Short Course **Day 1: Tuesday, 23 Nov. 2010**

Venue: Capri Hall

Short Course 3

The Physics and Mathematics of Multiantenna Systems and How to Improve Their Performances

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10:00 – 12:30

Abstract

The objective of this tutorial is to illustrate that the principle of superposition of power is not valid in electrical engineering, and hence not applicable to analysis of multi antenna systems. In electrical engineering, it is the voltage and the current that can be superposed and that is why another name of it is field theory, as the voltages and the currents are the results of the fields. Examples will be presented to illustrate how the Maxwellian physics can be introduced to improve the performance of multi antenna systems. This group also includes MIMO systems. Consider two plane waves of respective power densities 100 and 1 W/m^2 that are allowed to interact with each other. Even though one of the waves is only 1% in power density of the other, if the two waves interfere constructively or destructively, the resulting variation in the power density received is not 101 or 99 W/m^2 but rather or resulting in 121 or 81 W/m^2 – a 40% change and not 1%, since it is the field or voltages or currents that can be added in the electrical engineering context, and not the powers. Hence, the first objective of this presentation is to define the appropriate metric for comparison of performance between various multiantenna systems.

Also, we examine the phenomenon of *height-gain* in wireless cellular communication, and illustrate that under the current operating scenarios where the base station antennas are deployed over a tall tower, the field strength actually decreases with the height of the antenna over a realistic ground and there is no height gain in the near field. Therefore, to obtain a scientifically meaningful operational environment the vertically polarized base station antennas should be deployed closer to the ground. Also, when deploying antennas over tall towers it may be more advantageous to use horizontally polarized antennas than vertically polarized for communication in cellular environments. Examples will be presented to illustrate these cases. In addition we discuss what is the criterion for the far field of an

antenna over an imperfect ground plane. This is quite significant as an antenna has no defined radiation pattern in the near field!

In addition, when comparing the performance between systems, the input power needs to be the same for all the systems. It becomes clear that the use of the Hartley definition of channel capacity is more appropriate to use for a multiantenna system rather than the Shannon Channel capacity which uses the superposition of power as Shannon did not develop the theory for wireless systems where interference is present and the limiting factor is not background thermal noise. From a physics perspective, it is illustrated that a 1×1 SISO system may perform better than a 2×2 MIMO system. However, as the concept of channel capacity is developed on purely mathematical grounds based on entropy, it is difficult to relate the physics to the mathematics as the capacity is defined with respect to background thermal noise whereas no receiver can accept a signal weaker than 100 μV/m in the absence of interference, which is far above the background noise. One of the goals is also to illustrate that an $N \times N$ MIMO system does not necessarily have better performance than N separate SISO systems, using the same total input power.

Finally, an embarrassingly simple solution is presented based on reciprocity that can decouple all the receive channels leading to uncoupled MISO systems which can operate in any environment and under all scenarios. In this situation, it is not even necessary to characterize the electromagnetic environment through a singular value decomposition. Examples will be presented to illustrate this scenario and compare its performance with conventional systems illustrating that this system can perform equally well and sometimes better than a MIMO system.

About the speakers

Tapan K. Sarkar received the B.Tech. degree from the Indian Institute of Technology, Kharagpur, in 1969, the M.Sc.E. degree from the University of New Brunswick, Fredericton, NB, Canada, in 1971, and the M.S. and Ph.D. degrees from Syracuse University, Syracuse, NY, in 1975.

From 1975 to 1976, he was with the TACO Division of the General Instruments Corporation. He was with the Rochester Institute of Technology, Rochester, NY, from 1976 to 1985. He was a Research Fellow at the Gordon McKay Laboratory, Harvard University, Cambridge, MA, from 1977 to 1978. He is now a Professor in the Department of Electrical and Computer Engineering, Syracuse University. His current research interests deal with numerical solutions of operator equations arising in electromagnetics and signal processing with application to system design. He obtained one of the "best solution" awards in May 1977 at the Rome Air Development Center (RADC) Spectral Estimation Workshop. He received the Best Paper Award of the IEEE Transactions on Electromagnetic Compatibility in 1979 and in the 1997 National Radar Conference. He has authored or coauthored more than 300 journal articles and numerous conference papers and 32 chapters in books and fifteen books,

including his most recent ones, *Iterative and Self Adaptive Finite-Elements in Electromagnetic Modeling* (Boston, MA: Artech House, 1998), *Wavelet Applications in Electromagnetics and Signal Processing* (Boston, MA: Artech House, 2002), *Smart Antennas* (IEEE Press and John Wiley & Sons, 2003), *History of Wireless* (IEEE Press and John Wiley & Sons, 2005), and *Physics of Multiantenna Systems and Broadband Adaptive Processing* (John Wiley & Sons, 2007), *Parallel Solution of Integral Equation-Based EM Problems in the Frequency Domain* (IEEE Press and John Wiley & Sons, 2009), and *Time and Frequency Domain Solutions of EM Problems using Integral Equations and a Hybrid Methodology* (IEEE Press and John Wiley & Sons, 2010) .

