19-22 January, 2025

San Juan | Puerto Rico

CONFERENCE BOOK

104th ARFTG Microwave Measurement Symposium

Advanced Nonlinear and Linear Microwave Measurements

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General Chair Welcome Note

As Chair of the 104th ARFTG Microwave Measurement Symposium, it is my pleasure to welcome all our attendees, speakers, and organizers. This year, the 104th ARFTG conference is held for the first time in San Juan, Puerto Rico and is co-located with both the Radio Wireless Week (RWW) and Latin American Microwave Conference (LAMC).

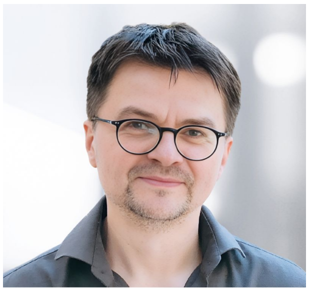
The organizers have worked throughout the last year to bring you an exciting program. Prof. Apolinar Reynoso Hernández, the TPC chair and I have selected "Advanced Nonlinear and Linear Microwave Measurements" for the conference theme. However, many other topics of interest to the measurement and metrology community will be covered. As usual we are also hosting the ARFTG-NIST short course, a half-day workshop, two users' forums, and a joint panel discussion with RWW's PAWR conference. The conference features 5 sessions: (A) Loadpull/Nonlinear Measurements, (B) Linearization, (C)mmWave Measurements, (D) Calibration & On-Wafer Measurements, and (E) Materials & Noise Measurements.
with additional topics covered in the Interactive Session. The conference opens on Monday Jan. 20 with a keynote talk given by Dr. Tony Gasseling of AMCAD on "Advancements in Transistor and Circuit Modeling for Next-Generation RF Circuit Design Techniques." Four invited speakers will present lectures to start each of the sessions on the conference themes: Prof. Zoya Popovic of University of Colorado Boulder, Prof. Nicholas Miller of Michigan State University, Dr. Jean Pierre Teyssier of Keysight Technologies and Prof. Roberto Quaglia of Cardiff University. On Tuesday Jan 21, in the plenary session held jointly with RWW, Prof. Larry Dunleavy of South Florida and co-founder of Modelithics will present a plenary talk on "The convergence of advanced models and measurements for virtual prototyping success." An awards luncheon will follow, during which the best papers and exhibitors from the ARFTG-103rd conference will be honored.

Before the conference, the ARFTG-NIST Short Course organized by Dr. Angela Stelson of NIST will be held on Sunday and Monday morning. It will feature presentations from 12 experts in the field. New topics are covered this year such as uncertainty calculations, above 100 GHz measurements, and cryogenic RF measurements. The ARFTG workshop on Wednesday morning organized by Dr. Mauro Marchetti will feature 5 exciting presentations on "Testing, Modeling and Linearization of Nonlinear RF/microwave Devices and Circuits."

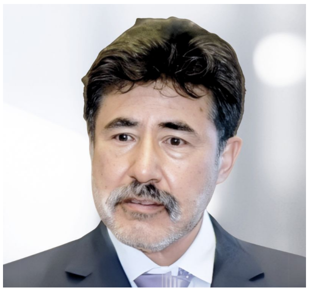
I would like to thank our sponsors, exhibiters, and all the members of the steering committee for their work and support in preparing this conference. ARFTG is devoted to both cutting-edge and practical measurements in RF, communications, microwaves, millimeter-waves, and related fields. The ARFTG conference offers the opportunity to interact with the developers of many of the modern measurement techniques used today. We are looking forward to seeing you in San Juan, Puerto Rico. We hope that you will enjoy the presentations and find them enriching.

Patrick Roblin, Professor, Ohio State University
ARFTG-104th General Chair

General Chair
Patrick Roblin
The Ohio State University



General co-Chair
Andrej Rumiantsev
MPI Corporation



TPC Chair
J. Apolinar
Reynoso-Hernández
CICESE

TPC co-Chair
Mauro Marchetti
Maury Microwave

NIST/ARFTG Short Course

Sunday, January 19th | Morning Session

MEASUREMENT FUNDAMENTALS

8:00-8:10
SC-i

Welcome Note and Introduction

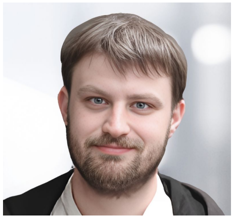
Angela Stelson (NIST)

8:10-8:55
SC-1

Microwave Power and Traceability

Aaron Hagerstrom (NIST)

International trade requires standardization of measurements between countries. In principle, this standardization is achieved through the concept of metrological traceability. Roughly speaking, a traceable measurement of a physical quantity can be compared to the physical constants that define the SI units, such as the speed of light and Planck's constant, through an unbroken chain of measurements with uncertainties. In this talk, we will discuss what traceability means in practical terms, from the perspective of a person who performs measurements. In particular, we will focus on microwave power measurements at NIST. These measurements are traceable to scattering parameters and DC power. We will describe how we achieve traceability for these measurements, and how traceability can be extended to other measurements. This talk will emphasize uncertainty evaluation, as understanding measurement uncertainty is important not just for traceability, but also for measurements in general.



Aaron Hagerstrom received the B.S. degree in Physics from Colorado State University in 2010, and the Ph.D. in Physics from the University of Maryland in 2015. He joined National Institute of Standards and Technology (NIST) in 2016 as an NRC postdoctoral associate and developed techniques for microwave-frequency characterization of nonlinear materials and devices. In 2019, he was hired into a staff position at NIST to research traceable power measurements at microwave and mm-wave frequencies. He was part of the team who received the 2022 Allen V. Astin Measurement Science Award for the development of a rigorous new traceability path for microwave power and scattering parameter measurements at millimeter-wave frequencies relevant for new 5G/6G wireless communications systems.

