic grid functions are available within this package, and they have been used in the present research to define the boundary grid.

Coulomb allows for the construction of the larger 3D structures containing periodically repeated cells with identical properties to represent uniform diphasic dielectrics. It should also be noted that the dielectric behavior of the composite can also be obtained through studying a single cell. Fig. 1 shows a cell with a "sphere enclosed in a cube" (SEC) geometry and its 3D translation in *x*, *y*, and *z* directions.

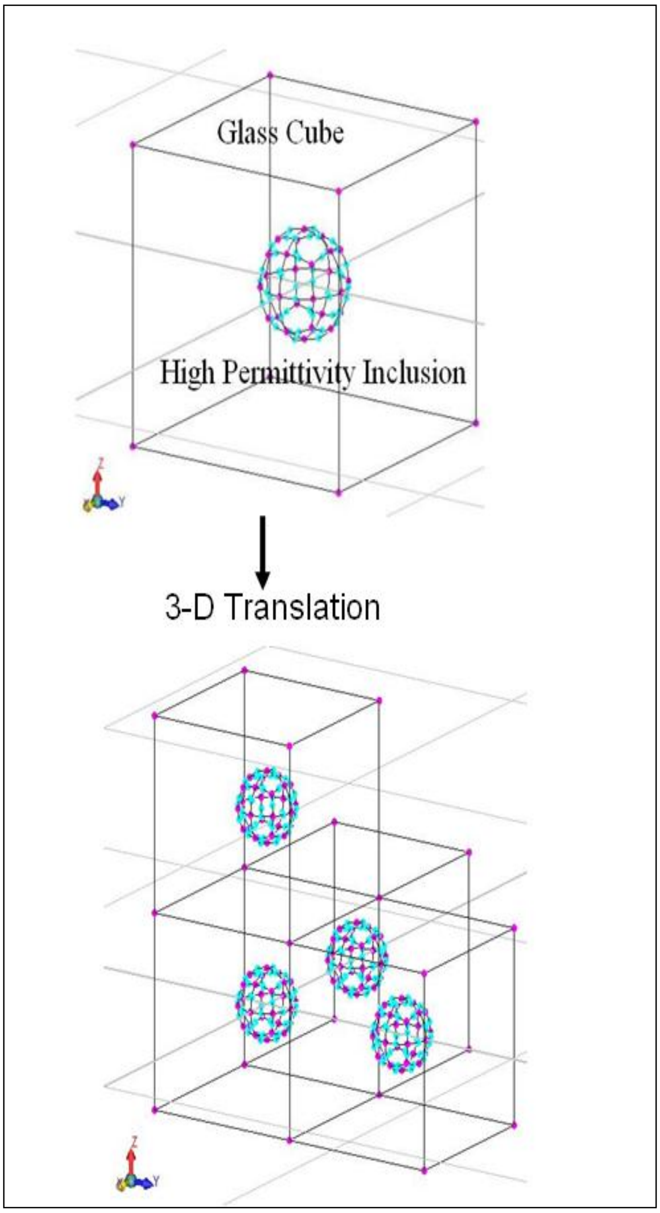


FIG. 1. **Basic building block of composite sphere enclosed in cube and 3-D translation in *x*, *y*, *z* directions.**

Simulations using *Coulomb* were run to understand local field distribution as a function of inclusion volume fraction and its impact on the energy stored in the composite. In these simulations, the applied electric field was $E_{appl} = 50$ kV/cm, the host phase was assigned a permittivity $\varepsilon_{r\,\mathrm{host}}$ ranging from 4 to 100, and the inclusion 'high-permittivity' phase was assigned a permittivity $\varepsilon_{r\,\mathrm{incl}}$ from 600 to 1200. The simulated dielectric body was a $9 \times 9 \times 9$ matrix of cubes (1.1 μm edge length/cube) and included 729 inclusion spheres. The linear periodic simulation function of the *Coulomb* code was used to create the dielectric body. The inclusion volume fraction varied from approximately 1 to 50 % by varying the radius of the spherical inclusions from 0.2 μm to 0.53 μm. Energy density predictions of *Coulomb* were compared with the MG results for inclusion volume fractions up to 30%.

The *Coulomb* software was also used to simulate the impact of the permittivity of the host phase on the field enhancement within that phase. Studies in this area are of interest since field enhancement can affect breakdown strength. The effects of dielectric contrast were studied by adopting two strategies: (1) varying the permittivity of host phase, and (2) varying the permittivities of both host and inclusion phases. Simulations were also carried out to map field penetration into the high-permittivity phase, since this can result in higher energy storage densities.

The results are presented below in Section III.

