Phased Array Antenna Measurements Tutorial Session
(Updated 7 July 2010)

2010 IEEE International Symposium
Phased Array Systems & Technology,
15 October 2010, Boston, Massachusetts,
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Organizers: Dr. Doren W. Hess, PhD, MI Technologies, USA
Dr. Alan J. Fenn, PhD, MIT Lincoln Laboratory, USA

Overview: Accurate characterization of phased array antenna systems, typically in an indoor anechoic chamber environment, is desired prior to field deployment for communications and radar applications. This tutorial reviews various measurement techniques currently being applied to characterize phased array antennas – both for determination of the far-field patterns and for element diagnostics and array alignment. Theory behind the methods and examples of measurement using the following techniques will be discussed:

- Planar near-field
- Spherical near-field
- Compact range and far-field
- Focused near-field - adaptive array

Other phased array measurement topics including array mutual coupling, scan reflection coefficient, and element gain measurements will be presented.

Time: 8:00 AM to Noon, Friday, 15 October 2010

Outline

Introduction: Doren W. Hess, PhD, MI Technologies, USA

Phased Array Antenna Measurements Using Near-Field Techniques, Alan J. Fenn, PhD, MIT Lincoln Laboratory, USA

Integration, Calibration and Verification of Phased Array Subsystems in a Planar Near-Field Facility, Dayel Garneski, Raytheon, USA

Spherical Near-Field Facility: Supporting Analog and Digital Array Antenna Calibration and System Performance Verification, Charles J. Kryzak, PhD, Lockheed Martin, USA

Adaptive Phased Array Antenna Measurements Using Focused Near-Field Techniques, Alan J. Fenn, PhD, MIT Lincoln Laboratory, USA

Course Materials:
Course Presentation Slides.
Abstract/Outlines of The Presentations
Phased Array Antenna Measurements Using Near-Field Techniques

Alan J. Fenn, PhD, MIT Lincoln Laboratory, USA

- Introduction / background
- Basic array parameters and measurements
  - Array mutual coupling
  - Scan reflection/transmission coefficients
  - Element gain
- Phased array antenna measurement techniques
  - Introduction
  - Measurement Techniques
    - Far-field
    - Compact range
    - Focused near-field
    - Near-field scanning
    - Planar near-field scanning for low-sidelobe arrays
      - Theory
      - Results
- Summary

Integration, Calibration and Verification of Phased Array Subsystems in a Planar Near-Field Facility,

Dayel Garneski, Raytheon, USA

- Phased array architectures
- Examples of deployed systems
- Phased array subsystem integration tasks
- Phased array subsystem calibrations:
  - Element state
  - Array magnitude/phase taper
  - Time delay unit
  - Subaperture channel balance
- Phased array subsystem verification
- Back projection: resolution limit, adaptation to array model, usage in calibration
- Phased array calibration example
- Examples of measurement system errors:
  - Temperature drift,
  - Leakage,
  - Periodic errors,
  - Beam pointing
- Power density mapping
A Spherical Near-Field Facility to Support Calibration of Analog and Digital Array Antennas and Verification of System Performance

Dr. Charles Kryzak, PhD, Lockheed Martin, USA

Abstract The development of independent digitally controlled transmitter and receiver phased array channel architectures has driven LM to address the difficult aspect of array-level channel balancing and equalization. To support this development, LM-Ground Based Radar Division has designed and constructed a very large “fully RF-shielded” Spherical Near-field Anechoic Chamber facility at its Syracuse, NY location. The commissioning of this facility is to begin in June 2010.

The choice of spherical near-field scanning was made to enable the measurement of far sidelobes and direct backlobes of the radar antenna pattern. The RF shielding is rated up through 18 GHz and the RF absorber is rated from the lower UHF through 40 GHz. The chamber absorber and HVAC system are designed to sustain average incident power levels in excess of 1500 Watts/sq-meter, allowing for operation of the antenna at high peak power levels.

The electronic data acquisition system was designed to address the testing of phased array systems with a variety of architectures: either analog-controlled or fully independent digitally controlled transmit functions plus digital I/Q channelized receive functions. To establish accurate pair-wise channel amplitude and phase mismatch, careful attention has been paid to transmit and receive “real-time” pulse I/Q characterization, together with receive channel amplitude and phase ripple equalization.

Techniques have been developed which address the more difficult test requirements dictated by independent “distributed” waveform generation which are driven by the subtle stable reference receiver-function required to remove residual measurement phase wander.

Adaptive Phased Array Antenna Measurements Using Focused Near-Field Techniques

Alan J. Fenn, PhD, MIT Lincoln Laboratory, USA

- Introduction / background
- Adaptive array testing considerations
- Comparison of far-field and near-field interference
- Focused near-field adaptive nulling test concept and simulations
- Adaptive phased array test bed and measurements
- Summary
Biographical Information
of
the Presenters
Alan Fenn is a senior staff member in the Advanced RF Sensing and Exploitation Group at Lincoln Laboratory, Massachusetts Institute of Technology. He is deputy manager for antenna measurements in the RF Systems Test Facility at Lincoln Laboratory. He has conducted extensive research in the area of phased array antennas. He joined Lincoln Laboratory in 1981 and was a member of the Space Radar Technology Group from 1982 to 1991, where his primary research was in adaptive phased-array antenna design and testing. From 1992 to 1999 he was an assistant group leader in the Radio Frequency Technology Group, where he managed programs involving RF measurements of atmospheric effects on satellite communications. From 1978 to 1981, he was a senior engineer in the Antenna Systems Design/Analysis Group in the RF Systems Department at Martin Marietta Aerospace, Denver, Colorado. He received a B.S. from the University of Illinois at Chicago in 1974, and an M.S. in 1976 and a Ph.D. in 1978 from The Ohio State University, Columbus, all in electrical engineering.

