IMC-5G

Atlanta, 2019

August 15th-16th 2019, Atlanta, GA, USA

IEEE MTT-S Georgia Tech

Atlanta, USA imc-5g.mtt.org

Sponsors

Gold Level Sponsors

Silver Level Sponsors and Exhibitors

On behalf of the Organizing Committee, I would like to warmly welcome you to Atlanta GA, USA, to attend the 2019 IEEE MTT-S International Microwave Conference on 5G Hardware and Systems (IMC-5G). The current and future generations of wireless networks, 5G and beyond, will have profound technological and economic impacts on our society. These wireless technologies are expected to radically reshape many existing applications and create numerous new opportunities. There are yet countless challenges lying ahead, many of which are happening at the "Physical Layer", due to several fundamental limitations imposed by the nature of electromagnetics or device physics and practical constraints from economics, engineering, technologies, and application considerations. Consequently, significant research is required to bring 5G communications to reality. The IEEE IMC-5G 2019 conference provides a focused forum to bring together researchers and practitioners from different backgrounds to share the most recent advances in hardware and system technologies for 5G and beyond.

IMC-5G is co-sponsored by the IEEE Microwave Theory and Techniques Society (MTT-S) and Georgia Institute of Technology (Georgia Tech). It is also technically sponsored by IEEE Future Networks. It received financial support from multiple local and international companies and organizations such as Mitsubishi Electric Corporation, Rohde & Schwarz, Keysight Technologies, MPI Corporation, Maury Microwave Corporation, and Georgia Tech 3D Systems Packaging Research Center.

IMC-5G 2019 will feature a two-day series of oral and poster presentations. There are three keynote talks and 10 invited talks given by world-leading distinguished speakers, together with 25 regular papers plus six poster presentations. The technical contents cover a wide range of areas, including advanced systems and networking technologies, mm-wave to THz circuits and technologies, beamforming, antennas, packaging technologies, system architectures and algorithms for 5G applications, and circuits techniques for high efficiency RF/mm-wave power amplifiers and high-performance front-ends. An industrial exhibition featuring a selection of state-of-the-art microwave products, measurement instruments and CAD software will also be held.

Atlanta is the capital and the largest city in the U.S. state of Georgia. The city serves as the cultural and economic center of the Atlanta metropolitan area, home to 5.8 million people and the ninth-largest metropolitan area in the nation. Atlanta has unique topographic features that include rolling hills and dense tree coverage, earning it the nickname of "the city in a forest."

In 2018, Atlanta was among the one of the first dozen US cities that were connected with AT&T 5G networks. Sprint's "bridge to 5G", Massive MIMO based technology, was deployed in Atlanta during the Super Bowl in February 2019.

I hope you enjoy the conference and have a wonderful time in Atlanta!

Hua Wang, Ph.D.

2019 IEEE IMC-5G Conference General Chair

IEEE IMC-5G 2019 Conference Steering Committee

Hua Wang
General Chair
Georgia Institute of Technology, USA

Anding Zhu
General Co-Chair
University College Dublin, Ireland

Timothy Lee
General Co-Chair
Boeing, USA

Harish Krishnaswamy
General Co-Chair
Columbia University, USA

Shahriar Shahramian
TPC Chair
Nokia, USA

Gee-Kung Chang
TPC Co-Chair
Georgia Institute of Technology, USA

Vadim Issakov
TPC Co-Chair
Infineon, Germany

Debabani Choudhury
TPC Co-Chair
Intel, USA

James S. Kenney
Local Chair
Georgia Institute of Technology, USA

Conference Organizing Committee

General Chair:	Hua Wang, Georgia Institute of Technology, USA
General Co-Chairs:	Anding Zhu, University College Dublin, Ireland
	Timothy Lee, Boeing, USA
	Harish Krishnaswamy, Columbia University, USA
Local Chair:	James S Kenney, Georgia Institute of Technology, USA

Technical Program Committee

TPC Chair: Shahriar Shahramian, Nokia, USA
TPC Co-Chair: Gee-Kung Chang, Georgia Institute of Technology, USA
TPC Co-Chair: Vadim Issakov, Infineon, Germany
TPC Co-Chair: Debabani Choudhury, Intel, USA
Nuno Borges Carvalho, University of Aveiro, Portugal
Anding Zhu, University College Dublin, Ireland
Maurizio Bozzi, University of Pavia, Italy
Paolo Colantonio, University Roma Tor Vergata, Italy
Christian Fager, Chalmers University of Technology, Sweden
Lei Guan, Nokia Bell Labs, Ireland
Harish Krishnaswamy, Columbia University, USA
Tim Lee, Boeing, USA
Rui Ma, Mitsubishi Electric Research Laboratories, USA
Arnaldo Oliveira, University of Aveiro, Portugal
Abbas Omar, University of Magdeburg, Germany
José Carlos Pedro, University of Aveiro, Portugal
Roberto Gómez-García, University of Alcala, Spain
Dominique Schreurs, KU Leuven, Belgium
Mohammad Sharawi, Polytechnique Montréal, Canada
Mikko Valkama, Tampere University of Technology, Finland
Hua Wang, Georgia Institute of Technology, USA
Jahnavi Sharma, Intel labs, USA
Taiyun Chi, Rice University, USA
Kirti Dhwaj, UCLA, USA
Trang Thai, Intel, USA
Kaushik Sengupta, Princeton University, USA
Chaojiang Li, Global Foundries, USA
Michael Schroeter, TU Dresden, Germany
Arun Natarajan, Oregon State University, USA
Jim Buckwalter, UCSB, USA
Steven Michael Bowers, University of Virginia, USA
Azadeh Ansari, Georgia Institute of Technology, USA

Program Timeline

<table>
<tr><th colspan="3">Thursday, 15th August 2019</th></tr>
<tr><td>08:00-08:45</td><td colspan="2">Registration and Coffee</td></tr>
<tr><td>08:45-09:35</td><td colspan="2">Opening Remarks, Hua Wang, Georgia Institute of Technology, USA
Keynote Talk 1, Christopher Hull, Intel Corporation, USA</td></tr>
<tr><td>09:35-09:50</td><td colspan="2">Coffee Break</td></tr>
<tr><td>09:50-11:20</td><td>Session 1: Advanced Systems and Networking Technologies</td><td rowspan="3">10:00-11:30 Exhibition
13:15-17:00 Poster
13:15-17:00 Exhibition</td></tr>
<tr><td>11:30-13:00</td><td>Luncheon Keynote Talk, Professor Gabriel Rebeiz, UCSD, USA</td></tr>
<tr><td>13:15-14:45</td><td>Session 2: Mm-Wave to THz Circuits and Technologies</td></tr>
<tr><td>14:45-15:00</td><td colspan="2">Coffee Break</td></tr>
<tr><td>15:00-16:00</td><td colspan="2">Session 3: Advanced RF PAs with Back-Off Enhancement Techniques</td></tr>
<tr><td>16:00-16:15</td><td colspan="2">Coffee Break</td></tr>
<tr><td>16:15-17:25</td><td colspan="2">Session 4: Beamforming, Antennas, and Packaging Technologies</td></tr>
<tr><td>19:00-21:30</td><td colspan="2">Conference Dinner / Social Event</td></tr>
<tr><th colspan="3">Friday, 16th August 2019</th></tr>
<tr><td>08:30-09:00</td><td colspan="2">Registration and Coffee</td></tr>
<tr><td>09:00-10:15</td><td colspan="2">Keynote Talk 2, Anirban Bandyopadhyay, Globalfoundries, USA
Keynote Talk 3, Professor Ali M. Niknejad, UC Berkeley, CA, USA</td></tr>
<tr><td>10:15-10:30</td><td colspan="2">Coffee Break</td></tr>
<tr><td>10:30-12:15</td><td>Session 5: System Architectures and Algorithms for 5G Applications</td><td rowspan="4">10:00 -12:00 Exhibition
13:00 -16:00 Exhibition</td></tr>
<tr><td>12:15-13:15</td><td>Lunch</td></tr>
<tr><td>13:15-14:40</td><td>Session 6: Circuits Techniques for High-Performance Front-ends</td></tr>
<tr><td>14:40-14:50</td><td>Coffee Break</td></tr>
<tr><td>14:50-16:15</td><td colspan="2">Session 7: Mm-Wave Power Amplifiers</td></tr>
<tr><td>16:15-16:30</td><td colspan="2">Closing Session</td></tr>
</table>

