2009 APS/URSI Short Course and Workshop Descriptions

SC-01 Electromagnetic Bandgap Structures in Antenna Engineering
Yahya Rahmat-Samii, UCLA & Fan Yang, Ole Miss.

Objective:
The objective of this short course is to provide researchers and engineers in the electromagnetics, microwaves, and antenna communities with an up-to-date knowledge on the theories, designs, and applications of EBG structures.

Prerequisite:
Basic knowledge of electromagnetics, microwaves, and antennas at upper undergraduate and graduate student level.

Course description:
In recent years, Electromagnetic Band Gap (EBG) structures have attracted increasing interests because of their desirable electromagnetic properties that cannot be observed in natural materials. In this respect, EBG structures are an important subset of metamaterials. Diverse research activities on EBG structures are on the rise in the electromagnetics and antenna community, and a wide range of applications have been reported, such as low profile antennas, active phased arrays, TEM waveguides, and microwave filters.

This comprehensive and applications-oriented short course on the state of the art in electromagnetic band gap (EBG) engineering explains the theories, designs, and antenna applications of EBG structures. The course will start with a detailed overview of the EBG research history and important results. An accurate and efficient FDTD/PBC algorithm will be introduced for EBG analysis. Next, an advanced presentation will be provided on the unique features and diverse designs of EBG structures. Furthermore, a wealth of practical examples and complete design details will be presented to illustrate promising applications of EBG structures in antenna engineering.

Course topics
This short course will include a wide range of topics in EBG structures, covering from fundamentals to applications of EBG structures. A list of course topics is provided below:
1. Introduction and classifications of meta-materials and basic properties of EBG structures. The EBG analysis methods and antenna applications are also summarized.
2. The FDTD method is presented with a focus on periodic boundary conditions (PBC), which is used for the analysis of general periodic structures.
3. Interesting properties of EBG structures are highlighted including the frequency band gap, the dispersion diagram, the reflection phase feature, and the soft/hard properties.
4. Various EBG designs, including the mushroom-like EBG, uni-planar EBG, polarization dependent EBG, compact spiral EBG, and stacked EBG structures.
5. EBG applications in microstrip patch antennas and arrays to increase the antenna gain, minimize the back radiation, and reduce mutual coupling.
6. EBG applications in low profile wire antennas designs. A series of design examples are illustrated, including dipole, monopole, and curl. Various functionalities have been realized, such as dual band operation, circular polarization, and reconfigurable radiation pattern.
7. Low profile surface wave antenna designs based on a grounded slab with periodic patch loading. A monopole like radiation pattern is realized with different feeding techniques.

8. An overview on the future developments and limitations of EBG structures will also be highlighted

Reference

1. Fan Yang and Yahya Rahmat-Samii, Electromagnetic Band Gap Structures in Antenna Engineering, Cambridge University Express, 2009.
2. A notebook of presentation slides will be provided.

SC-02 Microwave/mmW Photonic Feed Architectures for Large Phased Arrays
Dr. Dilip K. Paul, ACES, Inc.

This full-day short course will discuss several novel antenna feed architectures that are deemed immensely suitable for large and/or space-based arrays constrained by a host of critical requirements. Often, these stringent specifications such as compactness, light-weight, and prime power efficiency of the beam forming network (BFN) with much sought after capability for steering, nulling, reconfiguring, frequency agility, etc. render conventional RF/MW technologies unattractive. Whereas, judicious optical implementations of various signal processing functions such as generation, transmission, up/down block conversion, and distribution of high dynamic range MW/mmW signals have demonstrated elegant solutions to such feeds.

An overview of the innovative application of advanced photonics technology augmented by assessment of capability and market feasibility will be presented in this course. Relevant state-of-the-art optical technologies (fiber optics, laser optics, integrated optics, WDM, OADM, multiplexer, demultiplexer, filters, etc.), high speed optoelectronics (silicon photonics, OEICs, ADC, modulator, demodulator, etc.), MOEM switch matrix, and BFN subsystems and systems, including reliability and radiation hardness will be described in detail. Also, results of proof-of-concept demonstration and field deployment will be included. Recent advances in novelty nano-devices and technology bode well for all-optically implemented RF/MW/mmW systems.

