Phased Array Radar and Digital Beam Forming: Basics and Breakthroughs

Instructor:
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Abstract:
ARRAY BASICS: Electronic scanning, embedded element gain, time delay steering, element types, array factor, u-v space, errors, mutual coupling, feeds; Digital Beam Forming (DBF); Grating lobes (GL) and reduction using overlapped subarrays; limited scanning;
RECENT DEVELOPMENTS AND BREAKTHROUGHS:
Systems: 3, 4, 6 face “Aegis” systems. Patriot now has GaN AESA; S/X-band AMDR provides 30 times the sensitivity and number of tracks as SPY-1D(V)
Low Cost Packaging: Using COTS, PCBs
Extreme MMIC: 32 element 60 GHz T/R array on chip
Digital Beam Forming (DBF): A/D for every element
Materials: GaN can now put 5X to 10X the power of GaAs in same footprint, 38% less costly, 100 million hour MTBF
Metamaterial Antennas: $1K 20 GHz and 30 GHz AESAs
Very Low Cost Systems: Cars radar costing < $100, future few $’s
MEMS: Phase shifters
MEMS Piezoelectric Material = piezoMEMS: For flying insect robots
Printed Electronics: Low cost 1.6 GHz (goal 2.4 GHz) diodes printed
Electrical and Optical Signals on Same Chip; IR transparent in silicon
Graphene and Carbon Nanotube (CNT): Potential for Terahertz transistor clock speeds
Revolutionary 3-D Micromachining
Superconductivity
Biodegradable Arrays of Transistors or LEDs: Imbedded for detecting cancer or low glucose
Quantum Radar: See stealth targets

Intended Audience:
Directed toward those unfamiliar and familiar with phased array radars. The phased array basics is at a level for those not familiar with subject and covers subjects that experienced would gain from. The breakthroughs and future trends material is aimed at all levels of attendees. Have lectured around the world on the subject successfully to college students, professors, practicing engineers and scientists of all backgrounds. Attendees do not need laptops. I assume they will get a hard copy of charts and possibly CD with slides. Calculator not required although useful.
Attendees should have some knowledge of radar fundamentals as well as simple radar signal processing. Prerequisite: First three years of bachelor’s degree in electrical engineering or equivalent.

Learning Outcome:
Attendees will learn phased array basics and the latest developments and future trends in the technology relating to phased-array radars and radars. Important to all radar engineers.
Detailed Description:

ARRAY BASICS: Electronic scanning, embedded element gain, time delay steering, element types, array factor, u-v space, errors, mutual coupling, feeds; Digital Beam Forming (DBF); Grating lobes (GL) and reduction using overlapped subarrays; limited scanning

RECENT DEVELOPMENTS AND BREAKTHROUGHS:

Systems: Patriot now has GaN active electronically scanned array (AESA) providing 360° coverage, now a 2015 state-of-the-art AESA radar system; S/X-band AMDR provides 30 times the sensitivity and number of tracks as SPY-1D(V); JLENS aerostat radar system now deployed over Washington DC; 3, 4, 6 faced “Aegis” radar systems developed by China, Japan, Australia, Netherlands, USA

Low Cost, Low Power Extreme MMIC (Moore’s law at Microwave an mm-waves): 4 T/R modules on single chip at X-band costing ~$10 per T/R module; Intel single chip 32-Element 60 GHz Tx/Rx Phased Array, full phased array on wafer at 110 GHz; on-chip built-in-self-test (BIST), will be used in the internet-of-things and in cell phones which by 2020 is expected to number 50 billion, expect such single chip arrays to cost only few dollars in future; All the RF circuits for mm-wave automobile radars at 25 GHz and 77 GHz are being put on a chip with some believing that such arrays and radars will soon be produced for just a few dollars; Valeo Raytheon (now Valeo Radar) developed low cost, $100s, car 25 GHz 7 beam phased array radar; about 2 million sold already, more than all the radars ever built up to a very few years ago; DARPA had goal to build 28,000 element 94 GHz array costing $1/element, 50W total RF peak power