Keynote Talks

5G Evolution and Beyond

Christopher Hull, Intel Corporation, Hillsboro, OR, USA

Advent of the Internet of Things (IoT) where things and devices are becoming more intelligent and connected requires networks to become faster, smarter, and more agile to handle the unprecedented increase in volume and complexity of data traffic. The 5G era is upon us, ushering in new opportunities for technology innovation across the computing and connectivity landscape. It is transformative and presents an inflection point not only due to major improvements required over 4G/LTE data rates, throughput, and capacity, but also is the first wireless protocol to address the inclusion of a massive number of the machines/things in the network some of which require lower latencies and higher reliability. This talk will highlight the technology innovations required to make 5G and beyond a reality.

Christopher Hull received his PhD from the University of California, Berkeley, in 1992. He joined Rockwell Semiconductor Systems in Newport Beach, CA in 1992. In 1998 Chris joined Silicon Wave in San Diego, California. In 2001, Chris joined Innocomm Wireless, which was subsequently acquired by National Semiconductor. In May 2003, Chris joined the Wireless Networking Group of Intel, in San Diego, California, and in June 2005, Chris moved to Hillsboro Oregon. In 2013, Chris spent one year on international assignment in Munich, Germany to work closely with his colleges from Intel Mobile Communications on 4G cellular transceivers. Since May 2015, Chris has been working as a Director and Senior Principal Engineer for Intel Labs.

5G Radio: A perspective on Silicon Technologies and Solutions

Anirban Bandyopadhyay, Globalfoundries, CA, USA

5G, the next generation cellular standard will cover different usage scenarios like enhanced mobile broadband (eMBB), ultra-reliable, low latency communication (uRLLC) and low power massive machine-to-machine communication (mMTC). The radio access technologies for these usage scenarios have different requirements and pose different challenges in terms of hardware implementation. The talk will focus on some of the hardware implementation challenges for enhanced mobile broadband (eMBB) radio highlighting different architecture options, key figures of merits and how different silicon technologies can address those challenges to make an efficient 5G user equipment and base station radio a reality at both sub 6GHz and mmWave.

Dr. Anirban Bandyopadhyay is the Director of RF Strategic Applications & Business Development within GLOBALFOUNDRIES, USA. Anirban's current activity is focused on hardware architecture & technology evaluations and business development for different RF and mmWave applications. Prior to joining GLOBALFOUNDRIES, he was with IBM Microelectronics, New York and with Intel, California where he led teams in different areas like RF Design Enablement, Silicon Photonics, signal integrity in RF & Mixed-Signal SoC's. Dr. Bandyopadhyay earned his PhD in Electrical Engineering from Tata Institute of Fundamental Research, India and his Post-Doctoral research at Nortel, Canada and at Oregon State University, USA. He represents Globalfoundries in different industry consortia on RF/mmWave applications and is a Distinguished Lecturer in the IEEE Electron Devices Society.

ComSenTer: Pushing Frequency, Bandwidth, and Spectral Efficiency by 10X Cubed for mm-Wave and Terahertz Arrays for Communication and Imaging Applications

Ali M. Niknejad, UC Berkeley, CA, USA

The ultimate goal of the ComSenTer is to demonstrate record wireless transfer speeds, record high resolution mm-wave/THz imaging, and record distance and energy efficient mm-wave and THz links. These core technologies will enable a new breed of ubiquitous devices (both mobile and fixed) that will autonomously discover each other to form a hierarchical mesh network and support end-to-end connectivity without the need to tap into a physical fiber optic infrastructure. Moving to higher carrier frequencies allows arrays with thousands of elements to fit into relatively compact form factors. We envision a system that can simultaneously handle thousands of wireless beams using spatial multiplexing and interference cancellation with peak data rates up to 100 Gb/s per stream. Such a platform would be handling an aggregate data rate as high as > 10 Tb/s and lead to profound impacts in the capability of wireless networks for communication, imaging, and sensing. In comparison with projected 5G systems, our research aims to push the theoretical limits in terms of not only the bandwidth, but critically, the number of simultaneous beams. Dramatically expanding the number of beams is crucial to enabling the future vision of ubiquitously deployed devices that are able to seamlessly connect and communicate with each other (without being limited by interference), and represents a unique future direction for this center as compared to other on-going industrial as well as academic research. Two key testbeds will be highlighted that will be used to demonstrate the core technology.

Ali M. Niknejad received his Master's and Ph.D. degrees in electrical engineering from the University of California, Berkeley, in 1997 and 2000, where he is currently a professor in the EECS department at UC Berkeley, a faculty director of the Berkeley Wireless Research Center (BWRC), and the associate director of the ComSenTer, a multi-university center for converged terahertz communications and sensing. Prof. Niknejad and his co-authors received the 2017 IEEE Transactions on Circuits and Systems Darlington Best Paper Award, the 2017 Most Frequently Cited Paper Award (2010-2016) at the Symposium on VLSI Circuits, and the CICC 2015 Best Invited Paper Award. Prof. Niknejad is the recipient of the 2012 ASEE Frederick Emmons Terman Award, the co-recipient of the 2013 Jack Kilby Award for Outstanding Student Paper, the 2010 Jack Kilby Award for Outstanding Student Paper, and the co-recipient of the Outstanding Technology Directions Paper at ISSCC 2004. He is a co-founder of LifeSignals and inventor of the REACH(™)technology, which has the potential to deliver robust wireless solutions to the healthcare industry, and co-founder of RF Pixels, a 5G technology startup.

5G and the Rise of Directive Communications: THE END OF THE MARCONI ERA IS NEAR

Gabriel M. Rebeiz, UC San Diego, CA, USA

During the past 50 years, phased-arrays have being largely developed for the defense sector. Today, due to the increased demand for data, there is a need for base-station and mobile-user phased-arrays which can provide high-capacity data services through directional links. Both digital-beamforming at the element level (sub-6 GHz) and hybrid (i.e. analog/digital) beamforming for the mm-waves bands are being developed for 5G systems. These commercial investments are leading to dramatic changes in phased-arrays: High-EIRP high-performance systems at 12, 14 GHz and 28 GHz (SATCOM), X/Ku-band (Radars), 24-30 GHz, 37-42 GHz and even 60 GHz (all for 5G), and with multiple beams, are now available at low cost. The single most important aspect of these arrays is their use of advanced silicon technologies and planar antennas for dramatically lowering the development and unit cost. Also, new ways of doing complete BIST (built-in-self-test) are lowering the cost of phased-array test. The talk will summarize the work in this area, and present a roadmap for the future to further lowering the cost of phased-arrays.