SC-03 Radio Network Planning in 3G and HSPA Networks
Francisco Falcone, Universidad Publica de Navarra Spain

Aim:
Introduce concepts and tools involved in the process of planning a 3G network, as well as further implications regarding deployment of HSPA technology.

Audience:
Targeted to professionals in the field devoted to network deployment and optimization in wireless communication networks, as well as people interested in acquiring knowledge in the field.

Table of Contents
1. Description of 3G Networks and HSPA functionality
2. Radio Network Planning process and phases
3. Coverage-Capacity relationships
4. Propagation Models
5. System Simulation
6. Initial parameterization of radio network functionality

SC-04 Reflector Antenna Design and Analysis
Peter Meincke, Ticra

The course gives an introduction to the design and analysis of single and dual reflector antennas, center-fed as well as offset. After a review of the analysis methods commonly employed for space- and Earth-station reflector antennas, the basic design principles are presented. First, single and dual spot-beam antennas are considered with the relation between size, feed illumination, directivity, and sidelobe level. Second, the influence of blockage by struts, subreflector, and feed is discussed. Third, the origin of cross polarization in offset designs is addressed and it is shown how to improve the polarization characteristics in single reflector systems by using polarization grids and, in dual reflector systems, by employing the Mizuguchi compensation principle. Hands-on experience in reflector antenna design is obtained during the course by using the software package GRASP9 (participants must bring their own laptop).

SC-05 Advances in the Design of Electrically Small Antennas
S. Best, MITRE Corporation

Optimization of the performance properties of electrically small antennas represents a challenging design problem for the antenna engineer. As wireless devices decrease in size, there is an increasing demand for physically smaller antennas, yet the performance requirements are rarely relaxed.

This half-day workshop provides a detailed discussion on the theory, challenges and performance trade-offs associated with the design of electrically small antennas. The workshop begins with an overview of the basic theory and concepts associated with electrically small antennas. This segment of the presentation provides an understanding of antenna performance limitations in terms of impedance, radiation patterns, bandwidth, efficiency, and quality factor. Techniques used to design self-resonant electrically small antennas are described and compared. These include dielectric loading, linear loading (increasing wire length), top-loading, and “folded” configurations. The relationship between the antenna’s performance characteristics and its physical properties is discussed. Issues such as the significance of antenna geometry are considered. The performance of the small antenna on small finite ground planes is considered with a particular emphasis on how the antenna’s location on the ground plane affects impedance, pattern and polarization properties. The workshop concludes with a discussion on recent advances made in the design of low profile, conformal and integrated device antennas.

SC-06 RFID R/W Antenna Design and Practical Applications
Andrey S. Andrenko, Fujitsu Laboratories LTD.

This half-day course will cover all the technical aspects of UHF RFID R/W antenna design and applications. Several designs of circularly polarized and linearly polarized R/W antennas would be presented and their practical implementation in various RFID systems would be described in the detail.

SC-07 GPU Acceleration of the FDTD Technique
Matthew J. Inman and Atef Z. Elsherbeni, Ole Miss

This course will provide an overview of the recent advances in the development and application of acceleration techniques for the Finite-Difference Time-Domain (FDTD) method. Advances using graphical processing units (GPU's) found on video cards to accelerate the FDTD will be discussed. The foundations of GPU programming necessary for creating a GPU based FDTD code will be presented as well as the implementation of various advanced features (PML, etc). The technology behind the implementation and the various programming methods will be highlighted with various examples provided. The application of the methods will also be featured showing how the acceleration can be used in various environments such as teaching, optimization, and research.

