- *Prof. Eli Brookner*
- **Workshop :**

PHASED ARRAYS AND DIGITAL BEAM FORMING: BASICS AND BREAKTHROUGHS

Abstract: This tutorial covers: Array basics; Digital Beam Forming (DBF): Advantages of DBF; limited scanning; advances in radars and phased-arrays leading up to the latest amazing breakthroughs and future trends, including metamaterials, graphene, DBF, micromachining, very low cost arrays, signal processing.
Array Basics: Array phase scanning, embedded element gain, array factor, subarray time delay steering, thinned arrays, array elements, array blindness, mutual coupling, feeds; grating lobes due to forming multiple beams at the subarray level; how overlapped subarrays reduces these grating lobes). **Digital beam forming (DBF) Basics:** Advantages of; DBF at subarray and element level; Number of bits N_b needed; Reduction of N_b with increasing number of subarrays and sampling rate. **Systems:** 3, 4, 6 face "Aegis" systems developed by China, Japan, Australia, Netherlands, USA; Patriot now has GaN AESA providing 360^o coverage; S/X-band AMDR provides 30 times the sensitivity and number of tracks as SPY-1D(V). **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; **Extreme MMIC:** 4 T/R modules on single chip at X-band costing ~$10 per T/R module ; full phased array on wafer at 110 GHz; on-chip built-in-self-test (BIST); **Digital Beam Forming (DBF):** Elta, Thales and CEA AESAs have an A/D for every element channel, a major breakthrough; Raytheon developing mixer-less direct RF A/D having >400 MHz instantaneous bandwidth, reconfigurable between S and X-band; 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, 38% less costly, 100 million hr MTBF; SiGe for backend, GaN for front end of T/R module. **Metamaterials:** Material custom made (not found in nature): electronically steered antenna at 20 and 30 GHz demonstrated (with goal of $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; Provides isolation between antennas having 2.5 cm separation equivalent to 1m separation; used for phased array wide angle scan; n-doped graphene has negative index of refraction, first such material found in nature. **Very Low Cost Systems:** 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; Commercial ultra low cost 77 GHz car radar on $72mm^2$ chip with >8 bits 1 GS/s A/D and 16 element array; Low cost 240GHz 4.2x3.2x0.15 cm^3 5 gm radar for bird

inspired robots and crawler robots, Frequency scans 2^{o}x8^{o} beam ±25^{o}; DARPA has goal to build 28,000 element 94 GHz array costing $1/element, 50W total RF peak power. **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: 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 tuneable from 8-12 GH**z; MEMS Piezoelectric Material = piezoMEMS:** Enables flying insect robots; Printed Electronics: Low cost printing of RF and digital circuits using metal-insulator-metal (MIM) diodes, 2D MoS_2 ink and 1.6 GHz diodes made with Si and $NbSi_2$ particles; **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 MMIC 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; **Moore's Law:** Slowing down but expect increase in chip density of ~50 in next 30 years. **DARPA Signal Processing Power Consumption Reduction Program:** factor of ~75; **Graphene and Carbon Nanotube (CNT**): Potential for Terahertz transistor clock speeds, manufacture on CMOS demonstrated, could help Moore's law to march forward using present day manufacturing techniques; potential for non-volatile memory, flexible displays and camouflage clothing, self-cooling, switch with 100,000 to 1 on/off ratio, IBM produced 200 mm wafers with RF devices; **Electron spin:** For memory; **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; **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??