Amazing Breakthroughs and Trends in Phased Arrays and Radars
Dr. Eli Brookner, Raytheon Company (retired)

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 $72 mm^2$ chip with >8 bits 1 GS/s A/D and 16 element array; Low cost 240 GHz 4.2x3.2x0.15 cm^3 5 gm radar for bird inspired robots and crawler robots, Frequency scans 2^ox8^o beam ±25^o; 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 MoS_2, 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,

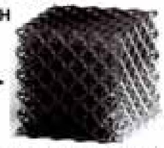
smaller size, components. **MIMO (Multiple Input Multiple Output):** Where it makes sense; contrary to what is claimed MIMO array radars do not provide 1, 2 or 3 orders of magnitude better resolution and accuracy than conventional array radars; MIMO does not provide better barrage-noise-jammer, repeater-jammer 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 cm^2 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

NANOSTRUCTUAL 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

ELECTRON MICROSCOPE IMAGE SHOWS NANO-LATTICES →



(K. BOURZAC, MIT TECHNOLOGY REVIEW, NOV-DEC, 2014, P. 19)

OPTICAL & ELECTRICAL SIGNALS PROPAGATED OVER SAME WIRE

SINGLE LAYER MoS_2

- ALLOWS ELECTRICAL SIGNALS TO GO AT SPEED OF LIGHT ON CHIP
- ALLOWS PHOTONICS & ELECTRONICS ON SAME CHIP

(K. GOODFELLOW, ET AL OPTICA VOL. 1, ISSUE 3, PP.149-152 [2014])

Extremely Low Profile Magnetic Metamaterial Antenna

Gregory Mitchell

- 250-505 MHZ; G=5-8.2 DB, VSWR <3
- ~2500 LAYERS; 3.3" THICK (λ/20 INSTEAD OF λ/4)
- ANISOTROPIC MAGNETIC DIELECTRIC METAMATERIAL ANTENNA
- USES: REPLACE LARGE VERY VISIBLE WHIP ANTENNA ON ARMY VEHICLES; THIN VHF AIRCRAFT FOPEN ANTENNAS
- ARMY RESEARCH LAB (ARL) CONTRACTED METAMETERIALS INC.

(ARL, ABERDEEN, MD, JUNE 4, 2014)

GRAPHINE & CARBON (C) NANOTUBES (CNT): HOPE FOR MOORE'S LAW CONTINUATION

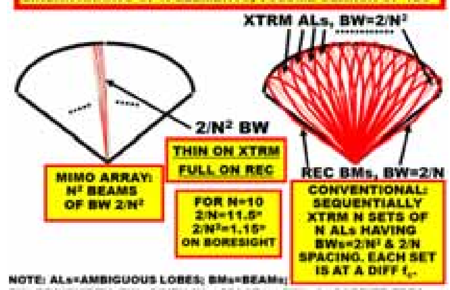
THZ CLOCK SPEED

GRAPHENE: 1 ATOM THICK C CRYSTAL; STRONGEST MATERIAL

CNT: MANUFACTURE ON CMOS DEMO'D

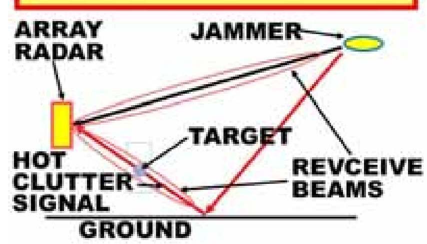
T. SIMONITE, MIT TECHNOLOGY REVIEW, SEPT-OCT, 2014, p. 17; ALSO E. BROOKNER, "RECENT ACHIEVEMENTS", IEEE ARRAY-2013; E. BROOKNER, "BREAKTHROUGHS IN PHASED ARRAYS & RADAR", IEEE ARRAY-2010.

MIMO THIN/FULL ARRAY & CONVENTIONAL EQUIVALENT: LINEAR ARRAYS OF N ELEMENTS; VOLUME SEARCH OF 120°



NOTE: ALs=AMBIGUOUS LOBES; BMs=BEAMs; BW=BEAMWIDTH; BWs GIVEN IN u-SPACE, u=SINθ; f_c=CARRIER FREQ.