Topics to be covered:
1. Current state of GPU technology
2. Foundations of GPU programming
3. Various Programming Languages for GPU's
4. Implementation of FDTD on the GPU
5. Programming Advanced Features of FDTD on the GPU
6. Interfacing GPU based FDTD for applications

SC-08 Planar Antennas for Wireless Communications and Their Recent Advances
Prof. Kin-Lu Wong, National Sun Yat-Sen University, Taiwan

Planar antennas, including printed antennas, metal-plate antennas, ceramic chip antennas, are generally flat in appearance and have a low profile. Such planar antennas have found extensive applications in WWAN (850/900/1800/1900/ 2050 MHz bands), WLAN (2.4/5.2/5.8 GHz bands), WiMAX (2.5/3.5/5.5 GHz bands), UWB (3.1~10.6 GHz band) systems, and other related communications systems. Many innovative planar antennas for related applications such as in the internal handset/laptop antennas, base-station/access-point antennas, WLAN/WiMAX antennas, and UWB antennas have been reported recently. These recently developed planar antennas will be addressed. The SAR (specific absorption rate) and HAC (hearing aid compatibility) results of some promising internal handset antennas will also be discussed.

The topics for this short course will include:
1. Internal multiband handset/laptop antennas for WWAN systems, including using the printed monopole ($\lambda/4$ and $\lambda/8$ mode excitation), PIFA ($\lambda/4$ and $\lambda/8$ mode excitation), loop (1λ, $\lambda/2$ and $\lambda/4$ mode excitation) and slot ($\lambda/2$ and $\lambda/4$ mode excitation) antennas; the printed antennas can have a very small size for penta-band WWAN operation and are suitable to be directly printed on the system circuit board of the mobile device, hence allowing the mobile device to have a very thin profile. The concept for EM compatible (EMC) internal mobile device antennas will also be introduced.
2. Base-station antennas for WWAN systems, including dual-band and/or dual-pol operations.
3. WLAN/WiMAX antennas, including dual-band and/or diversity operations for mobile devices. Promising antennas with broadband CP (broadside and omnidirectional) radiation, high-gain omnidirectional radiation and diversity operation for access points are also presented.
4. UWB antennas for mobile devices and access points, including the design techniques for UWB impedance matching, improved omnidirectionality, pattern stability, polarization purity and band-notching.

SC-09 Design of RFID Transponders and Systems
K. V. S. Rao, Intermec Technologies Corp; Raj Mittra, and Penn State University

The course is designed to provide an overview of various aspects of RFID tags and systems. Fundamental aspects of link budget and backscattering characteristics of RFID tags will be reviewed, as will be the problem of RF matching from ASIC to antenna. The design of platform-tolerant tags will be addressed and the problem of computer-aided design of antennas and tags for RFID application will be discussed. A list of topics to be covered is given below:

1. Basic RFID link budget calculations and backscattering fundamentals
2. RF front end considerations of ASIC.
3. RF matching from ASIC to antenna
4. Complete design, simulation and test of RFID tag, including antenna, ASIC and application examples
5. Near-field antenna considerations for RFID tags
6. An introduction to Battery Assisted Passive (BAP) tag
7. Platform-tolerant tag designs using EBG and metamaterials
8. Tag modeling and measurements

SC-10 Numerical Inversion of Laplace Transform: Its Theory and Application in Transient Analysis of Electromagnetic Pulses
Qingsheng Zeng, Communications Research Centre Canada

Abstract:

The advancement of electromagnetic engineering has been driving the need to develop efficient time domain techniques for transient analysis of transmission, propagation and reception of electromagnetic pulses. This workshop addresses one method based on numerical inversion of Laplace transform, which overcomes the restrictions in previous approaches on the relative dielectric constant and the incidence angle, leads to good accuracy in both late and early time, and has a simple algorithm, short calculation time, small required memory size and readily controlled error. The emphasis in this workshop is placed on how to extend and apply this method to transient analysis of reflection and transmission of pulses. The related theoretical work and combination with Prony's method are described for the extension and application purposes. Correctness and effectiveness of this work are validated through the comparisons between our results and the published results. Furthermore, the results that cannot be generated with the previous approaches are also provided. In closing, the extended method is summarized with a discussion of its advantages and limitations.

