WSA 08:00-12:00

Millimeter-Wave R&D for 5G: Systems, Phased Arrays, and Handset Transceivers
Sponsor: IMS; RFIC

Organizer: Alberto Valdes Garcia, *IBM Research*, Didier Belot, *CEA-LETI*, Huei Wang, *National Taiwan University*, Kamran Entesari, *Texas A&M University*, PierreBusson, *STMicroelectronics*, Telesphor Kamgaing, *Intel Corporation*

Abstract: Rapidly growing demand for broadband cellular data traffic is driving fifth generation (5G) standardization towards deployment by 2020. The anticipated key to enabling gigabit-per-second 5G speeds is mm-wave operation. Millimeter-wave bands offer 50 times the bandwidth available in existing RF bands but pose numerous technical challenges to the low-cost deployment of millimeter-wave solutions. U.S. regulators recently issued a notice of inquiry for provision of mobile services above 24 GHz. Additionally, reliable coverage over the typical 200 meter cell radius in non-line-of-sight dense urban conditions, and practical antenna array solutions for user equipment (UE) were both demonstrated at 28 GHz. High-volume implementation of the UE radio is also envisioned as multiple-element phased-array transceiver in silicon technologies. However, a great deal of discussion still surrounds how 5G standards and as a result their corresponding wireless accessories will evolve. This workshop is focused on gathering a combination of academic and industry experts in mm-wave circuits and systems and antennas to discuss integrated circuit, system and antenna solutions to potential mm-wave front-ends for 5G standards. This workshop will present state-of-the-art research results in this area and ultimately help participants identify the enabling radio technologies for 5G cellular communications.

1. 5G - Towards 10s of Radios and 10s of Gb/s
   Aleksandar Tasic; *Qualcomm, Inc.*
2. Efficient and Scalable Millimeter-Wave Beamforming Architecture Using 0.13 µm SiGe BiCMOS ICs
   Cagri Ulusoy; *IHP Microelectronics*
3. Millimeter wave access points and backhauling for 5G heterogeneous networks
   Cedric Dehos; *CEA-LETI*
4. Large-Scale Silicon Phased Arrays for 5G Communication Systems
   Gabriel Rebeiz; *University of California at San Diego*
5. Novel mmWave Communication Systems: From Highly-Digital Arrays to MIMO and Full-Duplex
   Harish Krishnaswamy; *Columbia University*
6. Introduction and Usage of 5G Wireless Systems
   Jan-Erik Thillberg; *Ericsson*
7. CMOS MM-wave Transceivers Towards 5G Cellular
   Kenichi Okada; *Tokyo Institute of Technology*
8. Research Advances in Millimeter Wave Integrated Circuits for 5G Applications
   Wei Hong; *Southeast University*

WSB 13:00-17:00

Highly Efficient 5G PA Design
Sponsor: RFIC

Organizer: Donald Lie, *Texas Tech University*, Nick Cheng, *Skyworks Solutions, Inc.*

Abstract: 5G cellular systems are expected to see significant deployment in 2020, promising up to 10 Gbps data rate for stationary users and enabling internet connection capacity for billons of devices for IoT applications (e.g., "connected city"). It is very challenging to meet the targeted 5G system specs such as less than 1 msec latency and greater than x1000 bandwidth per unit area, while still achieving the coveted big reduction in energy. Therefore, 5G wireless communication systems are likely to present a paradigm shift that includes very high carrier frequencies with 10+ Gbps bandwidths, extensive MIMO antennas usage, and very dense base station deployment and high device densities for IoT applications. 5G also needs to provide seamless transition and backward compatibility with LTE and WiFi to render universal high-rate coverage. To support all these unprecedented 5G device/system performance metrics, the power and cost efficiencies for the wireless device design will become even more critical. Therefore, high-efficiency and linear broadband RF power amplifier (PA) design for the microwave and millimeter wave frequencies is obviously becoming more challenging as they evolve from 4G to 5G handset and IoT applications. In this workshop, industry and academic experts will examine various perspectives, such as system, circuits and transistor-level design techniques and considerations in regards to the development of microwave/mmWave, highly-efficient linear PA suitable for massive MIMO, small cells, predistortion, new modulation schemes, etc., to meet the challenges and address the issues related to 5G cellular communication and IoT systems.

