University of Illinois at Chicago, Electrical and Computer Engineering Department
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Design and Fabrication of World's Smallest Submillimeter-wave Beam-Steering Radar for Autonomous Navigation

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Abstract: Autonomous navigation is considered the next important leap in transportation. Also the applications of autonomous robots in manufacturing, security, military, delivery and service sector, as well as in homes are of significant demand. This calls for the development of advanced lower power and compact suite of sensors for situation awareness, path-planning and collision avoidance. Although optical camera and stereo vision can significantly assist in navigation and obstacle detection, their operation is severely hampered in the dark and in poor atmospheric conditions such as dust, smoke, haze and rain. Ability to penetrate poor weather, dust, smoke, cloth and other low loss but optically opaque material makes millimeter-wave (MMW) and sub-MMW radars suitable for navigation and surveillance. Sensors for autonomous small robotic platforms must be low mass, compact size and low power due to the limited space. For such applications, as the dimensions of the structures are lowered, the standard machining and assembling methods are not suitable because of low fabrication tolerances and high cost in assembly. Difficulties in fabrication of RF front-end systems at very high frequencies also include error in alignment of parts, air gaps between conductive components, poor metal contact, complex assemblies of various parts, integration of active components to mention a few. However, micromachining offers high fabrication precision, provides easy fabrication and integration with active devices and hence is suitable for manufacturing of high MMW and submillimeter-wave frequency RF front-ends. A radar design compatible with micromachining process is developed to fabricate a Y-band high-resolution radar with a slot-fed patch array antenna composed of 1200 elements. A multi-step silicon DRIE process is developed for the fabrication of the waveguide structure while the slots are suspended on a thin oxide/nitride/oxide membrane to form the top cover of the waveguide trenches and the patch elements are suspended on a thin Parylene membrane. Gold thermocompression bonding and Parylene bonding are used to assemble different parts of the antenna. These processes result in a compact and light-weight (5 g) radar. The beam steering is accomplished by frequency scanning and the range resolution is obtained from the standard FMCW technique utilizing a chirped signal waveform with step discontinuities. The radar RF front-end has a small form factor (4.5 *cm* X 3.5

cm X 1.5 *mm*) and weighs only 5 grams, and provides a field of view of $\pm 25^0$ with angular resolution of 2^o and range resolution of 37.5 *cm*. Different fabrication methods and novel measurement and characterization methods at 235 *GHz* will also be presented.

BIOGRAPHY

Kamal Sarabandi (S'87-M'90-SM'92-F'00) received the B.S. degree in electrical engineering from the Sharif University of Technology, Tehran, Iran, in 1980, the M.S. degree in electrical engineering in 1986, and the M.S. degree in mathematics and the Ph.D. degree in electrical engineering from The University of Michigan at Ann Arbor in 1989.

He is currently the Director of the Radiation Laboratory and the Rufus S. Teesdale endowed Professor of Engineering in the Department of Electrical Engineering and Computer Science, The University of Michigan at Ann Arbor. His research areas of interest include microwave and millimeter-wave radar remote sensing, Meta-materials, electromagnetic wave propagation, and antenna miniaturization. He possesses 25 years of experience with wave propagation in random media, communication channel modeling, microwave sensors, and radar systems and leads a large research group including two research scientists, 16 Ph.D. students. He has graduated 43 Ph.D. and supervised numerous post-doctoral students. He has served as the Principal Investigator on many projects sponsored by the National Aeronautics and Space Administration (NASA), Jet Propulsion Laboratory (JPL), Army Research Office (ARO), Office of Naval Research (ONR), Army Research Laboratory (ARL), National Science Foundation (NSF), Defense Advanced Research Projects Agency (DARPA), and a large number of industries. Currently he is leading the Center for Microelectronics and Sensors funded in 2008 by the Army Research Laboratory under the Micro-Autonomous Systems and Technology (MAST) Collaborative Technology Alliance (CTA) program. He is also leading a newly established center in Microwave Sensor Technology funded by King Abdulaziz City for Science and Technology (KACST).

He has published many book chapters and more than 240 papers in refereed journals on miniaturized and on-chip antennas, meta-materials, electromagnetic scattering, wireless channel modeling, random media modeling, microwave measurement techniques, radar calibration, inverse scattering problems, and microwave sensors. He has also had more than 580 papers and invited presentations in many national and international conferences and symposia on similar subjects.

Dr. Sarabandi served as a member of NASA Advisory Council appointed by the NASA Administrator for two consecutive terms from 2006-2010. Currently he is serving as the President of the IEEE Geoscience and Remote Sensing Society (GRSS) He was a member of the Editorial Board of the PROCEEDINGS of the IEEE and an associate editor for the IEEE TRANSACTIONS ON ANTENNAS AND PROPAGATION and the IEEE Sensors Journal. He is a member of Commissions F and B of URSI and is serving as the vice Chair of the USNC URSI Commission F. Dr. Sarabandi was the recipient of the Henry Russel Award from the Regent of The University of Michigan. In 1999 he received a GAAC Distinguished Lecturer Award from the German Federal Ministry for Education, Science, and Technology. He was also a recipient of the 1996 EECS Department Teaching Excellence Award and a 2004 College of Engineering Research Excellence Award. In 2005 he received the IEEE GRSS Distinguished Achievement Award and the University of Michigan Faculty Recognition Award. He also received the best paper Award at the 2006 Army Science Conference.

In 2008 he was awarded a Humboldt Research Award from The Alexander von Humboldt Foundation of Germany and received the best paper award at the IEEE Geoscience and Remote Sensing Symposium. He was also awarded the 2010 Distinguished Faculty Achievement Award from the University of Michigan. The IEEE Board of Directors announced him as the recipient of the 2011 IEEE Judith A. Resnik Award. Professor Sarabandi was recognized by the IEEE GRSS with its 2013 Education Award. In the past several years, joint papers presented by his students at a number of international symposia (IEEE APS'95,'97,'00,'01,'03,'05,'06,'07; IEEE IGARSS'99,'02,'07;'11, '14, IEEE IMS'01, USNC URSI'04,'05,'06,'10,'11, AMTA '06, URSI GA '08,'14) have received best paper awards.