9:00-9:45

SC-2

Updating NIST's Traceability: S-Parameters and Beyond

Angela Stelson (NIST)

Traceability of S-parameters to fundamental SI quantities (the second and the meter) is key to assessing uncertainties of microwave measurements across the telecommunications industry. S-parameters are a fundamental microwave-frequency measurand and are part of the traceability chain for numerous quantities, including antenna factors, microwave power, and phase. Here, we outline a comprehensive uncertainty budget for S-parameters in the WR-15 waveguide band with the goal of establishing traceability for these S-parameters, wave parameters, and further derived measurements. The uncertainty analysis presented here begins by evaluating uncertainties related to the imperfect physical dimensions of the calibration standards and test ports. Then, we outline experiments to evaluate instrumentation uncertainties including drift, noise and receiver nonlinearity, and assess their contributions to the total uncertainty of the measurement. Overall, this talk aims to demonstrate a workflow to incorporate the major sources of systematic and statistical uncertainties in S-Parameter measurements to the measurement of unknown devices.

Angela C. Stelson received her B.S. in physics, mathematics, and political science from the University of Oregon in Eugene, OR, USA (2012), and her Ph.D. in Materials Science and Engineering from Cornell University in Ithaca, NY, USA (2017). Her graduate work focused on the electric field-directed assembly of colloids for photonic crystals. She joined the National Institute of Standards and Technology as a National Research Council Fellow in 2017. Currently, she works in the RF Electronics group developing traceable scattering parameter calibrations and new microwave microfluidics measurement techniques for chemical and biological applications.

9:45 - 10:15

Coffee Break

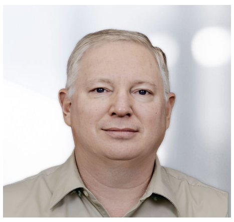
10:15 – 11:00

SC-3

Modern Network Analyzers Calibration Techniques

Rusty Myers (Keysight Technologies)

Calibration is crucial for making accurate measurements with a Vector Network Analyzer. This talk will start with basic explanation of VNA calibration to provide the background for historical 1-port and 2-port calibration methods. Next up, modern advances in calibration methods will be explained. It will wrap up with some real world measurement challenges and how these modern techniques can tackle them.



Rusty Myers is a Master Metrology Engineer at Keysight Technologies where he is involved in various projects related to measurement science and uncertainties of precision instruments. Most of his work is centered on Vector Network Analyzers and accessories including calibration kits, verification kits, ECal and network analyzer measurement accuracy. Rusty has extensive experience with passive microwave components and electromechanical devices ranging from RF to sub-mm. During more than a decade at Maury Microwave, Rusty was involved in simulation, design, manufacturing, and test of Maury's complete product portfolio. Over that time, he served in the role of Senior Engineer, Engineering Manager and Director of Engineering.

He previously had positions in R&D and manufacturing at Agilent/HP working with a wide range of microwave products. He has a BS in Electrical Engineering with microwave specialization from the University of Illinois, Urbana. Rusty is an executive committee member for the Automatic Radio Frequency Techniques Group (ARFTG) and has been involved with various aspects for ARFTG conferences. He is an IEEE MTT-S member and has given calibration talks at his local IEEE chapter with plant tours for local students. He is an active participant in the P287 working group for coaxial connectors and previously contributed to the P1785 working group for waveguide standards above 110 GHz.

11:00 – 11:45
SC-4

Uncertainties in Microwave Measurements

Uwe Arz (PTB)

Currently, on-wafer traceability is directly linked to Multiline TRL, which is widely recognized as one of the most accurate on-wafer calibrations. In industrial applications, however, fixed-distance calibrations such as SOLT, LRM or SOLR using commercial impedance standard substrates (ISS) are usually preferred for measurements in a great variety of substrate technologies. In this talk, we will show how traceable uncertainties can be obtained for reference multiline TRL calibrations on different substrates. Next, we will demonstrate how these traceable uncertainties can be transferred to industrial calibrations as mentioned above, enabling fixed-distance lumped-element calibrations with commercial ISS, suitable for the targeted application and including uncertainties. Key is the proper characterization of lumped-element standards on the commercial ISS with custom-made, application-specific reference calibration standards.

Uwe Arz (S'97-M'02-SM'09) received the Dipl.-Ing. degree in electrical engineering and the Ph.D. degree (summa cum laude) from the University of Hannover, Hannover, Germany, in 1994 and 2001, respectively. In 2001, he served as a Post-Doctoral Research Associate with the National Institute of Standards and Technology, Boulder, CO, USA. In 2002, he joined the Physikalisch-Technische Bundesanstalt (PTB), Braunschweig, Germany, where he develops metrology for on-wafer measurements. From 2015 to 2018, he led the European EMPIR Project PlanarCal as a Coordinator. He is currently the Head of the Working Group On-Wafer Scattering Parameter Measurements at PTB. Dr. Arz is the recipient of the first ARFTG Microwave Measurement Student Fellowship Award in 1999 and of the 2003 AHMT Measurement Award presented by the Association of German University Professors for Measurement Science. He received three ARFTG Best Poster and two ARFTG Best Paper Awards, and was a co-recipient of the 2011 European Microwave Prize. He has authored and coauthored more than 100 publications in the fields of on-wafer S-parameter measurements, broadband characterization of high-speed interconnects, high-impedance probing, network analyzer calibration and dielectric material measurements. In January 2023, he was honored as an ARFTG Life Member.