1. 5G What will it be?
   Peter Gammel; *Skyworks Solutions, Inc.*
2. CMOS Power Amplifiers for 5G
   Peter Asbeck; *University of California at San Diego*
3. RFFE and PA challenges with emerging 5G radios
   Paul Draxler; *Qualcomm, Inc.*
4. Design of Highly Efficient MMIC Power Amplifiers for 5G Communication
   Kris Kong; *QORVO, Inc.*
5. Linear CMOS PA at mm-Wave Band for 5G Application
   Bumman Kim; *Pohang University of Science and Technology*

WSC 08:00-17:00

How mm-Wave Systems Reshape the Future of Telecom and Sensing Applications
Sponsor: IMS; RFIC

Organizer: Harish Krishnaswamy, *Columbia University*, Vito Giannini, *Texas Instruments, Inc.*

Abstract: Due to high technology costs and limited integration capabilities, mm-wave systems have been mostly restricted to high-end markets. Today, however, we are witnessing a tipping point where both power consumption and cost can be lowered sufficiently to deploy economically viable solutions on a far larger scale. This workshop aims at showing the latest breakthroughs in millimeter-wave systems for mass-market applications. Thanks to these developments, the full potential of such mm-wave systems will become ever more apparent. The telecom industry will rely on mm-wave backhaul for transitioning to the so called 5G. The automotive industry is developing 77/79 GHz radar systems to boost road safety for all users. But millimeter-wave sensors are also applied in industrial, medical and home automation applications. Even consumer electronics will benefit from millimeter-wave technology to enable high-accuracy motion sensing.

1. Ubiquitous sensing with mm-Wave CMOS radars
   Davide Guermandi; *IMEC*
2. Highly Integrated mm-Wave Radar Transceiver Arrays
   Brian Ginsburg; *Texas Instruments, Inc.*
3. Project Soli: mmWave radar for ubiquitous gesture sensing
   Jaime Lien; *Google, Inc.*
4. Towards autonomic mmWave systems
   Alberto Valdes-Garcia; *IBM T.J. Watson Research Center*
5. Cost effective mmW system development leveraging silicon and digital manufacturing technologies
   Frederic Gianesello; *STMicroelectronics*
6. Material and Channel Measurements at mmWave Frequencies
   Andrzej Partyka; *Qualcomm, Inc.*
7. Large Phased Arrays for 5G Communication Systems
   Gabriel Rebeiz; *University of California at San Diego*
8. Reconfigurable millimeter-wave transmit-array antennas for backhaul/fronthaul applications in 5G mobile networks
   Laurent Dussopt; *CEA-LETI*

WSD 13:00-17:00

Circuit Techniques and System Architectures for Carrier Aggregation and Multi-Band Radios
Sponsor: RFIC

Organizer: Eric Klumperink, *University of Twente*, Osama Shana'a, *MediaTek, Inc.*

Abstract: During the last decades there have been several spectrum auctions of different parts of the mobile communication spectrum, and as a result mobile network operators now own non-contiguous parts of the spectrum. This non-contiguous spectrum allocation coupled with the increasing need for higher data-rate per user has led to the need for concurrent multi-channel operation, also known as carrier aggregation. Technically, this is extremely challenging, for instance because there may be strong unwanted signals between the carrier aggregation spectrum segments. This leads to new requirements and causes problems, for instance with respect to nonlinearity, crosstalk and LO pulling. This workshop will discuss these requirements and will primarily focus on advancements in RFIC transceiver architectures and circuits that enable carrier aggregation. It will also address some related aspects like broadband front ends, blocker detection, linearization, interference cancellation, etc.