Tutorial Outline:

1. Introduction
2. Theory on Numerical Inversion of Laplace Transform
3. Combination with Prony's Method
4. Pulse Transient Analysis
    - Reflection from a Conductive Interface
    - Transmission through a Lossy Dielectric Slab
    - Transmission in Plasma and Waveguides
5. Parameter Estimation of Pulse Distortion
6. Conclusions

Primary Audience:

Scientists and engineers in industrial and research agencies, faculty members, research fellows and graduate students in educational institutions

Novelty:

To our knowledge, this would be the first workshop that systematically treats the theory of numerical inversion of Laplace transform and its application in transient analysis of electromagnetic pulses. This workshop will highlight how to overcome the restriction that numerical inversion of Laplace transform has high demands on image functions, and will deliver the results for pulse propagation both in non-dispersive and in dispersive media, some of which cannot be achieved with the previous approaches.

SC-11 Dielectric Resonator Antenna: Theory, Design, and Applications
Ahmed A. Kishk and Branko Kolundzija, Ole Miss

Recently, interest in dielectric resonator antennas has increased because of their attractive features such as small size, high radiation efficiency (98%), wide bandwidth, and high power capability for radar applications and base stations. The dielectric resonator antenna is made from high dielectric constant materials and mounted on a ground plane or on a grounded dielectric substrate of lower permittivity. The short course will start by an overview for the development of the dielectric resonator antennas. The theory of operation will be discussed step by step to provide basic understanding. The discussion is provided in simple forms to satisfy audience of different background levels. Design curves will be provided for the circular disc and hemisphere dielectric resonators. Use of these models with other geometries is discussed.
Different excitation mechanisms are demonstrates such as the probe, slot, image line and waveguides. Applications of dielectric resonators in arrays are provided with discussion on the mutual coupling level and the wide scanning capabilities of the dielectric resonator antenna array. The array bandwidth limit is discussed based on the element size and the spacing between the array elements.

The problems related to the practical implementations are considered. Results of a numerical study pertaining to the effect of an air gap, between the dielectric disc and the ground plane or an air gap surrounding the feed probe, on the input impedance and resonant frequency of a cylindrical DRA operating in the TM01ä mode or HEM11ä mode as a function of dielectric constant will be presented. Some of the numerical results are validated experimentally.

Techniques for broadband applications are discussed. Some of the techniques are based on the material properties and some depends on the DRA shape. Several examples are provided. Some elements would provide a matching bandwidth over 40% with reflection coefficients better than –10dB for 50 Ohms ports. Finally, Techniques for size reduction of the DRA are presented to demonstrate the flexibility of the DRA to satisfy the required small size for some applications. The technique will result in small size and keeping wide bandwidth. The applications of the DRA for spatial power combiners are presented.

Electromagnetic modeling of DRA in frequency domain is considered. In general case DRA is made of metallic parts (wires and plates as ground plane) and dielectric parts, thus representing a typical composite metallic and dielectric structure. Various methods that can be used for EM modeling of such structures are discussed: surface or volume (integral or differential) equations, optimal test procedure, triangles or quads, sub-domain or entire-domain expansion functions.

General method is suggested for efficient and reliable analysis: EFIE+PMCHW+Galerkin test procedure+Higher order basis functions, as implemented in WIPL-D software package.

EM modeling of various DRAs is illustrated: Hemispherical DRA, Cubical DRA, Cylindrical DRA, and DRA of complex shape. Implementation of various feeders is considered: delta generator, coaxial feed, feeding by microstrip line through centered slot, and feeding through cavity baked slot. Results for input impedance, efficiency, near field, and radiation pattern are presented. Optimization of some DRAs is performed regarding S11 and/or Gain using various algorithms (genetic, simplex, ELM-multi-minima optimization), and results are compared. Arrays of DRAs are considered in two ways, using full 3D EM modeling and diakoptic method.

SC-12 Finite Element Analysis of Complex Antennas and Arrays
Douglas Riley, Northrop Grumman Space Technologies; Jianming Jin, University of Illinois Urbana-Champaign

This short course covers both the basics and advanced topics. It is intended for people who have basic ideas about the finite element method, but want to learn more about its modeling of complex antennas and phased-array antennas. Advanced topics are included to show the potential and capability of the finite element method for antenna analysis. Application examples will be given during the discussion of each topic. The following topics will be included in this one-day short course.