B. Maxwell Garnett mixing rule

The Maxwell Garnett (MG) formulation has historically been the simplest and the most popular mixing rule for homogenizing particulate composite media. Homogenization of a mixture is used in the quasistatic approximation, when sources and fields are varying slowly. This demands that the characteristic size of scattering particles or correlation distance (in the case of the medium is described by continuous permittivity function) is small compared to wavelength in the effective medium.[28] In addition, a mixture should be sparse, and inter-particle distances are big enough, so that multiple scattering is negligible.[17, 28]

The MG rule for a mixture of a base material with relative permittivity ε_b and spherical inclusions with relative permittivity ε_s as given by [1, 17]:

$$\varepsilon_{eff} \cong \varepsilon_{r\,host} + \frac{3 f_{incl}\,\varepsilon_{r\,host}\,(\varepsilon_{r\,incl} - \varepsilon_{r\,host})/(\varepsilon_{r\,incl} + 2\varepsilon_{r\,host})}{1 - f_{incl}\,(\varepsilon_{r\,incl} - \varepsilon_{r\,host})/(\varepsilon_{r\,incl} + 2\varepsilon_{r\,host})}, \qquad (4)$$

The electric energy stored within an elemental volume (energy density) is a function of the effective permittivity ε_{eff} and the square of the applied electric field E:

$$w = \frac{1}{2}\varepsilon_0 \varepsilon_{eff} E_{appl}^2 . \qquad (5)$$

The energy density calculated this way is compared with the energy density extracted from the *Coulomb* simulations. The comparison results are presented in Section III.

III. RESULTS AND DISCUSSION

A. FIELD BEHAVIOR IN COMPOSITES WITH DISPERSED INCLUSIONS

The effect of particle size on field distribution within the composite dielectric was studied. The electric field distribution over the cross-section for different size of inclusion spheres of a single cell is shown in Fig. 2 (a, b). The inclusion particle in Fig. 2 (a) has the diameter of 0.4 μm, and the particle in Fig. 2 (b) has the diameter of 0.8 μm. The single cell is translated in three directions to form the $9 \times 9 \times 9$ dielectric body. An electric field magnitude may be estimated by using the color scale on the left hand side of each figure. The most important result is that the field magnitude within the high permittivity particles is greatly reduced compared to the magnitude of the applied field. If the permittivity of the inclusion phase is 1200, the host phase permittivity is 4, and the applied electric field is 50 kV/cm, the field magnitude within the particle is below 5 kV/cm. This suggests that, despite the high permittivity of the inclusion phase, the energy storage density of this phase is greatly reduced due to minimal field penetration into the phase. This result agrees with the prior reports of limited energy storage characteristics for composite materials prepared from polymers and high permittivity inclusions.[25]

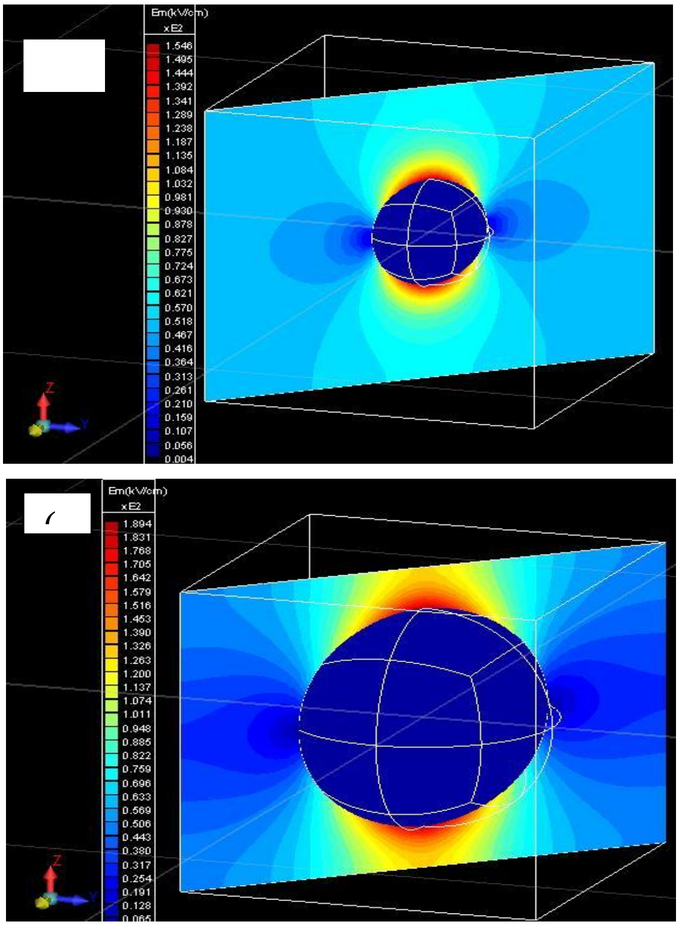


FIG. 2. Electric field distribution in the composite in the host low-permittivity phase and in the spherical high-permittivity inclusion phase: (a) low volume fraction of the inclusion (2.5 %); (b) high volume fraction of the inclusion (20.1 %).

