ARFTG-99th Microwave Measurement Conference

FROM FUNDAMENTAL TO CUTTING-EDGE MICROWAVE MEASUREMENT TECHNIQUES TO SUPPORT 6G AND BEYOND

June 24th, 2022

Conference Program

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ARFTG-99th Executive Committee would like to thank our sponsors for their great and valued support of the conference and the ARFTG organization.

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Welcome to ARFTG-99th Conference

General co-chairs Jeffrey Jargon and Marco Spirito would like to welcome you to the 99th ARFTG Microwave Measurement Conference on June 24, 2022, at the Hyatt Regency at Colorado Convention Center, Denver, CO, USA. Technical program co-chairs Andrej Rumiantsev and Marc Vanden Bossche have put together an outstanding program for the conference, the theme of which is “From Fundamental to Cutting-Edge Microwave Measurement Techniques to Support 6G and Beyond”.

The conference includes four oral sessions and a poster session, including an invited Keynote talk on “Characterizing Cryogenic Josephson Microwave Sources for Communications and Quantum Information” by Alirio S. Boaventura. The oral sessions include the following topics: “Enabling Wideband Characterization Techniques,” “mmWave Over-the-Air Characterization,” “Non-Linear, Large-Signal and VNA Techniques,” and “On-Wafer Techniques.” Oral technical sessions are presented in a single-track format. Extended breaks combine an exhibition and interactive forum of posters papers, which provides networking opportunities with vendors and colleagues.

The conference is preceded by the Nonlinear Network Vector Analyzer Users’ Forum and the On-Wafer Users’ Forum, both held on Thursday, June 23. Additionally, ARFTG is co-sponsoring two full-day workshops on Monday, June 20 – WMK: “On-Wafer mm-Wave Measurements” and WML: “Measurement and Modeling of Trapping, Thermal Effects and Reliability of GaN HEMT Microwave PA Technology.” On Thursday morning, June 23, ARFTG is co-sponsoring panel session PL7: “Modern Phased Arrays and OTA Testing: A Design or a Measurement Challenge?” and focus session Th1F: “Efficient Characterization and Test of Phased Array Antenna Systems: Is It Really a Nightmare?” And finally, ARFTG is co-sponsoring a technical session on Thursday morning – Th2A: “Measurement and Instrumentation Techniques for Evolving Standards in Future Technologies.”

In conclusion, we would like to recognize and thank all the participants of the 99th ARFTG Steering and Technical Program Committees for volunteering their time and effort to make this a successful conference. Details on content and scheduling can be found at the 99th ARFTG Conference web page.

Jeffrey Jargon
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General co-Chair
TU Delft

Andrej Rumiantsev
TPC Chair
MPI Corporation

Marc Vanden Bossche
TPC co-Chair
NI

Program at a Glance

MONDAY 20 JUNE 2022	TUESDAY 21 JUNE 2022	WEDNESDAY 22 JUNE 2022	THURSDAY 23 JUNE 2022	FRIDAY 24 JUNE 2022
8:00 – 17:00 WMK: IMS/ARFTG Workshop On-Wafer mm-Wave Measurements WML: IMS/ARFTG Workshop “Measurement and Modeling of Trapping, Thermal Effects and Reliability of GaN HEMT Microwave PA Technology”			8:00 – 9:40 Th1F: Joint IMS/ARFTG Focus Session 10:10 – 11:50 Th2A: Joint IMS/ARFTG Technical Session 12:00 – 13:30 PL7: Joint IMS/ARFTG Panel Session 15:30 – 16:45 NVNA User’s Forum 16:45 – 18:00 On-Wafer User’s Forum	8:00 – 9:30 Keynote: Characterizing Cryogenic Josephson Microwave Sources for Communications and Quantum Information Alirio S. Boaventura (NIST) Session A: Enabling Wideband Characterization Techniques 11:00 – 12:00 Session B mmWave Over-the-Air Characterization 13:30 – 14:50 Session C Non-Linear, Large-Signal and VNA Techniques 16:00 – 17:00 Session D On-Wafer Techniques

Monday 8:00 – 17:00

WMK: IMS/ARFTG Workshop "On-Wafer mm-Wave Measurements"

Organizers: Xiaobang Shang (NPL); Nick Ridler (NPL); Jian Ding (Spirit Semiconductor); Mike Geen (Filtronic)

Accurate on-wafer S-parameter measurement plays an important role in the development of mm-wave integrated circuits for communications and electronics applications. To this end, a group of international experts in this field will share their experience on making reliable on-wafer measurements at high frequencies (eg above 100GHz). The presenters come from different backgrounds — instrumentation manufacturers, metrology institutes, end-users in industry and academia — and so provide different perspectives on this topic. The emphasis of the workshop is on sharing practical tips (ie good practice) so that attendees can subsequently implement such methods in their own workplaces. The workshop will cover topics including calibration techniques, verification methods, guides on design of custom calibration standards, instrumentation, and applications, etc. The workshop includes two panel discussions: (i) an open discussion about the challenges/opportunities/outlooks for research into on-wafer measurements in coming years; and (ii) an opportunity for attendees to describe their own on-wafer measurement problems so that these can be discussed, and hopefully solved, during the workshop.

WMK-1

Review of Calibration Techniques for On-Wafer Measurements at mm-Wave Frequencies

Authors: Xiaobang Shang; Nick Ridler (all authors are with NPL)

High frequency on-wafer measurement underpins technological development of integrated planar circuits which are in widespread use for a large variety of applications. This talk provides a simple introductory guide to making reliable on-wafer S-parameter measurements at mm-wave frequencies, with a particular focus on choice of calibration techniques. The presentation briefly reviews different types of conventional calibration techniques suitable for 2-port high frequency measurement. Other considerations affecting the accuracy of calibration and measurement, eg design of calibration kits, are also covered.

WMK-2

Wafer-Level RF Measurement System Integrity: How to Verify and When and Why we have to do it

Andrej Rumiantsev (MPI Corporation)*; Ralf Doerner (FBH)

Wafer-level RF measurement system is a complex setup that consists of multiple components and accessories, such as: probe system, microscope, RF probes, cables, adapters, calibration standards, measurement instrumentation, etc. Configuring such a setup, obtaining accurate, repeatable and consistent measurement data require both experience and expertise in RF on-wafer measurements and calibration. This talk reviews the key contributing factors as well as practical methods for evaluating the wafer-level system integrity. By following the discussed strategy, even inexperienced engineers and operators are able to evaluate their system and deliver measurement results with high confidence.

WMK-3

Guidelines for Performing Accurate On-Wafer Measurements Including the Suppression of Parasitic Effects

Uwe Arz; Gia Ngoc Phung (all authors are with PTB)

For correcting on-wafer measurements in industrial applications, fixed-distance calibrations such as SOLT and LRM using commercial impedance standard substrates (ISSs) are usually preferred. This talk shows how the small measurement uncertainties obtained from reference calibrations like multiline TRL can be transferred to industrial calibrations as mentioned above. The talk further elaborates on the parasitic effects caused by eg multimode propagation, nonidealities of the microwave probes and crosstalk effects between adjacent structures. The impact of each effect is discussed, and measures are provided to mitigate these effects as much as possible.

WMK-4

Modeling and Correction of Probe-Probe Crosstalk at mm-Wave Frequencies

Chong Li (Univ. of Glasgow)

The crosstalk or leakage between probes may cause significant errors and uncertainties for on-wafer measurements. This is especially true at mm-wave frequencies when the probes are brought in closer proximity with each other. This talk first reviews the challenges that the existing on-wafer calibration techniques face and then introduces a new error model and the associated so-called “calibration on the fly” calibration method. The new method has been tested at 140GHz–220GHz.

