Amazing Breakthroughs and Trends in Phased Arrays and Radars
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Summary: Covered will be advances in radars and phased-arrays leading up to the latest amazing breakthroughs and future trends, including in the areas of metamaterials, graphene, DBF, micromachining, very low cost arrays, signal processing.

Systems: 3, 4, 6 face “Aegis” systems developed by China, Japan, Australia, Netherlands, USA. Digital Beam Forming (DBF): Israel, Thales and Australia AESAs have an A/D for every element channel, a major breakthrough; Lincoln Lab and AFRL developing X-band technology for element level DBF having 600 MHz instantaneous bandwidth; Raytheon developed mixer-less direct RF A/D having >400 MHz instantaneous bandwidth, reconfigurable between S and X-band; Low cost DBF at element for on-the-move Ethernet by IMST; Lincoln Lab increases spurious free dynamic range of receiver plus A/D by 40 dB; Radio Astronomers looking at using arrays with DBF. Materials: GaN can now put 5X to 10X the power of GaAs in same footprint. Extreme MMIC: 4 T/R modules on single chip at X-band costing ~$10 per T/R module; on-chip built-in-self-test (BIST) at W-Band; wafer scale integration at 110 GHz. Metamaterials: Material custom made (not found in nature): electronically steered antenna not using phase shifters at 20 and 30 GHz demonstrated (still 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; Provides isolation between antennas having 2.5 cm separation equivalent to 1m separation; n-doped graphene has negative index of refraction, first such material found in nature; used for phased array WAIM. Very Low Cost Systems: Valeo Raytheon (now Valeo Radar) developed low cost, $100s only, 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; Commercial ultra low cost 77 GHz Roach radar on 72mm² chip with >8 bits 1 GS/s A/D and 16 element array; Low cost 240 GHz 4.2x3.2x0.15 cm³ 5 gm radar for bird inspired robots and crawler robots, Frequency scans 2°x8° beam ±25°; DARPA has goal to build 28,000 element 94 GHz array costing $1/element, 50W total RF peak power. Low Cost Packaging: Raytheon funding development of low cost flat panel X-band array using COTS type printed circuit boards (PCBs); 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; Army Research Lab demonstrated 12 dB reduction in sidelobes for forward looking SAR back projection images for IED ultra wideband radar by use of Recursive Sidelobe Minimization (RSM) Algorithm. Technology and Algorithms: 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; Can provide microwave filters tunable from 8-12 GHz, 200 MHz wide. MEMS Piezoelectric Material = piezoMEMS: Enables flying insect robots. Printed Electronics: Low cost printing of RF and digital circuits using metal-insulator-metal (MIM) diodes and/or 2D MoS2 ink. Electrical and Optical Signals on Same Chip: Has been shown that both electricity and light can be simultaneously transmitted over a silver nanowire combined with single layer 2D MoS2, could be a step towards transporting on computer chips digital information at the speed of light. COSMOS: DARPA revolutionary program: Will allow integration of III-V, CMOS and opto-electronics on one chip without bonded wires leading to higher performance, lower power,
smaller size, components. **MIMO (Multiple Input Multiple Output):** Where it makes sense; contrary to what is claimed MIMO array radars do not provide 1, 2 or 3 orders of magnitude better resolution and accuracy than conventional array radars; MIMO does not provide better barrage-noise-jammer, repeater-jammer or hot-clutter rejection than conventional array radars. **Graphene and Carbon Nanotube (CNT):** Potential for Terahertz transistor clock speeds, manufacture on CMOS demo’d, could allow Moore’s law to march forward using present day manufacturing techniques; non-volatile memory, flexible displays and camouflage clothing, self-cooling, switch with 100,000 to 1 on/off ratio, IBM producing 200 mm wafers with RF devices; **Electron spin:** For memory. **Atomic Memory:** 12 iron atoms for 1 bit of memory; could provide hard drive with 100X density. **Revolutionary 3-D Micromachining:** integrated circuitry for microwave components, like 16 element Ka-band array with Butler beamformer on 13X2 cm² chip; **3D Display:** 3D display from 2D image without the need for special eyeglasses. **Superconductivity:** We may still achieve superconductivity at room temperature; Superconductivity recently obtained for first time with iron compounds. **DARPA UHPC (Ubiquitous High Performance Computing) Program:** 100 GFlops in cell phone using only 2 W instead of the present required 600 W, Goal of DARPA-Intel UHPC program is for 100 to 1000 reduction in computer required power by 2018. **Biodegradable Array** of Transistors or LEDs: Imbedded for detecting cancer or low glucose, can then dispense chemotherapy or insulin. **New polarizations, OAMs, (Orbital Angular Momentum):** unlimited data rate over finite band using new polarizations??
**O3b & Kymeta Agree to Develop Flat Panel Antenna**

![Image of O3b & Kymeta Antenna](image)

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**Nanostructural Ceramics**

- Nanomaterials exhibit new properties
- < 10 nm ceramic tubes are not brittle
- Spongelike, buckle then recover shape
- Super-light and super-strong
- Potentially used for battery electrodes – fast charging and lot of energy
- Prof. Julia Greer, Cal Tech

![Image of Electron Microscope](image)

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**Optical & Electrical Signals Propagated Over Same Wire**

- Light in
- Ag nano wire
- Single layer MoS2
- Allows electrical signals to go at speed of light on chip
- Allows photonics & electronics on same chip

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**Graphene & Carbon (C) Nanotubes (CNT): Hope for Moore's Law Continuation**

- THz clock speed
- Graphene: 1 atom thick C crystal, strongest material
- CNT: Manufacture on CMOS DEMO'D

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**Breakthroughs: Metamaterial**

- Microwave: GPS antenna
- Optical lens
- Multifunction
- Wide-bandwidth
- Dual polarization
- Wide scan angle
- Conformal

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**Surface of invisibility cloak**

- Multiband reflection (R) invisibility cloak
- Rectangular
- Deflection of light

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**Simulated Upgraded Haystack ISAR Images**

- Slant range
- Doppler res
- Now x-band
- Upgraded u/sir
- Compact range data

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**Synaptic Transistor**

- Leans like human brain synaps
- Brain has 86 billion neurons connected by synapses
- Human brain uses only ~20 W
- Leads to analog not binary computer

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**Conventional SAM vs Non-Convention OAM Polarization**

- Spin angular momentum (SAM)
- Orbital angular momentum (OAM)
- Plane constant phase surface
- Helical constant phase surface
- Near or circular, based on photon polarization
- Quantum states:
- Infinite number in the

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*Figures from E-Karim, OAM, Wikipedia*