12:00 - 13:00

Lunch Break

FUNDAMENTALS OF NONLINEAR MEASUREMENTS

13:10 – 13:55
SC-5

Everything You Can Do with Vector Nonlinear Microwave Measurements

Patrick Roblin (The Ohio State University)

The advent of nonlinear vector network analyzers (NVNA) has stimulated the introduction of new paradigms in microwave engineering for (1) the measurement, (2) the modeling and (3) the design of nonlinear microwave circuits such as microwave power amplifiers and oscillators. First the various types of NVNA architecture available, the procedure used to calibrate them and the calibration traceability will be presented. Then the various behavioral models used for the data representation will be reviewed. Circuit-based nonlinear microwave models of transistors can also be directly extracted from large-signal measurements. NVNA's can further be used to verify the nonlinear embedding device model which predicts from the desired internal PA mode of operation, the required amplitude and phase of the multi-harmonic incident waves at the transistor package reference planes. Example of design of power amplifiers (PA) such as Class F, J, Doherty and Chireix amplifiers will be presented.

Patrick Roblin was born in Paris, France, in September 1958. He received the Maitrise de Physics degree from the Louis Pasteur University, Strasbourg, France, in 1980, and the M.S. and D.Sc. degrees in electrical engineering from Washington University, St. Louis, MO, in 1982 and 1984, respectively. In 1984, he joined the Department of Electrical Engineering, at The Ohio State University (OSU), Columbus, OH, as an Assistant Professor and is currently a Professor. His present research interests include the measurement, modeling, design and linearization of non-linear RF devices and circuits such as oscillators, mixers, power-amplifiers and MIMO systems. In 2016 he served from three years as DML for IEEE-MTT. He is currently serving as vice-president of ARFTG and as co-chair of the MTT Technical Committee TC3 on Microwave Measurements.

14:00 – 14:45
SC-6

Load-Pull Measurement Techniques: Architecture, Accuracy, and Applications

Mauro Marchetti (Maury Microwave)

This presentation focuses on load-pull measurement systems and applications. We will discuss the architecture and the design aspects of state-of-the-art load-pull measurement systems. We will discuss how to evaluate and verify measurement accuracy and describe a procedure for evaluating traceable uncertainty of power measurements as a function of the load impedance. We will present several application examples, ranging from high speed load-pull for technology evaluations and power amplifier design to modulated testing for 5G applications.

Mauro Marchetti received the B.S. and the M.Sc. degree in electrical engineering from the University of Naples "Federico II," Italy, and the Ph.D. degree from Delft University of Technology, The Netherlands. In 2006 he joined the Electronics Research Laboratory, Delft University of Technology as a Ph.D. researcher. In 2010 he co-founded and was appointed CEO of Anteverta-mw B.V, a company providing pioneering solutions in the fields of load pull device characterization and high-performance power amplifier design. In 2015 Anteverta-mw B.V. was acquired by Maury Microwave Corporation. Since 2022 he is Vice President of Engineering at Maury Microwave Corporation.

14:45 – 15:30

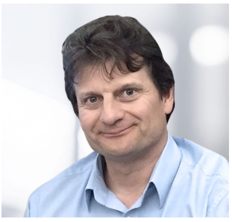
Coffee Break

15:30 – 16:10
SC-7

Measuring Modulation Distortion of Active Devices Using a Vector Network Analyzer

Jan Verspecht (Keysight Technologies)

A new method is described to characterize signal distortion of active devices like amplifiers, mixers and frequency converters under modulated operating conditions. The method is called ”Vector Component Analysis” and typically uses a vector signal generator and a vector network analyzer. Vector component analysis is based on the decomposition of the output signal into one part that is linearly correlated with the input signal, and another part that is the nonlinear distortion. The decomposition is based on calculating the statistical cross-correlation between the measured spectra of the input signal and the output signal. The input signals are repetitive and can be designed to match the statistical and spectral characteristics of any given modulation format. The method has unprecedented dynamic range and accuracy and provides derived quantities like error-vector-magnitude (EVM), noise-power-ratio (NPR), equalized channel capacity, adjacent-channel-power-ratio (ACPR), equalization filter response and best linear approximation filter response.



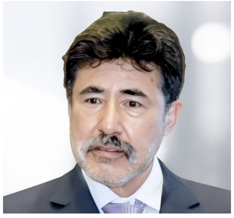
Jan Verspecht received a Ph.D. degree in Applied Sciences from the Vrije Universiteit Brussel (VUB), Brussels, Belgium, in 1995. From 1990 until 2002 he was a Research Engineer with HP and Agilent. In 2003 he started working as an independent consultant. In 2008 he co-founded the startup VTD. In 2012 VTD was acquired by Agilent Technologies, now Keysight Technologies, where he works as an Intrapreneur. He is a pioneer of and key contributor to Nonlinear Vector Network Analyzer (NVNA) technology, he invented X-parameters and Modulation Distortion Analysis. He holds 20 patents, and he authored and co-authored the book entitled “X-parameters”, over 40 conference papers and 12 refereed journal papers. His research interests include the large-signal characterization and behavioral modeling of RF and microwave components. In 2007 Dr. Verspecht was elevated to the grade of IEEE Fellow by the IEEE Board of Directors.

