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IMS2021 Microwave Week Workshops

Kaushik Sengupta, Glenn Hopkins, Danilo Manstretta, Mona Mostafa Hella, and Patrick Roblin

The Microwave Week 2021 workshops program will provide great learning opportunities for attendees, whether in person or virtually, focusing in depth on a diverse set of timely topics presented by industry, academia, and government leaders. These topics span the technical areas of the IEEE Microwave Theory and Techniques Society (MTT-S) International Microwave Symposium (IMS), RF Integrated Circuits (RFIC) Symposium, and Automated RF Techniques Group (ARFTG) Conference. The workshops include half- and full-day sessions covering the latest developments in RF, microwave, millimeter-wave (mm-wave), and sub-mm-wave technologies. Each workshop's technical program will highlight the most recent advances, future directions, and challenges. Workshop presenters are recognized experts representing industry, academia, and government, and they are selected based on their technical achievements and presentations skills. While plans are still evolving due to the COVID-19 situation, we expect all the workshops to be available in the virtual conference.

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Interactive discussions are encouraged to inspire ideas and stimulate new research and development. Presentation content often combines introductory, intermediate, and advanced material, making each workshop relevant and useful to novices and experts. After the presentations—typically, there are four in half-day sessions and eight in full-day sessions—a workshop generally concludes with a short panel, offering additional opportunities for the audience to interact with the speakers. Lecture material will be available in electronic form.

The workshops program for 2021 includes 26 full-day and six half-day sessions covering topics across the levels of abstraction, from materials and devices to the design, testing, and characterization of large systems as well as emerging applications. Among these topics are materials technologies, such as magnetic and microwave acoustics;

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TABLE 1. Microwave Week 2021 workshops.

Workshop Title	Event Abstract	Workshop Organizer(s)	Sponsorship/ Cosponsorship	Day of Workshop	Half Day (HD)/Full Day (FD)
MIMO and Digital Beamforming Systems for 5G and Beyond	5G networks aim for an order-of-magnitude increase in data traffic to support growing demand in mobile networks. Massive MIMO technology will improve capacity by delivering high data rates to multiple users, support real-time multimedia services, and reduce energy consumption by targeting signals to individual users utilizing digital beamforming. Additionally, element-level digital beamforming that supports emerging multibeam communications and directional sensing will expand the use of mm-wave arrays and make them broadly applicable across U.S. Department of Defense systems. The goal of this workshop will be to present state-of-the-art radio circuits and systems exploiting MIMO and digital beamforming for both civilian 5G New Radio (NR) and defense applications. Talks will focus on the development of digital beamformers as well as the efficient implementation and packaging of MIMO arrays at RF and mm-wave systems.	Kamran Entesari and Arun Natarajan	RFIC/IMS	Sunday	HD
Recent Advances in Frequency Generation Techniques for Sub-6-GHz, mm-Wave, and Beyond	In emerging 5G cellular communication and other mm-wave systems, the generation, distribution, and synchronization of the local oscillator (LO) signals remain a challenge. This workshop will cover the latest design techniques for frequency synthesis circuit components and systems to generate LO signals that have low phase noise, few spurious tones, fast hopping, and long-term stability across a wide operation frequency range. The first talk will address LO frequency synthesis and voltage-controlled oscillator (VCO) coupling mitigation in the advanced 5G cellular transceiver. The second will focus on ultrawide-tuning-range VCO design for mm-wave and sub-THz frequencies. The third will discuss design challenges and techniques for broadband fast-hopping direct digital frequency synthesizers. The final talk will introduce a new, low-cost reference clock generation method—a molecular clock—for wireless network synchronization and navigation.	Ruonan Han and Wanghua Wu	RFIC	Sunday	HD
Recent Advances in the Efficient Small- and Large-Signal Stability Analysis of Microwave Circuits	Instability is a fundamental problem in microwave circuits, giving rise to an experimental behavior that is qualitatively different from the expected one, with undesired oscillations, frequency divisions, hysteresis, and chaos. Posteriori correction is impossible in integrated technologies, and trial-and-error procedures, without an understanding of the phenomenon that causes a malfunction, turn out to be inefficient since the problem arises again in new prototypes, increasing the production cycles and cost. The stability investigation has been an ever-present effort in the microwave field, and significant advances have been achieved in recent times. This workshop will address new and innovative concepts, including experimental characterization of stability margins, stability analysis of complex systems, novel criteria for stability enforcement, and exploitation of nonlinear effects. The goal will be to frame the approaches within an effective high-frequency CAD environment and to make the typically rather abstract concepts of large-signal stability analysis comprehensible to the attendees, who will be able to pose questions during the presentations.	Marco Pirola and Almudena Suarez	IMS	Monday	HD