1. Systems Overview of Multi-Mode Multi-band Radios supporting Carrier Aggregation for LTE and LTE-A Standards
   Walid Ali-Ahmad; *Qualcomm, Inc.*
2. Design Challenges of Carrier Aggregation RF Receivers for LTE-Advanced
   Abdelatif Bellaouar; *GLOBALFOUNDRIES*
3. LO Generation and Reception Circuits for Carrier Aggregation
   Christopher Hull; *Intel Labs*
4. Design Challenges of Carrier Aggregation Transceivers
   Shahrzad Tadjpour; *Marvell Semiconductor, Inc.*
5. Design and Compensation of Concurrent, MIMO and Carrier-Aggregated Transmitters for Next-Generation Systems
   Fadhel M. Ghannouchi; *University of Calgary;* Abubaker Abdelhafiz; *University of Calgary*
6. Frequency-Agile, Scalable Carrier Aggregation using Frequency-Translating Quadrature-Hybrid Receivers
   Peter Kinget; *Columbia University*; Jianxun Zhu; *Columbia University*

WSE 08:00-12:00

Calibration and Correction Techniques for CMOS Radios
Sponsor: RFIC

Organizer: Danielle Griffith, *Texas Instruments, Inc.*, Mohyee Mikhemar, *Broadcom Corporation*

Abstract: The state of the art CMOS radios make use of wide range of calibrations and correction techniques to meet their stringent performance and cost requirements. It is therefore critical for the RF CMOS designer to understand the potential and the limitations of the most common calibration and correction techniques. In most cases, these techniques can be used to compensate for device imperfections and random mismatches, which otherwise would require an over design in the Analog/RF domain. For example, the standard digital I/Q correction in receivers frees the designer from the burden of oversizing the analog/RF devices to reduce the effect of random mismatch. In the workshop, the most-common calibration and correction techniques for receivers, transmitters, PLLs, and Power amplifier will be presented.

1. Calibration Techniques for Reference Oscillators used in IoT
   Danielle Griffith; *Texas Instruments, Inc.*
2. Practical correction and cancellation techniques in CMOS receivers and transmitters
   Masoud Kahrizi; *Broadcom Corporation*
3. Calibration of CMOS mm-Wave Circuits using Self-Healing
   Steven Bowers; *University of Virginia*
4. Digitally Assisted Calibration and Correction of CMOS RF PLLs
   Thomas Mayer; *Intel Corporation*

WSF 08:00-17:00

Advanced ICs and Systems for Wireless Charging and Energy Harvesting
Sponsor: IMS; RFIC

Organizer: David Wentzloff, *University of Michigan*, Jenshan Lin, *University of Florida*, Kenjiro Nishikawa, *Kagoshima University*, Patrick Riehl, *MediaTek, Inc.*

Abstract: Research into wireless power transfer has intensified in the past decade, with a wide spectrum of applications being addressed. Wireless power research spans many orders of magnitude of power (uW to kW), range (mm to km) and frequency (kHz to GHz). Although the basic principles of amplification, impedance matching and rectification have been well understood since Tesla’s time, a variety of new techniques are presently being developed to enhance the performance of wireless power transfer systems. In this interactive workshop, some of the leading researchers in the field will discuss the latest advancements in the campaign to free us from power cords, focusing on practical IC implementations. For consumers, the most exciting everyday application of wireless power today is mobile phone charging. A wide range of consumer devices such as tablets, laptops and wearables are expected to follow the same trend. We will hear from industry researchers pushing the boundaries of performance in mobile device charging using the Qi, PMA and A4WP specifications. Other speakers will focus in on challenging problems in the area of mobile device charging such as adaptive impedance tuning and EMI suppression. A related line of research deals with the problem of transmitting relatively low levels of power over large distance, or to inaccessible locations such as implantable devices. Energy harvesting circuits capture low levels of RF radiation to power the remote sensor nodes that will make up the Internet of Things. Expert presenters will cover the latest advancements towards efficiently extracting power from RF signals, including innovative rectifier designs and wave-shaping techniques.