Prof. Gabriel M. Rebeiz is a Member of the National Academy, Distinguished Professor and the Wireless Communications Industry Endowed Chair at the University of California, San Diego. He is an IEEE Fellow, and is the recipient of the IEEE Daniel E. Nobel Medal, the IEEE MTT Microwave Prize (2000 and 2014), the IEEE MTT 2010 Distinguished Educator Award, and the IEEE Antennas and Propagation 2011 John D. Kraus Antenna Award. His group has led the development of complex RFICs for phased array applications from X-band to W-band, culminating recently in wafer-scale integration with high-efficiency on-chip antennas. His phased array work is now used by most companies developing complex communication and radar systems. He has graduated nearly 100 PhD students and post-doctoral fellows.

Thursday, August 15th, 2019

Opening Session: 08:45 – 09:00
Chair: Hua Wang, Georgia Institute of Technology, USA

Keynote Talk 1: 09:00 – 09:35
5G Evolution and Beyond
C. Hull, Intel Corporation, Hillsboro, OR, USA
Advent of the Internet of Things (IoT) where things and devices are becoming more intelligent and connected requires networks to become faster, smarter, and more agile to handle the unprecedented increase in volume and complexity of data traffic. The 5G era is upon us, ushering in new opportunities for technology innovation across the computing and connectivity landscape. It is transformative and presents an inflection point not only due to major improvements required over 4G/LTE data rates, throughput, and capacity, but also is the first wireless protocol to address the inclusion of massive numbers of the machines/things in the network some of which require lower latencies and higher reliability. This talk will highlight the technology innovations required to make 5G and beyond a reality.

Session 1: Advanced Systems and Networking Technologies
Chair: Steven M. Bowers, University of Virginia, USA

S1-1: 09:50 – 10:15
Large Intelligent Surfaces Assisted MIMO Communication
M. S. Alouini[1], Q. A. Nadeem[1], A. Kammoun[1], A. Chaaban[2] and M. Debbah[3] (Invited Talk) [1]King Abdullah University of Science and Technology (KAUST), Saudi Arabia, [2] University of British Columbia, Canada, [3]Huawei, France
Massive multiple-input multiple-output (MIMO), millimeter wave (mmWave) communications, and ultra-dense deployments of small cells contributed to the improvement of the spectral efficiency of the 5G networks that are starting to be deployed. However, these technologies face two main practical limitations 1) the lack of control over the wireless propagation environment, and 2) the high power consumption of the wireless interface. To address the need for green and sustainable future cellular networks with control over the propagation channel, the concept of smart radio spaces using large intelligent surfaces (LIS) that reconfigure the wireless propagation environments is one of the promising technologies for beyond 5G networks. The idea is to use the large number of low-cost passive reflecting elements that constitute the LIS to artificially reconfigure the signal propagation for performance enhancement. In this paper, we discuss the role of passive LISs in reconfiguring wireless propagation environments, introduce an LIS-assisted MIMO communication system, and present performance evaluation results to illustrate the efficiency of the proposed system.

S1-2: 10:15 – 10:30
Towards Dynamic 5G Networks Utilizing Flexible Function Split
Y. Alfadhli [1], P. C. Cheng[2], S. Shen[1], S. Yao[1], M.S. Omar[1], Y.W. Chen[1], S.M. Mitani[3], and G. Chang[1],[1]Georgia Institute of Technology, USA, [2]National Taipei University Taiwan, [3]Tm R&D, Malaysia
The migration of wireless mobile networks from the relatively limited microwave radio spectrum to the "all-spectrum" principle of communication, which aims to make use of microwave and millimeter wave mobile networks as well as fixed point sub-terahertz and visible light communications, has predetermined the need for a new network paradigm. Therefore, designing an efficient network along with a specialized protection system that encompasses the densely distributed remote radio units (RRUs) as well as fronthaul fiber links and their RF interfaces becomes increasingly important and complex. In this paper, we first analyze the function split concept in the design of fronthaul schemes, mindful of the required fronthaul bandwidth and RRU complexity. We then experimentally demonstrate a mobile-fronthaul protection algorithm that supports proactive, low complexity self-healing by making use of low complexity RRUs while imposing minimum changes on fronthaul performance. The proposed scheme exploits RF domain switching to support seamless 5G-grade service restoration in less than 2 microseconds without causing any service disruption to connected users.

S1-3: 10:30 – 10:45
Reliable Multi-user Uplinks in Fiber-Wireless Integrated Network using Quasi-orthogonal Chirp Spreading OFDM
Y.-W. Chen[1], P.-C. Peng[2], L. Huang[3], G.-K. Chang[1], [1]Georgia Institute of Technology, USA, [2]National Taipei University of Technology, Taiwan, [3]Nanjing University, P.R. China
We experimentally demonstrate a grant-free multi-user upstream with a quasi-orthogonal chirp spreading (QOCS) orthogonal frequency division multiplexing (OFDM) in an intensity-modulation and direct-detection based fiber-wireless convergence over 120-cm wireless and 25-km fiber transmission. By applying the frequency chirp spreading, user subcarriers in a widely-adapted OFDM are re-allocated into the coding channels and occupy the whole available bandwidth. Time and frequency resources can be shared and fully utilized for all active users. Without a time-consuming request-and-grant process, the proposed scheme is suitable for the low-latency and emergency communications. The experimental results reveal a high tolerance of multi-user interference and a less than 3% of error vector magnitude degradation is measured in the most critical scenario that randomly distributed users are totally active and temporally overlapped. Furthermore, a 21.9 dB system power budget is achieved after 25-km fiber transmission. Therefore, our proposed scheme exhibits a high-reliability for the next generation low-latency applications in a fiber-wireless convergence network.

S1-4: 10:45 – 11:05
Key Techniques for High-Capacity 5G Wireless Networks
P.-T. (Boris) Shih, Corning, USA (Invited Talk)
With the full swing realization of 5G mobile communication systems across the world, new technologies, unique devices, advanced network architectures, and novel applications are continuously being proposed. Furthermore, materials – including glass are also expected to play role on the 5G stage – especially as we move to mmWave frequencies. Massive MIMO has been identified as one of the key technologies for 5G systems – particularly for sub-6GHz applications. Using optical fiber-based front-haul networks and distributed M-MIMO architectures, we experimentally demonstrated up to 10x improvement in wireless system capacity compared to collocated M-MIMO in an indoor environment. For mmWave applications, glass could provide critical device performance gains, owing to its smooth surface quality. In this paper we will also discuss potential applications for glass material – including in radome and substrate applications.

S1-5: 11:05 – 11:20
W-band PAM-4 Wireless Delivery Employing Intensity Modulation and Coherent Detection based on CMMA Equalization
W. Zhou, L. Zhao, Y. W. Chen, G.-K. Chang, Georgia Institute of Tech., USA

We have experimentally demonstrated PAM-4 signals generation and millimeter wave wireless transmission at 90-GHz W-band, respectively, enabled by using an intensity modulator and coherent receiver. The bit-error-ratio (BER) performance can be improved significantly by the offline digital signal processing (DSP) including cascaded multi-modulus algorithm (CMMA) equalization at the receiver side. We also investigated the DSP process difference between PAM-2 and PAM-4 signals recovery. The experimental results show that up to 10-Gb/s PAM-2 signal and 12-Gb/s PAM-4 signal over 9-m free space wireless delivery can be realized with a BER less than 7% hard-decision forward-error-correction (HD-FEC) threshold of 3.8×10^{-3}. To the best of our knowledge, this is the first time to achieve W-band PAM signal wireless transmission based on coherent detection. Our proposed scheme has important practical application of significance for the 5G broadband network.