Other characteristics of the field distribution in both composites (Fig. 2 (a) and (b)) are similar, though the magnitude and extent of the field enhancement in the host phase depends on the particle size of the high-permittivity inclusion. Composites prepared with the particles of the smaller diameter exhibit a lower field enhancement compared to the particles of larger diameter.

Smaller inclusion size and the proximity of the high-permittivity inclusions to each other can have a significant impact on the field *enhancement factor*. The enhancement factor is defined as the ratio of the maximum field present in the composite to the magnitude of the applied field.

$$F_e = \frac{E_{\max}}{E_{appl}} . \qquad (5)$$

The field enhancement for the 0.4-μm particle composite is approximately $F_e = 3.1$, while the field enhancement factor for the 0.8-μm particle composite is approximately $F_e = 3.8$. Other notable differences are that for the 0.4-μm particle composite, a field slightly greater than the applied field exists at most locations within the matrix phase, as indicated by the light blue color representing a field of E ~ 60 kV/cm. Other locations in the matrix exhibit a field of magnitude that is approximately equal to the applied field (next field gradation color of blue, E ~ 49.8 kV/cm).

The similar result is observed for the composite prepared from the 0.8-μm particle, though the specifics of the field distribution are noticeably different. For this composite, the significant field enhancement also extends to the cell border (in the field direction), albeit in a more localized fashion than for the 0.4-μm particle composite.

It should be mentioned that the field penetration, field enhancement, and field distribution characteristics are all the functions of not only volume fraction, as the particular case considered above demonstrates, but dielectric contrast as well. This will be shown below.

B. EFFECTS OF INCLUSION VOLUME FRACTION AND DIELECTRIC CONTRAST ON LOCAL FIELD DISTRIBUTION

This section contains quantitative results that show the effect of the dielectric contrast on both the field penetration in a high-permittivity region and the field enhancement. To the best of our knowledge, no quantitative estimates have been reported so far.

Field distribution inside a composite has three main regions, as described earlier. The first region has the enhanced field in the low-permittivity phase at the boundary separating two phases in the direction of the applied field, see the top and the bottom of the inclusion spheres in Fig. 2 (a, b). The second region is the low-intensity field in high permittivity phase, namely, inside the inclusion spheres. The third region is the intermediate-intensity field in the low permittivity phase, everywhere, except for the first region. The enhancement of the field in the first region is an important parameter that affects the breakdown strength of the composite. The higher field penetration into the high-permittivity inclusion (represented as the second region of field) will lead to the higher energy storage densities. It is critical to develop insights into field enhancement and field penetration that are the functions of the inclusion volume fraction f_{incl} and the dielectric contrast c . These insights would help in developing guiding principles for engineering dielectrics for high-energy capacitors.

Fig. 3 illustrates how the properties of the two phases and the size of the inclusion can impact the field enhancement within the composite. According to Fig. 3, for the smallest inclusions (0.2 μm radius), the field enhancement factor is about F_e = 2.6. In contrast, for larger inclusions (0.53 μm radius), the field enhancement factors F_e > 10 are observed. Thus, in a system with the inclusion permittivity ε_{incl} = 1200 and the host permittivity ε_{host} = 4, the local field in the vicinity of an inclusion can vary from ~ 140 kV/cm to ~ 600 kV/cm, when the applied field is 50 kV/cm.

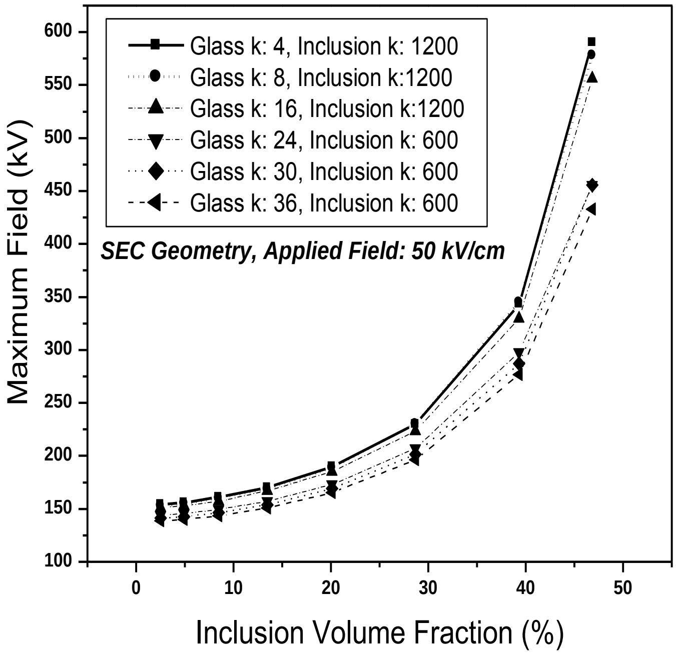


FIG. 3. Coulomb simulations of the maximum field in the host material as a function of the inclusion volume fraction (%).