WMK-5

Open Discussion 1: On-Wafer Measurement: Challenges and Opportunities for the Future

This part of the workshop gives the opportunity for speakers and audience to engage in an open discussion concerning what are the likely challenges and opportunities facing the on-wafer measurements community in the coming years. This is an interactive activity with contributions expected from all the workshop attendees.

WMK-6

Instrumentation Aspects of mm-Wave On-Wafer Measurements

Jon Martens (Anritsu)

A successful mm-wave on-wafer measurement campaign involves the positive interaction of many aspects including the probes, the calibration devices and method, the probing and DUT environment and the instrumentation. This talk focuses on the network analyzer hardware in a mm-wave setup and how it interacts with the probing problem as a deeper understanding of the important mechanisms may help one to configure the setup to optimize sensitivities and uncertainties. Specifically, mm-wave VNA architectures are presented and topics such as power control, receiver linearity and noise behavior, and port impedance and coupling characteristics are covered.

WMK-7

Broadband RF to mm-Wave S-Parameter Measurements for Semiconductor Transistor and IC Test

Gavin Fisher*; Anthony Lord (all authors are with FormFactor)

This talk presents on-wafer solutions for measurements from kHz to hundreds of GHz, for the purposes of device modeling of transistors and also the wideband characterization of integrated circuits. Approaches are discussed to overcome the challenges of over temperature measurements often required to provide full models of these devices and how automation greatly helps data volume and accuracy. Best practice calibration approaches are demonstrated and show real life verifications and device measurements in conjunction with automation approaches that allow unattended test and also easy measurement of a variety of verification structures of differing geometry. Some useful techniques within calibration software with real life data are shown to help evaluate system performance.

WMK-8

On-Wafer Measurements and Calibration at Sub-mm-Wave Frequencies Using Micromachined Probes

Robert M. Weikle (Univ. of Virginia)*; Matthew F. Bauwens (Dominion Microprobe); Michael E. Cyberey (Univ. of Virginia); Linli Xie (Univ. of Virginia)*; N. Scott Barker (Univ. of Virginia); Arthur W. Lichtenberger (Univ. of Virginia)

The first on-wafer measurements performed above 500GHz were accomplished using probes based on integrated micromachined silicon chips. The mechanics, geometry, contact tip material and calibration processes used for these probes each have significant influence on their performance as well as their use in obtaining accurate measurements. This presentation discusses the practical use and application of micromachined probes for sub-mm-wave on-wafer measurements up to 1THz, including considerations of probe skating and overdrive, contact force and resistance, measurement repeatability, and calibration. In addition, the prospects and progress towards integrating sensors and instrumentation onto the micromachined probe platform are described.

WMK-9

Combined mm-Waves and Nanorobotics for Traceable Electronics Technology

Kamel Haddadi (IEMN UMR 8520)

There is an urgent need to extend the frequency capabilities of electronics technology to support emerging communications and electronics technologies. In particular, repeatable and traceable measurement data are challenging at mm-wave and THz wavelengths. As RF signals are sensitive to both dielectric/electrical and dimensions/geometry of the device under test (DUT), RF instrumentation is combined with nanorobotics to provide fine distance and contact control between the sensing probe and DUT. In particular, on-wafer probing system, free-space and RF microscopy set-ups are augmented with piezoelectric nano-positioning stages controlled under Labview to provide fully automated solutions addressing RF sensing of macro- to nano-scale materials and devices. Measurement performance on reference materials including sensitivity and repeatability studies are shown to demonstrate the viability of the proposed solution. In addition, agile RF matching networks are proposed to enhance the measurement sensitivity of conventional vector network analyzers with 50 ohms reference impedance.

WMK-10

Open Discussion 2: Bring Your Own Measurement Problem

This part of the workshop gives the opportunity for members of the audience to describe particular problems they have faced whilst making on-wafer measurements. These problems will then be discussed, with contributions from both the workshop speakers and members of the audience. This is an interactive activity with contributions expected from all the workshop attendees.

WML: IMS/ARFTG Workshop “Measurement and Modeling of Trapping, Thermal Effects and Reliability of GaN HEMT Microwave PA Technology”

Organizers: Nicholas Miller (AFRL); Sourabh Khandelwal (Macquarie Univ.)

Gallium nitride (GaN) high electron mobility transistors (HEMTs) are an excellent technology for various microwave power amplifier applications due to the underlying semiconductor’s wide bandgap, high breakdown voltage and large peak electron velocity. A key bottleneck to the technology’s widespread and long-term adoption into commercial and military applications is its inherent electrical reliability. The physical mechanisms of GaN HEMT electrical degradation are largely unresolved and actively under investigation. In this full-day workshop, international experts in the fields of microwave measurements, trap characterization, thermal characterization, GaN HEMT nonlinear modeling, trap modeling, and TCAD modeling will present state-of-the-art research.

This interactive workshop aims to inform and excite the attendees on the advances in multiple aspects of this technology. Starting with a GaN technology overview, the planned talks will inform the audience into measurement and characterization of this technology including the charge trapping and thermal properties in these devices. Next part of the workshop covers the modeling and simulation research in GaN. Starting with an overview of modeling challenges in GaN devices, the workshop will cover the latest industry standard compact models and advances in TCAD-based modeling of GaN devices.

WML-1

The History of GaN electronics: A perspective

Authors: Umesh Mishra*; Matthew Guidry (all authors are with Univ. of California, Santa Barbara)

The development of Gallium Nitride HEMTs has been an amazing ride since its invention by Khan et al. in 1993. The first demonstration of microwave power by Wu et al. in 1996 was another significant milestone. The measured power of 1.1W/mm was higher than most GaAs devices at that time and showed the immediate promise of the AlGaN/GaN HEMT as a power source. Doped AlGaN/GaN devices without passivation showed power density of up to 4W/mm but the identification of dispersion being the cause of limited output power and the application of SiN passivation by Green et al. and Wu et al. (1999/2000) broke through this barrier and led to power densities greater than 6W/mm even on undoped HEMTs. Next the use of AlN spacers to enhance channel mobility by Shen et al. (2001) and the incorporation of gate connected field plates by Chini et al. (2004) enabled power densities (>10W/mm) with high efficiency. The optimization of both gate and source connected field plates led to an astonishing 40W/mm power density by Wu et al. in (2006). Today, thanks to the efforts of several companies such as Wolfspeed, SEDI, Qorvo and NXP amongst others, the 5G base station market is being enabled and served by AlGaN/GaN HEMTs. The development of AlGaN/HEMTs and its transition to DoD Systems was highlighted in 2018 at the DARPA D60 as one of the major achievements at DARPA. More recently the development of N-polar GaN at UC Santa Barbara has led to remarkable mm-wave performance of 8.8W/mm at 94GHz which demonstrates that the AlGaN/GaN HEMT roadmap shows tremendous promise for the next decade and beyond. The ONR, which has provided sustained funding of GaN since the 1990s, highlighted GaN electronics’ successes during its 75th anniversary celebrations.

WML-2

Measuring GaN HEMT Performance Degradation Under Nonlinear Dynamic Operation

Valeria Vadalà (Università di Milano-Bicocca)

The development of state-of-the-art microwave devices is a challenging task, especially nowadays when highly demanding applications are required by the upcoming 5G-related systems. The proper evaluation of device performance degradation and robustness is crucial to guarantee reliability and continuous improvements of the overall system. In this talk, the importance of measuring the performance degradation of microwave GaN HEMTs under actual load-line conditions is discussed with particular emphasis on the characterization technique adopted, which empowers one to gather information commonly hidden when standard DC stress tests are performed. The benefits of using nonlinear characterization techniques for assessing microwave device degradation are highlighted giving some practical examples on state-of-the-art GaN technologies.