Session 2: Mm-Wave to THz Circuits and Technologies
Chair: Shahriar Shahramian, Bell Labs – Nokia, USA

S2-1: 13:15 – 13:40
300-GHz-Band CMOS Transmitter and Receiver Modules with WR-3.4 Waveguide Interface
S. Amakawa, M. Fujishima (Invited Talk), Hiroshima Univ., Japan
This paper reviews 300-GHz-band CMOS transmitter (TX) and receiver (RX) modules with a WR-3.4 waveguide interface that allows a high-gain antenna or some other component like an amplifier to be connected. A CMOS TX or RX chip is mounted on a multilayer glass epoxy printed circuit board (PCB) by flip-chip bonding. A short section of on-board transmission line then leads to a waveguide transition with a back-short structure built into the PCB. The chip and the transition are completely covered by a WR-3.4 waveguide flange having a hollow for accommodating a chip and mounted onto the PCB. Wireless link between the TX and the RX modules achieves a data rate of 20Gb/s with 16QAM over 10cm.

S2-2: 13:40 – 14:05
Sub-THz and THz Signal Generation Using Photonic and Electronic Techniques
A. Banerjee[1], L. Zhang[1], H. Wang[2], P. Wambacq[3] (Invited Talk)
[1]imec USA,[2]Georgia Inst. of Technology, USA, [3]imec/VUB Belgium
To enable the use of the sub-THz and THz region of the electromagnetic spectrum from 100GHz to 10THz for next generation high-speed wireless communication and other emerging applications, it is important to generate the signal in this frequency range with high output power and high efficiency in a compact and cost-effective way. This paper reviews different photonic and electronic techniques for sub-THz and THz signal generation with implementation examples and discusses the future trends.

S2-3: 14:05 – 14:30
Packaging Approaches for mm-Wave and Sub-THz Communication
S. Ravichandran, KQ Huang, FM Rehman, S. Erdogan, A. Watanabe, N. Nedumthakady, F. Liu, M. Kathaperumal, M. Swaminathan (Invited Talk)
Georgia Institute of Technology, USA
The two approaches discussed here are laminate based approach and Glass Panel Embedding (GPE). Laminate based solutions provide for low cost and reasonable performance but have challenges in terms of supporting low profile. This approach can be made effective and efficient by introducing air cavities in the laminate stack-up to reduce losses, provided reliability can be addressed. Currently there are challenges in precisely structured air cavity fabrication for multi-layered substrates. Glass Panel Embedding (GPE) is a promising packaging approach for THz applications owing to its excellent dimensional stability and low profile. The GPE packaging approach using multiple dies can help support cavities, heterogeneous ICs such as PA and beamformer, interconnects, integrated phased array antennas, and passives along with a robust thermal solution.

S2-4: 14:30 – 14:45
High-Performance Optically Controlled RF Switches for Advanced Reconfigurable Millimeter-Wave-to-THz Circuits
Yu Shi, Jun Ren, Y. Deng, P. Fay, L. Liu, Univ. of Notre Dame, USA
In this paper, optically-controlled high-performance integrated RF switches have been proposed, investigated and discussed. The switching is based on the high conductivity change (5-6 orders) due to photo-induced free-carriers in semiconductors. Initial simulation for G-band CPW-based optical switches has shown that a record-high (compared to semiconductor and VO2 switches) intrinsic FOM (figure of merit evaluated by RonCoff constant) of 153 THz can be achieved using Ge (85 THz with Si). In addition, the on/off ratio can be maintained as high as 28.1 dB at 200 GHz. The proposed device has not only superior performance, but also the advantages of compact size, easy fabrication and integration, as well as high speed and reliability, making it a great candidate for enabling advanced tunable reconfigurable circuits that are required in millimeter-wave and terahertz communications.

Session 3: Advanced RF PAs with Back-Off Enhancement Techniques
Chair: Anding Zhu, University College Dublin, Ireland

S3-1: 15:00 – 15:15
Design and Characterization of An Outphasing Power Amplifier with Balun Combiner
A. Bogusz[1], J. Lees[1], R. Quaglia[1], S. Cripps[1], G. Watkins[2]
[1]Cardiff University, United Kingdom,[2]Toshiba Research Europe
This paper presents an outphasing power amplifier using a planar balun as power combiner. The balun with bandwidth extending to and over octave was fabricated using thin film technology on alumina substrate. The design adopts a hybrid approach, utilising a pair of bare die devices with bond-wire connections to the alumina passive networks, to minimise the extra parasitic effects introduced by packaging. The characterised prototype, that uses the TGF2023-01-2 12 W GaN HEMT from Qorvo, operates at centre frequency of 1.9 GHz and demonstrates a 15% bandwidth, where the maximum output power is maintained within 0.5 dB deviation from 41.2 dBm. On the same bandwidth, the PAE is above 55% and 44% when operating at its peak and 6 dB output back-off (OBO) output power, respectively. The Power back-off is realised by both amplitude and relative phase modulation.

S3-2: 15:15 – 15:30
Envelope Tracking for 5G Mobile Handsets
J. Retz[1], N. Khlat[2], J.-F. Chiron[2], [1]Qorvo USA,[2]Qorvo France
The arrival of 5th Generation (5G) New Radio (NR) brings challenges to Envelope Tracking (ET) systems for mobile handsets. Most notably, 5G NR brings 100MHz modulation bandwidth and Dual Connectivity. A Qorvo ET tracker solves these needs for 5G mobile. This work summarizes ET 100MHz performance with memoryless Digital Predistortion (DPD) for Band n77 and Band n41. A Memory DPD (MDPD) model is also examined for Band n41.

S3-3: 15:30 – 15:45
Linearity Characterizations of Highly Efficient, Infrastructure GaN Doherty Power Amplifier for 5G Applications
M. Masood, S. Embar, P. Rashev, NXP Semiconductors, USA
This paper presents a linearity characterization scheme of highly efficient, infrastructure Gallium-Nitride (GaN) Doherty power amplifiers (PA) for 5G applications. Linearization of high-power infrastructure GaN power amplifiers can be quite challenging due to inherent memory effects (especially trapping related). This requires special validation procedures to be developed for evaluation of linearity of GaN PA under various dynamic and static power conditions. In this work, static and dynamic power wave-forms, of Frequency Division Duplex (FDD) and Time Division Duplex (TDD) types are used to validate the linearity of 300W peak power, asymmetric GaN PA operating at 2600MHz (for 5G), with linearized efficiency of 60% (at 8-dB output back-off).

S3-4: 15:45 – 16:00
Linearity-Aware Design of Doherty Power Amplifiers
A. Piacibello[1], R. Figueiredo[2], V. Camarchia[1], M. Pirola[1], N.B. Carvalho[2] [1]Politecnico di Torino, Italy,[2]University of Aveiro, Portugal
The linearity is a crucial requirement of power amplifiers. At design level, it is typically assessed by means of AM/AM, AM/PM and IMR, which are extracted from 1- and 2-tone characterization. These however are not fully representative of the actual behaviour under modulated signal excitation, for which purpose other system-level metrics such as the NPR have been successfully introduced. In this paper, different linearity estimations are used to compare two GaN-on-Si Doherty MMIC power amplifiers for Ka-band space applications. One of the two amplifiers shows an AM/PM reduction of more than 30% with respect to the other. However, it is observed that this does not always lead to a reduction in NPR. The reasons for this disagreement between metrics are analyzed and discussed.