The impact of the "dielectric contrast" on the field enhancement may be also seen in Fig. 3. Based on the permittivities of the two phases, the dielectric contrast was varied from approximately 16 (ε_{host} = 36 and ε_{incl} = 600) to 300 (ε_{host} = 4 and ε_{incl} = 1200). As a particular case of a diphasic dielectric, a glass ceramic system, consisting of barium titanate inclusions in glass matrix is considered. Glass is the low permittivity phase. If the permittivity of the glass phase increases (36 vs. 4), the field enhancement factor reduces by approximately 25%. Because there is likely a strong link between the dielectric breakdown strength and the field enhancement, this result suggests that the ability to develop residual glass phases with higher permittivities (assuring the lower dielectric contrast with inclusions) can be beneficial in improving the breakdown characteristics of composites.

Fig. 4 shows the field penetration that takes places along the z-axis, when the electric field of 50 kV/cm is applied in the z-direction It is interesting to decouple the volume fraction and dielectric contrast effect from the Fig. 4. For a dielectric contrast of 300 and increase in volume fraction from 2.5 to 46.8 %, there is 17 times increase in the maximum field that has penetrated. However, with a dielectric contrast of 16 and for the same increase in volume fraction the maximum field penetrated increases 3.25 times. Also, for a constant volume fraction of 2.51 % and dielectric contrast varying from 300 to 16, it is seen that the maximum field penetration has increased almost 13 times. Considering the case for constant volume fraction of 46.84 % and for the same change in the dielectric contrast, maximum field penetrated has increased 2.5 times. These results are revealing very important information about volume fraction and dielectric contrast effects. Important observation is that for higher dielectric contrast, increase in volume fraction of the high permittivity phase will lead to higher field penetration. Also, it should be noticed that as the dielectric contrast decreases, the maximum field penetration at lower concentrations of inclusions is higher than at higher concentrations. It is seen from these simulations that the significant field penetration into a high-permittivity inclusion occurs only when the dielectric contrast is reduced below approximately 75. Fig. 4 also shows that the field penetration into the inclusion can increase when the volume fraction of the high permittivity phase increases. These results are important for the design of high energy density composites, since significant field penetration into the high-permittivity phase is required to achieve high energy density values. These quantitative results clarify the role that the properties of the phases and microstructural characteristics can exert on local field behavior within the dielectric.

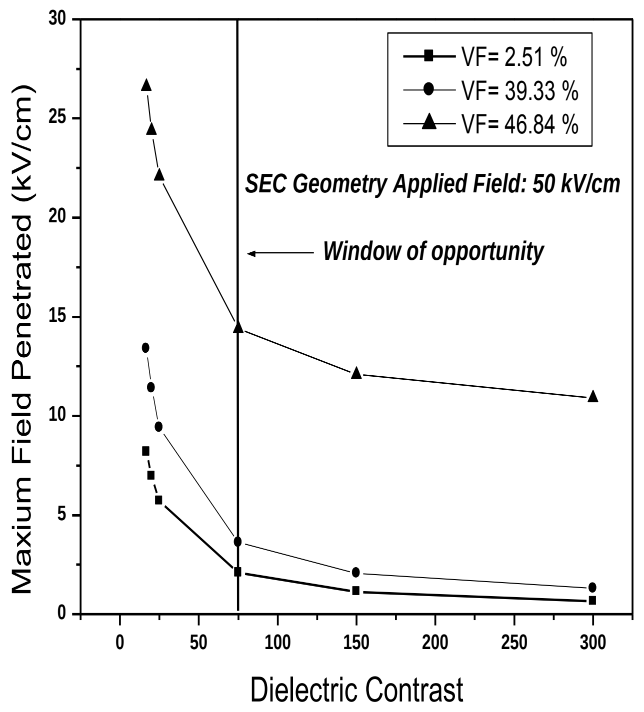
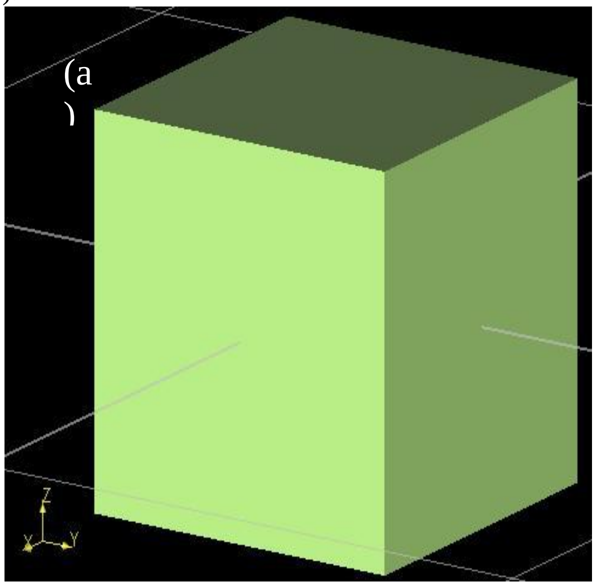