16:15 – 17:00
SC-8

Time-Domaine Low Frequency Active Harmonic Load-pull As a Tool for Verifying the Theory of PA Modes of Operation

Apolinar Reynoso-Hernández (CICESE)

The theory of all the classes of power amplifiers 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 three-harmonic time-domain Low Frequency (LF) active load-pull systems over their high frequency (HF) counterparts, they can be useful for investigating the resistive-reactive (R-R) continuous modes based on class-B. In this short course, the use of a three-harmonic time-domain (LF) active load-pull system, which is implemented using a Low-Frequency nonlinear vector network analyzer, is utilized for measuring the current and voltage waveforms at the intrinsic current source plane of SiC-MESFET, GaAs-MESFETs and GaN-HEMT packaged transistor operated as a R-R class-J, and Class-F modes. From the current and voltage waveforms, the device’s drain efficiency and output power (loading the transistor with fundamental and harmonic impedances corresponding to the design space of R-R class-J, and class-F modes) are calculated and compared with those predicted by the theory. The goal of this short course is to demonstrate that the R-R Class-J and R-R class-F modes can be experimentally studied by using three-harmonic time-domain Low Frequency (LF) active load-pull systems.



J. Apolinar Reynoso-Hernández (AM'92-M'2003) received his Electronics and Telecommunications Engineering degree, M. Sc. degree in Solid State Physics and Ph. D. degree in Electronics, from ESIME-IPN, Mexico, CINVESTAV-IPN, Mexico and Université Paul Sabatier-LAAS du CNRS, Toulouse, France, in 1980, 1985 and 1989 respectively. His doctoral thesis was on Low-frequency noise in MESFET and HEMTs. Since 1990 he has been a researcher at the Electronics and Telecommunications Department of CICESE in Ensenada, B. C., Mexico. His areas of specialized research interest include high-frequency on-wafer measurements, high-frequency device modeling, linear and non-linear device modeling. Among the most outstanding contributions of Prof. Reynoso-Hernández and his research group to the theory of VNA calibration techniques are developing the LZZ calibration technique and the generalized theory of the TRM calibration technique. He has contributed more 15 publications at the ARFTG and has leaded CICESE's, Microwave group to obtain the best interactive forum paper award five times. Since 2013 he has served as TPC of ARFTG and ARFTG-MTT Workshop organizer.

17:00 End of the First Day Short Course Session

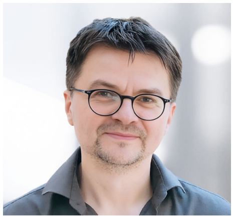
ON-WAFER MEASUREMENTS AND APPLICATIONS

8:00 – 8:45
SC-9

Fundamentals of Successful Wafer-Level Calibration at mm-Wave Frequencies

Andrej Rumiantsev (MPI Corporation)

The accuracy of the wafer-level calibration procedure can be hindered by several effects, such as unoptimized boundary conditions of calibration standards, unwanted modes propagating in the substrate, the parasitic coupling of calibration standards and RF probe with neighbor elements, specifics of the calibration algorithm used, the impact of the temperature, system operator and the laboratory environment, and others. In this discussion, we will review concepts and essential differences in widely used RF calibration methods and their sensitivity to various parasitic effects. We will also address aspects related to the instrumentation and system accessories. Finally, we will review and discuss several examples of improving the confidence of measured data at the mm-wave frequency range.



Andrej Rumiantsev received Diploma-Engineer degree (with highest honors) in Telecommunication systems from the Belarusian State University (BSUIR), Minsk, Belarus, and the Dr.-Ing. Degree (with summa cum laude) in Electrical Engineering from Brandenburg University of Technology (BTU) Cottbus, Germany, in 1994 and 2014, respectively. He joined SUSS MicroTec Test Systems (from 2010 Cascade Microtech) in 2001, where he held various engineering product management and marketing positions. He significantly contributed to developing the RF wafer probes, wafer-level calibration standards, calibration software, and probe systems. Dr. Rumiantsev is currently with MPI Corporation, holding the position of Director of RF Technologies of the Advanced Semiconductor Test Division. His research interests include RF calibration and wafer-level measurement techniques for advanced semiconductor devices. Dr. Rumiantsev is a member of the IEEE MTT-3 Microwave Measurements Committee, the chair of IEEE MTT-S P2822 Working Group "Recommended Practice for Microwave, Millimeter-wave and THz On-Wafer Calibrations, De-Embedding and Measurements" and the ExCom member of the Automatic RF Techniques Group (ARFTG). He holds multiple patents in wafer-level RF calibration and measurement techniques. His doctoral thesis was awarded as "Best Dissertation of 2014 at Brandenburg University of Technologies.

8:45 – 9:30
SC-10

Fundamentals and Challenges of On-wafer Measurements above 100 GHz

James Hwang (Cornell University)

Hexagonal semiconductors such as 4H SiC have important high-frequency, high-power, and high-temperature applications. These applications require accurate knowledge of their permittivity as functions of orientation, frequency, temperature, and humidity. However, due to challenges for suitable test setups and precision high-frequency measurements, little reliable data exists for these semiconductors especially at millimeter-wave frequencies. Further, the limited data often exist nonphysical dispersions due to measurement artifacts. Using innovative measurement techniques, we will show that the dielectric constant is constant, and the loss tangent is linear for 4H SiC from 55 to 330 GHz. In fact, the loss tangent, less than 10^{-4}, is significantly lower than that of sapphire, our previous low-loss standard.

James Hwang graduated from the Department of Materials Science and Engineering, Cornell University with a PhD degree. After years of industrial experience at IBM, Bell Labs, GE, and GAIN, he spent most of his academic career at Lehigh University. He cofounded GAIN and QED; the latter became the public company IQE. He used to be a Program Officer at the U.S. Air Force Office of Scientific Research for GHz-THz Electronics. He had been a visiting professor at Cornell University in the US, Marche Polytechnic University in Italy, Nanyang Technological University in Singapore, National Chiao Tung University in Taiwan, and Shanghai Jiao Tong University in China. He is an IEEE Life Fellow and a Distinguished Microwave Lecturer. He is also a Track Editor for the IEEE Transactions on Microwave Theory and Techniques. He has published approximately 400 refereed technical papers and been granted eight U.S. patents. He has researched electronic, optical, and micro-electromechanical devices and circuits. His current research interest includes scanning microwave microscopy, two-dimensional atomic-layered materials and devices, and electromagnetic sensors for individual biological cells.

