F1: Beamforming Techniques and RF Transceiver Design

Organizer: **Eric Klumperink,** *University of Twente, Enschede, The Netherlands*

Organizer: **Domine Leenaerts,** *NXP Semiconductors, Eindhoven, The Netherlands*

Chair: **Gabriel Rebeiz,** *UC San Diego, La Jolla, CA*

Phased arrays exploit electronic beamforming to create an electronically steerable beam pattern. This renders antenna gain in certain directions and rejection in others, i.e. spatial filtering. Until recently, phased array systems exploited dedicated RF technologies leading to relatively costly systems, e.g. for nautical, airplane radar systems, and satellite communication. More recently, low-cost highly integrated beamforming concepts received considerable interest in academia but also industry, enabling consumer applications e.g. in base-stations for macro- and femto-cells, car-radar and 60GHz wideband radio links. (Bi-)CMOS beamforming techniques are at the heart of such systems. This forum reviews beamforming techniques suitable for IC-integration, and discusses related (Bi-)CMOS transceiver designs. Several techniques will be discussed, e.g. RF phase-shifting, LO-phase shifting, I/Q Vector modulation and digital processing. Also the relation between key radar and communication system requirements and transceiver-IC requirements will be considered. Finally, trends and challenges will be discussed in a panel.

S-band Phased Array Radar with 2-D Digital Beamforming

Wim de Heij, *THALES Nederland BV, Hengelo, The Netherlands*

Wim de Heij received his MSc. in Electrical Engineering from Twente University in 1986. From 1986 to 1990 he worked at Twente University as a researcher and achieved his PhD in the field of analog integrated circuit design in 1990. In 1990, he joined Thales Netherlands BV, where he worked in several positions as analog design engineer until 1998 and system test engineer until 2003. In this period he worked on major phased array radar programs. Currently he is a principal system design engineer at Thales Netherlands BV. His activities focus on analog front-end design for phased array radars and advanced technology studies.

SiGe BiCMOS Single Chip Receiver for S-band Phased Array Radars

Frank van Vliet, *TNO, The Hague, The Netherlands*

Frank van Vliet was born in Dubbeldam, The Netherlands, in 1969. He received the M.Sc. degree, with honours, in Electrical Engineering in 1992 from Delft University of Technology, The Netherlands. Subsequently, he received his Ph.D. from the same university on MMIC filters. He joined TNO (Netherlands Organisation for Applied Scientific Research) in 1997, where he is currently working as a senior technology officer. He is responsible for the research on Front-Ends, a group of approximately 30 people, working on MMIC, antenna and transmit/receive module research. In 2007 he was appointed professor in microwave integration in the Integrated Circuit Design group of the University of Twente. His research interests include MMIC development, advanced measurement techniques and phased-array technology. He has authored and co-authored over 50 papers and has been involved in the definition and leading of a good number of national, EC and military programmes. He is a member of ESA's CTB microwave board and of the EDA IAP-01 captech. Frank van Vliet is an IEEE senior member.

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Silicon RF Phased-Arrays at X-, Q-, W-Band and Beyond

Kwang-Jin Koh, *Virginia Tech, Blacksburg, VA.*

Kwang-Jin Koh (M'09) joined the ECE dept. at Virginia Tech as an assistant professor in December 2011. From 2010 to 2011 he worked for Broadcom Corp., Irvine CA, as a senior staff scientist engaged in the development of TV tuner systems on a chip. From 2008 to 2010, he was with Intel Corp., Hillsboro OR, as a senior RF and analog IC design engineer. From 2001 to 2004, he worked for the Electronics and Telecommunications Research Institute (ETRI), Korea, where he was engaged in the research and development of RF CMOS ICs for CDMA, WCDMA and WLAN 802.11 a/b/g systems. He received the Ph.D degree in electrical and computer engineering from the University of California at San Diego, La Jolla in 2008. His doctoral study focused on on-chip CMOS/BiCMOS phased array transmitter and receiver designs at 6-50 GHz. His designs were reported as one of the most significant achievements in 2008 in a special "War Report" to the Pentagon by DARPA. He received the Best Design Team of the Year Award from Teledyne Scientific Corp. (formerly, Rockwell Scientific Corp.) in 2010 in recognition of his phased array design works. Dr. Koh was also the recipient of the 2002 Best Paper Award presented by the IEEE Solid-State Circuits Society and IEEE Electron Devices Society, Seoul Chapter.