WML-3

Experimental Characterization of Charge Trapping in GaN HEMTs using LF and RF Measurement Techniques

Gian Piero Gibiino; Alberto Maria Angelotti (all authors are with Univ. of Bologna)

During the last decades, Gallium Nitride (GaN) has demonstrated top-class performance in terms of power density at RF and microwave frequencies. Nevertheless, dispersive effects due to charge trapping and thermal phenomena are known to substantially influence the dynamic behavior of GaN, impairing classical modeling methods. In this talk, we present various characterization methods for the assessment of charge trapping effects applied to different GaN processes on both silicon carbide and silicon substrates. These include techniques based on pulsed and modulated excitation, current transient spectroscopy, and large-signal methods, which will be described along with custom measurement benches operating at both at low-frequency (LF) and at RF. Behavioral modeling procedures based on these techniques will also be described.

WML-4

Low Frequency Active Harmonic Load-Pull for Experimental Verification of Power Amplifiers' Modes

Patrick Roblin (Ohio State Univ.); J. Apolinar Reynoso-Hernandez (CICESE); Marlon Molina Ceseña (CICESE)

The theory of all the power amplifier classes has been developed based on the transistor's behavior at the intrinsic current source plane. Therefore, measurements of the transistor's behavior at that plane are intended to be the best way for experimentally studying it. Considering the advantages offered by time-domain Low Frequency (LF) active harmonic load-pull systems over their high frequency (HF) counterpart, they should be recommendable for investigating the resistive-reactive (R-R) continuous modes based on class-B. In this presentation, the use of a time-domain LF active harmonic load-pull system is proposed for measuring the current and voltage waveforms at the intrinsic current source plane of SiC-MESFET and GaN HEMT packaged transistor operated as a R-R class-J mode. From the current and voltage waveforms, the device's drain efficiency and output power, loading the transistor with fundamental and harmonic impedances corresponding to design space of R-R class-J modes, are calculated and compared with those predicted by the theory. The goal of this presentation is demonstrating that the R-R Class-J modes can be experimentally studied by using time-domain low-frequency active harmonic load-pull measurements.

WML-5

Advanced Thermal Characterization of GaN Devices, From Micro to Nanoscale, and New Heating Sinking Solutions

Paul Hayes (QFI Corporation); Martin Kuball (Univ. of Bristol)

Heat sinking is of ever increasing importance in semiconductor device technology. I will report on the latest advancements in thermal characterization techniques of devices with high spatial resolution, to the measurement of thermal conductivity and thermal boundary resistance of materials used for wide bandgap semiconductor device applications, using techniques ranging from Raman thermography, HQTI to low frequency FDTR. Examples of GaN, Ga_2O_3 to packaging materials will be used.

WML-6

Overview and Challenges of Modeling Microwave and mm-Wave GaN HEMT Technologies

Rob Jones (BAE Systems)

This presentation will review state-of-the-art GaN HEMT compact models and modeling approaches to support the wide range of microwave and mm-wave monolithic integrated circuits (ICs) being developed for military and commercial systems. Applications include high-power amplifiers (including narrow-band reactively matched, wide-band distributed, and wide-band cascode topologies), high dynamic range low-noise amplifiers, high-power switches, phase shifters, mixers, and fully integrated transmit/receive ICs that may also include automatic bias control and external logic control. Modeling challenges include traditional FET geometry and temperature requirements as well as the need for physically-based statistical simulation support. Present day GaN HEMT technologies also exhibit significant non-thermal (charge trapping) and thermal dispersive effects that must be modeled in an efficient and robust manner as a function of quiescent bias and drive level to provide the most accurate and scalable compact models with the best circuit simulation convergence properties. Ideally, a single base compact model formulation can support the wide range of applications and use conditions in a physically meaningful way. A range of proprietary and industry standard models and modeling approaches will be reviewed against these diverse requirements.

WML-7

Device and Circuit Co-Design Using MVSG Modeling Framework

Ujwal Radhakrishna (Texas Instruments)

This talk will focus on the device-design and circuit design carried out using the MIT Virtual Source GaNFET (MVSG) model. The model is an industry-standard charge-based physical model for GaNFETs suited for GaN-based HV and RF-circuit design. It has simple formulations that can capture a variety of device-phenomena: field plates, thermal and frequency-dispersion effects, charge-trapping, device-parasitics; calibrated against device-level measurements across technologies. In this talk, the speaker will go through model description, parameter extraction flow and various device-benchmarking steps essential to obtain a calibrated MVSG-model for a given GaN technology node. Example circuits for HV-converter and RF-front-end that use MVSG device-model for their design will be illustrated. The speaker will show the impact of device-field plate design on slew-rates, losses, and reliability of GaN converters. Using an RF-front-end MMIC, the speaker will show how the device parasitics and charge-trapping effects impact saturated power gains, power-added efficiencies, losses etc in power-amplifiers and oscillators. Novel-device designs using MVSG model that can boost circuit-performance metrics such as linearity will also be shown.

WML-8

Scalable Nonlinear RF Modeling of GaN HEMTs with Industry Standard ASM HEMT Compact Model

Sourabh Khandelwal (Macquarie Univ.)

This talk is divided into two parts. First part will discuss the industry standard ASM HEMT compact model. Core and numerous device effects included in this model will be discussed. Accurate non-linear RF modeling of several GaN technologies covering multiple voltage and frequency ranges. Design success with this model for Ka-band power amplifiers will be presented. Second part of the talk will cover new developments in the ASM HEMT model including computationally efficient field plate modeling, modeling of dynamic trapping effects, and extension of ASM HEMT model to advanced GaN device architectures. This talk will also show examples of using the ASM HEMT model for insightful analysis of non-linearities of GaN HEMT for device-circuit co-optimization.

WML-9

Nonlinear RF modeling of GaN HEMTs with Fermi kinetics transport and the ASM-HEMT compact model

Nicholas Miller*; Matt Grupen (all authors are with AFRL)

Rapid design and prototyping of next-generation microwave and mm-wave GaN technology requires reliable and accurate models. A paramount component of enabling first-pass design success of GaN microwave power amplifiers is the ability to model process variations inherent in GaN foundries. This talk will focus on the recent development of a statistical nonlinear ASM-HEMT model guided by the AFRL TCAD solver called Fermi kinetics transport (FKT). The FKT simulations will enable exact control of process variations in the GaN HEMT and will shed light on statistical nonlinear modeling of GaN microwave technology.

WML-10

Prediction by Technology Computer Aided Design of the Large Signal GaN HFET Performance

Christos Zervos; Dan Ritter (all authors are with Technion - Israel Institute of Technology, Technion)

In the silicon transistor industry, technology computer aided design (TCAD) is routinely used for device design. In most cases, the TCAD predicted performance of the silicon devices is very close to the experimental one. In the GaN technology, on the other hand, it is more common to match measured performance to the simulated one by tuning a fairly large number of unknown physical parameters. These parameters usually differ between different GaN foundries and may even differ for different devices fabricated by the same foundry. Hence, the predictive capability of TCAD for the GaN technology is still limited. In this lecture, we will present TCAD simulations using a very small number of physical tuning parameters that were obtained from dc measurements. Simulations of small and large signal RF performance based upon these parameters will be compared to measured performance of devices fabricated by two different foundries. The predictive capability of TCAD for GaN HFETs will be discussed.

