Saad Omar

CONTACT INFORMATION

Schlumberger-Doll Research
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RESEARCH INTERESTS

Computational and Applied Electromagnetics, Linear Complexity Direct Integral Equation solvers, Fast and High-capacity Numerical Methods, Large-Scale Parallel computing, High Frequency VLSI Circuit design and analysis, Scattering and Antenna Analysis, Inverse Scattering and Imaging Problems, Inversion techniques, Applied Mathematics, Mathematical Modeling of meta- and nano-materials, Novel modeling techniques for Electro-photonic circuits, Multi-scale analysis and design techniques, Microwave and Millimeter Wave circuits, Bio-electromagnetics.

EDUCATION

Purdue University, West Lafayette, IN., USA

Doctor of Philosophy **April** 2014

- CGPA: Major 4.0/4.0 Overall 4.0/4.0
- Advisor: Dan Jiao
- Thesis: *"Fast Direct Volume Integral Equation Solvers for Large-scale General Electromagnetic Analysis"*
- **Recipient** of the 2014 IEEE Antennas and Propagation Society Doctoral Research Award.
- **Best Student Paper Awards (Finalist)** in the 2014 IEEE Antennas & Propagation and International Microwave Symposia.
- **Honorable Mention Award** in the 2013 IEEE Antennas & Propagation Symposium.

Purdue University, West Lafayette, IN., USA

Master of Science in Computational Science and Engineering **December** 2012

- CGPA: Major 4.0/4.0 Overall 4.0/4.0
- Advisor: Dan Jiao

Purdue University, West Lafayette, IN., USA

Master of Science in Electrical Engineering **August** 2011

- CGPA: Major 4.0/4.0 Overall 3.93/4.0
- Advisor: Dan Jiao

University of Engineering & Technology, Lahore, Pakistan

Bachelor of Science in Electrical Engineering **August** 2009

- GPA Equivalent: 92.32% (Graduated at the TOP of 400+ students graduating class)
- **Seven Gold Medals** for Outstanding Academic Achievement in Bachelor studies.
- Senior Year Project Title: *"PARKOMATICO: Design and Implementation of an automated LPR based parking system"*

PROFESSIONAL EXPERIENCE

Schlumberger-Doll Research, Cambridge, MA, USA

Associate Researcher **May** 2014 – **present**

Working on well integrity issues using transient finite element analysis.

Purdue University, West Lafayette, IN, USA

Research Assistant **August** 2009 – **April** 2014

Worked with Professor Dan Jiao on an NSF supported project to design novel Integral Equation (IE) formulations for circuit parameter extractions and accelerate these as well as conventional IE based electrodynamic scattering and circuit analysis methods. The resulting system matrices using Method of Moments (MoM) in electromagnetics are not only dense but also are of gigantic dimensions. State-of-the-art methods like Fast Multipole Method (FMM) utilize *O(NlogN)* memory and computational resources. We on the other hand successfully achieved as fast as *O(N)* complexity and that too for **direct inverse** of the matrices resulting from integral equations unlike FMM based iterative solutions for circuit parameter extraction. On the electrodynamic side, for the first time ever, *O(N)* complexity iterative and *O(NlogN)* direct inverse based VIE solvers were successfully developed. A brief summary of the major projects I have completed and those still in progress is as below:

- **First-Principles VIE Formulation for Simultaneous Circuit-Scattering Analysis**
  Sensitive microwave, RF and VLSI circuits in devices operating in a battle-field, communication satellite and highly radioactive environment are exposed to severe ambient environment. The design of such circuits require a simultaneous circuit-scattering analysis otherwise it can lead to catastrophic results. In the prevailing state-of-art methods and commercial tools, there is

always a missing link between full-wave circuit and scattering analysis, thus a failure to deal with such problems. Exploiting all the inherent features which a Volume Integral Equation (VIE) has to offer, we have developed a novel first-principles based VIE formulation which essentially bridges the gap between full-wave circuit and scattering analysis thus enabling a simultaneous circuit-scattering analysis. The successful completion of this task was thoroughly appreciated by the Microwave Theory & Techniques (MTT) society in the International Microwave Symposium (IMS). Our paper detailing this project was ranked **FIRST** in the **frequency domain session of the IMS** 2013.