9:30 – 10:15

Coffee Break

10:15 – 11:00
SC-11

Fundamentals of On-Wafer Power

Christian Long (NIST)

Power measurements are critical for many applications, including development of energy-efficient electronics and characterization of non-linear electronics. Here we offer an introduction to the theory and practice of vector-network-analyzer (VNA) based power measurements for on-chip applications. We discuss the conventional approach of calibrating wave parameter amplitudes at a connectorized reference plane and then moving the reference plane to an on-chip reference plane with a second-tier calibration. We also discuss calibrating power directly at wafer probe tips with an on-chip power sensor. We show that in both approaches, power measurements can be traceable to the International System of Units (SI).

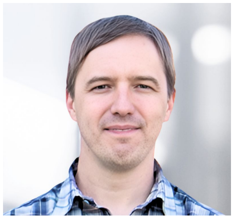
Christian J. Long is the project leader for the Radio-Frequency Power and Impedance project at the National Institute of Standards and Technology (NIST). Dr. Long received the B.S. and Ph.D. degrees in physics from the University of Maryland at College Park, College Park, MD, USA, in 2004 and 2011, respectively. His doctoral research focused on development of both near-field scanning probe microscopy techniques and new methods to analyze data from combinatorial materials experiments. From 2012 to 2015 he was a postdoctoral research fellow with NIST, Gaithersburg, USA, where he focused on techniques for characterizing nanoscale materials. In 2016, he joined the staff at NIST, Boulder, USA, to work on development of standards for radio-frequency, microwave, and mm-wave calibrations.

11:00 – 11:45
SC-12

Fundamentals of On-Wafer Cryogenic RF Measurements

Nathan Flowers-Jacobs (NIST)

Cryogenic microwave calibrations are becoming more important with rising interest and investment in superconducting quantum computing. Some calibration approaches closely follow room temperature methods. I will discuss the use of cryogenic probe stations with on-chip standards and the use of cryogenically compatible RF switches and coaxial standards to implement SOLR (Short Open Load Reciprocal) calibrations at relevant superconducting qubit frequencies below 10 GHz. Among other challenges, the cryogenic environment forces the use of long coaxial cables leading to a remote measurement. An additional challenge in the context of superconducting qubits is the low power and thermalization requirements which often results in over 30 dB of attenuation on the RF bias lines and makes using RF probes difficult. I will also discuss other approaches that leverage the cryogenic environment as part of the calibration. We have demonstrated a method that uses different temperature-dependent impedance states of an on-chip superconducting coplanar waveguide as calculable calibration standards. Superconducting qubits can also be used as in situ standards with nonlinear properties calculable from independent measurements. Using this approach, a qubit coupled to a transmission line can become an on-chip, wideband, calibrated power sensor. Finally, I will mention how we are extending audio frequency quantum-based voltage sources into the microwave regime.



Nathan Edward Flowers-Jacobs was born in Urbana, IL, USA, on June 15, 1979. He received the B.S. degree in physics from the California Institute of Technology, Pasadena, CA, USA, in 2001, and the Ph.D. degree in physics from the University of Colorado Boulder, Boulder, CO, USA, in 2010, for his work on a quantum-limited detector of nanomechanical motion based on electron tunneling across an atomic point contact. He was with Massachusetts Institute of Technology Lincoln Laboratory, modeling radar cross sections for two years, before joining the Graduate School at JILA and the University of Colorado Boulder. From 2010 to 2014, he was a Postdoctoral Associate with Yale University, New Haven, CT, USA, working on nanomechanical displacement measurements at the quantum limit using optical cavities. In 2014, he joined the Quantum Voltage Project, National Institute of Standards and Technology, Boulder, CO, USA, where he has been working on development, characterization, and applications of the Josephson arbitrary waveform synthesizer, which is an ac Josephson voltage standard based on pulse-biased arrays of Josephson junctions.

12:00

End of the NIST/ARFTG Short Course

ARFTG Users Forums

Monday, January 20th | NVNA Users Forum

8:30-8:35	**Welcome** Nick Miller (MSU, USA)
8:35-8:50	**Round table introduction of all attendees** Moderator: Nick Miller (MSU, USA)
8:50-9:50	**Panel: The future of NVNAs** Panel Members: Mauro Marchetti (Maury Microwaves, USA), Tony Gasseling (AMCAD, France), Patrick Roblin (OSU, USA), Apolinar Reynoso Hernandez (CICESE, Mexico) NVNA Applications: • Model verification • Modulated waveforms measurements • Low-frequency and real-time NVNA Architecture for mm-wave NVNA: • Sub-sampling down conversion/Sampling (Oscilloscope)/Mixer-based • Harmonic phase references for mm-waves
9:50-9:55	**Farewell** Nick Miller (MSU, USA)
10:00	**NVNA Users Forum Ends**

10:30-10:45	**We Turned 20!** Andrej Rumiantsev (MPI Corporation, Taiwan)
10:45-11:00	**Advanced Techniques for Extreme Impedance Characterization in Semiconductors: AI and Nanorobotics Perspectives** Kamel Haddadi (University of Lille, France)
11:00-11:15	**Discussion** Gia Ngoc Phung (PTB, Germany)
11:15-11:35	**Techniques for Minimizing On-Wafer Device Characterization Error through Calibration Kit Design from Gigahertz to Terahertz** Rob D. Jones (NIST / Colorado School of Mines, USA)
11:35-11:55	**Discussion** Gia Ngoc Phung (PTB, Germany)
11:55-12:00	**Farewell** Gia Ngoc Phung (PTB, Germany)
12:00	**On-Wafer Users Forum Ends**