WML-11

Physics-Based Large-Signal and Trap Modeling of GaN HEMTs

Petros Beleniotis; Matthias Rudolph (all authors are with Brandenburg Univ. of Technology, BTU)

This talk provides a strategy and useful insights for modeling the trapping effects in microwave PA designs based on GaN HEMT technology. We present an extended analysis of a trap description for the compact model ASM HEMT and its extraction procedure. Commonly used dopants in the buffer of GaN HEMTs such as iron enhance dispersive effects and often result in significant mismatch between model and real behavior of the device. Commercially available pulsed IV/ RF measurement systems can be utilized to both extract transistor model parameters and trapping characteristics. We provide a simple method to include the effects of drain-lag and use a parameter scaling technique to improve model accuracy. Measurement and simulation examples comparing the model with and without the trap description will be presented and discussed.

17:00

End of Monday’s Conference events

Thursday 8:00 – 18:00

Th1F: Joint IMS/ARFTG Focus Session "Efficient Characterization and Test of Phased Array Antenna Systems: Is It Really a Nightmare?"

Session Chair: Marc Vanden Bossche (NI); co-Chair: Matt Spexarth (NI)

8:00 — 8:20

Th1F-1

Calibrating RF/Microwave Front Ends in Multichannel Receiver and Transmitter Systems

Mike Jones (Analog Devices, Inc.)

Collocated hardened digital signal processing (DSP) blocks, analog-to-digital converters (ADCs) and digital-to-analog converters (DACs) on a single integrated circuit (IC) enable simpler, more efficient systems by reducing the amount of soft blocks historically-residing on power-hungry field-programmable gate arrays (FPGAs). This presentation provides experimental results showing how the use of these hardened DSP blocks across multiple digitizer ICs successfully achieves transmit (Tx) and receive (Rx) channel-to-channel phase and amplitude calibrations across the full instantaneous bandwidth used for the system. Also shown is that these hardened DSP blocks are capable of correcting RF/Microwave anomalies in the front-end networks attached to each transmitter and receiver, thereby simplifying the system's layout.

8:20 — 8:40

Th1F-2

Rydberg Atomic Electrometry: A Near-Field Technology for Complete Far-Field Imaging in Seconds?

D. Booth; K. Nickerson; S. Bohaichuk; J. Erskine; J.P. Shaffer* (all authors are with Quantum Valley Ideas Laboratories)

In this presentation, we describe how Rydberg states can be used for electromagnetic field sensing in the near field with minimal field distortion over a frequency range spanning almost six orders of magnitude, including from GHz to THz. We outline how Rydberg atoms packaged in electromagnetically transparent vapor cells can be used for high-sensitivity, absolute, self-calibrated sensing of electric fields. We present testing data on a Rydberg atom-based sensor prototype we have constructed and discuss applications like imaging, including the influence of vapor cells. In particular we study the effect of an interferer near the sensing frequency while demonstrating a wide carrier bandwidth. Taking limitations and current technology into consideration, the state-of-the-art Rydberg atom system presented here is promising for over-the-air test and measurement applications.

8:40 — 9:00

Th1F-3

A Novel OTA Near-Field Measurement Approach Suitable for 5G mmWave Wideband Modulated Tests

Michael Löhning; Thomas Deckert; Vincent Kotzsch; Marc Vanden Bossche* (all authors are with NI)

Over-the-Air measurements are critical for the validation and test of active antenna arrays required to operate at mmWave frequencies. In [1] a novel over-the-air near-field measurement approach was presented that targets specifically the validation and test of 5G mmWave antenna modules. It can provide the same quantities as known from classical chamber-based far-field measurements but with a significantly reduced form factor, at lower costs, and with higher measurement speed. While in [1] the capabilities of this novel near-field method were demonstrated for antenna pattern measurements using continuous wave signals, in this paper we describe an extension of this method that enables tests with wideband modulated signals. For an exemplary antenna array we demonstrate that this novel near-field approach is capable to perform 5G EVM measurements for different beam configurations with high accuracy.

9:00 — 9:20

Th1F-4

Fast Simultaneous Characterization of All Analog Phased Array Elements

Michael D. Foegelle (ETS-Lindgren)

Characterization of individual elements of a phased array involves determining not only the radiation pattern of each element and the response of the gain/phase control circuitry behind the element, but the interaction of each element with all of the other elements within the array. The obvious approach is to just turn off all but one element in order to test each element one at a time, but this is extremely time consuming and often does not work due to differences in behavior between the on and off states of individual elements. It will be shown in this paper how individual element performance can be extracted from the combined pattern of the array with all elements active using orthogonal coding applied to each element of the array through the onboard gain/phase control circuitry.

9:20 — 9:40

Th1F-5

Preliminary System Integration and Performance Features for an S-Band, Dual-Polarized, All-Digital Phased Array Radar

Caleb Fulton*; Nathan Goodman; Mark Yeary; Robert Palmer; Hjalti H. Sigmarsson; Jay McDaniel (all athors are with Univ. of Oklahoma)

A 1,344-element dual-polarized all-digital phased array radar system currently under development is leveraging trends in digital transceivers to explore the challenges and opportunities involved in this rapidly-developing technology space. This paper summarizes its features, specifications, and some of its promising research opportunities.

Th2A: Joint IMS/ARFTG Technical Session

"Measurement and Instrumentation Techniques for Evolving Standards in Future Technologies"

Session Chair: Jon Martens (Anritsu); co-Chair: Gian Piero Gibiino (Univ. of Bologna)

10:10 — 10:30

Th2A-1

3D Chip-Level Broadband Measurement Technique for Radiated EM Emission

Yin-Cheng Chang*; Jiayou Wang; Ta-Yeh Lin; Chao-Ping Hsieh; Yi Huang; Shawn S.H. Hsu; Da-Chiang Chang (all authors are with NARLabs-TSRI, National Tsing Hua Univ.)

This paper proposes a novel broadband 3D chip-level radiated EM emission measurement technique. Two different test carriers with the embedded CPW and coil conductors respectively are designed and realized by the integrated passive device (IPD) process, which allow collecting the EM emission via near-field coupling. Using an in-house designed 0.18-µm CMOS VCO as the DUT, the emission spectrum obtained using the CPW conductor demonstrates a broadband characteristic up to above 20 GHz with an excellent agreement of the direct measurements. Compared to the traditional IEC standard approaches typically limited below 3 GHz, the proposed high sensitivity and broadband technique is suitable for evaluating EM interference of high-frequency ICs in advanced 3D packaging.

10:30 — 10:50

Th2A-2

Linearity Metrics and Signal Statistics — The Need for Standards

Ricardo Figueiredo*; Nuno Carvalho (all authors are with Universidade de Aveiro)

Linearity metric dependence on signal statistics makes linearity requirements application specific, and hard to interpret and specify. This work presents and validates a simple method to relate linearity metrics obtained from signals with different statistical distributions, and evidences why specifying standard linearity test signals is so important to get universally traceable linearity metrics in microwave.

10:50 — 11:10

Th2A-3

A 110 GHz Comb Generator in a 250 nm InP HBT Technology

Jerome Cheron* (National Institute of Standards and Technology); Dylan Williams (National Institute of Standards and Technology); Richard Chamberlin (National Institute of Standards and Technology); Miguel Urteaga; Paul Hale (National Institute of Standards and Technology); Rob Jones (National Institute of Standards and Technology); Ari Feldman (National Institute of Standards and Technology)

We report a monolithic microwave integrated-circuit (MMIC) comb generator capable of producing a repetitive narrow pulse with sharp edges. The circuit is designed in a 250-nm Indium Phosphide (InP) Heterojunction Bipolar Transistor (HBT) technology, using differential pairs in a common-emitter configuration. We characterized the output signal with a 110 GHz sampling oscilloscope and de-embed the band-limited frequency spectrum of the pulse in the circuit reference plane. We measured a pulse width of 7.1 ps and a peak amplitude of -0.333 V. In the frequency domain, the comb generator provides -48.7 dBm of output power at 110 GHz while the circuit is fed with a 1-GHz input signal.