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Low-Power Radios and Wireless Technologies for Indoor Positioning and Localization	The Internet of Things (IoT) and low-power wireless devices encompass many protocols and standards, each optimized for its specific set of applications, with the unifying themes being battery operation, low average data rates, power-efficient processing, a low cost and small size, and extensive integration with sensors, processors, and power management. This workshop will present several talks covering the architectures and circuits for existing standards and applications, and it will explore research that will inform the next generation of these technologies. Application spaces that are increasingly gaining traction include wearables and indoor localization and positioning, with prime examples being smart buildings, distance-bounded security, and, most recently, COVID-19 tracking. This workshop will also address several state-of-the-art technologies in wearable devices and indoor localization in the context of low-power wireless communications.	Oren Eliezer, Arun Paidimarri, Yao-Hong Liu, and Gernot Huber	RFIC	Sunday	FD
100–300-GHz mm-Wave Wireless for 0.1–1-Tb/s Networks	Wireless systems using higher (100–300-GHz) mm-wave carrier frequencies will benefit from large available bandwidths and, given the very short wavelengths, massive spectral reuse via massive spatial multiplexing. Simple radio link budget analysis suggests that ~1-Tb/s capacities are feasible in both point–multipoint network hubs and point–point backhaul links. But the range is limited by a high Friss path loss and foul weather attenuation, and beams are readily blocked. We will examine the drafting, technical challenges, and potential arrangement of such systems, including the link architecture; link budgets; radio propagation characteristics; array tile module and antenna design; MIMO channel estimation; massive MIMO beamformer dynamic range analysis; digital beamformer design; mesh networks to accommodate beam blockage; RF front-end design in CMOS, silicon–germanium (SiGe), and III-V technologies; and estimates of system dc power consumption as a function of the architecture.	Jane Gu and Mark Rodwell	RFIC/IMS	Sunday	FD
CMOS mm-Wave Imaging Radars: State of the Art and a Peek Into the Future	Advances in mm-wave CMOS technology have resulted in fully integrated mm-wave radar sensors that offer a cost-effective and robust solution to automotive safety, provide accurate industrial sensing, and enable gesture recognition. This workshop will feature technical experts from academia and industry presenting the state of the art in mm-wave CMOS technology, such as all-digital architectures, higher carrier frequencies, sophisticated signal processing, and machine learning. These technologies promise to improve the achievable accuracy and push performance levels further. Speakers will also share their view of the next steps in this space and the possibilities for the future.	Vadim Issakov and Venkatesh Srinivasan	RFIC	Sunday	FD

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Coherent Optical Communications for Cloud Data Centers and Metro and Submarine Networks	The introduction of the IoT and cloud computing has accelerated the demand for higher-bandwidth and higher-capacity networks. Coherent detection, where the phase information of the optical carrier provides higher signal-to-noise ratios, has gained an ever-increasing momentum. Today, coherent communication dominates long-haul networks operating with data rates beyond 400 Gb/s/wavelength. Thanks to advances in digital signal processing that leverage ultralow-power implementations in deep submicron technologies (i.e., 7 nm), the cost and power of coherent transponders are becoming competitive for short-reach networks (inter- and intradata centers) as well. Reducing the cost and enhancing the overall performance of such networks are achievable only through highly integrated solutions that encompass complex digital signal processing algorithms, state-of-the-art transimpedance amplifiers and modulator drivers, and integrated Si photonics. Codesign and co-optimization become the key factors in further scaling the power and performance of coherent transponders. Different elements of optical communication systems have been subjects of prior workshops at the RFIC. This workshop, however, brings together a multidisciplinary team of experts to inform the audience about technology advances in all essential components that make up an integrated optical communication system. Codesign, co-optimization, and hybrid integration will be the theme and be addressed by several speakers from different perspectives. Emerging applications for coherent detection, such as lidar, will be discussed, and the use of AI and machine learning in the next generation of optical communication systems will be explored.	Ricardo Aroca and Bahar Jalali Farahani	RFIC/IMS	Sunday	FD
Fully Integrated Si Versus Hybrid RF Front-End Systems for mm-Wave 5G Highly Efficient PA Design Tradeoffs	Low-noise amplifiers (LNAs), PAs, switches, and phase shifters can all be integrated into one Si RF front-end IC for mm-wave 5G, and even multichannel integration may be possible. However, the advantages in the cost, robustness, and manufacturability for an all-Si RF front-end IC approach is not yet clear when compared to a hybrid III-V–Si solution. The power efficiency of mm-wave 5G broadband PAs is considerably lower than that of 4G, and gallium nitride (GaN)–Ga arsenide (GaAs)–III-V-based PAs have a high output power and good efficiency versus Si-based PAs. At the same time, the cost of hybrid integration approaches increases rapidly as the complexity grows, as will be covered in this workshop. Can newer technologies enable an all-Si RF front end that can match the performance of hybrid solutions? As we go to mm-wave frequencies, simultaneously achieving high efficiency and linearity for PAs becomes extremely challenging, and novel RF linearization techniques are required. All-Si solutions with superstrates for antennas are currently being investigated, and we will discuss the PA–antenna and PA–package codesign for 5G MIMO PAs, as well.	Debopriyo Chowdhury, Donald Lie, and Patrick Reynaert	RFIC	Sunday	FD

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Highly Linear and Linearized PAs for mm-Wave Communications	Presently, PAs do not fulfill all the requirements of linearity, energy efficiency, and bandwidth that are required for mm-wave operation for 5G and future communications, particularly for user equipment (UE). New techniques are required in the design of ultrahigh-linearity PAs and through improved linearization, efficiency enhancement, and bandwidth extension to dramatically improve performance and realize the full potential of future communications systems. It is noted that all aspects of mm-wave PA design become more challenging when the devices are placed in arrays that have nonnegligible element-to-element coupling. This workshop will explore PA designs in the mm-wave spectrum as well as linearization techniques (including digital predistortion, outphasing, and envelope tracking) and efficiency enhancement (such as load and supply modulation).	Margaret Szymanowski and Jeffrey Walling	RFIC	Sunday	FD
mm-Wave Phased-Array Transceiver Design: From Basics to Advancements	This tutorial-style workshop by top phased-array experts from academia and industry will provide an in-depth learning experience for attendees and walk participants through the different aspects of mm-wave phased-array transceiver design. The workshop will cover the following topics: 1) Si-based mm-wave phased-array basics; 2) phase and gain control circuits; 3) phased-array antenna and antenna interface design; 4) package, antenna, and module codesign and calibration for end-to-end design; 5) on-chip and over-the-air phased-array measurements; and 6) current 5G NR phased-array systems and limitations and the outlook for 6G.	Kenichi Okada and Bodhisatwa Sadhu	RFIC	Sunday	FD
Satellite Systems: A Top-Down Review of Satellites, Space Communication, and Hardware	Do you want to understand the *Go* in the GoGo Wireless In-flight Satellite Internet? Are you interested in learning about satellite orbits, link budgets, and CubeSats and their demands on RF electronics? Do you need to design on CMOS using a high-reliability process design kit or next-generation radiation-hard process? This vertically oriented workshop will provide technical know-how, from the satellite to the device, by bringing together commercial and defense leaders in space hardware. A review of satellite orbits and demands on antenna systems as well as a detailed overview of CubeSats and the drive for small-form-factor, high-reliability electronics will be included, followed by a comprehensive analysis of the market and challenges for satellite communication terminals and the need for high-reliability electronics. The workshop will then cover RFICs for space in CMOS and III-V technology, including a special overview of advanced very-low-power CMOS for deep space sensors. Finally, a technical discussion of radiation types and their effects on CMOS as well as techniques to successfully design in space using a radiation-hard library and a next-generation radiation-hard process on advanced bulk CMOS will be offered. This will be a great place for new and experienced engineers to learn about the adventure of space.	Tim LaRocca and Steven Turner	RFIC/IMS	Sunday	FD