Session 4: Beamforming, Antennas, and Packaging Technologies
Chairs: Jahnavi Sharma, Intel Labs, USA

S4-1: 16:15 – 16:40
Advanced Packaging and its Characterization for 5G mmWave Antenna in Package
S. W. Lu, H.S. Cho, H. Chang (Invited Talk)
Advanced Semiconductor Engineering, Taiwan
As the mmWave bands of the 5G become popular and available to the mass market, designing antenna in mmWave transceiver package becomes a popular choice. It is critical that a few key antenna design parameters must be kept in such advanced packaging, including low antenna loss, wide bandwidth matching, and directivity. To achieve these goals, the structure, the material used, and manufacturing process for the advanced packaging, in which antenna is designed in, must be carefully characterized and optimized. In addition, the scalability and the cost of the advanced packaging used for 5G mmWave has to meet the market targets.

S4-2: 16:40 – 16:55
28-32 GHz Dual-Polarized Single-Layer Microstrip Line Beamforming Network for 2×2 Beam
N. Ashraf, A. Kishk, A.R. Sebak, Concordia Univ., Canada
A 2×2 dual-polarized passive analog beamforming network is presented for millimeter-wave application in the range of 28-32 GHz. Two identical 2×2 networks, one for each polarization (H and V) are integrated on a single substrate layer. Highly isolated crossover is used to cross the RF signal for each polarization. To avoid spurious radiation, the microstrip line circuit is packaged with the AMC. The beamforming network has four beam-ports for each polarization. Therefore, eight beams can be generated, simultaneously. The 90° hybrid couplers are used to achieve a 2D progressive phase shift at two stages. The transmission of -6.5 ± 0.25 dB is achieved from the beam-ports to the array-ports. Similarly, the progressive phase shift of 900 ± 50 is achieved in X and Y direction.

S4-3: 16:55 – 17:10
Dual-Polarized Substrate-Integrated-Waveguide Cavity-Backed Monopulse Antenna Array for 5G Millimeter-Wave Applications
C. Chu[1], J. Zhu[2], S. Liao[3], Q. Xue[3], A. Zhu[1],[1]University College Dublin, Ireland,[2]Beijing University of Posts and Telecom., China, [3]South China Univ. of Technology, China
This paper presents a new substrate integrated waveguide (SIW) cavity-backed antenna array with dual-polarization monopulse radiation patterns. The monopulse comparator is realized by using SIW magic Tee that is directly fed by the WR-15 waveguide for wide phase balanced bandwidth. The radiating part is implemented by using aperture coupled cross-shaped patches that are enclosed by metallized cavity. In order to realize dual polarizations with high isolation, two independent monopulse feed networks are designed in two different layers and positioned orthogonally to feed the array. Taking advantages of good performance of the SIW-based magic Tee, the monopulse antenna array shows good performance including stable sum and difference patterns with high null-depth from 57.5 GHz to 64.2 GHz.

S4-4: 17:10 – 17:25
Wideband Front-End Integration and Unification of Circuit-Antenna for Simultaneous Stabilized Amplification and Steered Radiation
S. Nallandhigal, K. Wu, École Polytechnique de Montréal, Canada
A wide-band front-end integration of amplifying transistor within array antenna is proposed, analyzed and demonstrated in this paper, for simultaneous stabilized amplification and beam steered radiation, in a unified space. Source degeneration inductance realized through via is studied, from which appropriate via is utilized for stabilization. In addition, E-shaped patch antenna is used as the input matching network to enhance the impedance matching bandwidth, which also radiates. The prototype model is fabricated, and measured results agree very well with simulated counterparts. The unified prototype has the amplification gain varying form 10 dB to 8 dB across the matching bandwidth of 13.5 %, along with beam steered radiation at +35 degrees, observed from experiments. Furthermore, frequency tuning and related radiation performance realized through varying DC bias from measurements are also presented.

Friday, August 16th, 2019

Keynote Talk 2: 09:00 – 09:35
5G Radio: A Perspective on Silicon Technologies and Solutions
A. Bandyopadhyay, Globalfoundries, CA, USA

5G, the next generation cellular standard will cover different usage scenarios like enhanced mobile broadband (eMBB), ultra-reliable, low latency communication (uRLLC) and low power massive machine-to-machine communication (mMTC). The radio access technologies for these usage scenarios have different requirements and pose different challenges in terms of hardware implementation. The talk will focus on some of the hardware implementation challenges for enhanced mobile broadband (eMBB) radio highlighting different architecture options, key figures of merits and how different silicon technologies can address those challenges to make an efficient 5G user equipment and base station radio a reality at both sub 6GHz and mmWave.

Keynote Talk 3: 09:40 – 10:15
ComSenTer: Pushing Frequency, Bandwidth, and Spectral Efficiency by 10X Cubed for mm-Wave and Terahertz Arrays for Communication and Imaging Applications
A. M. Niknejad, UC Berkeley, CA, USA

The ultimate goal of the ComSenTer is to demonstrate record wireless transfer speeds, record high resolution mm-wave/THz imaging, and record distance and energy efficient mm-wave and THz links. These core technologies will enable a new breed of ubiquitous devices (both mobile and fixed) that will autonomously discover each other to form a hierarchical mesh network and support end-to-end connectivity without the need to tap into a physical fiber optic infrastructure. Moving to higher carrier frequencies allows arrays with thousands of elements to fit into relatively compact form factors. We envision a system that can simultaneously handle thousands of wireless beams using spatial multiplexing and interference cancellation, with peak data rates up to 100 Gb/s per stream. Such a platform would be handling an aggregate data rate as high as > 10 Tb/s and lead to profound impacts in the capability of wireless networks for communication, imaging, and sensing. In comparison with projected 5G systems, our research aims to push the theoretical limits in terms of not only the bandwidth, but critically, the number of simultaneous beams. Dramatically expanding the number of beams is crucial to enabling the future vision of ubiquitously deployed devices that are able to seamlessly connect and communicate with each other (without being limited by interference), and represents a unique future direction for this center as compared to other on-going industrial as well as academic research. Two key testbeds will be highlighted that will be used to demonstrate the core technology.

Session 5: System Architectures and Algorithms for 5G Applications
Chair: Tim Lee, IEEE MTT-S, USA

S5-1: 10:30 – 10:45
Flexible Architectures for Concurrent Reception of Multiple RF Carriers and Compressed-Sampling Signal Detection in Frequency and Direction-of-Arrival
T. Haque, G. Han, M. Bajor, J. Wright, P. Kinget, Columbia University, USA

The modulated-clock downconversion mixer (MC-DM) and the antenna-weight-modulated phased-array (AWM-PA) are explored as key enablers of ambient-aware, opportunistic receivers in emerging 5G deployments. The benefits of the MC-DM is demonstrated first with an out-of-channel interferer reflecting, inter-band carrier aggregation receiver architecture where the RF carrier combination is selected simply by programming the frequency of the CW waveform used to modulate the mixer clock. Second, a wideband spectrum scanner architecture utilizing pseudo-random modulation of the downconversion mixer clock and Compressed-Sampling (CS) DSP is explored where a few large interferers are detected in ns time. The benefits of the AWM-PA is demonstrated with a phased-array architecture utilizing pseudo-random modulation of the antenna weights and CS DSP where a few large DoAs are detected in µs time.

S5-2: 10:45 – 11:00
Linearizing Active Antenna Arrays: Digital Predistortion Method and Measurements
A. Brihuega[1], M. Abdelaziz[2], M. Turunen[1], T. Eriksson[3], L. Anttila[1], M. Valkama[1], [1]Tampere University of Technology, Finland, [2]Zewail City of Science and Tech., Egypt, [3]Chalmers University of Technology, Sweden

In this paper, we provide a framework for the efficient linearization of large antenna array transmitters. The proposed method is validated with extensive measurements on a 64-antenna transmitter operating at 28 GHz carrier frequency and transmitting a 200 MHz 5G New Radio signal. The results validate the excellent linearization capabilities of the proposed digital predistortion (DPD) solution, which allows for a very efficient implementation in practical systems.