11:10
—
11:30

Th2A-4

Silicon Micromachined Metrology Components for 0.5–1.1THz

James Campion*; Bernhard Beuerle (all authors are with TeraSi)

We present the development and experimental characterisation of silicon micromachined components for waveguide metrology from 0.5–1.1 THz. Silicon micromachining offers high precision and uniformity, while the mechanical properties of silicon allow for the creation of extremely thin layers. We harness these capabilities to create waveguide lines for the WM-380 (0.5–0.75 THz) and WM-250 (0.75–1.1 THz) bands in thicknesses as low as 70 μm. The development of such components enables new solutions in the field of THz metrology due to their high precision, repeatability and scaleable manufacturing. The experimental performance of the components is first characterised using commercial vector network analyzer calibration standards. The micromachined components are then used to implement Through-Reflect-Line calibrations in both bands, which are used to error correct multiple devices. The micromachined lines offer return losses as high as 40 dB, while their expanded phase uncertainty is as low as 2°.

11:30
—
11:50

Th2A-5

WG29/WR7 Band Thermoelectric Power Sensor Characterization Using Microcalorimetry Technique

Murat Celep (NPL); Gia Ngoc Phung* (PTB); François Ziadé (LNE); Daniel Stokes (NPL); Jürgen Rühaak (PTB); Karsten Kuhlmann (PTB); Djamel Allal (LNE)

NPL, PTB, and LNE designed and produced three different microcalorimeters for the WG29/WR7 band. The microcalorimeters used different correction methods to characterize effective efficiency. Finally, the three laboratories measured thermoelectric power sensors from 110 GHz to 170 GHz to demonstrate equivalence and results show good agreement.

PL7: Joint IMS/ARFTG Panel Session

"Modern Phased Arrays and OTA Testing: A Design or a Measurement Challenge?"

Organizers: Gerardo Orozco (NI); Thomas Williamson (Georgia Tech Research Institute); Jeffrey Jargon (National Institute of Standards and Technology); Jon Martens (Anritsu)

12:00 — 13:30

Panelists: Matt Little; Sidina Wane; Caleb Fulton; Michael Foegelle; Cesar Lugo; Rob Horansky

This panel addresses current and future challenges regarding over the air (OTA) characterization, measurement, and calibration of modern phased arrays. We will discuss various repeatable, practical, and economic methods for addressing challenges presented by emerging technology. We will draw on a breadth of knowledge from academia, the defense and aerospace industry, and the cellular industry to speak to the diversity of array technology for 5G, 6G, satellite-borne arrays, and radar.

Matt Little is the Chief Technologist for the Command, Control, Communications and Instrumentation mission area at Ball Aerospace. Matt has 20 years of experience developing phased array antennas for radar and communication systems for defense and commercial applications. This includes leading significant R&D efforts to improve calibration measurement accuracy and efficiency for phased array antenna systems. Prior to joining Ball Aerospace, he was an engineering fellow at Raytheon Technologies. He holds a master's and bachelor's degrees in Electrical Engineering from the University of Michigan, Ann Arbor.

Sidina Wane is President, Founder and CEO of eV-Technologies – a France based high-technology company providing leading edge energy-aware tools, instrumentations and chip-package-PCB-antenna co-design solutions for RF, millimeter-wave and optical applications. Sidina Wane holds a Dr.-Ing.-HDR degree in electronic circuits and systems with specialization in on chip-package-PCB co-design, co-simulation, and co-verification. His main interests and background are in the fields of power integrity, signal integrity, electromagnetic compatibility (EMC) and electromagnetic interference (EMI) in integrated circuits and systems for RF, mm-wave, and optical applications.

Caleb Fulton (S'05-M'11-SM'16) received the B.S. and Ph.D. degrees in electronics and communication engineering from Purdue University, West Lafayette, IN, USA, in 2006 and 2011, respectively. He is currently an Associate Professor of electronics and communication engineering with the Advanced Radar Research Center, The University of Oklahoma, Norman, OK, USA. His current research interests include antenna design, digital phased array calibration and compensation for transceiver and array polarization errors, integration of digital transceivers and high-power GaN devices, and advanced digital array design considerations. Dr. Fulton is a member of the IEEE Antennas and Propagation Society, the Aerospace and Electronic Systems Society, and the IEEE Microwave Theory and Techniques Society, where he also serves on the Education Committee. He was the recipient of the Purdue University Eaton Alumni Award for Design Excellence in 2009 for his work on the Army Digital Array Radar (DAR) Project, the Meritorious Paper Award for a summary of these efforts at the 2010 Government Microcircuit Applications and Critical Technologies Conference, and the 2015 DARPA Young Faculty Award for his ongoing digital phased array research.

Dr. Michael D. Foegelle is the Director of Technology Development at ETS-Lindgren in Cedar Park, Texas, and has more than 25 years of test and measurement experience in RF and wireless. He received his Ph.D. in physics from the University of Texas at Austin. Dr. Foegelle has been actively involved in standards development on the American National Standards Institute (ANSI) Accredited Standards Committee C63 on electromagnetic compatibility, CTIA Certification Program Working Group, Wi-Fi Alliance, WiMAX Forum, IEEE 802.11, and 3GPP. He has served as chair or vice-chair of various working groups in those organizations and currently co-chairs theCTIA MIMO OTA Subgroup. He has authored or co-authored numerous papers in the areas of Electromagnetics, EMC, Wireless Performance Testing, and Condensed Matter Physics, holds dozens of patents on wireless and electromagnetic test methods and equipment, and is dedicated to advancing the state of the art in radiated RF testing of emerging wireless technologies.

Dr. Cesar Lugo is a Senior Fellow at L3Harris. His research has focused on phased arrays, digital arrays, and other advanced technologies.

Robert D. Horansky received the B.A. degree in chemistry and the Ph.D. degree in physics from the University of Colorado, Boulder, CO, USA, in 1999 and 2005, respectively. His thesis work focused on low-noise dielectric measurements on novel materials in molecular electronics. Since 2005, he has been with the National Institute of Standards and Technology (NIST), Boulder, CO, USA, where he started out developing the highest resolving power energy dispersive sensor to date. He then went on to develop metrology techniques for single photon sensors in nuclear radiation and optical power measurements. In 2015, he joined the Metrology for Wireless Systems Project in the Communications Technology Laboratory, NIST developing calibrations and traceability for millimeter-wave wireless systems and reverberation-chamber measurements for cellular applications. He is the Secretary of the IEEE P1765 Standards Working Group on Uncertainty for EVM.

