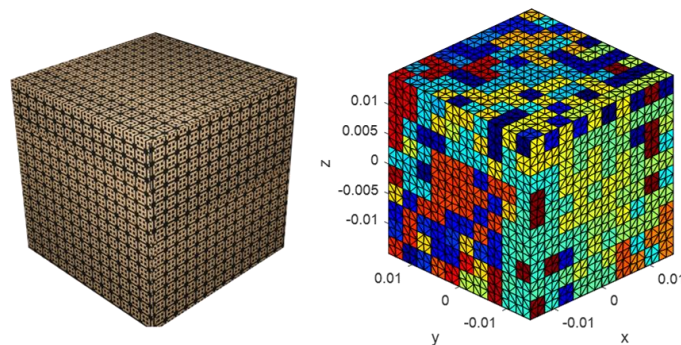


Integral Equation Based Synthesis of Metasurfaces

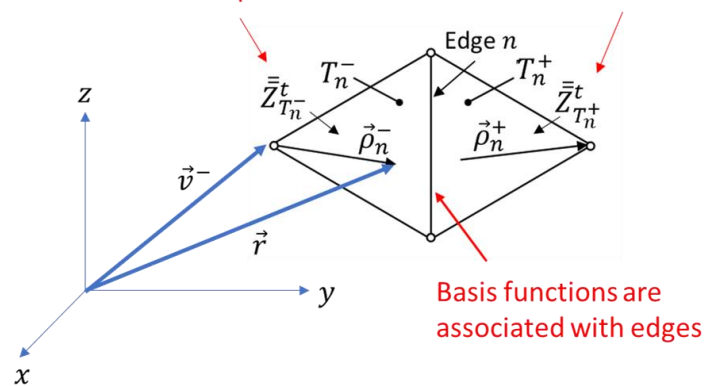
Abstract

This course will provide a solid foundation of numerical modelling of metasurfaces based on integral equations. Numerical design, analysis, and synthesis techniques for metasurfaces will be built up starting from Maxwell's equations. Both 2D and 3D algorithms will be presented. Rapid optimization schemes based on the Adjoint variable technique will also be presented. The student will leave with the ability to write their own integral equation based codes for metasurface design.

Graphical abstract



Each basis function has a pair of impedance tensors associated with it



Basis functions are associated with edges

Recommended prerequisites

The course will require basic knowledge of mathematics, radiation, electromagnetic theory, matlab programming.

Learning objectives

- 1) Understand integral equation modelling of metasurfaces.
- 2) Solve integral equations via the method of moments in 2D and 3D
- 3) Write a Matlab code for the design of metasurfaces via integral equations and the method of moments
- 4) Understand optimization techniques for metasurface design

Course outline

- 1- Impedance boundary condition describing homogenized sheet impedances
- 2- Construction of integral equations for modelling of impedance sheets
- 3- Solution of integral equations via the method of moments
- 4- Metasurface design via integral equations in 2D
- 5- Metasurface design via integral equations in 3D
- 6- Optimization techniques for metasurface design

Students should bring a laptop with Matlab installed if they want to follow along in real time. An example recording of a similar workshop presented by the proposer of this short course can be found on my YouTube page:

<https://www.youtube.com/watch?v=4wODcAIWxg&t=2s>

Instructor – biography



Jordan Budhu received his M.S. degree in electrical engineering from the California State University, Northridge, California, USA, in 2010, and the Ph.D. degree in electrical engineering from the University of California, Los Angeles, California, USA, in 2018.

He is currently Assistant Professor in the Bradley Department of Electrical & Computer Engineering at Virginia Tech. From 2019 to 2022, he was a Postdoctoral Research Fellow in the Radiation Laboratory and a Lecturer in the Department of Electrical Engineering and Computer Science at the University of Michigan, Ann Arbor, Michigan, USA. In 2011 and 2012, he was a Graduate Student Intern at the NASA Jet Propulsion Laboratory. In 2017, he was named a Teaching Fellow at the University of California, Los Angeles. His research interests are in metamaterials and metasurfaces, computational electromagnetics algorithms for metamaterial and metasurface design, nanophotonics and metamaterials for the infrared, 3D printed inhomogeneous lens design, CubeSat antennas, reflectarray antennas, scattering from inhomogeneous, anisotropic materials, and antenna theory.

Dr. Budhu's awards and honors include the 2010 Eugene Cota Robles Fellowship from UCLA, the 2012 Best Poster award at the IEEE Coastal Los Angeles Class-Tech Annual Meeting, the 2018 UCLA Henry Samueli School of Engineering and Applied Science Excellence in Teaching Award, and the first place award for the 2019 USNC-URSI Ernst K. Smith Student Paper Competition at the 2019 Boulder National Radio Science Meeting.

Key bibliography

Journal Papers:

J. Budhu and A. Grbic, "Perfectly Reflecting Metasurface Reflectarrays: Mutual Coupling Modeling Between Unique Elements Through Homogenization," in IEEE Transactions on Antennas and Propagation, vol. 69, no. 1, pp. 122-134, Jan. 2021.