- ***O(N)* Integral Equation Direct Solvers**
  The unparallel benefits of Integral Equation(IE) methods are eclipsed by the computational costs required to carry-out an EM analysis based on them. If the discretization of IE methods results in N degrees of freedom then it requires $O(N_{rhs}N_{iter}N^2)$ computational resources to solve the problem iteratively whereas $O(N^3)$ for direct methods like Gaussian Elimination. The current state-of-the-art iterative methods like Fast Multipole Method(FMM) utilize $N_{rhs}N_{iter}O(NlogN)$ computational resources. We on the other hand focussed to achieve as fast as $O(N)$ complexity and that too for **direct inverse** of the matrices resulting from integral equations unlike FMM based iterative solutions. We have been able to achieve this optimal $O(N)$ complexity in direct solvers for **circuit problems** which can invert a single dense VIE matrix of size 1Million by 1Million in 4 minutes and less than 5GB of Memory on a single processor running on 3GHz clock speed. This work has been as selected as the finalist for the **Best Student Paper** competitions of the top two conferences of EM community namely IMS and APS, to be held in June and July, 2014 respectively. For **dynamic cases**, where the size of the problem no longer remains in the sub-wavelength regime, for the first time, $O(N)$ complexity has been achieved for iterative and $O(NlogN)$ complexity has been achieved for direct inverse based VIE analysis.

- ***O(1)* Solution to Low- and High-frequency Breakdowns in IE Methods**
  The incorrect solutions (called as breakdown) obtained from the IE analysis of electrically small problems has always remained a mystery. Some credited this to improper discretization techniques while others devised sub-optimal trial and error techniques to partially address this issue. Teamed with other co-authors, the root-cause of this issue was identified to be the *finite machine precision*. A theoretically rigorous closed form expression for the inverse of an IE system matrix was derived using eigenvalue analysis. This expression also revealed that the breakdown is not a low-frequency phenomenon but can also occur for highly multi-scale examples with more than 7 orders of magnitude different feature details. An $O(1)$ solution to these problems is also proposed and was highly appreciated by the Antenna& Propagation Community in the 2013 IEEE International Symposium on Antennas and Propagation where a part of this project was awarded with an **HONORABLE MENTION AWARD**. For a scattering based analysis using IE methods, theoretically rigorous numerical expressions for correct right hand side and scattering field computation were also derived to overcome these pivotal breakdowns in field computations.

Schlumberger-Doll Research, Cambridge, MA, USA

Summer Research Internee **Summer** 2012

Each year the subdivision of Mathematics and Modeling Group in SDR working on inverse problems and managed by Aria Abubakar, assigns a novel project which has a potential of opening a new dimension in the inverse problem domain. During the summer of 2012, I was assigned the project of designing and implementing a new multiplicative regularizer which mimics the norm-1 behavior as much as possible. The multiplicative regularizer, originally mimicking norm-2 behavior as shown by their previous work, not only bypasses the a-priori selection of regularization parameters but also shows superior performance. In only a couple of months, not only was I able to design and implement the required novel regularizer but also showed its superior performance over multiple data sets. At the end of the internship period, in addition to the completion of the project I was also asked to hand over a considerably large set of source codes of huge interest to their group for future research purposes. They also intend to publish a journal paper on this summer research project.

Purdue University, West Lafayette, IN, USA

Summer Undergraduate Research Fellowship (SURF) Supervisor **Summer** 2013

Supervised Ryan Nobis, in his SURF project targeted at finding a novel methodology to get an explicit inverse for the general Volume integral equation based analysis. The research findings were summarized in a technical report titled "An Approximation Method for Solving Complex Electromagnetics Problems using the Volume Integral Equation". It can be easily downloaded from: http://docs.lib.purdue.edu/surf/2013/presentations/129

Undergraduate Research Supervisor **May** 2010 – **August** 2013
Supervised two undergraduate students , each semester, interested in exploring and ultimately doing research in the field of Computational Electromagnetics and Numerical Analysis in general. Initially they were exposed to general research methodology followed by a hands-on experience with a novel research topic.

Honorary Teaching Assistant **Fall** 2011
ECE-604 (Graduate-level) Field and Waves Electromagnetics : Delivered lectures , conducted help sessions , prepared homework and exam solutions.

Honorary Teaching Assistant **Fall** 2010 – **Fall** 2012
ECE-311 (Undergraduate-level) Electric and Magnetic Fields : Delivered lectures and conducted help sessions.