1. Integrated Circuit Design for Wireless Power Transmitters
   Patrick Riehl; *MediaTek, Inc.*
2. Considerations in the design of a Multi-Protocol Wireless Charging Receiver
   Glenn Crosby; *NXP Semiconductors*
3. Efficient and Adaptive Inductive Power Transmission and Management
   Mehdi Kiani; *Pennsylvania State University*
4. A Smart Wirelessly Powered HomeCage for Long-Term High Throughput Behavioral Experiments
   Maysam Ghovanloo; Georgia Institute of Technology
5. Electromagnetic Compatibility Issues on Wireless Charging
   Seungyoung Ahn; *KAIST*
6. High Efficient rectennas with high impedance antennas
   Kenji Itoh; *Kanazawa Institute of Technology*
7. Adaptive Threshold-Voltage Compensated RF Energy Harvester
   Kambiz Moez; *University of Alberta*; Zohaib Hameed; *3M*
8. Theoretical Energy-Conversion Efficiency for Energy- Harvesting Circuits Under Power-Optimized Waveform Excitation
   Christopher Valenta; *Georgia Institute of Technology*
9. Millimeter-wave Power Harvesting: From CMOS Circuits to Diode Platforms
   Ke Wu; *École Polytechnique de Montréal*; Simon Hemour; *École Polytechnique de Montréal*; Pascal Burasa;*É cole Polytechnique de Montréal*
10. Microwave and mm-Wave Near-Field and Far-Field Wireless Power Transfer
    Ali Niknejad; *University of California, Berkeley*

WSG 08:00-17:00

Frequency Synthesizers of Multi-Band, Multi-Standard Radios and Internet of Things (IoT)
Sponsor: IMS; RFIC

Organizer: Danielle Griffith, *Texas Instruments, Inc.,* Jaber Khoja, *Consultant,* Stefano Pellerano, *Intel Corporation*

Abstract: A frequency synthesizer capable of generating LO with a wide frequency range is essential for multi-band, multi-standard radios. For simultaneously working radios in multi-bands and carrier aggregations radios, multiple LOs and synthesizers are needed for them to co-exist in a single radio. This workshop will discuss topics like wide range VCO design, frequency planning for multiple LO supports, along with wide range and power efficient LO distribution. The workshop will continue by introducing the fundamental concepts of oscillator synchronization, the theoretical models which allow us to predict phase noise and lock range of such circuits, and the applications of these concepts to multi-band and multi-standard SOC radios. The workshop will then move onto the practical issues arising from unwanted coupling between oscillators and, in general, among multiple on-chip frequency synthesizers. It would include discussion on the effect of strong coupling from power amplifiers on frequency pulling and frequency locking of frequency synthesizers in multi-bands and carrier aggregations radios. The most recent methods to counteract the negative effects of coupling will be reviewed. The emerging Internet of Things (IoT) market requires radios that operate with very low average power consumption to enable battery life measured in years, or even battery-free operation. This workshop will introduce seven types of oscillators used in these IoT radios, explaining how the low power requirements influence the oscillator architecture, design, and performance targets. This would include an explanation of concepts such as duty-cycling to reduce power consumption, benefits of efficient sleep timers, and standard IoT applications.

1. Frequency Synthesizers Based on Realigned Oscillators
   Salvatore Levantino; *Politecnico di Milano*
2. Integrated Harmonic Oscillators
   Pietro Andreani; *Lund University*
3. A Low-Power Low-Complexity Multi-Standard Digital Receiver for Joint Clock Recovery and Carrier Frequency Offset Calibration
   Stefan Heinen; *RWTH Aachen University*
4. Designing RF Frequency Synthesizers Robust to Interference
   Robert Bogdan Staszewski; *University College Dublin*
5. Understanding VCO pulling and its mitigation in wireless transceivers
   Ahmad Mirzaei; *Broadcom Corporation*
6. Pulling Effect and Operating Range Improvement Techniques for Frequency Synthesizers
   Kang-Chun Peng; *National Kaohsiung First University of Science and Technology;* Tzyy-Sheng Horng; *National Sun Yat-sen University*
7. Oscillator design for IoT applications
   Danielle Griffith; *Texas Instruments, Inc.*
8. Fast-locking Techniques for Phase-locked Loops
   Tsung-Hsien Lin; *National Taiwan University*

WSH 13:00-17:00

RF/Analog IC Design Challenges in Advanced CMOS Technology
Sponsor: RFIC

Organizer: Madhukar Reddy, *MaxLinear, Inc.,* Eric Fogleman, MaxLinear, Inc.