ARFTG-104th Conference Program

Monday, January 20th | Afternoon Session

SESSION A: Loadpull and Nonlinear Measurements

13:10-13:35
A-1

KEYNOTE Advancements in Transistor and Circuit Modeling for Next-Generation RF Circuit Design Techniques

Tony Gasseling (AMCAD)

In the fast-evolving landscape of 5G and 6G telecommunications, achieving optimal RF performance is paramount. This presentation delves into new strategies for transistor and circuit modeling that aim to replace conventional approaches. A key focus of this presentation is the introduction of a pioneering methodology for characterizing GaN HEMT technologies. Through precise measurement of the current-voltage (I-V) characteristic in non-50 Ω environments, the methodolgy presented unlock the ability to accurately model dynamic trapping states. By dynamically controlling the trapping state of charge using calibrated RF pre-pulses, derived from preliminary large-signal load-pull measurements, a new level of accuracy in transistor modeling is achieved.Moreover, leveraging these advanced transistor models, a novel Power Amplifier modeling flow at the circuit design stage is showcased. This innovative approach enables us to capture Power Amplifier behavior under diverse conditions, including instantaneous input power, carrier frequency, and load impedance variations. The insights gained from this modeling flow are invaluable for optimizing circuit performance, refining system design, and seamlessly integrating next-gen technologies.

Tony Gasseling is CEO and co-founder of AMCAD Engineering, a spin-off Company from the CNRS XLIM research laboratory created in 2004. He oversees all the company's business areas, and focuses his efforts on defining and implementing AMCAD's strategy and mission: "To help our customers develop safe, efficient and more environmentally friendly communication systems. His role is to lead a customer-focused company, as well as harnessing the skills of the people involved in the team to create tomorrow's measurement and RF circuit modeling solution for an enhanced simulation experience.

13:35-14:00

A-2

INVITED Characterization of GaN Transistors and PAs with Modulated Signals

Zoya Popovic (University of Colorado at Boulder)*; Marc Vanden Bossche (Consultant); Reyes Lucero (University of Colorado at Boulder)

An analysis of Gallium Nitride (GaN) transistor and power amplifiers (PAs) behavior under modulated signal excitation is presented. Using a passive load-pull system and a large-signal vector network analyzer with an Arbitrary Waveform Generator (AWG) wideband source, we characterize two 6W GaN-on-SiC transistors from different manufacturers under various excitations. Experimental results with 300-tone 6.1MHz bandwidth signals indicate that the power-added efficiency, output power, and gain of transistors with narrowband OFDM-like signals are sufficiently represented by their CW performance at the same mean power. Additionally, a PA is characterized with different numbers of 10-MHz multi-carrier signals, evenly spaced within a 500MHz bandwidth centered around a 4.35 GHz carrier. The single-stage hybrid GaN PA is designed with CW output power above 10W from 4 to 5 GHz and with PAE exceeding 50% from 4.1-4.6 GHz with a saturated gain above 8 dB at 28V drain bias. The efficiency, output power, noise power ratio, and spectral efficiency are quantified in measurement and show that the overall performance can be appropriately defined by an equally-weighted figure of merit which is a function of the number of modulated signals.

Zoya Popovic received the Dipl.Ing. degree from the University of Belgrade, Serbia, Yugoslavia, in 1985, and the PhD degree from the California Institute of Technology, Pasadena, in 1990. Since 1990, she has been with the University of Colorado Boulder, where she is currently a Distinguished Professor and holds the Lockheed Martin Endowed Chair in RF Engineering in the Department of Electrical, Computer and Energy Engineering. In 2001, she was a visiting professor with the Technical University of Munich, Munich, Germany. Since 1991, she has graduated more than 50 PhD students. Her research interests include high-efficiency, low-noise, and broadband microwave and millimeter-wave circuits, quasi-optical millimeter-wave techniques for imaging, smart and multibeam antenna arrays, intelligent RF front ends, and wireless powering for batteryless sensors. Popovic was the recipient of the 1993 and 2006 Microwave Prizes presented by the IEEE Microwave Theory and Techniques Society (IEEE MTT-S) for the best journal papers, and received the 1996 URSI IssacKoga Gold Medal. In 1997, Eta Kappa Nu students chose her as a Professor of the Year. She was the recipient of a 2000 Humboldt Research Award for Senior U.S. Scientists from the German Alexander von Humboldt Stiftung. She was elected a Foreign Member of the Serbian Academy of Sciences and Arts in 2006. She was also the recipient of the 2001 Hewlett-Packard(HP)/American Society for Engineering Education(ASEE) Terman Medal for combined teaching and research excellence.

