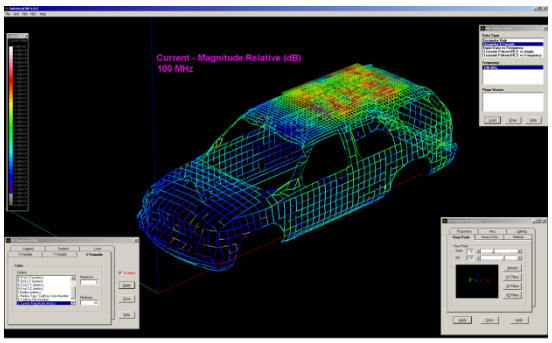
Electromagnetics Research Group
Materials Characterization Subgroup
PI: E. Rothwell (rothwell@egr.msu.edu)

The electromagnetic research group consists of four faculty members (Rothwell, Kempel, Balasubramaniam, and Chahal), and carries out a wide variety of research projects spanning the computational, theoretical, and experimental domains. The group comprises approximately 25 graduate and undergraduate students, post docs, and visiting scholars. This document describes work led by Professor Rothwell. Note that all group members collaborate widely, and most projects overlap among the domains.

1. Self structuring antennas



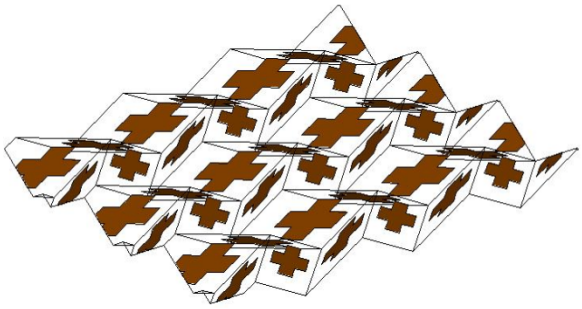
Self-structuring antenna systems are a new and innovative type of antenna that consists of a switchable template coupled to a controller and a feedback sensor that allows the system to change its electrical shape in response to changes in frequency, operating mission, or physical environment, and to self-repair in response to being damaged. Prof. Rothwell is the inventor on the fundamental patent held by MSU, and two additional patents are pending. The spin-out company Monarch Antennas Inc (www.monarchantenna.com) was created as a joint venture between Delphi Technologies and MSU to commercialize the technology. Applications include antennas for ground and air vehicles, cellular telephones, tablet computers, and televisions.

Past sponsors: Delphi Research, MEDC, NASA; **Current sponsors**: U.S. Navy, U.S. Air Force

Recent publications:

1. R. O. Ouedraogo, E. J. Rothwell and B. J. Greetis, "A Reconfigurable Microstrip Leaky-wave Antenna with a Broadly Steerable Beam," *IEEE Trans. Antennas Propagat.*, **59**, 3080-3083, 2011.
2. L. Greetis, R. Ouedraogo, B. Greetis, and E. J. Rothwell, "A Self-Structuring Patch Antenna," IEEE Antennas Propagat. Mag., **52**, 114-123, 2010.
3. C.M. Coleman, E.J. Rothwell, J.E. Ross, and L.L. Nagy, "Self-Structuring Antennas," IEEE Antennas Propagat. Mag., **44**, 11-22, 2002.

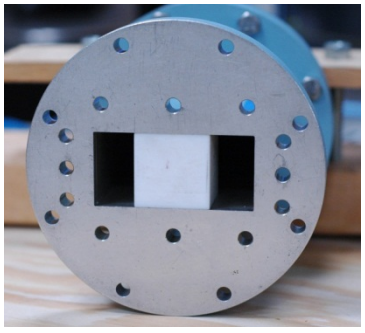
2. Miniaturized antennas and meta-material systems



Metamaterials are artificially constructed materials that have properties not found in nature, specifically negative permittivity and permeability. These properties may be exploited in a number of clever ways to create miniaturized antennas and microwave systems. We have explored techniques for optimizing the structure of metamaterials and have created several new types of miniaturized antennas, microwave filters, and frequency-selective surfaces. We have also explored novel techniques for tuning metamaterials including the use of origami folding of planar structures.

Collaborators: Shih-Yuan Chen, National Taiwan University; Alejandro Diaz, Leo Kempel, Prem Chahal, MSU
Past sponsors: NSF; **Current sponsors**: Air Force Research Laboratory
Recent publications:
1. R. Ouedraogo, E. Rothwell, A. Diaz, and K. Fuchi, "Waveguide Bandstop Filter Design Using Optimized Pixelated Inserts," Microwave and Opt. Tech. Lett., **5**, 141-143, 2013.
2. K. Fuchi, J. Tang, B. Crowgey, A.R. Diaz, E.J. Rothwell, and R.O. Ouedraogo, "Origami Tunable Frequency Selective Surfaces," IEEE Antennas and Wireless Propagat. Lett., **11**, 473-475, 2012.
3. K. Fuchi, A. R. Diaz, E. Rothwell, R. Ouedraogo, and J. Tang , "An Origami Tunable Metamaterial," J. Appl. Phys., **111**, 084905 (2012).
4. R. Ouedraogo, E. Rothwell, A. Diaz, K. Fuchi, and A. Temme, "Miniaturization of Patch Antennas Using a Metamaterial-Inspired Technique," IEEE Trans. Antennas and Propagat., **60**, 2175-2182, 2012.

3. Characterization of the electromagnetic properties of materials



The EM research group has been developing techniques for characterizing the electromagnetic properties of materials for nearly 25 years. Recently the group has been examining methods to characterize absorbing materials, composite materials, artificially engineered materials, and anisotropic materials, and has been working with researchers at several universities to develop applications for these materials. We have developed specialized applicators to be used with free space (antenna-based), waveguide, microstrip, and stripline systems.
Collaborators: Michael Havrilla, Milo Hyde, Air Force Institute of Technology; Lydell Frasch, Boeing; Andrew Bogle, University of Dayton; Leo Kempel, Balasubramaiam Shanker, Lawrence Drzal, Martin Hawley, MSU.
Past sponsors: Dow Chemical, Motorola, Boeing; **Current sponsors**: Air Force Office of Scientific Research, Air Force Research Laboratory, General Electric
Recent publications:
1. R. A. Fenner, E. J. Rothwell, and L. L. Frasch, "A comprehensive analysis of free-space and guided-wave techniques for extracting the permeability and permittivity of materials using reflection-only measurements," Radio Science, **47**, RS1004, pp. 1004-1016, January 2012.
2. E. J. Rothwell, A. Temme, and L. L. Frasch, "Characterization of conductor-backed MagRAM layer using a reflection measurement," Electronics Letters, **48**, 1131-1133, 2012.
3. B. Crowgey, O. Tuncer, J. Tang, E. Rothwell, B. Shanker, L. Kempel, and M. Havrilla, "Characterization of Biaxial Anisotropic Material Using a Reduced Aperture Waveguide," IEEE Trans. Instrumentation and Measurement, to appear.
4. M. W. Hyde IV, M. J. Havrilla, A. E. Bogle, E. J. Rothwell, G. D. Dester, "An Improved Two-Layer Method for Nondestructively Characterizing Magnetic Sheet Materials Using a Single Rectangular Waveguide Probe," Electromagnetics, **32**, 411-425, 2012.