TITLE: Adaptive Array Antennas: Principles and Applications

- PRESENTERS:

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- DESCRIPTION:

This course describes the antenna technology (arrays, low sidelobe-, high directivity-, and reconfigurable antennas) and signal processing algorithms that are used in modern radar systems to reject interference. Particular emphasis is placed in this tutorial on an intuitive understanding of array operation and of the interference nulling process. Numerous adaptive techniques, most of which seek to optimize SINR (the ratio of signal to interference-plus-noise), are available to the system designer. They offer differing levels of complexity and performance. Attendees will survey these techniques and learn both the practical and mathematical aspects of their use. The course begins by reviewing the basics of antenna arrays and beamforming, establishing a firm context for the introduction of array-based adaptive algorithms. A simplified and practical explanation of the array covariance matrix with its eigenvalues and eigenvectors is presented, together with an understanding of their role in adaptive nulling. Classic covariance matrix-based approaches are introduced next, including the LMS gradient-based algorithm and the LS and MVDR block processing algorithms. Intuitive graphical explanations of beamforming and nulling will accompany mathematical descriptions of how the algorithms work. Guidance on which algorithms are best in specific applications will be presented, providing valuable practical information that is often missing from conference tutorials. The remainder of the course covers specialty techniques useful for large arrays, such as sidelobe cancellation and partially adaptive arrays, as well as non-digital techniques such as reconfigurable arrays.

This short course is broken into four parts:

(1) Fundamentals—arrays, signals, terminology, beamforming, null synthesis
(2) Introduction to adaptive nulling—digital beamforming and non-digital beamforming approaches, reconfigurable arrays, an intuitive introduction to eigenvalues and eigenvectors of the covariance matrix, array calibration
(3) Covariance-based algorithms—least squares, MVDR, LMS and Howells-Applebaum nullers, and their relations to each other
(4) Implementation details and practicalities—block processing methods, iterative methods, diagonal loading, sub-optimal methods (subarray-level beamforming, e.g.), guidance on which methods to use for which applications

The material in the course is based on the two books:

R. A. Monzingo, R. L. Haupt, and T.W. Miller, Introduction to Adaptive Arrays, 2nd ed., SciTech Publishing, 2010.
R.L Haupt, Antenna Arrays: A Computational Approach, New York: Wiley, 2010.

• INTENDED AUDIENCE AND PREREQUISITES:

The audience should be interested in antenna arrays and in signal processing associated with arrays. A BS in engineering, science or math is a prerequisite, and some familiarity with linear algebra will be helpful.

• LEARNING OUTCOME:

The student will learn

1. The historical development of adaptive arrays.
2. Basic signal and antenna principles of adaptive antennas.
3. Significance of the signal correlation (covariance) matrix and its eigenvectors and eigenvalues.
4. The algorithms used in digital beamforming.
5. Guidance on strengths and weaknesses of each algorithm, and suggestions on which work best in specific applications.
6. Non-digital beamforming adaptive nulling algorithms.
7. The basics of reconfigurable arrays.

• PREVIOUS VERSIONS OF THIS COURSE:

R. Haupt and M. Leifer, "Adaptive Array Antennas: Principles and Applications," 2018 - 2019 IEEE Radar Conference
R. Haupt and M. Leifer, "Adaptive Antennas," 2015 – 2017 IEEE Radar Conferences
R. Haupt and M. Leifer, "Introduction to Adaptive Nulling," 2012 IEEE AP-S Symposium
R. Haupt, "Introduction to Adaptive Nulling," 2012 IEEE International Conference on Wireless Information Technology and Systems
R. Haupt, "Introduction to Adaptive Nulling," 2011 IEEE AP-S Symposium and 2011 IEEE Radar Conference

Attendance at recent courses:

Year	Attendance
2017	14
2018	26
2019	16

• MATERIALS:

Each attendee will receive the slides used in the presentation, either as a paper copy or on CD ROM. A bibliography and references are provided within.

- PRESENTER BIOGRAPHIES:

Randy L. Haupt received the BSEE from the USAF Academy (1978), the MS in Engineering Management from Western New England College (1982), the MSEE from Northeastern University (1983), and the PhD in EE from The University of Michigan (1987). He is Professor of Electrical Engineering at the Colorado School of Mines and was an RF Staff Consultant at Ball Aerospace & Technologies, Corp., a Senior Scientist and Department Head at the Applied Research Laboratory of Penn State, Professor and Department Head of ECE at Utah State, Professor and Chair of EE at the University of Nevada Reno, and Professor of EE at the USAF Academy. He was a project engineer for the OTH-B radar and a research antenna engineer for Rome Air Development Center early in his career. He retired from the USAF as a Lt Col in 1997. Dr. Haupt's research interests and expertise spans a wide range of topics in electromagnetics that include theoretical, numerical, and experimental projects. He is co-author of the books Practical Genetic Algorithms, 2 ed., John Wiley & Sons, 2004, Genetic Algorithms in Electromagnetics, John Wiley & Sons, 2007, and Introduction to Adaptive Antennas, SciTech, 2011, as well as author of Antenna Arrays a Computation Approach, John Wiley & Sons, 2010, Timed Arrays, John Wiley & Sons, 2015, and Wireless Communications Systems: An Introduction, John Wiley & Sons, 2019. Dr. Haupt was the Federal Engineer of the Year in 1993 and is a Fellow of the IEEE, Applied Computational Electromagnetics Society (ACES), and Electromagnetics Academy. He is Associate Editor of the URSI Radio Science Bulletin and Associate Editor of the IEEE AP-S Magazine.

Mark C. Leifer is an internal Staff Consultant and the RF Chief Engineer at Ball Aerospace in Colorado, where he works on radar, communications and EW systems. He received his B.S. in Physics and Ph.D. in Applied Physics from Stanford University. He spent 15 years designing Magnetic Resonance Imagers for clinical use, later working on adaptive beamforming and “Smart Antenna” systems for cellular communications at ArrayComm, Inc. in San Jose and at Ericsson Wireless in Colorado. His patented spatial null-deepening algorithm has been installed in more than 300,000 cellular base stations world-wide. At Ball Aerospace, Dr. Leifer resides in the Phased Array and RF Technology group, where his work includes algorithm development for both spatially and temporally adaptive systems.