14:00-14:20

A-3 Student

Rapid Characterization of the Impact of Dynamic Trapping on GaN HEMT IVs Using a Real-Time NVNA

Miles Lindquist (Ohio State University)*; Patrick Roblin (Ohio State University); Matthew Nichols (The Ohio State University)

This paper presents a novel testbed in which a pulsed real-time active-loadpull (pulsed-RTALP) measurement is performed before and after a class-B pulsed active-loadpull (pulsed-ALP) excitation to extract the IV curves of a transistor in less than a microsecond. The class-B ALP loadline is utilized in this measurement to provide a realistic way for the transistor to achieve a high instantaneous drain voltage in order to fill traps like is observed during moments of peak power in OFDM communication signals. The RTALP measurement is configured by driving the gate and drain of the transistor with signals at two different frequencies such that the resulting modulated loadline covers a large area of the transistor's IV space. A modulation frequency of 5 MHz is selected with 95 and 100 MHz gate and drain excitations for RTALP and the transistor's IV is extracted from a single 200 ns period of the RTALP loadline. The RTALP and ALP measurements are performed with a real-time nonlinear vector network analyzer (RT-NVNA), enabling the capture of pulsed multiharmonic loadlines period-per-period and across 50 successive pulses. This testbed allows for the tracking of the evolution of the transistor's IV characteristics before and after each repeated pulsed class-B RF stress. By changing the pulse duty rate, a recovery time close to 4 ms is observed while the capture time is on the order of tens of nanoseconds. For a class-B RF stress with a 44 V peak voltage and a 24.5 V drain bias, the post-stress degraded IV characteristics are in good agreement after a single pulse with a pulsed-IV characteristics drain biased at 35.25 V.

14:20-14:40

A-4 Student

Anomalous Behavior of Continuous Class-F Mode Power Amplifier

Daniel Alonso-Tejera (CICESE); J. Apolinar Reynoso-Hernandez (CICESE)*; Manuel Alejandro Pulido-Gaytan (CICESE); Maria del Carmen Maya-Sánchez (CICESE); Jaime Sanchez-Garcia (CICESE); Eduardo Antonio Murillo-Bracamontes (CNyN-UNAM); Jose Raul Loo-Yau (CINVESTAV-GDL)

This paper presents a three-harmonic, time-domain low-frequency active load-pull (LF-AHLP) system, which uses a fully calibrated low-frequency nonlinear vector network analyzer (LF-NVNA) operating across a range of 1 MHz to 120 MHz. By providing precise control over up to three harmonics, the LF-AHLP system enables experimental validation of theoretical models of continuous class-F power amplifier, and it confirms the onset of soft breakdown voltages in GaAs technology (MESFETs and HEMTs) under large drain-source voltage waveforms, influenced by the load impedance design space. A pronounced negative peak in the igs waveform and a positive peak in the ids waveform—where ideally, the current would be zero—demonstrate this effect as the amplifier transitions to continuous mode.

14:20-14:40

ARFTG Business Meeting

Rusty Myers (ARFTG President)

15:00-15:35

Coffee Break & Exhibition

Joel Dunsmore (ARFTG Exhibition Chair)

15:35-16:00

B-1

INVITED Trends in DUT Characterizations with Wideband Test Signals

Jean-Pierre Teyssier (Keysight Technologies, Inc.)*, Johan Ericsson (Keysight Technologies, Inc.)

Active component testing at sub-THz frequencies rely on the pertinent choice of instruments, test signals and data processing algorithms as the dynamic range margins of instruments are drastically reduced. In the meantime, the modulation bandwidths and data flows are larger than ever, often reaching 100GBits/s or more. Advanced measurement setups are pushed to their limits to do accurate and relevant DUT characterizations.

Jean-Pierre Teyssier received the Master and Ph.D. degrees from Limoges University, France, in 1990 and 1994, respectively. From 1995 to 2012, he has been a Researcher and Professor with the XLIM Laboratory at University of Limoges, and he has been co-founder of the VTD (Verspecht Teyssier DeGroote) startup company in 2007. He is since 2012 a master research engineer with Keysight Technologies. He is the inventor and currently the main engineer for the multi-port Spectrum Analyzer capability of the PNA-X. His recent contributions include the phase coherent mode of PNA-SA, the wideband phase stitching extended to mm wave frequencies, the PNA-X link to VSA for wideband signal demodulation.

16:00-16:20

B-2

Characterization and Correction of Homodyne Systems Enabling Single-Carrier 40 Gb/s in E-band

Talley Amir (Keysight Technologies, Inc.)*; Jan Verspecht (Keysight Technologies, Inc.); Sam Kusano (Keysight Technologies, Inc.)

Linear distortions in homodyne systems are caused by variations in amplitude gain, time delay, and phase between the in-phase and quadrature components of an input signal. In this paper, we offer a novel technique for correcting these imbalances at a system level. We offer a frequency-dependent characterization and correction procedure that supports high-frequency and wideband modulation signals at arbitrary resolution bandwidths. We demonstrate the application of our method by pre-distorting modulated waveforms transmitted through a 4-millimeter waveguide at E-band frequencies. Our results show that the received signals have a dynamic range of at least 40 dB, a large improvement over historical correction techniques. We assess our technique on 256-QAM constellations at 5 GBd (40 Gb/s) and measure 3.2% error vector magnitude, where comparable historical methods require various modifications in order to compare.

16:20-16:40

B-3 Student

A Piecewise Interpolation based Digital Predistortion of Power Amplifiers Across Wide Power Ranges

Nizar Messaoudi (Keysight Technologies, University of Waterloo)*; Ahmed Ben Ayed (University of Waterloo); Slim Boumaiza (University of Waterloo)

This paper introduces a novel piecewise linear interpolation scheme designed to enhance power amplifer (PA) linearity across a wide power range in MIMO systems. By interpolating between pre-determined digital predistortion (DPD) solutions, the proposed method reduces the complexity of the linearization process and eliminates the need for frequent retraining under varying operating conditions. Theoretical analysis and experimental validation on a Gallium Nitride (GaN) PA at 13 GHz to confirm the effectiveness of the scheme, achieving an Adjacent Channel Power Ratio (ACPR) better than -44 dB using just four sets of pre-trained DPD coefficients across a 17dB power range. With five training points, the method improves linearization to yield Error Vector Magnitude (EVM) beyond -40 dBc, significantly outperforming conventional single-point DPD techniques, which experience signal quality degradation of over 15 dB ACPR and EVM as output power fluctuates compared to DPD re-trained at every power level. This approach offers a scalable and efficient solution for maintaining high linearity and offers insight into how PA linearizability performance should be assessed in next-generation multi-antenna systems.