Dr. Sarkar is a Registered Professional Engineer in the State of New York. He received the College of Engineering Research Award in 1996 and the Chancellor's Citation for Excellence in Research in 1998 at Syracuse University. He was an Associate Editor for feature articles of the IEEE Antennas and Propagation Society Newsletter (1986-1988), Associate Editor for the IEEE Transactions on Electromagnetic Compatibility (1986-1989), Chairman of the Inter-commission Working Group of International URSI on Time Domain Metrology (1990–1996), distinguished lecturer for the Antennas and Propagation Society from (2000-2003), Member of Antennas and Propagation Society ADCOM (2004-2007), on the board of directors of ACES (2000-2006), vice president of the Applied Computational Electromagnetics Society (ACES), and a member of the IEEE Electromagnetics Award board (2004-2007). He is currently an associate editor for the IEEE Transactions on Antennas and Propagation. He is also on the editorial board of Digital Signal Processing – A Review Journal, Journal of Electromagnetic Waves and Applications and Microwave and Optical Technology Letters. He is the chair of the International Conference Technical Committee of IEEE Microwave Theory and Techniques Society # 1 on Field Theory and Guided Waves. He is a member of Sigma Xi and International Union of Radio Science Commissions A and B.

He is also the president of OHRN Enterprises, Inc., a small business incorporated in New York state (1985) performing various research work for various organizations in system analysis.

He received Docteur Honoris Causa both from Universite Blaise Pascal, Clermont Ferrand, France in 1998 and from Politechnic University of Madrid, Madrid, Spain in 2004. He received the medal of the *friend of the city of Clermont Ferrand*, France, in 2000.

Magdalena Salazar-Palma was born in Granada, Spain. She received the MS and PhD degrees in *Ingeniero de Telecomunicación* (Electrical and Electronic Engineer) from *Universidad Politécnica de Madrid* (UPM), Spain. She has been *Profesor Colaborador* and *Profesor Titular de Universidad* at the Department of Signals, Systems and Radiocommunications, UPM. Since 2004 she has been with the Department of Signal Theory and Communications, College of Engineering, *Universidad Carlos III de Madrid*, Spain, where she is *Catedrático* (Full Professor) and Chairperson of the Department. She has developed her research in the areas of electromagnetic field theory; computational and numerical methods for microwave passive components and antenna analysis; network and filter theory and design; design, simulation, optimization, implementation, and measurement of microwave circuits both in waveguide and integrated (hybrid and monolithic) technologies; and history of telecommunications.

She has authored 6 books and 23 contributions (chapters or articles) for books published by international editorial companies, 13 contributions for academic books and notes, 61 papers in scientific journals, 225 papers in international conferences, symposiums, and workshops, 69 papers in national conferences and more than 80 project reports, short course notes, and so on. She has coauthored two European patents and one US patent, and several software packages for the analysis and design of microwave and millimeter wave passive components, antennas and antenna arrays, as well as computer aided design (CAD) of advanced filters and multiplexers for space applications. She has delivered numerous invited presentations, lectures, and seminars. She has lectured in a number of short courses, some of them in the frame of Programs of the European Community and others in conjunction with IEEE International AP-S Symposium and IEEE MTT-S Symposium. She has participated at different levels (researcher or principal investigator) in a total of 80 research projects and contracts, financed by international, European, and national institutions and companies, among them: the National Science Foundation, USA; the European Office of Aerospace Research and Development of the Air Force Office of Scientific Research (one of the Air Force Research Laboratory Directorates), USA; the European Union; Spain Inter-ministry Commission of Science and Technology (CICYT), Spain Ministry of Education and Culture (MEC), and Council of Education of the Regional Government of Madrid (CAM). She has assisted the Spain National Agency of Evaluation and Prospective (ANEP) and the Spain Inter-ministry Commission of Science and Technology (CICYT) in the evaluation of projects, research grants applications, and so on. She is member of the Accreditation Committee of Full Professors of the Spanish Agency of Quality Evaluation and Accreditation (ANECA). She has also served in several evaluation panels of the Commission of the European Communities. She has been a member of the editorial board of three scientific journals. She has been associated editor of several scientific journals, among them, IEEE Antennas and Wireless Propagation Letters. She is associated editor of the European Microwave Association Proceedings and the International Journal of Antennas and Propagation. She is member of the Technical Program Committees of several international and national symposiums and reviewer for different international scientific journals, symposiums, and editorial companies. She is a registered engineer in Spain. She has received two individual research awards.

Since 1989, she has served IEEE under different volunteer positions: vice chairperson and chairperson of IEEE Spain Section AP-S/MTT-S Joint Chapter, chairperson of IEEE Spain Section, Membership Development Officer of IEEE Spain Section, member of IEEE Region 8 Committee, member of IEEE Region 8 Nominations and Appointments Subcommittee, chairperson of IEEE Region 8 Conference Coordination Subcommittee, member of IEEE WIE Committee, liaison between IEEE WIE Committee and IEEE Regional Activities Board, chairperson of IEEE Women in Engineering (WIE) Committee, member of IEEE Ethics and Member Conduct Committee, member of IEEE History Committee, member of IEEE MGAB (Member and Geographic Activities Board) Geographic Unit Operations Support Committee, and member of IEEE AP-S Administrative Committee. Presently she is serving as member of IEEE Spain Section Executive Committee (officer for Professional Development), member of IEEE MTT-S Subcommittee # 15, member of IEEE AP-S Transnational Committee. In December

2009 she was elected 2011 President of IEEE AP-S Society, acting as President Elect during 2010 and Past President from 2012 onwards.