ELECTROMAGNETICS AREA

School of Electrical, Computer and Energy Engineering
Arizona State University

Constantine A. Balanis
Regents’ Professor of EE
What is Electromagnetics

• **Electromagnetics** is the study of the effect of charges at rest and charges in motion.

• **Electromagnetics** is described within the context of the theoretical framework of Maxwell’s equations and special cases thereof including circuit theory (Kirchhoff's Laws, Geometric Optics, Physical Optics, etc.)
James Clerk Maxwell (1831-1879)
Maxwell’s Equations
In Integral Form

\[ \oint_C \mathbf{E} \cdot d\ell = -\iint_S \mathbf{M}_i \cdot d\mathbf{s} - \frac{\partial}{\partial t} \iiint_S \mathbf{B} \cdot d\mathbf{s} \]

\[ \oint_C \mathbf{H} \cdot d\ell = \iint_S \mathbf{J}_i \cdot d\mathbf{s} + \iint_S \mathbf{J}_c \cdot d\mathbf{s} + \frac{\partial}{\partial t} \iiint_S \mathbf{D} \cdot d\mathbf{s} \]

\[ \iiint_S \mathbf{D} \cdot d\mathbf{s} = Q_e \]

\[ \iiint_S \mathbf{B} \cdot d\mathbf{s} = Q_m \]
WHY ELECTROMAGNETICS

• EM is the basis of Electrical Engineering
• Fundamental and challenging problems in:
  1. Wireless Communication
  2. Packaging of mobile units
  3. Stealth technology
• Solving complex and practical problems using:
  1. Full-wave techniques; treating problems as distributive devices, not lumped elements
  1. Modeling and simulating devices using full-wave solvers
• Other
Why Study Electromagnetics

Analyze, model and design:

1. Antennas
2. RF/Microwave circuits
3. Fiber optics systems
4. Electronic packaging; EMI/EMC
Antennas for Mobile Devices
TO BE SUCCESSFUL
IN EM RELATED COURSES:

Requires a solid foundation on the fundamentals of:

- Mathematics
- Physics
- Circuits

EEs are engineers, not technicians.
PREREQUISITE COURSES

• EEE 241: Fundamentals of Electromagnetics
• EEE 202: Circuits I
• Physics 131: University Physics II: Electricity & Magnetism
• Physics 132: University Physics Lab II
Gateway Course

- EEE 241: Fundamentals of Electromagnetics
  *(fall and spring)*
  Static and time varying vector fields; boundary value problems; dielectric and magnetic materials; Maxwell's equations; boundary conditions. Prerequisites: EEE 202; PHY 131, 132.
UG EM COURSES

• EEE 241: Fundamentals of Electromagnetics  
  *(fall and spring)*
  Static and time varying vector fields; boundary value problems; dielectric and magnetic materials; Maxwell's equations; boundary conditions.  
  Prerequisites: EEE 202; PHY 131, 132.

• EEE 341: Engineering Electromagnetics  
  *(fall and spring)*
  Time-varying electromagnetic fields, waves in homogeneous and stratified media, transmission lines, waveguides and cavity resonators, radiation and antennas.  
  Lecture, Laboratory. Pathway course, required for EM majors.  
  Prerequisite: EEE 341
**Senior EM Courses**

- **EEE 443: Antennas for Wireless Com’s**  
  (fundamental parameters, dipoles, loops, arrays, smart antennas, microstrips, measurements)

- **EEE 445: Microwaves**  
  (devices, sources, impedance matching, measurements)

- **EEE 448: Fiber Optics**  
  (principles of fiber optics communications)
GRADUATE COURSES

EEE 540 – Fast Computational Electromagnetics
EEE 541 – Electromagnetic Fields and Guided Waves
EEE 543 – Antenna Analysis and Design
EEE 544 – High Resolution Radar
EEE 545 – Microwave Circuit Design
EEE 546 – Advanced Fiber Optics
EEE 547 – Microwave Solid-State Circuit Design I
EEE 548 – Coherent Optics
EEE 549 – Lasers
EEE 641 – Advanced Electromagnetic Field Theory
EEE 643 – Advanced Topics in EM Radiation
EEE 647 – Microwave Solid State Circuit Design II
**GRADUATE SCHOOL**