University of Engineering & Technology, Lahore, Pakistan
Visiting Instructor **February** – **May** 2012
(Undergraduate-level) Linear Algebra for Engineers : Delivered lectures , conducted help sessions , prepared homework and exam solutions.

Knowledge Inn Preparatory School, Lahore, Pakistan
Visiting Motivational and Course Strategy making Instructor **September** 2005 – **July** 2009
(High School level) Mathematics, Physics and Chemistry : Delivered motivational lectures , conducted help sessions and helped students in making optimal learning and preparatory strategy.

Conference Publications

S. Omar and D. Jiao, "An $\mathcal{H}^2$-matrix based fast volume integral equation solver for electrodynamic analysis," *the* 27*th International Review of Progress in Applied Computational Electromagnetics (ACES)*, March 2011.

S. Omar and D. Jiao, "An explicit inverse based direct volume integral equation solver for electromagnetic analysis," *the* 2011 *IEEE International Symposium on Antennas and Propagation*, July 2011.

J. Zhu, **S. Omar**, W. Chai and D. Jiao, "A rigorous solution to the low-frequency breakdown in the electric field integral equation," *the* 2011 *IEEE International Symposium on Antennas and Propagation*, July 2011.

S. Omar and D. Jiao, "An $\mathcal{H}^2$-matrix based fast direct volume integral equation solver for electrodynamic analysis," *the* 28*th International Review of Progress in Applied Computational Electromagnetics (ACES)*, April 2012.

S. Omar and D. Jiao, "A novel volume integral formulation for wideband impedance extraction of arbitrarily-shaped 3-D lossy conductors in multiple dielectrics," *the* 2012 *IEEE International Symposium on Antennas and Propagation*, July 2012.

S. Omar and D. Jiao, "Solution to the "High" frequency breakdown in EFIE," *the* 2013 *IEEE International Symposium on Antennas and Propagation.*(**HONORABLE MENTION AWARD**)

S. Omar and D. Jiao, "A new volume integral formulation for fullwave extraction of 3-D circuits in inhomogeneous dielectrics exposed to external fields," *the* 2013 *IEEE International Symposium on Antennas and Propagation.*

S. Omar and D. Jiao, "An analytical approach to the low-frequency breakdown of the right hand side and scattered field computation in EFIE," *the* 2013 *IEEE International Symposium on Antennas and Propagation.*

S. Omar and D.Jiao," A new volume integral equation formulation for analyzing 3-D circuits in inhomogeneous dielectrics exposed to external fields," *the* 2013 *IEEE International Microwave Symposium.*(**TOP RANKED PAPER by reviewers in *Frequency Domain Session***)

J. Zhu, **S. Omar** and D. Jiao, "The frequency band where the solution to Maxwell's Equations is unknown – a challenge facing the analysis of multiscale problems and its solution." *IEEE International Symposium on EMC,* 2013.

S. Omar and D.Jiao," A linear complexity $\mathcal{H}^2$-matrix based direct volume integral solver for broadband 3-D circuit extraction in inhomogeneous materials," accepted for publication, *the* 2014 *IEEE International Microwave Symposium.* (**BEST STUDENT PAPER AWARD-FINALIST**)

S. Omar and D. Jiao, "An $O(N)$ direct volume IE solver with a rank-minimized $\mathcal{H}^2$-representation for large-scale 3-D circuit extraction in inhomogeneous materials," accepted for publication, *the* 2014 *IEEE International Symposium on Antennas and Propagation.* (**BEST STUDENT PAPER AWARD-FINALIST**)

Peer-reviewed Journal Publications

S. Omar and D. Jiao, "$\mathcal{H}^2$-matrix based fast volume integral equation iterative solver for electrodynamic analysis," *IET Microwaves, Antennas and Propagation*, vol: 7, Iss. 14, pp.: 1145-1153, Nov. 2013.(doi: 10.1049/iet-map.2013.0090)

S. Omar and D. Jiao, "A new volume integral formulation for broadband 3-D circuit extraction in inhomogeneous materials with and without external electromagnetic fields," *IEEE Trans. on Microwave Theory & Techniques*, vol: 61, Iss. 12, pp.: 4302-4312, Dec. 2013.(doi: 10.1109/TMTT.2013.2285355)

J. Zhu, **S. Omar** and D. Jiao, "Solution to the electric field integral equation when it breaks down," accepted for publication, *IEEE Trans. on Antennas and Propagation*, 2013.