FIG. 4. *Coulomb* simulations of the maximum field present in a high-permittivity spherical inclusion enclosed in the glass matrix as a function of dielectric contrast for different inclusion volume fractions.

C. BENCHMARKING OF ENERGY STORAGE CALCULATIONS

Consider a single-phase dielectric (glass $\varepsilon = 41$) cube with a side of 1.1 μm, as is shown in Fig. 5 (a). In our computations, the electric field applied in the vertical direction of the cube is assumed to be 81 kV/mm. We used the same value of electric field as in the experiments carried out in Penn State University[6]. We calculated energy storage within glass using the software *Coulomb*. The cube in this example is subdivided into 1000 tetrahedral elements to increase the accuracy of simulations. *Coulomb* predicts energy stored within the cube of $1.55 \cdot 10^{-12}$ J, which corresponds to the energy density of 1.16 J/cm^3. These results match with those obtained at Penn State University[6]: the experimentally predicted energy storage for glass with permittivity of 40 was also 1.16 J/cm^3, as is shown in Fig. 5(b).



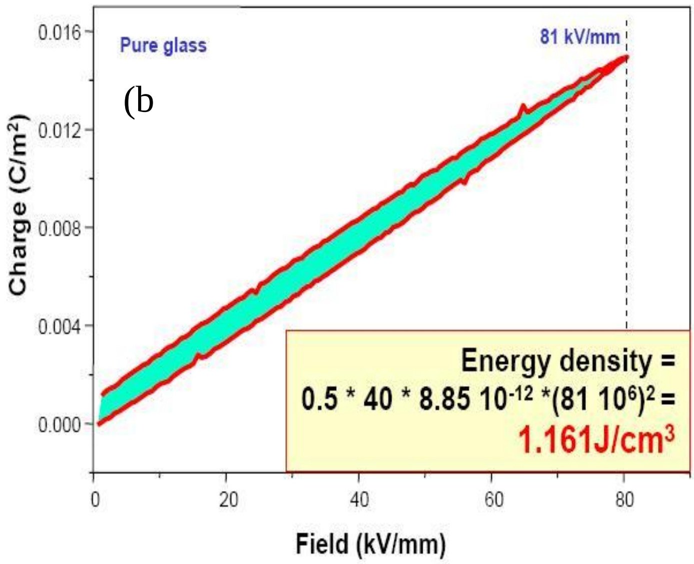


FIG. 5. (a) 3D cube, generated in *Coulomb*, representing pure glass phase; (b) Experimentally obtained energy storage in the pure glass phase system.

Though the results of computations and experiments agree well for a single-phase system, it is immensely difficult to compare predictions for diphasic systems. *Coulomb* is well-suited for ordered non-random composites. However, it is extremely difficult to reproduce the realistic irregular (non-periodic) grain structure in *Coulomb*.

D. COMPARISON OF *COULOMB* AND MAXWELL GARNETT MODELS

One of the primary limitations of mixing theories is inability to predict energy density beyond a particular limit of the inclusion volume fraction, as was discussed in Section 2.2. According our knowledge, a precise limit at which mixing theories correctly take into account field enhancement and penetration has not been established. This is a topic of the present investigation.

Maxwell Garnett theory was applied to the same models developed in *Coulomb* for different volume fractions of inclusions. The host matrix is assumed to be glass with different permittivities. The inclusions are spheres with permittivity of 1200. The effective permittivity obtained using MG formula (*4*) as a function of the volume fraction at different values of the host permittivity is plotted in Fig. 6. As seen from the plot, the effective permittivity increases significantly with the increase of the host permittivity.

