Professor Ralf Hiptmair

Main research areas

Professor Hiptmair's research in Applied Mathematics focuses on the design and analysis of *discretizations* and *fast solution algorithms* for the numerical solution of boundary value problems for partial differential equations. He has made particular contributions to the development of *finite element methods*, *boundary element* methods and *multilevel iterative solvers*.
His research can also be viewed from the angle of application areas: it is *computational electromagnetics*, which forms the core of most of his research. His activities range from issues of modeling, via discretization techniques, to special multigrid methods for the boundary value problems of electromagnetism. Questions from the related field of computational acoustics are also covered in his research.

Research since 1999

Modeling in computational electromagnetism.

- Systematic and mathematically sound treatment of how to take into account lumped sources in variational electromagnetic boundary value problems [11].
- Rigorous non-asymptotic modeling error analysis of quasi-static approximations [1].
- Efficient modeling of thin conducting sheets [4].
- Continuous and discrete variational formulations for the eddy current boundary value problem on non-matching meshes (hybrid coupling) [13].

Discrete differential forms.

- Comprehensive and abstract analysis of requirements to be met by discrete Hodge operators [28, 26].
- Unified construction of higher-order discrete differential forms [29, 26].
- Generators of discrete co-homology classes on triangulated surfaces [24].

Fast iterative solvers for H(curl)-elliptic boundary value problems.

- Abstract operator preconditioning [9].
- Geometric multigrid methods for $\mathbf{H}(\mathbf{curl})$-elliptic boundary value and eigenvalue problems [30, 30, 23, 21, 3].
- Auxiliary space preconditioning in $\mathbf{H}(\mathbf{curl})$ [8, 2].

Boundary element methods in computational electromagnetics and acoustics.

- Analysis of Galerkin boundary element methods (BEM) for magneto-quasistatic boundary value problems [27, 16].
- Convergence theory of Galerkin BEM for electromagnetic scattering [25, 18, 17].
- Symmetric coupling of finite elements and boundary elements for electromagnetics [27, 22].
- Stabilized combined field integral equations for acoustics and electromagnetics [14, 15, 7].

Sparse tensor product approximation.

- Discrete differential forms on sparse grids [20].
- "$H(\mathbf{curl},\Omega)$-multigrid" on sparse grids [19].
- Sparse adaptive tensor product Galerkin discretization for radiative transfer [6].

Important publications since 1999

[1] K. Schmidt, O. Sterz, and R. Hiptmair, *Estimating the eddy-current modelling error*, IEEE Trans. Magnetics, (2008). Accepted.

[2] R. Hiptmair and J. Xu, *Nodal auxiliary space preconditioning in H(curl) and H(div) spaces*, SIAM J. Numer. Anal., 45 (2007), pp. 2483–2509.

[3] R. Hiptmair and W.-Y. Zheng, *Local multigrid in* $\mathbf{H}(\mathbf{curl})$, Tech. Rep. 2007-03, SAM, ETH Zürich, Zürich, Switzerland, March 2007. Submitted to JCM.

[4] J. Ostrowski, R. Hiptmair, and H. Fuhrmann, *Electric 3D-simulation of metallized film capacitors*, COMPEL, 26 (2007), pp. 524–543.

[5] C. Gittelson, R. Hiptmair, and I. Perugia, *Plane wave discontinuous Galerkin methods*, Preprint NI07088-HOP, Isaac Newton Institute Cambride, Cambridge, UK, December 2007. Submitted to M2AN.

[6] G. Widmer, R. Hiptmair, and C. Schwab, *Sparse adaptive finite elements for radiative transfer*, Tech. Rep. 2007-01, SAM, ETH Zürich, Zürich, Switzerland, January 2007. To appear in JCP.

[7] R. Hiptmair and P. Meury, *Stabilized FEM-BEM coupling for Helmholtz transmission problems*, SIAM J. Numer. Anal., 44 (2006), pp. 2107–2130.

[8] R. Hiptmair, G. Widmer, and J. Zou, *Auxiliary space preconditioning in* $\mathbf{H}_0(\mathbf{curl}, \Omega)$, Numer. Math., 103 (2006), pp. 435–459.

[9] R. Hiptmair, *Operator preconditioning*, Computers and Mathematics with Applications, 52 (2006), pp. 699–706.

[10] B. Zeller and R. Hiptmair, *Conservative discretization of the Einstein-Dirac equations in spherically symmetric spacetime*, Classical and Quantum Gravity, 23 (2006), pp. S615–S634.