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Sub-6-GHz Advanced Transmitter Architectures and PA Linearization Techniques	5G communications in sub-6-GHz frequencies offer enhanced data rates, capacity, and flexibility but face challenges, such as energy efficiency, linearity, integration, and scalability. To increase battery life, optimizing PA efficiency is of utmost importance. This workshop will investigate digitally intensive transmit architectures and predistortion techniques that enhance the efficiency of transmitters and PAs used in these next-generation wireless systems. Experts from industry and academia will share their latest research on linearization techniques to build highly efficient linear PAs in various technologies, employing Doherty, outphasing, and polar topologies. Circuit topologies and digital signal processing algorithms for the predistortion of these PAs will also be covered.	Antoine Frappé, Jennifer Kitchen, and Raja Pullela	RFIC	Sunday	FD
Advanced Multichip Modules and Packaging for 5G and Beyond	The realization of advanced 5G–beyond mm-wave front-end multichip modules (MCMs) and their packaging poses daunting design challenges to fit significant electrical functionality within a relatively small space while meeting or exceeding electrical, mechanical, thermal, and reliability requirements for UE and base stations (BSs). As a result, it will be more important than ever to resolve the signal integrity, reduce the insertion losses imposed by various interconnects and packaging techniques at the chip, and analyze and optimize module and board levels through co-engineering across different design disciplines. This workshop will be organized to address current and future design and manufacturing techniques by bringing together subject matter experts from the IEEE Electronic Packaging Society and MTT-S communities. Presentations will cover the state of the art in advanced MCM and packaging processes and materials, circuit and system design for signal diversity, and RFIC and beamforming approaches to leverage emerging capabilities. In particular, the workshop will highlight advances in 2.5D and 3D heterogeneous integration, antennas-in-package, embedded high-Q passives, wafer-level packaging and testing challenges, 3D antennas with a transient Earth voltage and EZL, Ka-band phased-array modules for 5G BSs, 28-GHz modules with software-defined radio, and a system-in-package-based embedded wafer-level ball grid transceiver at 60 and 77 GHz.	Lim Lee, Kamal Samanta, and Harrison Chang	IMS	Monday	HD

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Calibrated Testbeds for the Characterization, Optimization, and Linearization of Multiple-Input PAs	With the deployment of sub-6-GHz 5G, a strong interest in power-efficient broadband amplifiers has emerged. Multiple-input PAs, such as outphasing PAs (OPAs) operating in the Doherty–Chireix continuum and load-modulated balanced amplifiers (LMBAs), appear to provide promising opportunities. This workshop will focus on the new types of calibrated testbeds, test equipment, and associated control and measurement techniques that have been developed for characterization, optimization, and linearization. The characterization of multiple-input PAs introduces new challenges. Different RF sources need to be phase locked if they do not share the same LO. The modulation needs to be time synchronized. The testbed itself must be calibrated at its test ports for power, the LO phase, and the group delay. The measurements also must consider reflections since multiple-input PAs exhibit dynamically varying input impedances. New types of test solutions are emerging to facilitate the characterization and linearization of multiple-input PAs, including the use of multiport vector network analyzers (VNAs) operated as multiple-channel vector signal analyzers, the synchronization of modular instruments, and the use of built-in self-tests combined with machine learning. In support of the workshop theme, two talks will also review the theory of multiple-input PAs, such as OPAs and LMBAs, to establish the drive requirements, and two talks will address the linearization of multiple-input PAs. An emphasis throughout the workshop will be placed on describing the various testbeds that have been developed, their calibration, and their use for the characterization, optimization, and linearization of multiple-input PAs.	Apolinar Reynoso Hernandez and Karun Rawat	IMS/ARFTG	Monday	FD
Cryogenic Electronics for Quantum Computing and Beyond: Applications, Devices, and Circuits	Quantum computing has spurred intense research activity toward the development of cryogenic electronics to control quantum devices. Furthermore, several applications beyond quantum computing require cryogenic electronics, either to be compatible with very low ambient temperatures or to outperform their room-temperature counterparts. This workshop will present an overview of cryogenic electronics, from applications to device operation, focusing on ICs. First, typical applications that demand cryogenic temperatures, such as quantum computing (the first talk) and particle physics (the second talk), will be presented to highlight requirements, current limitations, and future perspectives. Next, the operation of SiGe (the third talk) and CMOS (the fourth talk) at cryogenic temperatures will be discussed. Finally, four design examples of ICs that employ SiGe, bulk CMOS, and fully depleted Si-on-insulator CMOS and that target low-noise amplification and quantum computing will be shown, thus practically demonstrating techniques to exploit (or circumvent) cryogenic operation.	Joseph Bardin and Fabio Sebastiano	RFIC	Sunday	FD