Digital Beam Forming (DBF): Israel, Thales and Australia AESAs under development have an A/D for every element channel; Raytheon developing mixer-less direct RF A/D having >400 MHz instantaneous bandwidth, reconfigurable between S and X-band; Radio Astronomers looking at using arrays with DBF

Materials: GaN can now put 5X to 10X the power of GaAs in same footprint, 38% less costly, 100 million hour MTBF, Raytheon invested $150 million to develop GaN; SiGe for backend, GaN for front end of T/R module

Metamaterials: Material custom made (not found in nature): using 20 and 30 GHz metamaterial electronically steered antennas about the size of a laptop developed for transmission to satellites and back was demonstrated December 2013, goal is $1K per antenna, remains to prove low cost and reliability; 2-20GHz stealthing by absorption simulated using <1 mm coating; target made invisible over 50% bandwidth at L-band; Focus 6X beyond diffraction limit at 0.38 μm; 40X diffraction limit, λ/80, at 375 MHz; In cell phones provides antennas 5X smaller (1/10th λ) having 700 MHz-2.7 GHz bandwidth; The Army Research Laboratory in Adelphi MD has funded the development of a low profile metamaterial 250-505 MHZ antenna having a □/20 thickness; Provides isolation between antennas with 2.5 cm separation equivalent to 1 m separation; used for phased array WAIM; n-doped graphene has negative index of refraction, first such material found in nature

Digital Processing and Moore’s Law: Not dead yet; Slowed down but has much more to go; Expect increase in transistors density by about a factor of ~50 in the next 30 years and reduction in signal processing power consumption by factor of ~75; and then there is graphene which has potential for terahertz transistor clock
speeds, manufacture on CMOS demonstrated, could allow Moore’s law to march forward using present day manufacturing techniques; there is also spintronics which could revolutionize the computer architecture away from the John von Neumann model; and there is finally doing computation the way the brain efficiently and amazingly does perhaps by using synaptic transistors and/or memristors, remember the brain only weighs about 2-3 pounds and uses only ~20 W, we have a long way to go

Low Cost Packaging: Raytheon funding development of low cost flat panel X-band AESA using COTS type printed circuit boards (PCBs); Rockwell Collins doing it for airborne AESA; Lincoln- Lab./MA-COM developing low cost S-band flat panel array using PCBs, overlapped subarrays and a T/R switch instead of a circulator

SAR/ISAR: Principal Components of matrix formed from prominent scatterers track history used to determine target unknown motion and thus compensate for it to provide focused ISAR image

Technology and Algorithms: A dual polarized, low profile, (π/40), wideband (1:20) antenna can be built using tightly coupled dipole antennas (TCDA); Lincoln Lab increases spurious free dynamic range of receiver plus A/D by 40 dB

MEMS: reliability reaches 300 billion cycles without failure; Has potential to reduce the T/R module count in an array by a factor of 2 to 4; Provides microwave filters like 200 MHz wide tunable from 8-12 GHz

MEMS Piezoelectric Material = piezoMEMS: Enables flying insect robots

Printed Electronics: Low cost 1.6 GHz (goal 2.4 GHz) diodes printed with Si and NbSi2 particles

Electrical and Optical Signals on Same Chip: IR beams could be used for transporting on computer chips digital information at the speed of light

COSMOS: DARPA revolutionary MMIC program: Allows integration of III-V, CMOS and opto-electronics on one chip without bonded wires leading to higher performance, lower power, smaller size, components

Graphene and Carbon Nanotube (CNT): potential also for non-volatile memory, flexible displays and camouflage clothing, self-cooling, IBM producing 200 mm wafers with RF devices

Superconductivity: We may still achieve superconductivity at room temperature; Superconductivity recently obtained for first time with iron compounds