[11] R. Hiptmair and O. Sterz, *Current and voltage excitations for the eddy current model*, Int. J. Numer. Model, 18 (2005), pp. 1–21.

[12] T. Bubeck, R. Hiptmair, and H. Yserentant, *The finite mass mesh method*, Computing and Visualization in Science, 8 (2005), pp. 49–68.

[13] A. Alonso-Rodriguez, R. Hiptmair, and A. Valli, *A hybrid formulation of eddy current problems*, Num. Meth. Part. Diff. Equ., 21 (2005), pp. 742–763.

[14] A. Buffa and R. Hiptmair, *Regularized combined field integral equations*, Numer. Math., 100 (2005), pp. 1–19.

[15] A. Buffa and R. Hiptmair, *A coercive combined field integral equation for electromagnetic scattering*, SIAM J. Numer. Anal., 42 (2004), pp. 621–640.

[16] R. Hiptmair and J. Ostrowski, *Coupled boundary element scheme for eddy current computation*, J. Engr. Math., 51 (2004), pp. 231–250.

[17] A. Buffa and R. Hiptmair, *Galerkin boundary element methods for electromagnetic scattering*, in Topics in Computational Wave Propagation. Direct and inverse Problems, M. Ainsworth, P. Davis, D. Duncan, P. Martin, and B. Rynne, eds., vol. 31 of Lecture Notes in Computational Science and Engineering, Springer, Berlin, 2003, pp. 83–124.

[18] A. Buffa, R. Hiptmair, T. von Petersdorff, and C. Schwab, *Boundary element methods for Maxwell equations on Lipschitz domains*, Numer. Math., 95 (2003), pp. 459–485.

[19] V. Gradinaru and R. Hiptmair, *Multigrid for discrete differential forms on sparse grids*, Computing, 71 (2003), pp. 17–42.

[20] V. Gradinaru and R. Hiptmair, *Whitney forms on sparse grids*, Numer. Math., 93 (2003), pp. 471–495.

[21] R. Hiptmair, *Analysis of multilevel methods for eddy current problems*, Math. Comp., 72 (2003), pp. 1281–1303.

[22] R. Hiptmair, *Coupling of finite elements and boundary elements in electromagnetic scattering*, SIAM J. Numer. Anal., 41 (2003), pp. 919–944.

[23] R. Hiptmair and K. Neymeyr, *Multilevel method for mixed eigenproblems*, SIAM J. Sci. Comp., 23 (2002), pp. 2141–2164.

[24] R. Hiptmair and J. Ostrowski, *Generators of* $H_1(\Gamma_h, \mathbb{Z})$ *for triangulated surfaces: Construction and classification*, SIAM J. Computing, 31 (2002), pp. 1405–1423.

[25] R. Hiptmair and C. Schwab, *Natural boundary element methods for the electric field integral equation on polyhedra*, SIAM J. Numer. Anal., 40 (2002), pp. 66–86.

[26] R. Hiptmair, *Finite elements in computational electromagnetism*, Acta Numerica, 11 (2002), pp. 237–339.

[27] R. Hiptmair, *Symmetric coupling for eddy current problems*, SIAM J. Numer. Anal., 40 (2002), pp. 41–65.

[28] R. Hiptmair, *Discrete Hodge operators*, Numer. Math., 90 (2001), pp. 265–289.

[29] R. Hiptmair, *Canonical construction of finite elements*, Math. Comp., 68 (1999), pp. 1325–1346.

[30] R. Hiptmair, *Multigrid method for Maxwell's equations*, SIAM J. Numer. Anal., 36 (1999), pp. 204–225.