S5-3 11:00 – 11:15
Digital Cancellation of Passive Intermodulation: Method, Complexity and Measurements
M. Waheed[1], D. Korpi[2], A. Kiayani[3], L. Anttila[3], M. Valkama[3], [1]Nokia Mobile Networks, Finland, [2]Nokia Bell Labs, Finland, [3]Tampere University, Finland

This paper addresses digital cancellation of passive intermodulation (PIM) products in simultaneous transmit-receive systems, with specific emphasis on frequency-division duplexing (FDD) based LTE and 5G New Radio (NR) networks. Building on mathematical modeling of the passive intermodulation, a computationally efficient digital cancellation and associated parameter learning solutions are derived and presented. The performance of the method is analyzed through interband carrier aggregation based RF measurements at LTE/NR bands 1 and 3. The measurement results show that the proposed canceller can efficiently cancel the PIM products down to the receiver noise floor. Additionally, the proposed canceller is shown to be of substantially lower complexity compared to the reference methods.

S5-4: 11:15 – 11:30
Pattern Sensing Based Digital Predistortion of RF Power Amplifiers under Dynamical Signal Transmission
H. Yin[1], C. Yu[1], Q. Lu[1], J. Xia[2], X. Zhu[1], W. Hong[1], A. Zhu[3], [1]Southeast University, China, [2]Jiangsu University, China, [3]University College Dublin, Ireland

In this paper, a pattern sensing based digital predistortion (DPD) technique for radio frequency (RF) power amplifiers (PAs) under dynamical signal transmission is proposed. Unlike conventional methods where real time re-calibration is required, this approach utilizes a low resolution amplitude-modulation to amplitude-modulation (AM/AM) pattern to sense PA characteristics and then quickly select proper DPD coefficients to linearize the PA. Experimental results show that the proposed method can provide an efficient and effective way to deal with complex dynamic signal transmission scenarios and maintain very good linearization performance, which is very suitable for future 5G applications.

S5-5: 11:30 – 11:45
Phase Calibration of a Massive MIMO System for Direction of Arrival Applications
M.D. Al-Dabbagh[1], A. Gaber[2], A. Omar[1], [1]University of Magdeburg,Germany, [2]National Instruments, Germany
In this paper we perform a Uniform Linear Array (ULA), Multiple Input Multiple Output (MIMO) system calibration, to measure the Direction of Arrival (DoA) of multiple User Equipment (UE). We consider wired, wireless, Over-the-Air (OTA) calibration operations. The calibrated signals are then processed using Matrix Pencil (MP) estimation technique to achieve the DoA measurements. The results show that DoA stability and accuracy can be achieved using both of the procedures. The results show that an offline calibration vector can be a replacement for real time calibration. It also shows the feasibility of mutual wireless calibration among distant wireless systems, to avoid the need for the costly, and permeant wired calibration connections.

S5-6: 11:45 – 12:00
Parallel-Processing-Based Digital Predistortion Architecture and FPGA Implementation for Wide-band 5G Transmitters
H. Huang, J. Xia, S. Boumaiza, University of Waterloo, Canada
This paper presents a bandwidth-scalable and hardware-efficient parallel-processing-based DPD architecture for wide-band 5G transmitters. By computing multiple data samples at each clock cycle in parallel, the proposed DPD architecture extends the bandwidth of a conventional serial DPD architecture, as limited by the maximum FPGA clock rate, to a much higher rate that is proportional to the number of parallel data paths. With a cross-bar structure devised to re-route the intermediate computation results between the parallel data paths, it allows advanced DPD model with memory and cross-terms to be constructed efficiently. For proof-of-concept, the pruned Complexity-Reduced-Volterra (CRV) DPD with four parallel data paths has been implemented using an Xilinx Ultrascale+ FPGA to achieve a total linearization bandwidth of 1.25 GHz. Subsequently, a 28 GHz power amplifier modulated with 400MHz QAM64 signals has been successfully linearized in the proposed DPD system in real-time.

S5-7: 12:00 – 12:15
88.9-GHz W-Band Multi-Channel Integrated Fiber-Wireless Access Network with KK Coherent Receiver
S. J. Su, Y. W. Chen, S. Shen, Gk Chang, Georgia Tech, USA
A novel fiber-wireless integrated access system supporting multi-channel data transmission via the same network infrastructure was experimentally demonstrated with a proposed KK receiver over baseband/IF and W-band at 88.9 GHz. By tuning the operating frequency of the embedded laser carrier, the signal is available to be transmitted over different frequency ranges with over 21 dB optical power margin, and the system can serve up to 128 subscribers.

Session 6: Circuits Techniques for High-Performance Frontends
Chair: Gee-Kung Chang, Georgia Institute of Technology, USA

S6-1: 13:15 – 13:40
Sub-Sampling PLL For Millimeter Wave Applications: An Overview
Xiang Gao (Invited Talk), Zhejiang University, P.R. China
The sub-sampling PLL utilizes a PD that sub-samples the high frequency VCO output with the reference clock. The PD and CP noise in this PLL is greatly attenuated by the high phase detection gain due to the high VCO dv/dt slew rate. It is now a proven PLL architecture and widely used for achieving low phase noise or integrated jitter yet with low power consumption. This article reviews the development of the sub-sampling PLL techniques and their usage in the millimeter wave applications.

S6-2: 13:40 – 13:55
An Integrated 28 GHz Front-End Module for 5G Applications in 45 nm PD-SOI
R. Ciocoveanu[1,2], V. Lammert[1,2], R. Weigel[2], V. Issakov[1], [1]Infineon Technologies, Germany, [2]University of Erlangen, Germany
This paper presents an integrated 28 GHz front-end module (FEM) for 5th Generation (5G) applications and fabricated in a 45nm partially depleted silicon on insulator (PD-SOI) technology. In transmit (Tx) mode at 28 GHz, the measured saturated output power (Psat), maximum power-added efficiency (PAEmax), output-referred 1-dB compression point (OP1dB) are 17.2 dBm, 26% and 16.7 dBm, respectively, with 86.4mW dc power consumption from a 1.8V supply. In receive (Rx) mode at 28GHz, the measured gain, noise figure (NF), input-referred 1-dB compression point are 9 dB, 3.6 dB and −10 dBm, respectively, with 14.8mW dc power consumption from a 1V supply. The chip core size is 0.62mm x 0.75 mm.

S6-3: 13:55 – 14:10
A 9-Bit Vector-Sum Digital Phase Shifter Using High Resolution VGAs and Compensated Quadrature Signal Generator
J. Zhou, H. Qian, X. Luo, University of El. Science and Tech., China
In this paper, a 90-98 GHz vector-sum digital phase shifter with high phase accuracy and low power consumption is presented for W-band phased-arrays. The proposed phase shifter is based on a quadrature all-pass filter (QAF) and four identical variable gain amplifiers (VGAs) with 7-bit current-digital to analog converters (I-DACs). To eliminate the parasitic loading capacitance influence of the VGAs on the QAF, a inductor-based compensation network is utilized. Then, specific phase shifting could be obtained. Meanwhile, the digital pre-distortion (DPD) technology is used to further improve the phase error performance.