J. Budhu, E. Michielssen and A. Grbic, "The Design of Dual Band Stacked Metasurfaces Using Integral Equations," in IEEE Transactions on Antennas and Propagation, vol. 70, no. 6, pp. 4576-4588, June 2022, doi: 10.1109/TAP.2022.3142277.

J. Budhu and A. Grbic, "Fast and Accurate Optimization of Metasurfaces with Gradient Descent and the Woodbury Matrix Identity," – Under Review in IEEE Transactions on Antennas and Propagation, July 2021. (available on arxiv.org, arXiv:2108.02762 [math.NA])

J. Budhu and A. Grbic, "Recent Advances in Bianisotropic Boundary Conditions: Theory, Capabilities, Realizations, and Applications," in Nanophotonics, vol. 10, no. 16, 2021, pp. 4075-4112, <https://doi.org/10.1515/nanoph-2021-0401>. Invited Paper

J. Budhu, L. Szymanski, and A. Grbic, "Design of Planar and Conformal, Passive, Lossless Metasurfaces That Beamform," in IEEE Journal of Microwaves, vol. 2, no. 3, pp. 401-418, July 2022, doi: 10.1109/JMW.2022.3181719.

Books and Book Chapters:

J. Budhu and A. Grbic of Part, "Aperiodic Metasurface Synthesis Techniques and Designs," in Title: Metamaterials-by-Design: Theory, Technologies, and Vision, ELSEVIER-SPIE Joint Series on Photonic Materials and Applications, Amsterdam, Netherlands, 2023. (Invited book chapter)

Conference Papers:

J. Budhu and Y. Rahmat-Samii, "An efficient spectral domain method of moments for Reflectarray antennas using a customized impedance matrix interpolation scheme," 2013 US National Committee of URSI National Radio Science Meeting (USNC-URSI NRSM), 2013, pp. 1-1.

J. Budhu and Y. Rahmat-Samii, "Accelerating the Spectral Domain Moment Method for reflectarray's by two-orders of magnitude," 2013 IEEE Antennas and Propagation Society International Symposium (APSURSI), 2013, pp. 1340-1341.

J. Budhu and A. Grbic, "A Rigorous Approach to Designing Reflectarrays," 2019 23rd International Conference on Applied Electromagnetics and Communications (ICECOM), 2019, pp. 1-3.

J. Budhu, A. Grbic, and E. Michielssen, "Design of Multilayer, Dualband Metasurface Reflectarrays," 2020 14th European Conference on Antennas and Propagation (EuCAP), 2020, pp. 1-4. Invited Paper

J. Budhu, E. Michielssen, and A. Grbic, "Dualband Stacked Metasurface Reflectarray," 2020 IEEE International Symposium on Antennas and Propagation and North American Radio Science Meeting, 2020, pp. 821-822.

J. Budhu and A. Grbic, "A Reflective Metasurface for Perfect Cylindrical to Planar Wavefront Transformation," 2020 Fourteenth International Congress on Artificial Materials for Novel Wave Phenomena (Metamaterials), 2020, pp. 234-236.

J. Budhu and A. Grbic, "Passive Reflective Metasurfaces for Far-Field Beamforming," 2021 15th European Conference on Antennas and Propagation (EuCAP), 2021, pp. 1-4. Invited Paper

J. Budhu and A. Grbic, "Accelerated Optimization of Metasurfaces with the Woodbury Matrix Identity," 2021 ACES conference, Online, 2021, pp. 1-4. Invited Paper

J. Budhu, L. Szymanski, and A. Grbic, "Accurate Modeling and Rapid Synthesis Methods for Beamforming Metasurface," 2021 IEEE International Symposium on Antennas and Propagation and North American Radio Science Meeting, Singapore, 2021.

J. Budhu and A. Grbic, "Passive Metasurface Antenna with Perfect Aperture Efficiency," 2021 Fifteenth International Congress on Artificial Materials for Novel Wave Phenomena (Metamaterials), New York, NY, USA, 2021.



**The 17th European Conference on
Antennas and Propagation
(EuCAP)
26 - 31 March 2023**



J. Budhu and A. Grbic, " Unit Cell Polarizability and Sheet Impedance Extraction in Highly Aperiodic Environments," 2022 16th European Conference on Antennas and Propagation (EuCAP), 2022, pp. 1-5. Invited Paper

J. Budhu, L. Szymanski, and A. Grbic, "Design of 3D Conformal Metasurfaces", 2022 IEEE International Symposium on Antennas and Propagation and North American Radio Science Meeting, Denver, CO, 2022.

J. Budhu and A. Grbic, "Patterned Unit Cell Design in Aperiodic Metasurfaces," 2022 Sixteenth International Congress on Artificial Materials for Novel Wave Phenomena (Metamaterials), Siena, Italy, 2022.