1. Finite Element Formulations in the Frequency and Time Domains
2. Modeling of Complex Dispersive Materials
3. Finite Element Mesh Truncation Techniques
    - 3.1 Absorbing Boundary Conditions
    - 3.2 Perfectly Matched Layers
    - 3.3 Boundary Integral Equations
4. Hybrid FETD-FDTD Technique
5. Antenna Source Modeling and Parameter Calculation
6. Modeling of Complex Structures (Thin layers, wires, slots, circuits, feed networks)
7. Infinite Phased-Array Modeling Via Floquet Theorem
8. Finite Phased-Array Modeling Via Domain Decomposition
9. Antenna-Platform Interaction Modeling
10. Application Examples and Numerical and Practical Considerations

Note that this is not code training. However, a better understanding of the basic theory and solution technique behind the finite element codes can result in more effective use of the codes.

SC-13 Miniaturization Methods for UWB and Multiband Antennas
John Volakis, The Ohio State University

This short course will cover several topics related to small antennas for narrowband and ultrawideband applications. The course will start a presentation on small antenna performance limits for narrowband and UWB antennas. This will be followed by various methods for achieving miniaturization. Techniques such as (a) inductive/capacitive loading (lumped or distributed RF circuits), (b) shaping, (c) matching circuits (passive and active), (d) novel modes and metamaterials and (d) materials and composites will be presented followed by examples. Among example antennas/applications to be presented are miniature spirals (from VHF and higher), GPS, SATCOM, automotive and body-worn, RFID, and a variety of printed designs, possibly on layered textured dielectrics. A good part of the course will be also devoted to a variety of metamaterial antennas, particularly on substrates and coupled circuit lines that emulate anisotropy for achieving optimal gain x bandwidth limits. Throughout, the employed analysis and optimizations methods will be described, and a discussion on multistage passive and active impedance matching will be discussed.

The afternoon component of the short course will be focused on specific antenna miniaturization examples: (a) GPS and SATCOM, (b) conformal arrays, including the current sheet array, (c) RFIDs, (d) Spirals and other conformal wideband antennas, (e) Polymer-based and Carbon Nanotube (CNT) antennas, (f) on-chip and mm-wave antennas, and (g) body-worn antennas with diversity. In all cases, the focus will be on conformal applications or integrated solutions with emphasis on size reduction.

DRAFT OUTLINE
Introduction to Antennas
-Review of Antenna Parameters
    Efficiency, Directivity, Gain, Impedance, Polarization
Small Antenna Theory
- Q limits
- Performance limitations: gain, bandwidth, pattern, impedance
Antenna Miniaturization Techniques
- Shaping
- Artificial transmission line concept (loading using LC circuits)
-- Material loading
--Magnetic Materials
- Metamaterials and novel resonance modes
- Emulating anisotropy using printed circuits
Material Design and Optimization
Optimization approaches
Interfacing optimization and antenna analysis tools
Data mining approaches for optimal multi-objective designs
Small Antenna Design Examples
- Narrowband miniature antennas:
    dipoles, patches, GPS, SATCOM, body-worn, RFID etc.
- Broadband miniature antenna: bowties, spirals, helices, new shapes
Conformal Wideband Arrays
Polymer-Based and Carbon Nanotube Antennas
Body Worn Antennas and Diversity
WPAN and mw-wave antennas

SC-14 Advanced CEM Techniques for Solving Time Harmonic Maxwell Equations
Jin-Fa Lee, The Ohio State University; Romanus Dyczij-Edlinger, Saarland University Germany

This short course is intended for engineers who are interested in recent advancements in CEM (computational electromagnetic) techniques in the frequency domain. Of particular emphasis are: the application of the interior penalty methods to hybridize finite and boundary elements with non-conformal meshes (non-matching grids) for unbounded and/or infinite periodic electromagnetic (EM) radiation and scattering problems, and various non-conformal domain decomposition methods for solving electrically large EM problems; developments and integration of multi-level multigrid methods with adaptive mesh refinements (h-, p-, and hp-versions) for obtaining full-wave solutions accurately and efficiently; and finally model order reduction techniques are introduced for fast frequency sweeps as well as for multi-parameter design optimizations.