S. Omar and D. Jiao, "A linear complexity direct volume integral equation solver for full-wave 3-D circuit extraction in inhomogeneous materials," in review process, *IEEE Trans. on Microwave Theory & Techniques*, 2013.

S. Omar and D. Jiao, "Rank-minimized linear complexity $\mathcal{H}^2$-matrix based direct volume integral equation solver for full-wave 3-D circuit extraction in inhomogeneous materials," in preparation.

S. Omar and D. Jiao, "Linear complexity rank-minimized $\mathcal{H}^2$-matrix based LU factorization for full-wave 3-D circuit extraction comprising of inhomogeneous materials using volume integral equation," in preparation.

S. Omar and D. Jiao, "An optimal complexity direct volume integral equation solver for large scale electrodynamic analysis," in preparation.

Technical Reports

The following reports can be freely downloaded online from Purdue e-Pub. The current total readership of these reports is 475 based on full-text downloads.

J. Zhu, **S. Omar** and D. Jiao, "Solution to the Electric Field Integral Equation at Arbitrarily Low Frequencies," TR-ECE-12-05, School of Electrical Engineering, Purdue University, May 2012, 11 pages.

R. Nobis, **S. Omar** and D. Jiao,"An Approximation Method for Solving Complex Electromagnetics Problems using the Volume Integral Equation", (MS#1015).

Honours and Awards

Doctoral Research Award, 2014($2500) from the IEEE Antennas & Propagation Society.

Best Student Paper Award - Finalist($1500) in the 2014 IEEE Antennas & Propagation Symposium.

Best Student Paper Award - Finalist($1000) in the 2014 IEEE International Microwave Symposium.

Honorable Mention Award($1000) in the 2013 IEEE Antennas & Propagation Symposium.

Top Ranked Paper(Frequency Domain Session) in 2013 IEEE International Microwave Symposium.

Seven Gold Medals for Outstanding Academic Achievement in Bachelor studies,U.E.T,Lahore, 2009.

Presidential Award(PKR 200,000) for Breaking a **58** year National Academia Record, M.O.E, 2005.

Eight Gold Medals for Outstanding Academic Achievement in High School, B.I.S.E, Lahore, 2005.

National Talent Scholarship, Govt. of Pakistan, 2005-2009.

Golden Key Purdue University Scholarship Award($250) from GOLDEN KEY INTERNATIONAL HONOUR SOCIETY, 2013.

Programming

C, C++, FORTRAN, MATLAB, LaTeX.

Completed Course Work

Purdue University, West Lafayette, IN., USA

- Field and Waves Electromagnetics
- Inverse Scattering Problems for Wave Propagation
- Antenna Analysis and Design
- Numerical Electromagnetics
- Digital Signal Processing
- Solid-state Devices
- MOS VLSI Design
- Design and Optimization of High Performance Interconnects
- Computational Models and Methods
- Numerical Linear Algebra
- Structured Matrix Computations
- Linear Programming
- Linear Algebra with Applications
- Numerical Analysis
- Parallel Numerical Linear Algebra (Listener only)
- Theoretical Foundations of Optimization (Listener only)
- Numerical Solution of Ordinary Differential Equations (Listener only)

- Computer Architecture (Listener only)

Professional Memberships

Student Member IEEE.
Member IEEE Antennas & Propagation Society.
Member IEEE Microwave Theory & Techniques Society.
Member GOLDEN KEY INTERNATIONAL HONOUR SOCIETY.
Member TAU BETA PI - The Engineering Honor Society.
Member Interdisciplinary group of Computational Science and Engineering (CS&E) at Purdue.
Member Student Chapter of the Society for Industrial and Applied Mathematics (SIAM) at Purdue.

Professional Activities

Graduate Committee Member The School of Electrical & Computer Engineering, Purdue University.
Paper Reviewer The Applied Computational Electromagnetics Society(ACES) Journal.
Paper Reviewer AEU - International Journal of Electronics and Communications.

Side Activities

Gold medal winning captain of First ever Pakistani team in Purdue Nataraj Iyer Cricket League with 14 participating teams from around the globe.
Treasurer Pakistani Students Association (PSA) at Purdue.
Think-Tank of United for Pakistan Alliance at Purdue for supporting flood-victims in Pakistan, eventually raising $10,000 within one month.
Gold and **bronze** medal winning captain of School Cricket and Basket-Ball teams, respectively.

Referees

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