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Workshop Title	Event Abstract	Workshop Organizer(s)	Sponsorship/ Cosponsorship	Day of Workshop	Half Day (HD)/Full Day (FD)
Cryogenic RF and mm-Wave Technology and Circuit Platforms: A Path Toward Quantum Computing	Cryogenic electronics will have a strong impact on our society through applications such as high-performance and quantum computing and space communication. Quantum computers, for instance, have the potential to radically advance our computational capability and are predicted to strongly impact fields such as medicine, chemistry, science, and finance by solving problems that cannot readily be handled by classical computers. Quantum computer hardware implementations rely on various quantum bit (qubit) technologies, such as superconducting qubits, spin qubits, and Majorana fermions. All these qubits require cryogenic temperatures (<4,000 K) to operate efficiently, and they need analog RF signals for their manipulation and results. Thus, there is a demand for cryogenic electronics that have a large array of functionalities, operating under extremely low noise conditions and with limited power budgets. Achieving this will require an enhanced understanding of existing transistor technologies, 3D integrated systems, and novel nanoelectronic devices that employ unique low-temperature effects. With these new devices, new ultralow-noise, ultralow-power, and wideband circuits and systems are emerging, laying the groundwork for the next computing revolution. In this workshop, we will explore state-of-the-art quantum computing applications and their associated technologies, circuits, and analog RF platforms.	Michael Schroeter, Didier Belot, and Adrien Morel	IMS	Monday	FD
Machine Learning and AI Techniques With Intelligent Systems for Wireless Communication, Sensing, and Computation	The recent development of machine learning and AI techniques has extended the capability of conventional RF and mm-wave systems beyond their classical limits to solve unconventional problems. This workshop will showcase intelligent mixed-signal, RF–mm-wave, and microwave photonics systems, which exploit machine learning and AI techniques in three focused application areas: advanced wireless communication, sensing, and computation. With a theme focusing on wireless communication, the workshop will explore machine learning and AI techniques exploited for RF signal conditioning, dynamic wireless spectrum collaboration, microwave device modeling, wireless PA linearization, and mm-wave phased-array beamforming. Examining sensing and imaging applications, the workshop will present machine learning-based radar signal processing techniques for autonomous navigation and implementations in frequency-modulated continuous-wave radar systems. The unique advantages of using neural networks in superresolution radar signal processing will also be discussed in comparison to classical approaches, such as maximum likelihood estimation. Regarding computation, the workshop will culminate in mixed-signal and photonic IC techniques to accelerate energy-efficient, multidimensional signal processing for intelligent RF–mm-wave systems with machine learning and AI algorithms. In addition, the workshop will discuss several applications of photonic deep learning hardware accelerators in wireless communication, such as RF fingerprinting. The emphasis will be on the design considerations and interactions between underlying hardware system architectures and signal processing algorithms for advancing the capability of classical systems by leveraging machine learning and AI techniques.	Markus Gardill, SungWon Chung, and Young-Kai Chen	IMS/RFIC	Monday	FD

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Workshop Title	Event Abstract	Workshop Organizer(s)	Sponsorship/ Cosponsorship	Day of Workshop	Half Day (HD)/Full Day (FD)
mm-Wave and THz Technologies for Multigigabit-per-Second Wireline Interconnects	High-frequency communication has traditionally been used for wireless transmissions between devices and network access points. With the continuous data demand in fifth- and sixth-generation wireless communication standards (5G and 6G), assuring extremely high data rates at different system and platform levels is critical. While electrical cables have traditionally been used to address information transmissions in data centers and many enclosed platforms, it is becoming more evident that alternative interconnects will play a critical role in future platforms. This workshop will review the most recent advances in using mm-wave and THz interconnects in conjunction with waveguide channels, including dielectric waveguides and parallel plate waveguides. Selected experts from academia and industry will discuss end-to-end components and the challenges associated with novel wireline interconnects. The topics will include semiconductor technology selection, mm-wave wireline transceivers, high-frequency packaging, waveguide channels, and materials as well as relevant equalization techniques. Each speaker will base his presentation on full interconnects that he has designed and experimentally characterized. These include transceivers, waveguides, packaging, and testing. Transceivers addressed in the talks will have carrier frequencies in the range of 130–325 GHz.	Jim Buckwalter, Telesphor Kamgaing, and Ahmet Cagri Ulusoy	IMS	Monday	FD
Platforms, Testbeds, and Trials: The Next Step for 5G and Future Wireless Networks	Emerging RF technologies for 5G, such as MIMO, scaled phased arrays, and mm-wave transceivers, have reached a significant level of maturity, enabling initial product deployments and standards completion. While RF-specific challenges remain, significant wireless R&D efforts around the world are now integrating the new RF capabilities into end-to-end wireless networking platforms and application demonstrations. Such testbeds and application proofs of concept are key to accelerating the commercial deployment of 5G, augmenting the technology's impact and value, and ultimately igniting the vision for what 6G may become. This workshop will present a comprehensive overview of multidisciplinary efforts in the areas of advanced end-to-end platforms for wireless research, emerging 5G trials, and testbeds for NR concepts, including those expected to play a key role in 6G. Common themes will include the enablement and execution of real-world wireless experimentation and projects where emerging RF hardware capabilities (such those provided by multiantenna mm-wave systems) are a main differentiator. The expert speakers will present diverse perspectives on these topics, including university- and industry-led research, government–academia collaborations, and deployments by telecommunication equipment providers. The audience will gain a broad understanding of the challenges associated with incorporating RF hardware into these testbeds and performance results from platform-scale experimentation. Last but not least, a common thread of discussion throughout the workshop, and particularly during the concluding panel, will concern an initial set of requirements, concepts, and implementation challenges for 6G networks.	Alberto Valdes-Garcia, Christian Fager, and Zhizhang Chen	IMS/ARFTG	Monday	FD