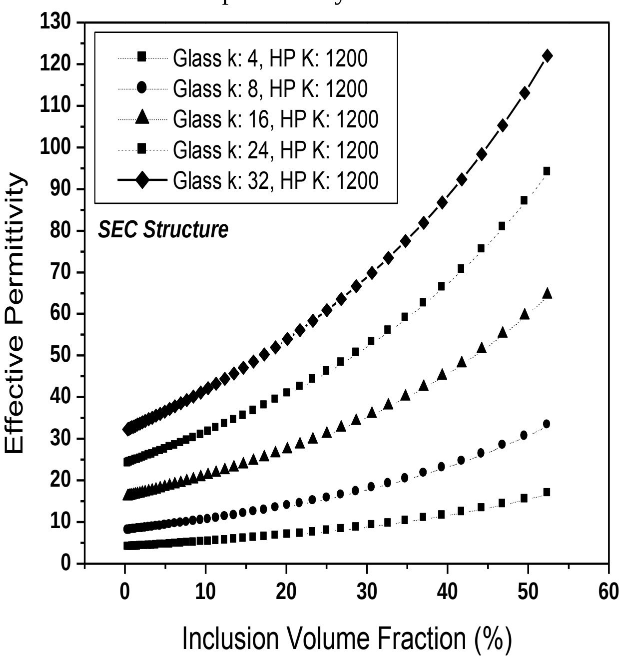


FIG. 6. MG prediction of effective permittivity for a sphere enclosed in cube as a function of volume fraction for different values of host permittivity

The energy storage can be easily calculated using (5), if the effective permittivity is known. The energy density for the SEC structure was calculated up to the inclusion volume fraction of 30 % using both *Coulomb* and the MG model. It was noted that the deviation between the *Coulomb* and the MG predictions occurs at very low volume fractions of inclusions. It is convenient to introduce a criterion on how well the MG and *Coulomb* results agree,

$$p = \frac{\left|E_{MG} - E_{Coulomb}\right|}{E_{av}} \cdot 100\%, \qquad (6)$$

where $E_{av} = \frac{E_{MG} + E_{Coulomb}}{2}$ is the average energy stored in the cube with a sphere, calculated through both the MG model and *Coulomb* software.

Herein, it was assumed that the $p >$ 10% *discrepancy* between the MG and *Coulomb* is a significant difference between the two approaches. Fig. 7 shows a plot of discrepancy p (in %) between the MG and *Coulomb* as a function of the volume fraction f_{incl} for the SEC structure. The applied field is 50 kV/cm. When the dielectric contrast is 300, the significant discrepancy between the MG and *Coulomb* (more than 10 %) occurs at the volume fraction of inclusions f_{incl} > 4%. This is the *volume fraction limit* denoted as f_{lim}. The value f_{lim} shifts to about 5.5%, when the dielectric contrast c reduces to 16. The value f_{lim} shifts to around 7%, when the dielectric contrast c is further decreased to 6. Thus, Fig. 7 demonstrates that the volume fraction limit f_{lim} increases as the dielectric contrast decreases. This means that the smaller the difference between the permittivities of the two phases, the higher volume fraction up to which the MG formulation can be applied.

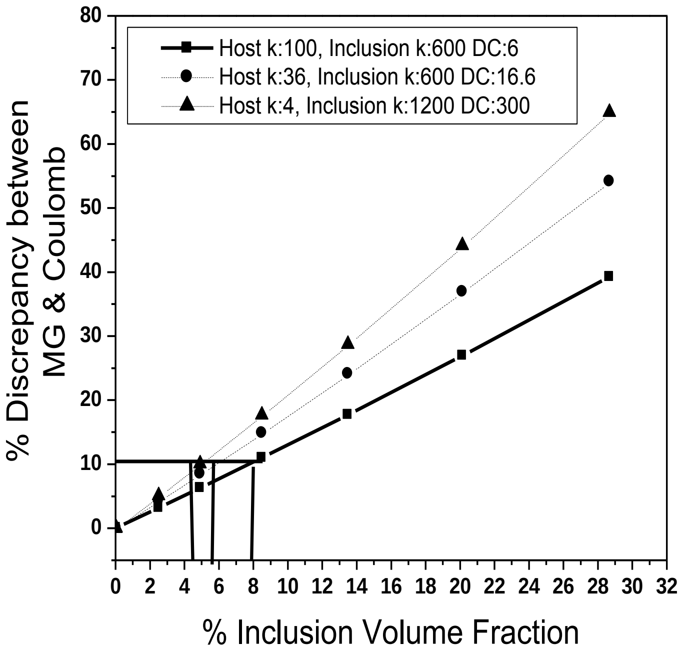


FIG. 7. Discrepancy between MG and *Coulomb* predictions as a function of inclusion volume fraction. The dielectric contrast is varied by varying both host and inclusion permittivity.