S6-4: 14:10 – 14:25
A 27-29GHz Integer-N PLL with Quadrature Phases for 5G Applications
V. Aggarwal[1], S. Aniruddhan[2], [1]Cadence, India, [2]Indian Ins. Tech.
This paper presents a quadrature 27-29GHz mm-wave Integer-N PLL with an input reference frequency of 25MHz in a bulk CMOS 45nm technology. The PLL utilizes a Cascode Injection based Quadrature Voltage Controlled Oscillator (VCO) with a low phase noise of -87dBc/Hz @1MHz offset, and a 1024-2046 modular divider in step of 2. The PLL achieves a normalized phase noise of -90dBc/Hz at an offset of 1MHz even at a very high divide ratio of 1120 while consuming power of 65mW from a 1.1V power supply in post layout EM simulations. The jitter-power FOM is -231dBc/Hz which is at par with state of the art PLL designs for 5G applications.

S6-5: 14:25 – 14:40
Approaches to Nonoverlapping Clock Generation for RF to Millimeter-Wave Mixer-First Receivers
S. Hari, A. Bhat, C. Wilson, B. Floyd, NC State Univ., USA
N-phase mixer-first receivers are an ideal choice for broadband frequency-selective receivers. These receivers can now operate near millimeter-wave frequencies using fast-rising four-phase clock generation in advanced CMOS. This paper compares four-phase clock-generation approaches used in two high-frequency mixer-first receivers–a polyphase filter-based scheme as part of a 20-30 GHz receiver and a divider-based scheme as part of 5-31 GHz receiver. We discuss circuits for quadrature and 25% duty-

cycle generation and compare clock performance in terms of area, power, quadrature accuracy, and receiver metrics. Both receivers demonstrate typical noise figure below 8 dB and conversion gains above 18 dB.

Session 7: Mm-Wave Power Amplifiers
Chair: Shahriar Shahramian, Bell Labs – Nokia, USA

S7-1: 14:50 – 15:15
High-Efficiency Stacked Cell CMOS SOI Power Amplifiers for 5G Applications
S. Mohammadi (Invited Talk), Purdue University, USA
Design, implementation and characterization of high efficiency CMOS SOI power amplifiers based on stacked cell approach and suitable for 5G standard are presented. The PAs designed in this work are implemented in GF 45 nm CMOS Silicon on Insulator (SOI) technology. For 26 and 28GHz 5G bands, a PA operating in 24-28 GHz frequency range delivers measured maximum linear power gain of 15.2 dB (16 dB), saturated output power P_{SAT} of 25.2 dBm (24.8 dBm), -1 dB output compression power P_{1dB} of 22.5 dBm (17.3 dBm) and a peak power-added efficiency PAE of 20% (15%) at 26 GHz (28 GHz).

S7-2: 15:15 – 15:30
An Artificial-Intelligence (AI) Assisted Mm-Wave Doherty Power Amplifier with Rapid Mixed-Mode In-Field Performance Optimization
F. Wang, K. S. Xu, J. K. Romberg, H. Wang, Georgia Inst. Tech., USA
This paper presents an artificial-intelligence (AI) assisted "intelligent" millimeter-wave (mm-wave) Doherty power amplifier (PA) architecture that achieves robust adaptive operation over antenna VSWR. A built-in machine-learning core utilizes online function estimation and reinforcement learning algorithms for dynamic Doherty performance optimization. As a proof of concept, a 3-bit mixed-signal Doherty PA (MSDPA) at 28GHz is used as a hardware platform to demonstrate the performance improvement with the AI core. Over 2:1 antenna VSWR variation, simulations using extracted Doherty PA schematic show up-to 4.9 dBm P1dB improvement and up-to 7% PAE improvement at P1dB.

S7-3: 15:30 – 15:45
A 21 to 31 GHz Multi-Stage Stacked SOI Power Amplifier with 33% PAE and 18 dBm Output Power nodes
T. Ren, B. Floyd, North Carolina State University, USA
This paper presents a compact two-stage K/Ka-band power amplifier implemented in GF 45RFSOI CMOS technology for millimeter-wave phased arrays. The PA features a linear pre-driver stage with 1.6 V supply and a three-stack FET output stage with 3.6 V supply. Measurement results show that at 26 GHz, the PA achieves a peak gain of 16.6 dB and a saturated output power (Psat) of 18.3 dBm with maximum power-added efficiency of 32.8%. The 1-dB compression point is 16.2 dBm with PAE of 29.7%. The PA operates across 21 to 31 GHz with Psat above 17.3 dBm and gain above 13.6 dB.

S7-4: 15:45 – 16:00
High Power Ka Band Amplifier Using Multigate Structure With Capacitive Feedback in CMOS-SOI
N. Rostomyan[1], T. Torii[2], S. Alluri[1], P. Asbeck[1], [1]UCSD, USA, [2]Mitsubishi
In order to increase output power, transistor stacking is often employed in CMOS-SOI technology. This paper reports 4-stack devices and power amplifiers which use a multigate layout to reduce parasitic resistances and capacitances, together with feedback capacitances connected between drain and the floating nodes between transistors in order to increase gain and efficiency. For single 4-stacked devices, power amplifiers reach Psat=23dBm at 27GHz, with peak efficiency of 35%. Power-combined 4-stacked devices in a differential structure, together with a driver stage, achieve saturated power of 25.5 dBm, with peak efficiency of 31%.

S7-5: 16:00 – 16:15
Implementation of a Differential Mm-Wave CMOS SOI Power Amplifier
J. Peterson, S. Mohammadi, Purdue University, USA
A mm-wave class AB power amplifier is implemented in GF 45 nm CMOS SOI technology. The PA is designed in the frequency range of 40 to 50 GHz based on a differential stack of triple transistor cells. It achieves a single-ended saturated output power Psat of 22.2 dBm and a peak PAE of 30% at 44 GHz. The overall power performance in the range of 44 GHz to 50 GHz remains acceptable.

Closing Remarks: 16:15 – 16:30
Chair: Hua Wang, Georgia Institute of Technology, USA
Co-Chair: Anding Zhu, University College Dublin, Ireland

Poster Papers

P-1: W-band Low-Power Millimeter-Wave Direct Down Converter Using SiGe HBTs in Saturation Region
A. Mukherjee, M. Schroter, Technische Universität Dresden, Germany

P-2: 5G mm-Wave SPDT Switch IMDn Investigation
K. Barnett, Globalfoundries, USA

P-3: Behavioral Modeling of Power Amplifiers With Modern Machine Learning Techniques
S. Dikmese, L. Anttila, P. P. Campo, M. Valkama, M. K. Renfors, Tampere University of Technology, Finland

P-4: Resilient Mobile Fronthaul Links with Heterodyne Detection in Integrated Fiber-MMW-Fiber Transmission
R. Zhang, Y. Chen, S. Liu, Y. Alfadhli, Y. Tang, G.-K. Chang, Georgia Institute of Technology, USA

P-5: A compact, 42% PAE, two-stage, LDMOS Doherty PA Module for Massive MIMO Applications
H. Ladhani, E. Maalouf, J. Jones, M. Masood, and J. S. Kenney, NXP Semiconductors, USA and Georgia Institute of Technology, USA

P-6: A 180 GHz High-Gain Cascode Amplifier in 130-nm SiGe process
X. Li, W. Chen, Z. Feng, Tsinghua University, P.R. China

P-7: 3D Glass-Based Panel-Level Package with Antenna and Low-Loss Interconnects for Millimeter-Wave 5G Applications
A. Watanabe, M. Swaminathan, R. Tummala, M. M. Tentzeris, Georgia Institute of Technology, USA

Social Events

Conference Lunch
Date: Thursday August 15th, 11:30-13:00
Location: Global Learning Center, Rooms 156 and 158

A lunch ticket is included in the registration pack. You will be required to present this ticket at the entrance of rooms 156 and 158. The lunch will be immediately followed by the Conference Luncheon event in the same rooms.