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Spatiotemporal Metastructures for Microwave Applications	Spatiotemporal metastructures represent an emerging class of dynamic and multifunctional microwave systems. These systems present unique, efficient, and multifaceted operations that are not available in conventional microwave components and traditional static metamaterials. Such operations are endowed by peculiar properties of the space–time modulation technique, which leads to structures featuring nonreciprocal shifts in their temporal frequencies, spatial frequencies, and phase. The space–time modulation technique is a promising paradigm for nonreciprocity and frequency generation in several microwave applications, such as magnet-free isolators and circulators, pure frequency mixers, nonreciprocal phase shifters, unidirectional beam splitters, compact transceiver front ends, versatile multifunctional diffraction gratings, traveling-wave parametric amplifiers, full-duplex beamsteering devices, and multifunctional metasurfaces.	George Eleftheriades and Sajjad Taravati	IMS	Monday	FD
Wireless Power Transmission: Myths and Reality	Wireless power transmission has gained a lot of attention during the past decade, and various applications have been proposed, from low-power IoT device nondirective powering to beaming mm-waves for propulsion. The goal of this workshop will be to present a critical review of wireless power transmission applications, from very low-power to high-power ones, using kilohertz to gigahertz frequencies. Near-field inductive and capacitive power transfer in the kilohertz and low-megahertz industrial, scientific, and medical bands will be reviewed and compared in the context of kilowatt-level power for stationary and in-motion electric vehicles. Power transfers for implants will be discussed and near-field instances compared to midfield ones. Directive beaming for space solar satellites will be examined in the context of existing demonstrations, and roadblocks to real systems will be presented. Finally, nondirective, far-field, low-power simultaneous wireless information and power transfer will be addressed as a way to make the 5G massive IoT a reality. The 5G massive IoT vision calls for thousands of interconnected devices using a multitude of sensors to provide useful information. As a result, mechanical and electrical properties become important, such as a conformal profile, compact size, flexibility, stretchability, and even biodegradability. The combination of wireless power transmission and information can be the solution to the needs of the massive IoT, due to the simplicity of the circuit and the ability to minimize the use of batteries, perhaps completely eliminating them.	Nuno Carvalho and Zoya Popovic	IMS	Monday	FD

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State-of-the-Art Characterization and Test Techniques, From Design to Production of Antenna-in-Package Modules and Antenna-On-Chip	Following industry trends, phased-array antennas and beamforming techniques have had a prominent place in IMS talks in recent years. These antennas have been around for decades but resurfaced as solutions for essential industrial applications as carrier frequencies increase and applications range from telecom to radar. Presently, the most current form factors for extremely compact phased arrays are the antenna-in-module and the antenna-in-package. Meanwhile, the antenna-on-chip has been demonstrated and will become a reality going toward and into the THz frequency range. To become commercially viable, it is essential that these parts can be tested fast, in large quantities, at a low cost, and with confidence. There are different approaches to achieve this. A possibility is to spend more effort on extensive precharacterization during design to reduce tests during production. Or maybe built-in testing is the way to go. On the other hand, adapted near-field characterization techniques can replace the anechoic chamber and meet the requirements of the production test. Finally, reverberation chamber techniques could offer a solution for some test requirements. The goal of this workshop will be to give an overview of different over-the-air characterization techniques, from design to production testing. Two categories of production test are distinguished: go/no-go and parametric, such as error vector magnitude measurements. In addition, the differences between the characterization and testing of BS panels and UE need to be taken into account. This workshop will go over the different existing and new over-the-air characterization techniques that can be used from design to production testing. Additionally, some presentations will explain which characteristics of phased-array antennas need to be measured and how they can be tested, characterized, and calibrated using clever techniques to speed up the evaluation process.	Marc Vanden Bossche	IMS	Friday	HD
Past and Future of Microwave Passive Components (in Memory of Prof. Arthur A. Oliner)	This workshop will present a road map of microwave passive components and transmission lines, starting from a historical overview and a review of the state of the art and providing an outlook for forthcoming technologies, solutions, and applications. Transmission lines and passive components have always represented a fundamental part of electronic systems, due to the functions they perform and the need to interconnect different elements, devices, and subcircuits. The investigation of novel passive components as well as compact and broadband transmission lines has attracted significant interest in the microwave community, and, today, it covers a notable portion of the scientific literature. This workshop will have a twofold aim: to illustrate the roots of the microwave community in the area of passive components (well represented by the scientific activity of late Prof. Arthur A. Oliner, to whom the workshop is dedicated) and to indicate the current trends and future lines of development in the area, also considering the wide range of applications that require advanced passive components and transmission lines.	Tatsuo Itoh, Aly Fathy, Maurizio Bozzi, and Ke Wu	IMS	Friday	HD

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Advanced Microscale Fabrication and Integration Techniques for Emerging mm-Wave and Sub-mm-Wave Applications	Micromachining, high-precision computer numerical control (CNC) milling, 3D printing, substrate-integrated waveguides: which fabrication and system integration technology will dominate in the future for waveguide-based mm- and sub-mm-wave systems? What are their advantages and limitations? Which method is suitable for which frequency range and for which applications? Which technology is preferred for prototyping for low volumes? Which one is scalable to high-volume production for emerging THz applications? What is left of the initial hype about micromachining and 3D printing? How much has high-precision CNC milling progressed in recent years? This workshop, whose speakers are leading the development and application of these fabrication methods in industry and academia, will aim to provide a fair comparison of these technologies, show current trends and developments toward the future, and investigate the advantages and limitations in view of different frequency bands, from mm-wave to THz frequencies, for different applications, from telecommunication to space, and for low-volume prototyping, up to the 24/7 volume production of advanced microwave systems. Performance and commercial aspects and limitations of state-of-the-art, high-precision CNC milling in low- and medium-volume production will be presented by representatives of Virginia Diodes and Rohde & Schwarz. Different micromachining techniques, including Si micromachined hollow and dielectric waveguides, polymer micromachining, and laser machining, will be presented by speakers from the NASA Jet Propulsion Laboratory, KTH Royal Institute of Technology, and Birmingham University. State-of-the-art commercial 3D printing for microwave applications will be provided by market leader SwissTo12. Substrate-integrated waveguide technology will be presented by one of the strongest innovation drivers in this field, Polytechnique Montreal. Since space applications often drive technology development, a talk by a representative of the European Space Agency will summarize manufacturing requirements and the organization's experience with novel fabrication methods. After a day of intense information exchange, the workshop will conclude with an interactive panel discussion.	Petronilo Martín-Iglesias, Gerd Hechtfischer, Jeffrey Hesler, Joachim Oberhammer, Choonsup Lee, Ke Wu, Yi Wang, and Esteban Menargues	IMS	Friday	FD