Two sets of simulations were run to determine the effect of permittivities of the inclusion and host phases on the inclusion volume fraction limit f_{lim}. First, the permittivity of the inclusion was varied, while the host permittivity remained the same. Second, the host permittivity was varied, while the inclusion permittivity was kept constant. Fig. 8 shows the discrepancy between the MG model and *Coulomb*. It may be seen that there is a substantial difference in the inclusion volume fraction limit, when only the permittivity of the host is varied. This suggests that the volume fraction limit for applicability of the MG formalism varies from approximately 5 to 8%.

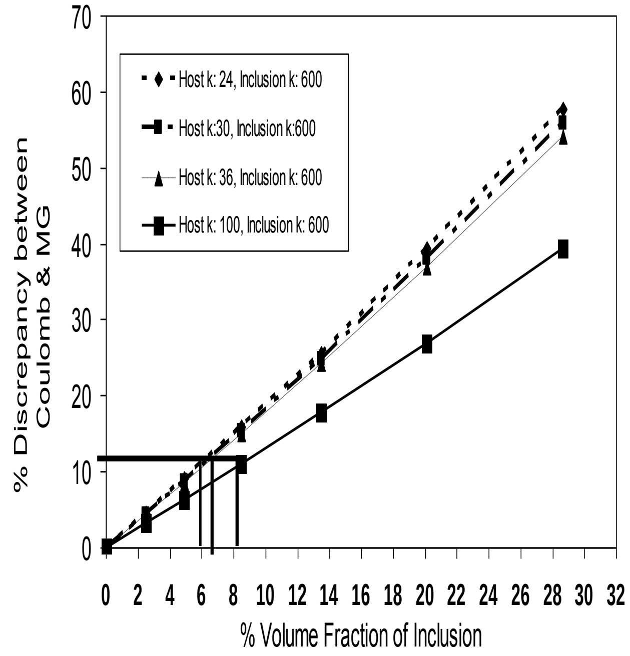


FIG. 8. Discrepancy between the MG and *Coulomb* predictions as a function of the inclusion volume fraction. The dielectric contrast is varied by varying only host permittivity (inclusion permittivity is constant).

Fig. 9 shows that when the inclusion permittivity varies, there is *almost no effect* upon the inclusion volume fraction limit f_{lim} . Thus, the volume fraction limit definitely depends on the dielectric contrast; however, it is the host permittivity that plays the crucial part in governing this limit.

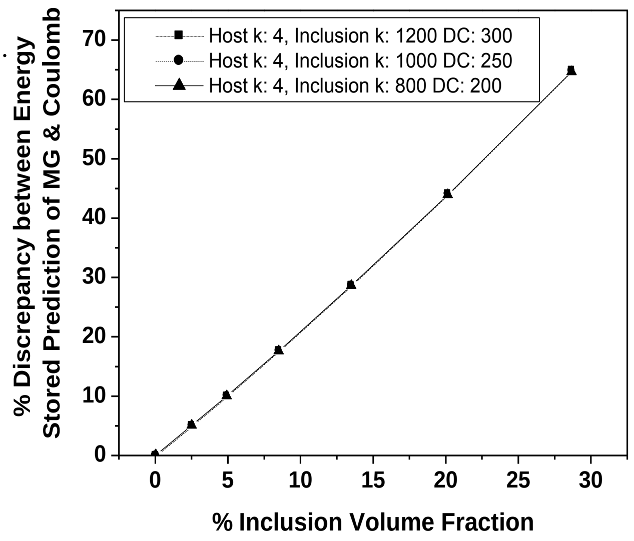


FIG. 9. Discrepancy between the MG and *Coulomb* predictions as a function of volume fraction of inclusions. The dielectric contrast is varied by varying only inclusion permittivity (host permittivity is constant).

It is important to mention that though this inclusion volume fraction limit has been estimated for the first time, there are other ways to extend applicability limit of the MG theory. For example, there is an incremental MG model proposed by A. Lahtakia [19], where the inclusion phase is always dilute, and it is added incrementally to the new homogenized host at every iteration cycle. The resultant effective permittivity converged to the result predicted by Bruggeman's formula.[29] Another approach is described in A.Sihvola's paper,[28] where the ν-parameter is introduced to take into account the interaction of polarizations of neighboring inclusions, when calculating the dipole moment of a single scatterer. The parameter $\nu = 0$ corresponds to the MG formulation; $\nu = 2$ corresponds to the Bruggeman's formula, and $\nu = 3$ gives the CP ("Coherent Potential") formula.[30, 31] The discrepancy between the MG ($\nu = 0$) and the other mixing rules ($\nu = 1, 2, 3$) starts to be noticeable, when the inclusion volume fraction is around 10 % [30, Fig. 3]. The dielectric contrast in these computations appears to be very low. Our comparison of the MG formulation with *Coulomb* numerical modeling yields the limit from 4 to 8 %, depending on the dielectric contrast ($c = 16 - 300$), which reasonably agrees with the results in papers.[30, 31]