Dr. Fenn was elected a Fellow of the IEEE in 2000 for his contributions to the theory and practice of adaptive phased-array antennas. He is currently serving as the Technical Program Chair of the 2010 IEEE International Symposium on Phased Array Systems & Technology. He was technical program co-chair of the 2001 IEEE Antennas and Propagation Society Symposium. He has served as an associate editor in the area of adaptive antennas for the IEEE Transactions on Antennas and Propagation. In 1990 he was a co-recipient of the IEEE Antennas and Propagation Society's H.A. Wheeler Applications Prize Paper Award. He also received the IEEE/URSI-sponsored 1994 International Symposium on Antennas (JINA 94) award. Dr. Fenn has authored the book *Adaptive Antennas and Phased Arrays for Radar and Communications* as well as two other books and numerous journal articles, patents, and short-course lectures and conference presentations on adaptive phased array antennas.
Dayel Garneski is an Engineering Fellow with Raytheon Space and Airborne Systems (SAS) in El Segundo, California. His current responsibilities include active array subsystem design, development of advanced active array near field integration and test capabilities, and technical leadership of the integration and test staff. He also provides support as a subject matter expert to numerous Raytheon active array production and development programs.

He joined the legacy Hughes Aircraft Company in 1979, and has over 20 years of experience in the development, integration, calibration, and verification testing of phased array antenna subsystems, primarily in near-field test facilities. He implemented the near-field transformation processing codes used in most active array production programs at SAS, as well as back projection techniques for array calibration and diagnostics, active array calibration techniques, volumetric power density mapping, and diagnostic imaging of array scattering for radar cross section control. He is a Senior Member of the Antenna Measurement Techniques Association and serves as a technical reviewer for the IEEE Antennas and Propagation Society. He received the BSEE from the University of Southern California in 1983 and the MSEE from UCLA in 1986.
Chuck Kryzak is a Lockheed Martin Fellow and Hardware-Systems Architect under Ground Base Radar Systems in Syracuse, NY. He received a Ph.D. in Physics from RPI, Troy, NY and jointly served as Research Assistant under the EE department. He is the lead Surveillance Radar (SR) antenna aperture designer for the Tri-National “US Army’s” MEADS SR/MFCR Missile Defense System, and has designed and developed the associated RF, radar timing, and digital control/data distribution networks applicable to both SR and MFCR. He lead the design group, developed high resolution radiating element models, and simulated the full SR phased array using a combination of FEM, MoM, and FDTD techniques. The 3D EM array simulation and optimization established the SR array front-side/back-side beam and null generation performance capabilities, and margins, against program mission requirements.

He is directly responsible all the LM Syracuse’s Spherical Near-Field chamber performance specification, chamber development, and is technical lead for the MEADS SR antenna calibration and performance verification. During the past several years he has developed numerous RF receiver modules and optical transceivers data/control distribution network modules required by LM’s independent digitally controlled phase array architectures supporting both adaptive beam-space beam-forming and co-operative multi-static radar/sensor applications. He designed, developed, and reduced to full production the fully ruggedized Quad-Channel Optic Transceivers which are architecture and production baselines for the entire tactical avionic digital distribution networks within the Joint Strike Fighter (JSF) and F-16 Block60 aircraft.

His research included the design and demonstration of the following: wide dynamic range optical RF transmission, the development of MEMS based optical switching techniques for avionic optical system self-test, design/demonstration of high current DC-DC switch mode power converters, design of FPGA and DSP based modular real-time digital processor functions, and the design of both ceramic and polyimide thin film digital and analog hybrids. He is a member of Sigma Xi, IEEE, the American Physical Society, and has nine patents and publications related to optical array transceiver design, MMIC wafer processing, and non-blocking computer network switching architectures.
Dr. Doren W. Hess - Biography

Doren Hess is a Senior Staff Engineer with MI Technologies in Suwanee, Georgia. His work there is focused on near-field scanning and compact range applications. Dr. Hess received his Bachelor of Science degree from Duke University in 1965 and his Ph.D. from The University of North Carolina at Chapel Hill in 1973. Following two years as a Postdoctoral Research Associate at Chapel Hill, he joined Scientific-Atlanta in 1974 where his work was centered on industrial applications of compact ranges and near-field scanning. He was responsible for final development of the first Scientific-Atlanta compact range product, and for the first commercial spherical near-field product offered by Scientific-Atlanta. He was the senior technical member of a design team for Scientific-Atlanta's planar near-field system.

He is the author of articles and conference presentations on spherical and planar near-field scanning, compact range measurements, and automatic antenna measurements. His professional interests include electromagnetic scattering and radar cross-section, radome and antenna measurements. Dr. Hess is a member of the IEEE Antenna and Propagation Society, where he has served as a member of the AdCom. He was the founding editor of the Measurements Column of the AP-S Magazine and a past President of the Antenna Measurement Techniques Association. In 1997 the Antenna Measurement Techniques Association honored him with its Distinguished Achievement Award. He joined MI Technologies in 2001. In 2007, Dr. Hess was made an Edmond S. Gillespie Fellow of the Antenna Measurement Techniques Association.