Abstract: Huge demand for lowering power, area and cost of digital circuits in highly integrated SOCs has led to fast development of deep submicron technologies to 28nm and beyond. With these advances and high levels of integration, several new challenges have emerged for RF, Analog and Mixed circuit designers who now have to design circuits in the same technology node as determined by the digital circuit designers. This workshop is aimed at covering the areas related to process technology, device modeling, RF/Analog/Mixed signal circuit design challenges and CAD tools and methodologies in these new advanced nodes. This first talk in this workshop will go through the details of the new process technology development for achieving high volume, production quality deep submicron processes and also explain the various new challenges introduced in these technology nodes. The second talk will explain the various physical effects of both the active and passive devices in these nodes and describe how the device models are being advanced to capture these effects to help the circuit designers predict the performance in simulations. The third and fourth talks will describe the challenges as seen from circuit designers point of view and how they are being tackled. Despite the numerous challenges, these advanced nodes also offer some advantages which bring benefits to RF, Analog and Mixed signal circuits and new circuit topologies are being innovated to take advantage of these benefits. The final talk in this workshop will focus on CAD tools and methodologies being developed to ensure first silicon success in these nodes where mask and fabrication costs are prohibitively expensive. The workshop is aimed to provide a comprehensive view of technology to help both new and experienced circuit designers to adapt to the challenges in these advanced CMOS nodes.

1. Advances in Process Technology Performance in Nanoscale CMOS
   Juan Cordovez; *Global Foundries*
2. Device Modeling for RF/Analog Design in Advanced CMOS Technology
   Kimihiko Imura; *MaxLinear, Inc.*
3. Challenges for RF/Analog Circuits in 28nm and beyond
   Uli Klepser; *Intel Corporation*
4. Challenges in Mixed Signal Circuit Design in 28nm and beyond
   Yun-Shiang Shu; *MediaTek, Inc.*
5. Advances in CAD Tools & Methodologies for First-Silicon Success in Advanced CMOS Nodes
   Ravi Subramanian; *Mentor Graphics Corporation*

WSJ 13:00-17:00

Millimeter-Wave Electronics: From Applications to Manufacturing
Sponsor: IMS; RFIC

Organizer: Didier Belot, *CEA-LETI,* Marco Pirola, *Politecnico di Torino,* Pierre Busson, *STMicroelectronics*, Vittorio Camarchia, *Politecnico di Torino*

Abstract: This workshop is dedicated to mmw applications in communications, both for end-user and infrastucture equipment. New products are emerging to answer the increasing market demand, or are in the last development phase. the workshop introduces these applications and products. The final cost of such products, together with the public acceptance of this growing technology, are key factors for the success of the mmw industry. The workshops also addresses these aspects, in particular regarding the efficient test of products and the health related issues of mmw.

1. Introduction: opportunities for the millimiter-wave industry
   Roberto Quaglia; *Cardiff University*
2. Capacity Increase: Millimeter-wave Systems for Backhauling
   Matteo Oldoni; *SIAE Microelettronica*
3. Monolithic Solutions for Digital Radio Link Transceivers
   Maurizio Pagani; *Huawei Technologies Co., Ltd.*
4. Mm-wave MMIC power amplifier with integrated linearizer.
   Marcus Gavell; *Gotmic AB*
5. Antenna-Module with Integrated Shaped Lens for WiGig Applications in Eyewear Devices
   Cyril Luxey; *Université de Nice Sophia Antipolis*
6. Low cost industrial mmW test, a wish or a reality
   Cedric Mayor; *Presto*
7. The Human Body and Millimeter Wave Wireless Communication Systems: Interactions and Implications
   Philippe Leveque; *University of Limoges*