IV. CONCLUSIONS

Modeling of electrostatic field distribution and energy storage in diphasic dielectrics containing high-permittivity $BaTiO_3$ in a glass host material have been studied using numerical simulations using software *Coulomb* and an analytical modeling based on the Maxwell Garnett mixing rule. Studies focused on a dielectric structure consisting of a cube of low permittivity phase (glass or polymer) and isotropic spherical inclusion representing high permittivity inclusion phase (ceramic, e.g., $BaTiO_3$). Using *Coulomb*, it is found that the field distribution inside a structure can be subdivided into three regions: (1) the field enhancement that takes place as the electric field lines encounter a sharp discontinuity in permittivity across a diphasic interface; (2) low-intensity field penetration into the high permittivity phase; and (3) intermediate-intensity field inside the low-permittivity region. The first region is where the breakdown might happen, so it determines the breakdown strength of the composite. The field in the second region depends on the dielectric contrast of the composite, and it determines the highest possible energy storage density.

This research has resulted in quantification of the field enhancement and field penetration. The field distribution was studied as a function of the dielectric contrast and volume fraction of the inclusion phase. For the geometry with a high-permittivity barium titanate sphere enclosed in a low-permittivity glass cube, it was found that the dielectric contrast of 75 and volume fraction of 46.8% lead to the enhanced field penetration into the high permittivity phase, which allows for increasing energy density stored within the composite, assuming that the breakdown behavior can be effectively optimized.

These results suggest opportunities for microstructural and compositional engineering to achieve high energy density dielectrics. For composites with lower inclusion volume fractions, a field enhancement factor of 2.6 was observed, whereas for higher volume fraction composites, a field enhancement of 10 was observed. The higher the field enhancement factor, the higher the probability of electric breakdown.

The upper limit of applicability of the MG formulation in terms of the inclusion volume fraction was also investigated. This limit depends on the dielectric contrast. It was found that as the dielectric contrast decreases, the MG applicability range increases. As the dielectric contrast was reduced to 16, the limit shifted to around 5.5% and when it further decreases to 6, the limit shifted to around 7 to 8%. This indicates that for mixing rules to be valid, dielectric contrast should be low enough. Variation in the host material permittivity caused substantial variation in the limit of applicability of the MG mixing rule, while variation in the permittivity of inclusion phase did not affect the limit.

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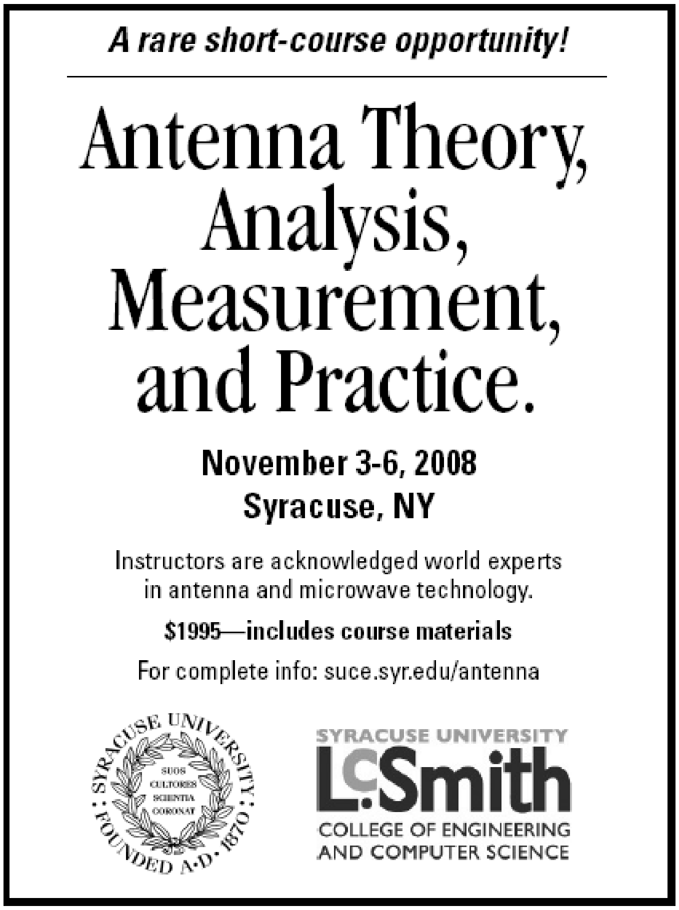

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