Selected invited presentations

1. *Plane Wave Discontinuous Galerkin Methods*, Workshop on High-order methods for computational wave propagation and scattering, American Institute of Mathematics (AIM), Palo Alto, CA, Sep 10-14,2007.
2. *Plane Wave Discontinuous Galerkin Methods*, workshop on "Effective computational methods for highly oscillatory problems: The interplay between mathematical theory and applications" at Isaac Newton Institute, Cambridge, UK, July 1-5, 2007.
3. *Multigrid for Maxwell Eigenproblems*, plenary lecture at European Multigrid Conference, Scheveningen, the Netherlands, 27-30 September 2005.
4. *Current and Voltage Excitations for the Eddy Current Model*, International Conference on Hot Topics in Applied and Industrial Mathematics, Guiyang, Guizhou, China, July 13-16, 2005.
5. *Conservative Discretization of Einstein-Dirac Equations with Spherical Symmetry*, BIRS Workshop on Numerical Relativity, Banff, Canada, April 16-21, 2005.
6. *Edge Elements and Coercivity* and *Multigrid for Edge Elements* 29th Woudschoten Conference, Zeist, The Netherlands, October 6-8, 2004.
7. *Higher Order Whitney Forms*, IMA Special Topics Workshop on "Compatible Spatial Discretizations for Partial Differential Equations", Minneapolis, May 11-15, 2004.
8. *Non-reflecting Boundary Conditions for Maxwell's Equations*, 20th GAMM Seminar on Numerical Methods for Non-local Operators, Leipzig, Jan 22-24, 2004
9. *Boundary Element Methods for Eddy Current Computation*, plenary lecture at ENUMATH'03 conference Aug 18-22, 2003, Prague
10. *Domain Decomposition Preconditioners for Edge Elements: A survey*, 15th International Conference on Domain Decmposition Methods, July 21-25,2003, Berlin, Germany
11. *A Coupled Boundary Element Scheme for Eddy Current Computation*, 2. Kolloquium Elektromagnetische Umformung, Universität Dortmund, Germnay, May 27, 2003.
12. *Multigrid for Edge Elements: A Survey*, plenary lecture at European Multigrid Conference, Oct 7-10, 2002, Hohenwart, Germany
13. *Discretization of Maxwell's Equations*, Workshop on numerical relativity, IMA Minneapolis, MN, June 24-29, 2002.
14. *Discrete Differential Forms*, NSF-CBMS regional conference in the mathematical sciences "Numerical methods in forward and inverse electromagnetic scattering", Golden, CO, June 3-7, 2002.
15. *FEM-BEM Coupling for Eddy Current Problems*, plenary lecture at GAMM-Workshop "Computational Electromagnetism", Kiel, January 26- 28, 2001

These presentations have been accompanied by quite a few contributed presentations on the occasion of conferences and workshops. Besides I have given numerous seminars whiling visiting various places. For details please consult my internet pages.

Active collaborations

- with numerical simulation group at ABB Corporate Research, Baden. ABB researchers involved are J. Ostrowski, H. Nordborg, B. Cranganu-Cretu. The collaboration addresses many different topics from computational electromagnetism, like boundary element methods, stable formulations, plasma simulation, etc.
- with J. Xu (CCMA, Mathematics Department The Pennsylvania State University, USA), on multigrid methods for discrete differential forms.
- with J. Zou, CUHK, on interface problems and the numerical analysis of the chimera method.
- with R. Kotiuga (Electrical Engineeting, Boston University, USA) and S. Tordeux (Département de Génie Mathématique et Modélisation, INSA Toulouse, France) on self-adjoint curl operators, (discrete) eigenvalue problems for curl, and discrete helicity functionals.

- with S. Tordeux (Département de Génie Mathématique et Modélisation, INSA Toulouse, France), on asymptotics for thin conducting sheets (co-supervision of PhD project of K. Schmidt).
- with O. Sterz (CST GmbH, Darmstadt, Germany) on the coupling of fields and circuits, treatment of electromagnetic forces in finite element context, and practical aspects of multigrid.
- with C. Hafner (Computational Optics Group, IFH, ITET, ETH Zurich, Switzerland) on (spectral) boundary element methods for nano-optics (plasmonics).
- with Z. Chen (Institute of Computational Mathematics, Academy of Mathematics and Systems Science, Chinese Academy of Sciences Beijing, PR China) on adaptive and multilevel methods for edge elements.
- with I. Perugia (Dipartimento di Matematica, Universitá di Pavia, Italy) on plane wave discontinuous Galerkin methods.