There will be four lectures, and they are:

1. Lecture 1: Hybrid Finite/Boundary Element Methods for Solving Unbounded and Periodic Electromagnetic Problems using Interior Penalty Formulation. (Prof. Jin-Fa Lee)

    a. Applying interior penalty formulation to hybridize finite and boundary element methods through non-conformal but symmetric couplings;

    b. Deriving and discussion of the coercive sesquilinear form, and mitigation of the notorious internal resonances in the hybrid finite/boundary element formulation;

    c. Applying interior penalty method to hybridize finite and boundary element (periodic Green's function via Ewald transformation) methods for solving infinite periodic time harmonic Maxwell equations; numerical examples include infinite antenna arrays and frequency selective surfaces (FSS);

    d. Discussions on the choices of the penalty factors, lossless and lossy interior penalties and the introduction of stabilization terms for coercive seisequlinear forms;

2. Lecture 2: Multigrid and Multilevel Solution Techniques for Solving Matrix Equations for Time Harmonic Maxwell Equations. (Prof. Romanus Dyczij-Edlinger)

    a. h-multigrid solver: fundamentals, intergrid operators, and non-uniform refinement levels;

    b. p-multilevel solver: additive and multiplicative Schwarz methods and smoothing strategies;

    c. hp-hierarchical methods: cycle design;

3. Lecture 3: Interior Penalty Formulation for Non-Conformal Domain Decomposition Methods. (Prof. Jin-Fa Lee)

    a. Introduction to domain decomposition methods (DDMs): the cement method, finite element tearing and interconnecting (FETI) technique, Robin and high order transmission conditions; Numerical examples include simple large finite antenna arrays, frequency selective surfaces, and metamaterials;

    b. Geometric non-conforming DDM for problems with different periodicity: The geometric non-conforming DDM is very suitable for modeling various electromagnetic problems with different periodicities at different portions of the domain. We shall demonstrate its application through antenna arrays with frequency selective surfaces that are of different periodicity;

    c. Multi-region DDM with different EM solvers: Hybridization of different EM solvers (PO, MoM, FEM etc) through DDM framework;

4. Lecture 4: Model Order Reduction Techniques for Parameter Sweeps and Design Optimizations. (Prof. Romanus Dyczij-Edlinger)

    a. Fundamentals: Projection-based reduced order modeling (ROM), single- and multi-point methods, and moment-matching;

    b. Single-parameter models: Frequency sweeps, single-point methods (both linear and polynomial parameter dependence), and multi-point methods;

    c. Application: Single- and multi-point method for waveguide problems;

    d. Multi-parameter models: theoretical foundations, reduction to sequence of single-parameter sweeps, and geometric parameters;

SC-15 Physics of Multiantenna Systems and Adaptive Processing Incorporating Antenna Effects

Tapan Sarkar, Syracuse University; Magdalena Salazar-Palma, Universidad Carlos III de Madrid; Eric Mokole, US Naval Research Laboratory

The objective of the presentation is to present a scientific methodology which can be used to analyze the physics of multi antenna systems. The multi antenna systems are becoming exceedingly popular because they promise a different dimension than what is available to the current communication systems engineers. That is spatial diversity. Use of multiple antennas as transmit and receive at least from a theoretical standpoint present a scheme to perform spatial diversity and in this way one can increase the capacity of existing systems which are already exploiting time, and frequency diversity. The deployment of multi antenna systems is equivalent to using an overmoded waveguide where simultaneously information is being transmitted using not only the dominant but also all the higher order modes. We look into this interesting possibility and study why the communication engineers advocate the use of such a system whereas the electromagnetic and microwave engineers have avoided such a propagation mechanisms in their systems. We study the physical principles of multi antenna systems using the Maxwell's equations and utilize them to perform various numerical simulations to observe how a typical system will behave in practice. As Gabor observed, wireless communication systems are due to the generation, reception and transmission of electromagnetic signals. Therefore all wireless systems are subject to the general laws of radiation. Communication theory has up to now been developed mainly along mathematical lines, taking for granted the physical significance of the quantities which are fundamental in its formalism. But communication is the transmission of physical effects from one system to another. Hence communication theory should be considered as a branch of physics. Thus it is necessary to embody in its foundation such physical data. Hence we can apply to our problem the well known results of the theory of radiation by the Maxwell-Poynting theory. Following this fifty-five year old suggestion of Gabor, we look at the quality of transmission of information in a wireless system by using the concept of channel capacity under very general circumstances, including a deterministic one.