NVNA Users Forum

NVNA User’s Forum Organizers: Patrick Roblin (OSU), Apolinar Reynoso Hernandez (CICESE), Jean-Pierre Teyssier (Keysight Technologies), Dominique Schreurs (KU Leuven), Tibault Reveyrand (XLIM), Karun Rawat (I.I.T)

15:30 — 16:45 EDT

Forum Session

Program TBA

On-Wafer Users Forum

On-Wafer User's Forum Organizers: Andrej Rumiantsev (MPI Corporation), Marco Spirito (Delft University of Technology), and Jon Martens (Anritsu)

16:45 — 18:00	Forum Session Program TBA
18:00	End of Thursday's Conference events

Friday 8:00 – 17:00

Conference Opening

8:00 — 8:10

Welcome to the 99th ARFTG Conference

Conference Co-Chairs: Jeffrey Jargon and Marco Spirito

TPC Co-Chairs: Andrej Rumiantsev and Marc Vanden Bossche

8:10 — 8:50

Keynote: Characterizing Cryogenic Josephson Microwave Sources for Communications and Quantum Information

Alirio S. Boaventura (NIST)

Robust modeling and accurate characterization of microwave devices and circuits in the cryogenic environment will be key to upscale quantum computation systems. In this talk, I will address the development of new high-frequency cryogenic measurement, calibration, and characterization approaches and their application to the design of a superconductor microwave reference source. This discussion will include the application of characterization concepts like wave-parameters, load-pull, and X-parameters at cryogenic temperatures. Some of the approaches discussed here are suitable for application in superconducting quantum computers and could help to optimize the quantum-classical interfaces in these systems. I will touch on ongoing efforts to apply these techniques at millikelvin temperatures, and I will briefly discuss the application of EDA tools to support the design and optimization of superconducting quantum electrical circuits.

Dr. Boaventura is a research associate at the Department of Physics, University of Colorado Boulder, and a guest researcher at NIST Boulder, where he has worked on high-frequency metrology and quantum microwave engineering. Alirio led the development of cryogenic microwave measurement capabilities to help bring the NIST quantum voltage standard from audio frequencies into the RF/microwave band for application in communications metrology and quantum information. Boaventura has been involved in the design and optimization of cryogenic on-wafer calibration kits, low-temperature microwave and millimeter-wave measurements, and characterization of superconducting devices. His research interests include EDA modeling and simulation tools for the design and optimization of superconducting quantum electrical circuits (e.g., Josephson junction arrays, SQUIDs, quantum-limited amplifiers). Alirio has authored or co-authored over fifty peer-reviewed papers and has served as a reviewer for the IEEE Transactions on Microwave Theory and Techniques and the IEEE Journal of Emerging and Selected Topics in Circuits and Systems. Dr. Boaventura is the author of the (forthcoming) book "*Radio Frequency Identification Engineering*", Cambridge University press. Alirio received a merit scholarship from the Gulbenkian Foundation, he was nominated twice for the IEEE International Microwave Symposium best student paper, he was the recipient of an IEEE MTT-S Microwave Engineering Graduate Fellowship Award, and the co-recipient of an International Union of Radio Science (URSI)/Portugal Prize. Dr. Boaventura was featured in the magazine "University of Aveiro, 40 Years, 40 Inventors, 40 Entrepreneurs."

Session A: Enabling Wideband Characterization Techniques

Session Chair: Patrick Roblin (Ohio State Univ.)

8:50
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9:10

A-1

VNA-Based Testbed for Accurate Linearizability Testing of Power Amplifiers Under Modulated Signals

Nizar Messaoudi (Keysight Technologies)*; Ahmed Ben Ayed (University of Waterloo); Jean-Pierre Teyssier (Keysight Technologies); Slim Boumaiza (Nil)

This paper presents a vector network analyzer (VNA) based testbed for accurate power amplifier (PA) linearizability testing under wideband modulated signals. The proposedtestbed utilizes two of the VNA’s receivers to simultaneouslycapture the calibrated input and output signals of the PA. Thetestbed corrects the linear and nonlinear distortions exhibitedby the underlying components (e.g., arbitrary waveform generator, up-converter, driver amplifiers, and couplers) so thatthe linearizability testing is solely indicative of the performanceof the PA under test. Experiments conducted using two PAdemonstrators confirmed the capacity of the proposed testbedto support digital predistortion based linearization testing under5G NR OFDM test signals with modulation bandwidths (e.g., 200 MHz) that significantly exceed the VNA receivers bandwidth. More importantly, the pre-correction of the linear and nonlinear distortions yielded an improvement of the adjacent channelpower ratios at the output of the PAs by up 7 dB comparedto the uncorrected case.

9:10
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9:30

A-2

Wideband Vector Corrected Measurements on a Modified Vector Network Analyzer (VNA) System

Christoph Schulze (Ferdinand-Braun-Institut)*; Wolfgang Heinrich (Ferdinand-Braun-Institut); Joel Dunsmore (Keysight Technologies); Olof Bengtsson (Ferdinand-Braun-Institut, Leibniz-Institut für Höchstfrequenztechnik)

Vector corrected wideband measurements on a modified vector network analyzer system are presented using wideband modulated signals as stimulus. The modified system allows intermediate frequency (IF) bandwidths exceeding 5 GHz based on external wideband IF access, signal conditioning and digitalization. A combined RF and IF calibration has been developed that allows full-band calibration using CW excitation, while measurements are made with wideband modulated signals. Impedance measurements verify excellent accuracy at - 59 dB deviation for an electrically switched impedance which is only a few dB less than for narrowband measurements. Repeatability of calculated error terms for consecutive calibrations also show comparable performance as for narrow-band measurements. Wideband one-port impedance measurements at 12.5 GHz using a Schroeder signal with 500 MHz instantaneous bandwidth show less than -50 dB deviation with coherent averaging even without correcting for mixer distortion.

9:30 — 11:00

Break

Exhibits and Interactive Forum

Interactive Forum

Session Chair: Marc Vanden Bossche (NI)

9:30 — 15:40

P1

Demonstration of non-invasive probing of CMOS devices with aluminum pads at frequencies up to 500 GHz

Ryo Sakamaki (National institute of Advanced Industrial Science and Technology)*; Ryoko Kishikawa (National Institute of Advanced Industrial Science and Technology); Seitaro Kon (AIST); Yuya Tojima (AIST); Ichiro Somada (Mitsubishi Electric Company); Shunpei Matsui (Hiroshima University); Gakuto Taoka (Hiroshima University); Takeshi Yoshida (Hiroshima University); Shuhei Amakawa (Hiroshima University); Minoru Fujishima (Hiroshima University)

This paper demonstrates non-invasive probing measurement of transmission lines on CMOS chips from 100 MHz to 500 GHz. The surface of aluminum pads are covered with a natural oxide film, which usually needs to be penetrated by probe tips through extended skating. In this work, the oxide film is kept intact by reducing probe skating down to 10 µm using a precision-controlled probe station. This, in turn, allowed the use of extremely small 20 µm × 15 µm, 25-µm-pitch pads. The oxide film did not show significant resistance variations even after repeated probe touchdowns that would normally have worn out the pads. Stability of the measurement was investigated by comparing measured propagation constant in a wide frequency range, covering 1-mm coax, WR6, WR3, and WR2 bands. The propagation constant turned out to be continuous even at band crossings. The non-invasive probing could be particularly useful for characterizing CMOS passive devices, which do not require dc biasing.

9:30 — 15:40

P2

Determination of the Coplanar Waveguide Propagation Constant via Non-contact, On-wafer Measurements in WR1.5 Band

Mitch Wallis (NIST)*; Charles Little (NIST); Richard Chamberlin (NIST); George Burton (NIST); Nathan Orloff (NIST); Christian Long (NIST); Kubilay Sertel (TeraProbes Inc)

We investigate on-wafer measurements made by use of a non-contact probe station in the WR1.5 band (500 GHz to 750 GHz) in order to demonstrate the potential utility of the self-defined, multireflect-thru (MRT) calibration technique. The propagation constant of the on-wafer, coplanar waveguide (CPW) test environment is determined by use of the one-port, reduced reflectometer calibration method. The results of the one-port, calibrated, non-contact measurements are compared to two-port contact measurements calibrated with the multiline thru-reflect-line (TRL) method. The non-contact approach is shown to be promising for self-defined determination of the propagation constant, provided that steps in the CPW center conductor width and CPW gap are introduced into the calibration standards to suppress the coupled-slot-line (CSL) mode.