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TABLE 1. Microwave Week 2021 workshops. (*continued*)

Workshop Title	Event Abstract	Workshop Organizer(s)	Sponsorship/ Cosponsorship	Day of Workshop	Half Day (HD)/Full Day (FD)
Beamforming in Massive MIMO for mm-Wave NR	There are two perspectives in dealing with beamforming in massive MIMO. The IEEE Communications Society community has performed MIMO signal processing, including beamforming, in the digital domain, without much consideration of hardware implementation challenges. This would require significant computational capacity at BSs and mobile units if it were transferred to massive MIMO in mm-wave NR, where hundreds and maybe thousands of antennas are involved. Following such a "fully digital solution" perspective necessitates that each array element has its own RF front end. The MTT-S community, on the other hand, must be in some doubt about the costs of providing such a huge number of RF front ends with PA–LNAs, up/down-converting mixers, digital-to-analog and analog-to-digital converters, filters, and so forth, backing each individual array element of a massive MIMO antenna array. A major cost factor in this scenario is the heat generation by the PAs and the proximity of the LNAs, whose noise performance strongly depends on the ambient temperature. Despite the fact that oversized, fully digital phased arrays have been developed for military purposes, the built-in heatsinking mechanisms are very costly and might not be suitable for commercial purposes. Splitting a large array into separate medium-size ones is one of the scenarios recently implemented. However, the directivity of such separate arrays is much lower than that of the large one. Therefore, the individual arrays are not capable of generating beams as narrow as those produced by the composite version. Multiple beam operations benefit considerably from narrow beams (there is more power bundling, less interference between neighboring beams, and so on). The alternative, which is called the *hybrid solution*, is to use subarrays, with a single RF front end for each. Multiple steerable beams would require Butler matrices and/or Rotman lenses, with several couplers and phase shifters for each subarray. The geometry and topology of subarrays are also crucial parameters for avoiding the generation of grating lobes with the associated ambiguity. A comparison between these two alternatives in terms of hardware–software complexity, power consumption in both the RF front end and the digital signal processing, PA linearity and efficiency, signal distortion, and so forth is one of the main aspects of this workshop. Another will be to identify meaningful beamforming architectures from implementation feasibility and information theory perspectives. In particular, optimal architectures can sacrifice a small amount of traffic capacity in favor of a significant reduction of the implementation complexity. The related analog–digital balance must be in line with the network deployment strategies of mobile network operators. This workshop will be part of the first IMS forum, which will cover this rapidly evolving topic. The presenters are well-known experts. Afterward, discussions between the speakers and the audience will lead to a comprehensive review of the current state of the art, existing challenges, and future outlook for this very promising area.	Abbas Omar and David Chen	IMS	Friday	FD

(*continued*)

TABLE 1. Microwave Week 2021 workshops. (*continued*)

Workshop Title	Event Abstract	Workshop Organizer(s)	Sponsorship/ Cosponsorship	Day of Workshop	Half Day (HD)/Full Day (FD)
Cutting-Edge THz Solid-State Technologies, From Devices to Earth–Space Applications: Surfing on Noise, Signal, and Power Generation	With the amazing growth of THz technologies, solid-state approaches have been pushed forward to fill gaps. This workshop will aim to provide a deep overview of the recent features of mm-wave–THz active devices and circuits regarding 1) signal generation (oscillator architecture, harmonic generation, on-chip harmonic combination, and phase management); 2) amplification (medium- and high-PAs, LNA architectures, and performance); and 3) the noise performance of single devices and circuits. Targeting the complete characterization of such advanced technologies, the workshop will also focus on advances in characterization methods for solid-state Si–III-V active devices and noise sources at room temperature, up to the sub-THz/THz range. In particular, power measurements, linearity, and new noise measurement techniques will be covered for accurately extracting the noise performance up to mm-wave and THz ranges. State-of-the-art performance for a broad range of cutting-edge mm-wave–THz (0.1–1-THz) technologies, such as Si (CMOS–bipolar CMOS) and III-V [GaAs, indium phosphide (InP), and GaN], will be presented. The noise properties and amplification process of InP high-electron mobility transistors at THz frequencies will be discussed in detail. Theoretical considerations about how to optimize a technology for low-noise performance and LNA examples in the mm-wave and sub-mm-wave frequency ranges will be given as well as PA and transceiver applications in the higher mm-wave frequency range. Signal generation (power, efficiency, and phase noise) will be covered using technologies including III-V and CMOS THz oscillators as enablers of the development of systems in the 0.1–1-THz frequency range, with system waveguide blocks and single-chip THz products for communication, imaging, sensing, and radar. Finally, packaging and integration approaches as well as system-level examples of enabled applications will be discussed. High-data-rate communications for future wireless backhauls are now envisaged in the D band (110–170 GHz) as well as in the H band (around 300 GHz). With mm-wave and sub-mm-wave technologies, these systems can now target 100 Gb/s, with link budgets that are close to those of technologies up to the kilometer range. Other THz applications in space (intersatellite links and CubeSats) with high performance at the chip scale and low costs will drive future developments and road maps.	Guillaume Ducournau and François Danneville	IMS	Friday	FD