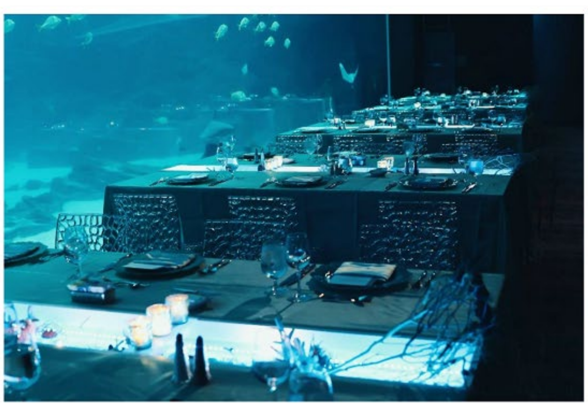
Conference Dinner
Date: Thursday August 15th, 19:00-21:30
Location: Georgia Aquarium, Ocean Voyager Theater, 225 Baker St NW, Atlanta, GA 30313

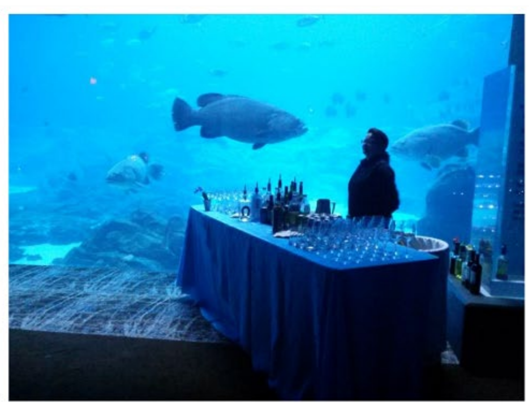
All registered conference delegates are invited to the Conference Dinner. A dinner ticket is included in the registration pack. You will be required to present this ticket at the entrance of the Aquarium.

At the Ocean Floor, a buffet style dinner will be served alongside the largest aquarium viewing window in North America. Please enjoy your dinner as tens of thousands of fish swim overhead!

Shuttle Bus Service:

Pick-up Time/Location	18:30 at the entrance of Global Learning Center
Drop-off Time/Location	18:45 at the entrance of Georgia Aquarium
Pick-up Time/Location	21:30 at the entrance of Georgia Aquarium
Drop-off Time/Location	21:45 at the entrance of Global Learning Center





Best Student Paper Awards

The Best Student Paper Awards will be given to recognize outstanding technical contributions from individual students. Three prizes will be awarded based on quality of the technical content and oral/poster presentation:

- First place: 750 USD
- Second place: 500 USD
- Third place: 250 USD

To be considered for an award, the student must (i) be a full-time student during the time the work was performed, (ii) be the first author of the paper, and (iii) present the paper in person at IMC-5G conference.

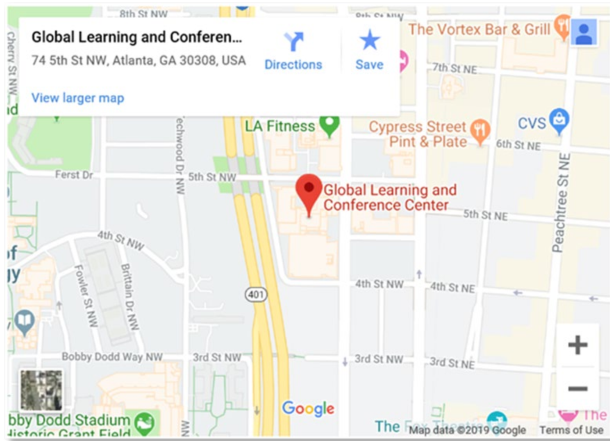
The following papers have been shortlisted for the awards:

Sandeep Hari	Approaches to Nonoverlapping Clock Generation for RF to Millimeter-Wave Mixer-First Receivers
Shang-Jen Su	88.9-GHz W-Band Multi-Channel Integrated Fiber-Wireless Access Network with KK Coherent Receiver
Srinaga Nikhil Nallandhigal	Wideband Front-End Integration and Unification of Circuit-Antenna for Simultaneous Stabilized Amplification and Steered Radiation
Mohanad Dawood Al-Dabbagh	Phase Calibration of a Massive MIMO System for Direction of Arrival Applications
Yu Shi	High-Performance Optically Controlled RF Switches for Advanced Reconfigurable Millimeterwave-to-THz Circuits
Yahya Alfadhli	Towards Dynamic 5G Networks Utilizing Flexible Function Split
Aleksander Bogusz	Design and characterisation of an outphasing power amplifier with balun combiner
Tanbir Haque	Flexible Architectures for Concurrent Reception of Multiple RF Carriers and Compressed-Sampling Signal Detection in Frequency and Direction-of-Arrival

The Best Student Paper Awards will be announced at the closing session of the conference.

Conference Venue Information

The IMC-5G 2019 conference will take place in the Georgia Tech Global Learning Center (GLC), Auditorium Room 222, 800 Spring St NW, Atlanta, GA 30308. The Georgia Tech Global Learning Center (GLC) is located in Midtown Atlanta at the intersection of 5th and Spring Streets in the heart of Tech Square — Atlanta's thriving innovation community. It is easily accessible from Interstates 75/85 and just 15 miles from Hartsfield-Jackson Atlanta International Airport.



Parking

The Tech Square parking deck, attached to the GLC, is accessible from Spring Street. Hourly rates range from $1.50 for less than an hour to $15 per day. The GLC can be accessed from the second level of the parking deck. The parking garage address is 770 Spring St. NW, Atlanta, GA 30308-1031.

Directions to the GLC

From south Atlanta or Hartsfield-Jackson Atlanta International Airport (Interstate 75/85 north)

Take Interstate 75/85 north to Exit 250 (10th Street/14th Street/Georgia Tech). Merge onto Williams Street and turn right onto 10th Street. You will make an immediate right onto Spring Street. Travel approximately 0.4 miles on Spring Street to 5th Street. Proceed half a block further and turn right at the next light into the parking deck.

From northeast or northwest Atlanta (Interstate 75/85 south)*

Take Interstate 75 south to Exit 250 (14th Street/10th Street) or Interstate 85 south to Exit 84 (14th Street/10th Street). Continue straight onto Techwood Drive and use the left two lanes to turn left onto 14th Street. Turn right at the second cross street onto Spring Street. Continue on Spring Street for 0.7 miles to 5th Street. Proceed a half block further and turn right at the next light into the parking deck.

*If you are coming from north Atlanta, take Georgia 400 south to Interstate 75/85.

From east or west of Atlanta (Interstate 20)

Take Interstate 20 to Interstate 75/85 north to Exit 250 (10th Street/14th Street/Georgia Tech). Merge onto Williams Street and turn right onto 10th Street. You will make an immediate right onto Spring Street. Travel approximately 0.4 miles on Spring Street to 5th Street. Proceed half a block further and turn right at the next light into the parking deck.

Public Transportation

MARTA (Metropolitan Atlanta Rapid Transit Authority) and Tech Trolley

MARTA trains are available from Hartsfield-Jackson Atlanta International Airport and from multiple locations throughout the metro Atlanta area. Take the red or gold rail lines (northbound) to the Midtown MARTA station. Exit the station at Peachtree Place and board the free Tech Trolley. GLC is the first stop before the trolley enters the main Georgia Tech campus. View route maps and estimated arrivals here:
https://pts.gatech.edu/tech-trolley-and-midnight-rambler

Notes

Notes

Notes