9:30
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15:40

P3

A Single-Element CMOS-LRRM VNA Electronic Calibration Technique

Jun-Chau Chien (National Taiwan University)*; Ali Niknejad (University of California Berkeley)

This paper presents a single-element CMOS-based electronic calibration (E-Cal) technique for millimeter-wave VNA measurements. The structure employs a CMOS transmission line loaded with a shunt NMOS transistor at its center tap. By taking advantage of the structure symmetry, the standard LRRM calibration flow can be implemented with the transistor biased at different impedance states. The approach is justified using a 65-nm CMOS test chip and the measurements of passive DUTs.

9:30
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15:40

P4

The w-plane as a Graphical Representation of Sampler Configuration in a Sampled-Network Reflectometer

Devon Donahue (University of Colorado Boulder)*; Taylor Barton (University of Colorado Boulder)

This paper presents a study of sampler configuration within a sampled-network reflectometer, an extension of the sampled-line. The sampled-network impedance sensing approach leverages a six- to four-port reduction technique that produces a graphical representation known as the w-plane. In this work, an experimental setup in which the samplers can be located near-arbitrarily within the network is used to explore the w-plane's characteristics and relationship to the physical reflectometer.

9:30
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15:40

P5

Single-Sweep vs. Banded Characterizations of a D-band Ultra-Low-Loss SiC Substrate Integrated Waveguide

Lei Li (Cornell University)*

A D-band (110–170 GHz) SiC substrate-integrated waveguide (SIW) is characterized on-wafer by two different vector network analyzers (VNAs): a 220-GHz single-sweep VNA and an 110-GHz VNA with WR8 (90–140 GHz) and WR5 (140–220 GHz) frequency extenders. The two VNAs are connected to wafer probes via coaxial cables and waveguides. Since both types of probes terminate in a coplanar waveguide (CPW), to facilitate probing, the SIW input and output are transitioned to grounded coplanar waveguides (GCPWs). From the probed scattering parameters, two-tier calibration is used to de-embed the SIW-GCPW transitions and to extract the intrinsic SIW characteristics. In general, the two VNAs are in agreement and both result in an ultra-low insertion loss of approximately 0.2 dB/mm for the same SIW, despite stitching errors at band edges. This validates the banded characterization of passive devices, although the newly available 220-GHz single-sweep VNA may be more convenient for broadband characterization of active devices.

Session B: mmWave Over-the-Air Characterization

Session Chair: Rusty Myers (Keysight)

11:00
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11:20

B-1

Traceable mmWave Modulated-Signal Measurements for OTA Test

Joshua M Kast (Colorado School of Mines)*; Paritosh Manurkar (University of Colorado Boulder); Kate Remley (NIST); Rob Horansky (NIST); Dylan Williams (NIST)

We present a single-instrument solution to traceable mmWave wide-band modulated-signal measurement in OTA test environments. The approach can be used to characterize transmitters, receivers and transceivers using either time-domain or frequency-domain multiplexing on a fine frequency grid.

11:20
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11:40

B-2

On coupling-related distortion behavior in mm-wave phased arrays

Jon Martens (Anritsu)*

Nonlinear coupling and element pulling can be contributors to distortion behavior in mm-wave phased arrays, particularly as sensitive power stages get closer to the antenna as may be more likely at the highest frequencies. Methods for assessing these behaviors may be of value for development and modeling. This paper will look at an element interrogation approach based on separable asymmetric intermodulation distortion measurements to look at angle, position and coupling dependence with example V/E/W-band arrays.

11:40
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12:00

B-3

D-band Free Space Dielectric Characterization of a Low-Cost Ultradense Microdiamond Composite for Heat Spreading

Shu-Ming Chang (UCSB)*; Chelsea Swank (UCSD); Andrew Kummel (UCSD); Muhannad Bakir (Georgia Tech); Mark Rodwell (UCSB); James Buckwalter (UCSB)

Low-cost dielectric materials are needed above 100 GHz with low permittivity and loss tangent as well as significant thermal conductivity (∼100 W/m · K). A free-space measurement setup is demonstrated to characterize a proposed ultradense diamond composite material at D-band. We leverage free-space calibration with the NIST iterative method to extract the permittivity and loss tangent and compare this approach with other methods. Time-domain gating is employed to reduce the uncertainty in the free space characterization. Our measurement indicates the diamond composite offers a relative permittivity of 3.5 and loss tangent of 3 × 10−2 from 110-140 GHz. To the author’s knowledge, this is the first report of diamond composite compatible with packaging requirements at D-band.

12:00
—
13:30 EDT

Awards Luncheon

Session C: Non-Linear, Large-Signal and VNA Techniques

Session Chair: Mauro Marchetti (Anteverta)

13:30 — 13:50

C-1

Local-Oscillator Third-Harmonic Injection for Improved Broadband Mixer Linearity

Akim A. Babenko (Anritsu)*; Jon Martens (Anritsu)

We have studied dependencies of the mixer linearity upon injecting a third local oscillator (LO) harmonic of various magnitudes and phases relative to the LO fundamental. Two packaged double-balanced-mixer samples from independent manufacturers were tested for two-tone third-order IM (IM3) products. The two-tone RF input signal covered a 13 GHz to 18 GHz frequency range with a 4 MHz tone spacing and with the LO 52 MHz above the lower RF input tone. For both samples and at select third LO harmonic phases, we observed around 4 dB average third-order input intercept point (IIP3) improvement across the entire frequency range, with about 5 dB increase at frequencies where IIP3 was below 20 dBm with purely sinusoidal LO. In contrast, certain harmonic phases resulted in more than 10 dB increase, compared to no injection, of the IM3 products that were also unstable over time. The results in this paper form the basis for further research toward optimal LO waveforms for improved broadband mixer linearity.

13:50 — 14:10

C-2

Surmounting W-band Scalar Load-Pull Limitations Using the ASM-HEMT Model for Millimeter-Wave GaN HEMT Technology Large-Signal Assessment

Nicholas C. Miller (Air Force Research Laboratory)*; Michael Elliott (SelectTech Services); Ryan Gilbert (KBR); Erdem Arkun (HRL Laboratories); Daniel Denninghoff (HRL Laboratories)

This paper presents for the first time an accurate ASM-HEMT model for millimeter-wave GaN HEMT technology validated with W-band scalar load-pull and power sweep measurements. The accurate model is used to characterize the optimal performance of the GaN HEMT with operating conditions beyond the limitations of the scalar W-band load-pull system. The GaN HEMT measurements exhibited a peak PAE of 35% and the ASM-HEMT model predicts a peak PAE of 42%.

14:10 — 14:30

C-3

Impact of Broadband Modulation in Active Load-Pull On-Wafer Measurements of GaN HEMTs

Alberto Maria Angelotti (University of Bologna)*; Gian Gibiino (University di Bologna); Troels Nielsen (Keysight Technologies, Inc.); Alberto Santarelli (University of Bologna); Jan Verspecht (Keysight Technologies, Inc.)