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TABLE 1. Microwave Week 2021 workshops. (*continued*)

Workshop Title	Event Abstract	Workshop Organizer(s)	Sponsorship/ Cosponsorship	Day of Workshop	Half Day (HD)/Full Day (FD)
Enabling Technologies for Efficient Ultrahigh-Speed Wireless Communication Systems Toward 100 Gb/s	Recently, major advances in analog front ends for ultrahigh-speed wireless communication systems targeting data rates toward 100 Gb/s have been demonstrated at frequencies between 100 and 300 GHz. To deliver this performance in a complete system, these devices need to be integrated with very-high-bandwidth baseband components, analog-to-digital converters, and high-speed digital signal processors. Substantial challenges must be addressed, most notably, high relative and absolute bandwidth, high frequencies at technological limits, and low efficiency in terms of power consumption and system size. Consequently, reconsidering central system architecture decisions from a holistic perspective can be beneficial to achieve efficient implementations. Enabling technologies will be covered, including front-end designs in different frequency ranges (75–300 GHz) and various technologies (SiGe, InP, and CMOS), along with antenna-to-baseband integration, phased-array–MIMO, synchronous sampling receivers–analog-to-digital converters, and efficient real-time basebands.	Noriaki Kaneda and Christian Carlowitz	IMS	Friday	FD
Materials by Design for Microwave and mm-Wave Communications	Innovations in materials science are crucial for the development of wireless communications at microwave and mm-wave frequencies. Materials-by-design approaches offer the enticing possibility of engineering optimal property–performance relationships. Such methods can be applied across a wide variety of systems, including ferrite ceramics, tunable oxides, perovskites, and novel nanomaterials. This workshop will bring together researchers in all facets of this approach in the context of microwave and mm-wave communications. We will focus on a multifaceted technique that includes materials engineering, materials and device modeling, measurements, and the incorporation of material building blocks into microwave and mm-wave systems.	Thomas Wallis and Nathan Orloff	IMS	Friday	FD
Microwave Acoustics and RF Microelectromechanical Systems Enabling 5G	The development of 5G systems promises paradigm-shifting applications while presenting unique challenges across materials, devices, modules, and systems. One area that calls for innovative solutions is front-end acoustic filtering at sub-6 GHz and beyond. To that end, this workshop will feature a group of international experts who will present upcoming solutions from industry as well as innovative approaches from academia. The workshop will first highlight system-level considerations and then delve into new materials and device design/modeling techniques before exploring comprehensive solutions that require the codesign of devices, circuits, integration, and packaging. A panel discussion will conclude the workshop with insights into and outlooks for trending acoustic technology candidates as well as the long-term prospects of acoustic devices in RF front end.	Songbin Gong and Andreas Tag	IMS	Friday	FD

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TABLE 1. Microwave Week 2021 workshops. (*continued*)

Workshop Title	Event Abstract	Workshop Organizer(s)	Sponsorship/ Cosponsorship	Day of Workshop	Half Day (HD)/Full Day (FD)
Microwave Magnetic Materials and Devices for Novel Microwave Functionality	Microwave magnetic materials and devices provide a rich range of functions and capabilities that cannot be achieved with traditional microwave electronic devices. Magnetic devices offer opportunities for nonreciprocal behavior, frequency-dependent nonlinear responses, and size reduction for high-frequency components. If current materials and mechanical challenges are overcome, these unique devices are expected to enable future system capabilities, such as full-duplex operation, improved adaptability, and reduced size, weight, and power. Academic and industry speakers will cover topics such as magnetic materials and physics, materials synthesis and integration, and device performance and properties. Thus, this workshop will provide both a background on these technologies for nonexperts and an up-to-date perspective on the state of the art in magnetic materials and devices.	Chris Nordquist and Dimitra Psychogiou	IMS	Friday	FD
Noncontact Vital Sign Detection and Human Motion Tracking Using Wi-Fi and Radar Techniques	Short-range microwave radar sensors are capable of remotely detecting precise movements and wirelessly estimating the distance from the sensor to the subject. In recent years, they have been attracting a lot of attention in biomedical applications for noncontact vital sign sensing. Biomedical radars are not to be deployed alone but as part of multimodal wireless sensor networks that remotely control radar hardware settings to enable a diverse range of applications, from vital sign monitoring to counting people and observing activity. Due to the importance of vital signs, breathing and heart rates have been widely used in health care. In the past few years, various systems and approaches have been proposed to detect and monitor breathing and heartbeats. Radar sensing has enabled several interactive human–machine interfaces too, such as human sensing and tracking for presence, occupancy, and counting. Moreover, techniques beyond vital sensing for touchless human–computer interaction have been developed. Our human hands are natural tools for performing actions and gestures to interact with the physical world. Traditional radar signal processing involves 2D fast Fourier transforms to translate raw analog-to-digital converter data into range–Doppler images, followed by moving target indicators to remove static targets and minimum variance distortionless response beamforming across channels to produce range–angle images. This is followed by a constant false alarm rate detector and clustering algorithm to localize human targets. During the past few years, a new class of human sensing systems using Wi-Fi signals has been developed. The fundamental principle that enables human sensing via Wi-Fi is that when a user moves in a wireless channel, his or her motion causes wireless channel metrics, such as the channel state information, received signal strength, signal polarization, and signal's angle of arrival, to change. The patterns of change in wireless channel metrics are unique for different human movements. By learning these patterns for any given movement, a Wi-Fi-based human sensing system can recognize motions. Meanwhile, advances in machine learning, parallelization, and the speed of graphics processing units, combined with the availability of open, easily accessible implementations, have brought deep neural networks to the forefront of research in many fields. Likewise, deep learning has offered significant performance gains in the classification of radar micro-Doppler signatures and Wi-Fi-based human sensing, paving the way for new civilian applications of RF technologies that require a greater ability to recognize a larger number of classes that are similar in nature.	Aly Fathy, Jenshan Lin, and Changhi Li	IMS	Friday	FD