HOT CLUTTER

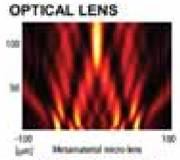


BREAKTHROUGHS: METAMATERIAL

Raytheon Integrated Defense Systems

MICROWAVE: GPS ANTENNA

OPTICAL LENS

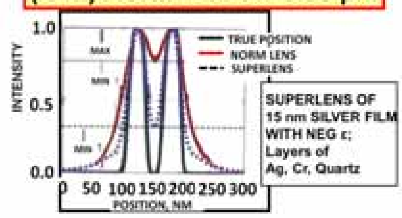


- MULTIFUNCTION
- WIDE-BANDWIDTH
- DUAL POLARIZATION
- WIDE SCAN ANGLE
- CONFORMAL

- THIN, ULTRA-LIGHT
- WIDEBAND: 0.5 – 5 MM
- WAVELENGTH SELECTIVE
- CAN ETCH ON DETECTOR
- HIGHER SNR

(RAYTHEON TECHNOLOGY TODAY, 2012, ISSUE 1)

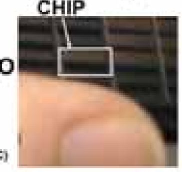
6X DIFFRACTION LIMIT (λ/12) ACHIEVED AT 0.36 μm



(NICHOLAS FANG, APP. PHYSICS LET, 2010, UN. ILLINOIS)

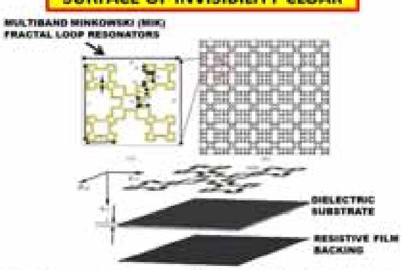
RADAR-ON-A-CHIP (ROACH) 77GHz, 72mm²

- ON CHIP: 16 ELEMENT ARRAY, > 8 Bit 1 GS/s A/D, 2 ns T/R SWITCH
- 100's m RANGE FOR 0.5m2 (MAN σ)
- Pt=80mW; NF=3.6dB
- IBM BULK CMOS
- PULSE DOPPLER/VIDEO
- UN.-MELBOURNE/IBM/ RAYTHEON



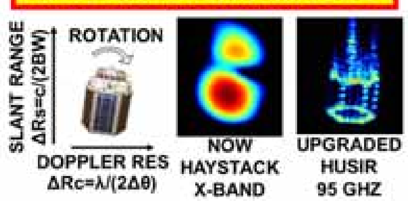
(EVANS ET AL, IEEE RADAR2010, WASH DC)

SURFACE OF INVISIBILITY CLOAK



(F. YUE-NONG, ET AL, CHINA PHYS. B VOL. 22, NO. 6, 2013, 067801)

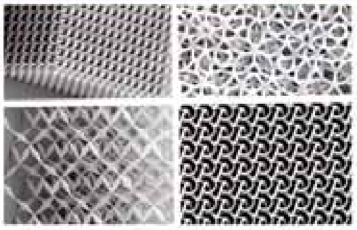
SIMULATED UPGRADED HAYSTACK ISAR IMAGES



COMPACT RANGE DATA

(J. USOFF, RADARCON-2007, BOSTON, MA)

3-D METAMATERIALS NOW MADE TO ORDER AT VISIBLE WAVELENGTHS



(J. JISCHER ET AL, IEEE SPECTRUM, 2/14P.35-.)

SYNAPTIC TRANSISTOR

- LEARNS LIKE HUMAN BRAIN SYNAPS
- BRAIN HAS 86 BILLION NUERONS CONNECTED BY SYNAPSES
- HUMAN BRAIN USES ONLY ~20W
- LEADS TO ANALOG NOT BINARY COMPUTOR

(SHI, JIAM, ET AL, A CORRELATED NICKELATE SYNAPTIC TRANSISTOR", NATURE COMMUNICATION OCT 31, 2013)

CONVENTIONAL SAM VS NON-CONVENTIONAL OAM POLARIZATION

SPIN ANGULAR MOMENTUM (SAM): PLANE CONSTANT PHASE SURFACE

ORBITAL ANGULAR MOMENTUM (OAM): HELICAL CONSTANT PHASE SURFACE

NEAR OR CIRCULAR POLARIZATION

BASED ON PHOTON QUANTUM STATES; INFINITE NUMBER IN THE

(FIGURES FROM E-KARIMI, OAM, WIKIPEDIA)