Biodegradable Array of Transistors or LEDs: Imbedded for detecting cancer or low glucose; can then dispense chemotherapy or insulin

Quantum Radar: See stealth targets

New polarizations: OAMs, (Orbital Angular Momentum) unlimited data rate over finite band using new polarizations

Prior Presentations:
Given with updates each time at various past conferences:
Indian International Radar 2007 in Bangalore (300 attended),
RadarCon 2008 in Rome, Italy (45 attended),
IEEE International Symposium on Phased Array Systems and Technology (ARRAY-2013) Boston (52 attended), ARRAY-2010 Boston (~85’ attended), ARRAY-2000 Dana Point, CA (~50 attended), ARRAY-2003 Boston (~94 attended),
ARRAY-1996 Boston (120 attended), Radar-2000 Arlington (29 attended),
Raytheon, Colorado (60 attended), Nat’ TelesysteGms Conf. San Diego (50 attended),
Radar 2014 in Lille, France where it had the 3rd largest registration out of 15 tutorials.
Radar 2015 in Washington, DC (14 attended - one of the largest attended tutorials).
IET International Radar 2015 Conference in Hangzhou, China where 100 attended.

Have given radar and phased array courses to over 10,000 around the world. New
material data on GaN AESA Patriot upgrade, newly released detailed AMDR performance
re AEGIS, deployment of JLENS over Washington DC, Printed Electronics at 1.6 GHz,
Quantum Radar, explanation of how Kymeta metamaterial electronically scanned antenna
works, latest on extreme MMIC, status of Moore’s Law. Metamaterial low profile (λ/20),
wideband 250-505 MHz VHF antenna, low profile (λ/40), wideband (1:20), dual polarized
tightly coupled array. Will update further.

Bio-sketch:

Dr. Eli Brookner: BEE: The City College of the City of New York, ’53, MEE
and DrSc: Columbia University ’55 and ’62. worked at Raytheon Company
from 1962 until 2014 when he retired. There he was a Principal Engineering
Fellow and worked on ASDE-X airport radar, ASTOR Air Surveillance Radar,
RADARSAT II, Affordable Ground Based Radar (AGBR), major Space Based
Radar programs, NAVSPASUR S-Band upgrade, COBRA DANE, PAVE
PAWS, Missile Site Radar (MSR), COBRA JUDY Replacement, THAAD,
Brazilian SIVAM, SPY-3, Patriot, BMEWS, UEWR, Surveillance Radar
Program (SRP), Pathfinder marine radar, Long Range Radar (upgrade for >70 ATC ARSRs),
COBRA DANE Upgrade, AMDR, Space Fence, 3DELRR, FAA NexGen ATC radar program.
Prior to Raytheon he worked on radar at Columbia Un. Electronics Research Lab. (now RRI),
Nicolet and Rome AF Lab.

Received IEEE 2006 Dennis J. Piccard Medal for Radar Technology & Application “For
Pioneering Contributions to Phased Array Radar System Designs, to Radar Signal Processing
Designs, and to Continuing Education Programs for Radar Engineers”; IEEE ’03 Warren White
Award; Journal of the Franklin Institute Premium Award for best paper award for 1966; IEEE
Wheeler Prize for Best Applications Paper for 1998. Fellow of IEEE, AIAA, MSS. Member of
the National Academies Panel on Sensors & Electron Devices for Review of Army Research

Published four books: Tracking and Kalman Filtering Made Easy, John Wiley and Sons,
and Radar Technology (1977), Artech House. Gives tutorial courses on Radar, Phased Arrays
and Tracking around the world (25 countries). Over 10,000 attended these tutorial courses. Gave
over 150 tutorial courses. Banquet/keynote speaker twelve times. >230 papers, talks and
correspondences, >100 invited. 6 paper reprinted in Books of Reprints (one in 2 books).
Contributed chapters to three books. 9 patents.