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TABLE 1. Microwave Week 2021 workshops. (*continued*)

Workshop Title	Event Abstract	Workshop Organizer(s)	Sponsorship/ Cosponsorship	Day of Workshop	Half Day (HD)/Full Day (FD)
Recent Advances in mm-Wave Radar Circuits and Systems for Emerging Sensing Applications	The number of radar-based 3D sensing applications at mm-wave frequencies is continuously growing. Radar sensors are used almost everywhere to make daily life more comfortable and safer. Driven by the demand for size reductions, radar module operating frequencies keep increasing, as one can integrate antennas in packages and on chips to achieve smaller dimensions. A compact module size, low dc power consumption, and affordable price present numerous opportunities for radar sensors to be employed in a new range of applications. Thus, there is growing interest in using radar sensors beyond classical applications as, e.g., automotive radar and door openers. Recent advances in modulation techniques and radar signal processing techniques, in combination with MIMO radar arrays, enable achieving very high spatial resolutions for 3D radar imaging. Hence, radar has become a viable option for such emerging applications as wearable devices and robot-assisted surgery. In this workshop, distinguished speakers from leading companies and academia will present the latest advances in a wide range of topics, from chip design to advanced system architectures and modulation techniques for emerging (nonautomotive) radar applications, such as industrial, health care, unmanned aerial vehicle detection, smart presence detection, and indoor people monitoring. The novel system architectures addressed in this workshop will include reconfigurable transmitters toward software-defined radar, reconfigurable systems-on-chip with power duty cycling using a finite-state machine, radar interference detection and mitigation techniques, and achieving high spatial resolutions via a single radar sensor using delay lines as well as MIMO radar in combination with chirp modulation and frequency-division multiplexing. Additionally, physical implementation aspects will be addressed by comparing Si-on-insulator CMOS and SiGe technology for mm-wave radar realizations. Finally, design aspects of integrated antennas-on-chip for radar applications will be discussed. A brief concluding discussion will round out the workshop by summarizing the key information.	Vadim Issakov and Amelie Hagelauer	IMS	Friday	FD

transceiver circuits and power amplifiers (PAs); advanced microfabrication, integration, and packaging technologies, from RF to terahertz (THz); and the design and calibration of complex phased and multiple-input/multiple-output (MIMO) arrays for 5G and beyond.

We have an exciting array of workshops for IMS2021, focusing on emerging technologies and system-level topics, including cryogenic quantum computing, machine learning and artificial intelligence (AI) for sensing and imaging, positioning and localization, noncontact vital sign measurement, wireless power transmission, and satellite and optical communication systems for cloud and data center applications. There is also a special workshop in memory of Prof. Arthur A. Oliner that covers past and future microwave passive components.

The titles, abstracts, and organizers of each workshop are listed in Table 1. For updates and the full program, including schedules, speakers, presentation titles, and abstracts, please check the IMS2021 website, at https://ims-ieee.org/ims2021. The IMS2021 Workshops Committee believes these events provide a great opportunity to learn about key advancing technologies, a chance to connect with subject matter experts, and an opportunity to exchange ideas with other attendees.

The workshops program is an ideal reason to extend your stay in Atlanta (or your virtual visit online) and to take full advantage of the offerings of Microwave Week with the IMS, RFIC Symposium, and ARFTG Conference. And, for those attending in person, in the evenings there will be additional time to take advantage of all the city of Atlanta has to offer, including the Georgia Aquarium, Atlanta Braves baseball, and fried pie at the Varsity. On behalf of the workshop organizers and speakers and the IMS, RFIC, and ARFTG Technical Program Committees, we hope you join us at Microwave Week 2021.

IMS2021 Focus Sessions *(continued from page 38)*

high-performance switches for use in a wide range of RF applications. The proposed focus session will bring together the best laboratories involved in this field and present their latest advances in the development of highly reliable RF switches, integrated PCM/CMOS circuits, switches capable of operating up to mm-wave frequencies, and highly miniaturized switch matrices. This area of research is arriving at an interesting time, when efforts at companies are beginning to yield very promising results while, at the same time, a growing number of academic laboratories are introducing new applications.

Emerging Machine Learning Techniques for CAD of RF/Microwave Circuits

The purpose of this session is to disseminate knowledge about and discuss the latest advances in ML techniques for CAD in terms of microwave and RF circuits. Recent research has shown that ML techniques are uniquely capable of developing closed-form parametric surrogate models of general passive and active circuits that could be used in lieu of rigorous and computationally cumbersome models for extremely fast numerical analyses and virtual prototyping. However, issues such as intractable computational training and testing costs for ML models, especially for a large number of parameters (i.e., high-dimensional feature spaces), remain an open problem. Moreover, newer applications of ML models, such as optimization, uncertainty quantification, and statistical variability analysis, are constantly emerging. The proposed focus session will include papers covering these immediate areas—something not possible in regular IMS technical sessions. Hence, the proposed focus session is of critical importance and interest to the microwave CAD community and an essential addition to the IMS2021 program.

Heterogeneous and High-Density Flex RF Package Integration

High-functional-density heterogeneous package integration will drive future innovations in wireless devices and sensing for medical applications, home monitoring, and security, among other application areas. Such packaging should be adaptable to different market segments based on their respective technology drivers. For example, Internet of Things RF modules will need scalable and low-cost flex-rigid hybrid packaging with sensing and other component integration for specific applications. Although several technologies have been proposed and developed as key building blocks, a clear challenge is the integration of basic package innovations to address the aforementioned application areas. This focus session will compile the latest packaging materials and processes for various segments, highlighting their specific opportunities and remaining challenges while bringing together key building blocks with flex-compensated features in flexible and wearable packaging and package-integrated RF components for 5G+, smart cities, smart skin, and autonomous cars applications.