This work deals with the impact of broadband modulated excitations on the load-pull characterization of gallium nitride (GaN) on-wafer high-electron-mobility transistors (HEMTs). An experimental assessment is performed by comparing HEMT performance metrics obtained using typical continuous-wave (CW) load-pull characteristics (and their input-statistics weighted version) against the ones directly measured with a wideband active load-pull (WALP) system which allows to set a user-prescribed load profile across arbitrarily-wide measurement bandwidths (BWs). Experimental results across a 100-MHz WALP BW under realistic modulated

input excitations at a 6 GHz carrier frequency are reported for a 150nm-gate-length GaN HEMT, highlighting the differences between the various load-pull measurement approaches.

14:30
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14:50

C-4

Effective AM/AM and AM/PM Curves Derived from EVM Measurements on Constellations

Jacques B. Sombrin (TESA Laboratory)*

Non-linear amplifiers distort signal constellations through their amplitude (AM/AM) and phase (AM/PM) curves versus input amplitude. This causes an increase in the average Error Vector magnitude (EVM) of the amplified signal. Most commercial EVM measurement devices display the ideal and distorted constellations. When computing separate EVMs for each value of ideal symbol power, it is possible to obtain a representation of the effect of AM/AM and AM/PM curves on the constellation. A new type of display, with distorted constellation folded up, like a fan, on the real axis is proposed to get a direct representation of the amplifier non-linearity. This can also be used for nonlinear equalization of the signal to improve the EVM.

14:50
—
16:00

Break

Exhibits and Interactive Forum

Session D: On-Wafer Techniques

Session Chair: Leonard Hayden (Qorvo)

16:00
—
16:20

D-1

Parasitic Coupling Effects in Coplanar Short Measurements

Gia Ngoc Phung (Physikalische Technische Bundesanstalt)*; Uwe Arz (Physikalisch-Technische Bundesanstalt (PTB))

On-wafer measurements are indispensable for the characterization of electronic devices at millimeter-wave and terahertz frequencies. Recent investigations have demonstrated parasitic effects stemming e.g. from probes, multimode propagation and crosstalk using line standards as devices under test. However, for short-circuited coplanar structures which are often used as reflect standards in on-wafer calibrations, these parasitic effects have not been thoroughly investigated. Therefore, this paper presents a detailed study of parasitic mode effects in conjunction with probe influences occuring in coplanar short measurements.

16:20
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16:40

D-2

Extending the Open-Short De-embedding Frequency via M1 On-Wafer Calibration Approaches

Ciro Esposito (TU Dresden)*

In this contribution, we analyze the bandwidth/accuracy trade-offs of conventional two-step de-embedding approaches when extracting device model parameters. The accuracy limitation of incorporating the pad/line section of classical DUT test-fixtures into shunt-series complex and frequency-dependent elements are analyzed by means of linear circuit simulations. The de-embedding accuracy is then evaluated employing metrics based on the introduced resonance of the simple model. To validate the presented analysis, classical device monitoring parameters are extracted versus frequency for the same device embedded in two different fixtures. One allowing only a pad level calibration plane, thus bounded the accuracy limitation of the conventional two-step de-embedding approach. The second allowing a direct on-wafer calibration (reference plane set on M1 in close proximity of the DUT) thus extremely reducing the residual parasitic to be removed by the de-embedding approach. Experimental data up to 220GHz are then presented and compared with extensive simulation test-benches, validating a modelling accuracy of better than XX% up to 220GHz of the M1 calibration approach.

16:40 — 17:00

D-3

Wideband mm-Wave Integrated Passive Tuners for Accurate Characterization of (Bi)CMOS Technologies

Marc Margalef-Rovira (IEMN Laboratory)*; Caroline Maye (IEMN Laboratory); Sylvie Lepilliet (IEMN Laboratory); Daniel Gloria (STMicroelectronics); Guillaume Ducournau (IEMN Laboratory); Christophe Gaquiere (MC2-Technologies)

This paper presents an innovative impedance tuner architecture aiming at on-wafer characterization. The proposed impedance tuner is composed of an integrated attenuator, which can be tuned in an analog manner, and a transmission line. Thanks to the use of an external short-circuited probe, the effective length of the transmission line can be modified, leading to a phase shift of the reflection coefficient while the attenuator controls its magnitude. Measurement-based results are presented to prove the precision obtained using the external short-circuited probe, while simulation-based results show the performance of the overall system. The system allows complete coverage of the 140-220 GHz band with 2.5-4.2 dB maximum reflection coefficients and minimum reflection coefficients greater than 20 dB, which can be continuously tuned. On the other hand, thanks to the short-circuited probe, virtually, continuous tuning of the phase is also achievable.

17:00

Closing Notes

End of 99th ARFTG Conference

See you again at ARFTG-100th Conference!

100th ARFTG Microwave Measurement Conference

Measurement Challenges for Emerging RF-to-THz Technologies

Las Vegas, Nevada, US, January 22-25, 2023

www.arftg.org

Conference Co-Chairs
Joe Gering
Qorvo
joe.gering@qorvo.com

Joel Dunsmore
Keysight Technologies
joel_dunsmore@keysight.com

Technical Program Co-Chairs
Dominique Schreurs
KU Leuven
Dominique.Schreurs@kuleuven.be

Andrej Rumiantsev
MPI Corporation
a.rumiantsev@ieee.org

CALL FOR PAPERS

The theme for the 100th ARFTG Conference is “Measurement Challenges for Emerging RF-to-THz Technologies”. Through the course of ARFTG’s existence, microwave measurements have evolved from scalar network measurements to complex set-ups, tailored for emerging technologies in the RF-to-THz field. We encourage the submission of original papers demonstrating innovative approaches to tackle measurement challenges inherently linked to the high explosion of diverse applications based on EM waves. Suggested topics include but are not limited to:

- *Calibration and characterization, incl. cryogenic, for quantum technology*
- *EM characterization, incl. de-embedding, of materials and biological samples*
- *On-wafer measurements of RF to subTHz devices and circuits*
- *Waveguide and free-space subTHz and THz measurements*
- *Generation and measurement of sub-THz signals with wideband modulation*
- *Nonlinear characterizations, incl. linearization, of devices, circuits, and systems*
- *Over the air (OTA) calibration and measurement for 5G/6G and Internet of Things (IoT)*
- *Other recent developments in metrology incl. measurement uncertainty*

ARFTG will again be co-located with Radio and Wireless Week, www.radiowirelessweek.org.

DEADLINES

September 12, 2022	Electronic abstract/summary is due in PDF format.
October 12, 2022	Paper acceptance and classification will be communicated.
November 4, 2022	Publication-ready paper is due in PDF format.

Instructions for Authors

Instructions for authors are briefly outlined below. More details can be found on the ARFTG website: https://www.arftg.org/index.php/upcoming-conference/author-instructions. Authors should use the template on that page to prepare initial summaries and final paper submissions.

We request that authors submit a 4-page summary with supporting figures of both experimental setups and measurement results to enable evaluation with respect to the interests of the participants and the novelty of the work.

Contributed papers will be presented as 20-minute talks or in an interactive poster session. Final papers will be published as part of the ARFTG proceedings and in IEEE Xplore, provided it has been presented at the conference.

Financial Support for Students

To encourage student papers, *ARFTG will waive the conference registration for any student presenting a paper* at the 100th ARFTG Conference. Also, graduate students in the RF to THz measurement field are encouraged to apply for the ARFTG Roger Pollard Student Fellowship in Microwave Measurement (https://www.arftg.org/index.php/membership/student-fellowship).

Exhibit & Sponsorship

The 100th ARFTG Conference also offers an outstanding exhibition and corporate sponsorship opportunity. Please contact our Exhibits Chair (Joel Dunsmore, exhibits@arftg.org) or our Sponsors Chair (Joe Gering, sponsorship@arftg.org) directly for further information.

For more information on the next ARFTG-100th Conference, visit the conference web page.