Butler Matrix Beamforming Phased Arrays and CMOS Implementation

Heng-Fuh R. Chang, *Chung Cheng University, Chiayi, Taiwan*

Sheng-Fuh R. Chang (S'83-M'92-SM'07) received his B.S. and M.S. degrees in communications engineering from the National Chiao-Tung University, Taiwan and his Ph.D. degree in electrical engineering from The University of Wisconsin at Madison in 1991. He is currently a Professor with the Department of Electrical Engineering, Department of Communications Engineering, National Chung Cheng University, Taiwan. He is also the director of the Center for Telecommunication Research, National Chung Cheng University. In 1991, He worked on high-power microwave and millimeter-wave sources at the Center for Plasma Theory and Computation at The University of Wisconsin. From 1992 to 1994, he was with the Hyton Technology Corporation, where he contributed to C-band and Ku-band Satellite low-noise down-converters and MMDS transceivers. His group has recently developed RF beamforming phased arrays in S-, Ka-, V-, and W-bands for broadband wireless transmissions and wireless indoor positioning applications. His group also developed bio-radars for user-aware vital signal detection. His research interest also includes IPD/CMOS millimeter-wave chip filters and antennas. Prof. Chang is a member of Phi Tau Phi and Sigma Xi

Silicon-based Integrated Beamforming and On-Chip Radiators

Ali Hajimiri, *California Institute of Technology, Pasadena, CA.*

Ali Hajimiri received his Ph.D. degrees in electrical engineering from Stanford University. He has been with Philips Semiconductors, Sun Microsystems, and Lucent Technologies (Bell Labs), before joining the Faculty of the California Institute of Technology, Pasadena, where he is the Thomas G. Myers Professor of Electrical Engineering and the director of the Microelectronics Laboratory. His research interests are high-speed and RF integrated circuits for applications in sensors, biomedical devices, and communication systems. Dr. Hajimiri was selected to the TR35 top innovator's list in 2004. He is a Fellow of IEEE and has served as a Distinguished Lecturer of the IEEE Solid-State and Microwave Societies. He was a co-recipient of the IEEE Journal of Solid-State circuits Best Paper Award, the International Solid-State Circuits Conference (ISSCC) Jack Kilby Outstanding Paper Award, a two-time co-recipient of the CICC best paper award.

Vector Modulation Techniques and Interference Nulling

Jeyanandh Paramesh, *Carnegie Mellon University, Pittsburgh, PA*

Jeyanandh Paramesh received the B.Tech, degree from IIT, Chennai (Madras), the M.S degree from Oregon State University and the Ph.D degrees from the University of Washington, Seattle, all in Electrical Engineering. Between 1998 and 2001, he held product development positions with Analog Devices, where he designed high-performance data converters, and Motorola where he designed analog and RF integrated circuits for cellular transceivers. Between 2002 and 2004, as a doctoral candidate at the University of Washington, he collaborated extensively with the Communications Circuit Lab, Intel where he developed multi-antenna receivers, high-efficiency power amplifiers and high-speed data converters for next-generation wireless transceivers. Since 2007, he has been an Assistant Professor of Electrical and Computer Engineering at Carnegie Mellon University. His research interests include the design of RF and mixed-signal integrated circuits and systems for a wide variety of applications..

RF Beamforming and 60GHz BiCMOS Chipsets

Scott K. Reynolds, *IBM T.J. Watson Research Center, Yorktown Heights, NY*

Scott K. Reynolds received a Ph.D. in electrical engineering from Stanford in 1987. He joined IBM in 1988 and has worked on a wide variety of IBM products, including ICs for disk drive channels, electrical and optical I/O, and RF communication. He has recently been engaged in the development of silicon millimeter-wave ICs and packaging for high-data-rate wireless links and other applications. He has more than 30 U. S. patents issued and was named an IBM Master Inventor in 2008. He also has many technical publications, including two papers on 60-GHz wireless transceiver circuits which won the best paper awards at the International Solid State Circuits Conference in 2004 and 2006. He is currently a Research Staff Member and manages the RF Circuits & Systems group at the IBM T. J. Watson Research Center.