- **MS:**
  1. Somewhat specialized
  2. Applications oriented
  3. Often the most marketable degree for pursuing a career in industry or government

- **PhD:**
  1. Very specialized – one ends up knowing quite a bit about one area/topic.
  2. Research and development (R & D)
  3. Usually required for university position
CAREER OPPORTUNITIES

• Academia (need PhD)

  Teaching, research (grant proposals, papers, reviewing papers of others, supervising graduate students, etc.), consulting (so you can pay the bills).

• Industry, Government (BS, MS, PhD)

  Applications of EM in antennas, RF and microwave communications, radar or remote sensing systems, fiber optics communications systems, and electronic packaging.
JOBS OPPORTUNITIES

• Industry

Boeing, General Dynamics, Northrop-Grumman, L-3 Com, Lockheed-Martin, Motorola, Intel, Rockwell International, Raytheon, Honeywell, Texas Instruments, IBM, Qualcomm, Broadcom, United Technologies, Bell Helicopters, Andrew Corporation, etc.

• Government/Government National Laboratories

Facilities

Electromagnetic Anechoic Chamber (EMAC) – antenna and radar cross section measurements.
Facilities

Wireless Communications Circuits Lab:
mixed signal measurements for Antenna/RF/Microwave systems.
Facilities

Laboratory for Wave-Material Interactions
EM FACULTY

- James T. Aberle (PhD: Univ. of Mass.)
- Constantine A. Balanis (PhD: Ohio State U)
- Joseph C. Palais (PhD: Univ. of Mich.)
- George Pan (PhD: Univ. of Kansas)
- Georgios Trichopoulos (PhD: Ohio State U)
JAMES T. ABERLE
ASSOCIATE PROFESSOR OF EE

• Research interests include antennas, computational electromagnetics, metamaterials, RF and microwave circuit design, software-defined radio.
• PhD from UMass (Amherst)
• Dave Pozar was PhD advisor
• ASU Professor since 1989
• Extensive experience with industry – working for start-up, consulting – as well as basic research on government-funded grants and industry consortia.
• More info: http://aberle.faculty.asu.edu
Research of Professor James T. Aberle

Automatically tuning antennas for SDR (Software Defined Radio)

Non-Foster reactances for ESAs (Electrically Small Antennas) and meta-materials

Passive sensors for nuclear threat detection
Georgios Trichopoulos
Assistant Professor, ECEE

Research Interests: Millimeter wave and Terahertz Systems

- On-chip antennas for sensors and imaging
- Terahertz Imaging Systems
- Near field imaging for biometric sensing
- Terahertz metrology

Experience with Industry
- Developed THz camera in collaboration with Traycer Systems Inc.
- Co-founder of TeraProbes Inc. (THz metrology)

More Info: http://faculty.engineering.asu.edu/trichopoulos
CONSTANTINE A. BALANIS  
REGENTS’ PROFESSOR OF EE

- PhD from Ohio State University (1969)
- ASU Professor since 1983
- Research interests include:
  1. Computational ElectroMagnetics (CEM)
  2. Planar (PHIS), Curved (CHIS), and Flexible (FHIS) High Impedance Surfaces for:
     - Ground planes
     - Surface wave suppression and coupling reduction
     - Amplitude pattern control and synthesis
     - RCS reduction using checkerboard HISs
  3. Holographic HISs for pattern control and beam scan
  4. Smart Antennas
- Experience with industry and government
  1. Worked consulted for government and industry
  2. Taught short courses for government and industry
  3. Performed basic research on government-funded grants, and industry contracts and consortia.
- More info: http://balanis.faculty.asu.edu
GEORGE PAN
PROFESSOR OF ELECTRICAL ENGINEERING

PhD: University of Kansas

- Computational electromagnetics
- High-speed electronics packaging,
- Magnetic resonant imaging
- RF coil design and analysis
- Inverse scattering
- Rough surface scattering
- Millimeter-wave antenna systems
JOSEPH C. PALAIS
PROFESSOR OF ELECTRICAL ENGINEERING