Inherent in the idea of channel capacity is the concept of information content. If information is to be conveyed, signals must change unpredictably with time. If information transmission is related to changing signals unpredictably with time, then why not change the signal as rapidly as we like and additionally vary the amplitude over all real numbers. Each change would imply increasing the information indefinitely. Intuitively, more rarely occurring events thus carry more information than frequently occurring events. In practice, we deal with physical systems, which have two qualitative limitations on the amount of information per unit time (system capacity) a system can transmit:

1. Inability of the system to respond instantaneously to signal changes due to presence of energy storage devices. In all networks, inherent capacitance and inductance limit the time response. These limitations are related to the useful bandwidth of the operating system.
2. Inability of the system to distinguish infinitesimally small changes in signal levels (due to inherent voltage fluctuations or noise), which are related to the signal-to-noise ratio (SNR).

These two qualitative limitations determine system capacity, which is the maximum amount of information per second in bits (binary digits) that a system can transmit.

Currently, two forms of the channel capacity are in vogue. The first form, Hartley's Law does not consider background statistical noise to be important in impeding the reception of wireless communication signals. The quantification in this case is done in terms of signal amplitudes. The second form, derived by Shannon, uses a stochastic model for the signal and additive noise. The objective of Shannon's model was to introduce enough redundancy in the source, which he termed the transmitter, so that the redundancy in the form of coding will combat this induced noise very effectively when the corrupted signal is received after propagating through the noisy channel. Through the use of redundant codes it is possible to reduce signal power. Here, the quantization of the channel capacity is expressed in terms of the background SNR. However, real multipath interference appears as a convolution and hence should be multiplicative noise. In that situation, the first form of the channel capacity is more useful.

We also look at both methodologies and demonstrate that either form will provide similar answers if one properly accounts for the Maxwellian physics and the transmit and receive antenna systems are matched, even when the signal power is at least two orders of magnitude larger than the noise floor, which is typically the case for mobile wireless communication. This similarity stems from the fact that at resonance the power is real and the reactive component of the power does not enter into the picture. How to introduce the engineering aspects relating to the computation of power in the near field is described through the application of the Maxwellian physics. Another reason for introducing the physics related to radiation of energy is: the highly mathematical concept of channel capacity has its roots in physics via the concept of entropy. For example, if we were to quantify the channel capacity in terms of entropy (a function of statistical probability) and the SNR (a function of the received power), then the pertinent question is: how should one apply these concepts in a near-field electromagnetic environment in which many cellular wireless communication systems operate? In addition, the concept of bandwidth is determined by the group velocity of the device and the phase response of the total transmit-receive system. Since the group velocity is related to the derivative of the phase response with respect to frequency, the deviation of the actual phase response from a linear phase response introduces undesired dispersion in the system. Thus the phase response essentially determines the useful bandwidth of a system. Therefore, we need to link the mathematical equations evolving from the concepts of entropy and information content to the fundamental physics that delineates the realistic parameters of a wireless system. In this presentation, we discuss the historical evolution of the concept of entropy, illustrate how the physics can be inserted into such a highly abstract mathematical concept, and relate entropy and physics to practical situations.

The basic point of departure in this presentation over the classical statistical based methodology is that firstly, we use the antenna gain rather than the directivity which incorporates the radiation efficiency of the system. Secondly, the various electromagnetic effects and the mutual coupling between the antennas are taken into account in evaluating the system performance. The combination of the signals from the various antennas for the different modes poses a significant challenge due to the vector nature of the problem. Thus, MIMO can only be realized in the form an adaptive phased array problem. Thirdly, the total power input to the antennas in all the simulations is kept constant rather than the radiated power. Numerical examples will be presented to illustrate how the vector nature of the problem differs from a scalar formulation.