Grants and external funding since 2002

- ETH grant for three year project on "High Resolution Numerical Simulation of Electromagnetic Fields in Thin Conducting Sheets" funding the PhD research of K. Schmidt (2003-2006).
- SNF grant for three year project on "Stable Boundary Element Galerkin Schemes for Direct Acoustic and Electromagnetic Scattering" funding PhD project of P. Meury (2004-2007) .
- Co-investigator (together with R. Jeltsch and C. Schwab) in KTI funded industrial project on "Model for High Current Arc in Generator Circuit Breaker" (10/04-12/07). Industrial partner: ABB corporate research
- Industrial project on "Fast Transients in Thin Conductors" funded by ABB corporate research (04/07-11/07), total amount: CHF 23,000.
- Industrial project on "Preconditioned Boundary Element Methods for Electromagnetic Scattering at Dielectric Objects" funded by Thales Systemes Aeroportes S.A. for 3 years from 2008, total amount: CHF 318,000.
- SNF grant for three year project on "Spectral Galerkin Boundary Integral Equation Methods for Plasmonic Nano-Structures" (jointly with Prof. C. Hanfer, IFH, ETH Zürich), starting 04/2008.

PhD students since 1999

1. V. Gradinaru (1998-2002 at University of Tübingen), thesis on "Whitney elements on sparse grids"
2. J. Ostrowski (2000-2003 at University of Tübingen), thesis on "Boundary Element Methods for Inductive Hardening"
3. T. Bubeck (1999-2003 at University of Tübingen), thesis on "The Finite Mass Method and Fields"
4. P. Meury (2003-2007 at ETH Zürich), thesis on "Stable Finite Element Boundary Element Galerkin Schemes for Acoustic and Electromagnetic Scattering"
5. K. Schmidt (PhD student since 2003, PhD expected 2008), PhD project on "Numerical Computation of Electromagnetic Fields in Thin Conducting Sheets"
6. B. Zeller (PhD student since 2004, PhD expected 2008), PhD project on "Numerical Modelling of Dirac-Einstein Equations in Spherical Symmetries"
7. G. Widmer (PhD student since 2003, PhD expected 2008), PhD project on "Sparse Tensor Product Methods for Radiative Transfer"
8. H. Heumann (PhD student since 2006), PhD project on "Discretization of Generalized Convection Diffusion Equations"
9. L. Raguin (PhD student since 2007), PhD project on "Spectral Galerkin Boundary Integral Equation for Plasmonic Nano-Structures" (co-supervised with C. Hafner)

Ongoing projects and future research directions

Frequency-Robust Electromagnetic Boundary Value Problems.
Discretization of generalized convection–diffusion equations.
Adaptive plane wave discontinuous Galerkin methods.
Multi-dielectric electromagnetic scattering.
Boundary element techniques in nano-optics.
Sparse adaptive tensor product discretization.

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Teaching

Undergraduate courses (computer assisted, MATLAB based):

- *Numerische Mathematik für CSE* (Numerical analysis for CSE curriculum)
- *Numerical treatment of differential equations* (CSE curriculum)
- *Numerical treatment of elliptic and parabolic boundary value problems* (BSc Math)
- *Numerical treatment of hyperbolic boundary value problems* (BSc Math)
- *Numerische Mathematik* (Numerical analysis, BSc Math)

Prof. Hiptmair also initiated the development of the LehrFEM library at the Seminar for Applied Mathematics. This is a collection of MATLAB modules offering routines and templates for the easy implementation of a broad range of finite element schemes (Lagrangian FEM, mixed FEM, edge elements, discontinuous Galerkin schemes, etc.). This library has been widely adopted for practical exercise for classes on the numerical treatment of PDEs. Moreover, it has become popular with students for doing numerical thesis projects. It is even being used by some PhD students for parts of their projects.
Graduate level courses:

- *Inverse Problems* (graduate course, summer term 2007)
- *Multiscale iterative solvers* (graduate course, summer term 2006)
- *Computational electromagnetism* (graduate course, summer term 2003)
- *Multigrid methods* (graduate course, winter term 02/03)

These are complemented by students seminars on *Goemetric numerical integration*, *Absorbing boundary conditions*, *Fast Fourier transform and generalizations*, *hierarchical matrices*, and *algebraic multigrid methods*.

Other profession oriented activites

- Organizer of *Oberwolfach Conference on Computational Electromagnetism and Acoustics*, Feb 4-10, 2007.
- Organizer of *Oberwolfach Conference on Computational Electromagnetism*, Feb 22-28, 2004.
- MACSI-NET Working Groups 13 and 2 Annual meeting and workshop on *Model reduction in electromagnetics* and *Coupling of field models and circuits* May 2-3, 2003.
- Managing editor of *Zeitschrift für Angewandte Mathematik und Mechanik (ZAMM)*, since 1/2008.
- Member of editorial board of *Journal of Computational Mathematics* since 1/2007.