- Fiber Optic Communications
- Fiber Optic Sensors
Optical Electromagnetics

FOUR CLASSES
EEE448/591 Fiber Optics
EEE546 Advanced Fiber Optics
EEE548 Coherent Optics
EEE549 Lasers
Instructor: Professor Palais

Course descriptions at: http://engineering.asu.edu/graduate/ee/courseprerequisites
BALANIS’ RESEARCH PROJECTS

• Flexible and Conformal Antennas (Bow-Tie)
• High Impedance Surfaces (HIS)
• Conformal High Impedance Surfaces (CHIS)
• RCS Reduction Using Checkerboard HIS
• Circularly Symmetric HIS
• Holographic Multilayered Metasurfaces
• Flexible Reconfigurable Antennas
• Other
Synthesized Artificial Magnetic Conductor as Ground Planes for Low-Profile Antenna Applications
Lockheed F-117 Nighthawk
Antenna Elements Above PEC and PMC Ground Planes

- PEC
- PMC

**Antenna Elements Above PEC and PMC Ground Planes**
Geometry of PMC/EBG Textured Surface of Square Patches

(a) Perspective view
Geometry of PMC Textured/EBG Surface of Square Patches

(b) Top view

- $g$
- $w$
- $h$
- $a$
- $\varepsilon_1$
Phase Reflection Coefficient $S_{11}$ of PMC/EBG Textured Surface with Square Patches

- **Phase of $S_{11}$ (degrees)**
- **Frequency (GHz)**

- **HFSS Simulation**
- **Design Equations**

- **$\Delta f$**
- **10.35 GHz**
- **14.25 GHz**
Bandwidth Enhancement for RCS Reduction Using Checkerboard EBG Surfaces
EBG1 and EBG2
Checkerboard Design
Bistatic RCS Pattern
Bistatic RCS Pattern of PEC Ground Plane
EBG1 and EBG2 Checkerboard Design
Prototype of Checkerboard
Bistatic RCS Pattern
Normal Incidence @ 4.7 GHz

φ = 135° plane

φ = 45° plane
Hexagonal Checkerboard Design
Hexagonal Checkerboard
Bistatic RCS Pattern
Normal Incidence @ 7.5 GHz

\[ \phi = 0^\circ \]

\[ \phi = 60^\circ \]

\[ \phi = 120^\circ \]
Checkerboard EBG HIS Surface on Helicopter

Flat Checkerboard

Curved Checkerboard

A *generic* scale model helicopter depicted with an EBG checkerboard surface
Circularly Symmetric High Impedance Surfaces (HIS) as Ground Planes
Loop Antenna above Rectangular HIS
Spiral Antenna above Rectangular HIS
Loop Antenna above Circular HIS
Fabricated Circular HIS with a Loop Antenna at a Height of 0.01λ
Spiral Antenna above Circular HIS
Fabricated Circular HIS with a Spiral Antenna at a Height of 0.01λ
Loop Antenna above Rectangular HIS
Loop Antenna above Circular HIS
Broadside Gain of the Loop Antenna Above Circular and Rectangular HIS

![Graph showing gain vs frequency for loop antennas above circular and rectangular HIS. The graph includes two curves representing different types of antennas. The difference in gain is noted as 2.6 dB.]
Comparison Between the Simulations and Measurements (Input Impedance)
Comparison Between the Simulations and Measurements (Gain Pattern)
Scaled-Model Helicopter in ASU EMAC
Books by ASU EM Faculty

ANTENNA THEORY
ANALYSIS AND DESIGN
FOURTH EDITION
CONSTANTINE A. BALANIS
WILEY

ANTENNA THEORY
ANALYSIS AND DESIGN
THIRD EDITION
CONSTANTINE A. BALANIS
WILEY

ADVANCED ENGINEERING ELECTROMAGNETICS
Second Edition
Constantine A. Balanis

Introduction to Smart Antennas
Constantine A. Balanis
Panayiotis I. Ioannides

Modern Antenna Handbook

Fiber Optic Communications

Wavelets in Electromagnetics and Device Modeling