SC-16 On Ultrawideband Antennas
Tapan Sarkar, Syracuse University; and Eric Mokole, US Naval Research Laboratory

Conventionally, the design of antennas is narrowband and little attention is paid to the phase responses of the devices as functions of frequency. Even the use of the term broadband is misleading as one essentially takes a narrow band signal and sweeps it across the band of interest. In fact, it is not necessary to pay too much attention to the phase for narrowband signals, as the role played by the frequency factor is that of a scalar multiplier. However, if one now wants to use multiple frequencies and attempts to relate the data obtained at each frequency, then this frequency term can no longer be ignored. Depending on the application, this scale factor can actually have significant variations, which also depend on the size and the shape of the bandwidth over which the performance of the system is observed. In the time domain, the effect of this frequency term creates havoc as it provides a highly nonlinear operation and hence must be studied carefully. By broadband we mean temporal signals with good signal integrity. When it comes to waveform diversity, which implicitly assumes time-dependent phenomena, it is not possible to do any meaningful system design unless the effects of the antennas are taken into account. These effects will be illustrated in terms of the responses of the antennas and on the applicability of the current popular methodology of time reversal for the vector electromagnetic problem.

To provide background, notions of bandwidth will be discussed, especially in light of recent interest in ultrawideband (UWB) systems – the last decade has witnessed significantly greater interest in UWB radar. In that time, more than 15 nonmilitary UWB radars have been designed and fielded, which include applications to forestry, detecting underground utilities, and humanitarian demining. Since an antenna is an integral part of sensing systems, selected highlights of UWB antenna development will be very briefly summarized.

Some fundamental problems in studying concepts involving the responses of antennas in the time domain are related to our subconscious definition of reciprocity. In the frequency domain, reciprocity is related simply to the fact that the spatial response of the sensor in the transmit mode is EQUAL to the spatial response of the sensor in the receive mode at any frequency of interest. In the time domain, the spatial response of the sensor will be time dependent. Hence, both the transmit and the receive impulse responses of the sensor will be a function of azimuth and elevation angles. However, for a fixed spatial angle, the transmit impulse response is NOT EQUAL to the receive impulse response of ANY sensor. In fact, mathematically one can argue that the transmit impulse response is the time derivative of the receive impulse response for any sensor. One may then conclude that somehow reciprocity is violated through this principle. The important fact is that the product in the frequency domain results in a convolution in the time domain and that the reciprocity relationship is no longer a simple one. Even though the transmit impulse response is the time derivative of the receive impulse response, reciprocity still holds! The above principle now helps us in characterizing different sensors for different applications as their temporal responses are quite different.

Another important principle is the phenomenon of time reversal, which has showed great promise for the scalar acoustic problem where relationships between the sources and the fields are much simpler. For example, an acoustic sensor quite faithfully reproduces the same signal both in the transmit mode and in the receive mode, as one knows from daily experience with the telephone. However, for the vector electromagnetic problem where signals are being radiated through a sensor and received by the same sensor, the sensor has different responses for transmission and reception. As a first example, an electrically large wide-angle biconical antenna on transmit does not distort the waveform, whereas on receive it does an integration of the waveform for certain loading conditions. In contrast, a TEM horn antenna on transmit differentiates the input waveform, whereas on receive it does not distort the waveform. Furthermore, the small antenna on top of cell phones doubly differentiates a waveform on transmit and singly differentiates it on receive. In addition, one must consider the effect of polarization, where the magnitude of the transmit or receive power is determined by the physical orientation of the structure with respect to the direction of the incident fields.

This half-day short course will present these principles, as well as relate them to current antennas to illustrate the various effects.

W-01 MEMS Reconfigurable and Steerable Antennas
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MEMS switches and tuning elements can be used in creative ways to alter the frequency and radiation characteristics of antenna elements and arrays. MEMS-enabled reconfigurable antennas present a great potential for applications in multi-band and software-defined radios, radars, and satellite communication. This workshop explores the most recent advancements in the area of reconfigurable and electronically-steerable antennas afforded by the application of RF MEMS technology.