WSK 08:00-17:00

E-Health: Implantable Systems and Communications in the Human Body
Sponsor: IMS; RFIC

Organizer: Amin Arbabian, *Stanford University*, Francois Rivet, *University of Bordeaux*

Abstract: This workshop aims to provide an overview of various in-body electronic systems, from applications to devices, with an emphasis on new technologies and emerging applications. Experts will discuss topics related to medical applications of implantable systems, device technologies to enable safe and long-term use of these technologies, in-body communication schemes and related tradeoffs, energy harvesting in the body, sensing and stimulation mechanisms for closed-loop operation, and future directions in the field. Various technological and legal questions are raised and the role of electronics and communication capabilities are assessed.

1. Advanced Implantable Neuromodulation Systems
   Kevin Kilgore; *Case Western Reserve University*
2. Capsule Endoscope Ultrasound Imaging
   Pierre Khuri-Yakub; *Stanford University*
3. Photovoltaic Restoration of Sight in Animals with Retinal Degeneration
   Daniel Palanker; *Stanford University*
4. Brain Stethoscope: A tool for listening to the tone of the human brain
   Josef Parvizi; *Stanford University*
5. Optimizing devices and processing at the bio-electronic interface
   Sylvie Renaud; *Bordeaux Institute of Technology*
6. Ultrasonically Powered mm-Sized Implantable Devices With Applications in Closed-Loop Neuromodulation
   Amin Arbabian; *Stanford University*
7. Intra-Body Communications - Radio-Frequency versus Ultrasonic
   Yann Deval; *University of Bordeaux*
8. Applications of Signal Propagation Through the Human Body
   Daniel Lai; *Victoria University*
9. Soft Bio-integrated Sensors
   Roozbeh Ghaffari; *MC10 Inc.*

SSA 08:00-17:00

Technologies for 5G
Sponsor: IMS

Organizer: Vinod Kumar, *Alcatel Lucent Bell Labs,* Sudhir Dixit, *Skydoot, Inc.*

Abstract: The 5G wireless and mobile communication networks will deploy Radio Access Network and Core Network technologies for providing 1000x network capacity, 0.1 to 1Gb/sec transmission rates thus enabling the ultimate experience in web browsing and in audio and video streaming. Technologies like enhanced MIMO, massive MIMO and hot spots of micro/pico/femto cells using mm-Wave ultra broadband transmission will enable coverage enhancement and multi-fold capacity increase respectively. Other widely deployed technologies in 5G will include energy efficient air interfaces optimized for massively parallel transmissions from IoT devices, Cloud RAN, Software Defined Networking and Network Function Virtualization. Features like traffic offloading in inter-technology HetNets (LTE-Adv overlay cells and mmWave and/or IEEE 802.11x underlay hotspots); decoupling of user data/control planes in SDN/NFV and software implementations on general purpose hardware will bring dimensioning flexibility and enhanced QoE for 5G users. The proposed full day course will cover the aforementioned technologies and accompanying market directions.

SSB 08:00-17:00

Introduction to RF Power Amplifier Design
Sponsor: MTT TC 5

Organizer: John Wood, *Obsidian Microwave,* Gayle Collins, *IEEE*

Abstract: This is an introductory course on RF/microwave power amplifier (PA) design. It will cover the fundamentals of PA design, using simple models and load-pull methods to derive the basic PA. The amplifier classes A, AB, B, C, D, E, F, J, and S will be presented and compared, illustrating the use of harmonic loading to improve efficiency. Modern digital communications signals, such as those used in cellular wireless, are characterized by high peak-to-average-power ratios (PAPR), and there are several PA architectures that have been developed to accommodate such signals while still providing high efficiency: Doherty, Polar modulation/envelope tracking (ET), and Outphasing systems will be described, and design procedures for these PAs will be presented. Some approaches to PA linearization will also be outlined.