16:40-17:00

B-4 Student

Comparative Study of Two Architectures Suitable for the Generation of Wideband Signals at Sub-THz

Zi Jun Su (University of Waterloo)*; Ahmed Ben Ayed (University of Waterloo); Slim Boumaiza (University of Waterloo,Canada); Patrick Mitran (University of Waterloo)

This paper presents a comparative study of two architectures for generating wideband modulated signals at sub-THz frequencies using a frequency bonding approach, focusing on achievable output signal quality. The first architecture generates a wideband signal at an intermediate frequency (IF) and up-converts it to sub-THz frequencies using a heterodyne mixer. The second approach generates multiple narrowband signals at IF, up-converts each to sub-THz, and then combines them. The study shows that, under linear up-converter operation, both architectures achieve similar signal-to-noise ratios (SNR) and are limited by the noise floor. However, replacing the combiner in the second architecture with a frequency duplexer improves the SNR by 3 dB. At higher IF power levels, where up-converter nonlinearity becomes significant, both architectures require digital predistortion to mitigate distortion. Despite this, the second architecture demonstrates superior adjacent-channel power ratio (ACPR). D-band measurements confirm that the second architecture enhances ACPR by up to 8 dB at high IF power levels when generating a modulated signal with a carrier frequency of 142.5 GHz and a modulation bandwidth of 1.2 GHz, while performance at lower power levels remains comparable.

17:00

End of the ARFTG-104 First Day

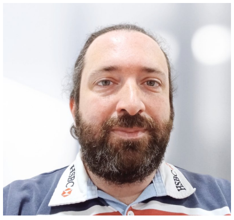
SESSION C: Millimeter-Wave Measurements

8:00-8:25
C-1

INVITED Paving the Way to Accurate mm-Wave NVNA Measurements

Roberto Quaglia (Cardiff University)*

This paper summarizes the ongoing activities at Cardiff University to establish an accurate measurement setup for the characterization of mm-wave transistors in large signal conditions. The setup is a Nonlinear Vector Network Analyzer (NVNA) with a bandwidth of 100 GHz with passive tuners for source/load pull. The paper describes how the underpinning 67 GHz Vector Network Analyzer (VNA) was adapted to achieve. single-sweep operation up to 110 GHz using frequency extenders and frequency diplexers, and the use of a 100 GHz oscilloscope for measuring the phase and reconstructing waveforms. The paper also discusses the adjustments made to the system and to the calibration procedure once it was realized that the main contributor to systematic errors was the mechanical perturbations that occur when changing the system configuration between the calibration states and the measurement state.



Roberto Quaglia received his PhD from Politecnico di Torino, Italy. After working for Huawei Technologies on some of the first mm-wave 5G prototypes, he joined Cardiff University with a Marie Sklodowska Curie Fellowship under Prof Cripps's supervision. He is now a Senior Lecturer at Cardiff University, where he leads the Centre for High Frequency Engineering, researching advanced power amplifier design and mm-wave characterisation and modelling.

8:25-8:45
C-2

Trends in DUT Characterizations with Wideband Test Signals

Bradley Thrasher (Nuvotronics)*

A test method with a novel test setup was developed to obtain a single-sweep 5-port probed S-parameter measurement of an 18-40 GHz Wilkinson power combiner. On-wafer characterization of devices with 5+ ports in a single sweep has not been documented, as previous characterization efforts have used multiple reduced port measurements to obtain the full S-parameter matrix of the device. A novel test setup was required to land probes on the four input ports of this power combiner that were all oriented in the same direction. This paper will summarize the challenges and outcomes of this probed 5-port test setup of the 4-way power combiner DUT.

8:45-9:05
C-3

Probeable Microstrip Adapter Substrates Enabling Chip Testing Into D-Band

Hugo Morales (Modelithics Inc.); Larry Dunleavy (Modelithics Inc.)*; Chris DeMartino (Modelithics Inc.)

This paper focuses on a new broadband thin-film probe adapter solution that enables accurate microstrip S-parameter measurements at frequencies extending into D-band. These low-loss alumina microstrip adapter substrates act as a convenient interface between RF/mm-wave coplanar ground-signal-ground (GSG) test probes and devices that may not be directly probeable with GSG probes. A calibration can be performed using a commercially available multi-line thru-reflect-line (TRL) microstrip calibration substrate that is directly compatible with the new adapter substrates. This paper presents high-quality device measurements up to 150 GHz that are made possible by the probe adapter solution. Measurements of broadband capacitors and a broadband resistor are shown to demonstrate the utility of the new adapter substrates.

9:05-9:25

C-4 Student

Affordable Frequency Extension for Wide Bandwidth mm-Wave Spectrum Analysis with a Lower Frequency VNA

Matthew Nichols (The Ohio State University)*; Patrick Roblin (The Ohio State University); Nicholas Ellis (The Ohio State University)

This paper presents a cost-effective measurement testbed to enable the use of a lower frequency vector network analyzer (VNA) as a multi-GHz vector signal analyzer (VSA) for modulated mm-Wave waveforms. We demonstrate various 80–640 MHz, 16-QAM signals generated with a carrier frequency of 40 GHz that are down-converted and demodulated. Digital post-distortion (DPoD) is used to perform the nonlinear deembedding of the down-conversion stage. Measurement of the testbed without the DUT yielded 0.26% error vector magnitude (EVM) and 3.93 % EVM with a DUT. After DPoD, the DUT EVM is reduced to 0.55 % at a 640 MHz symbol rate. This work demonstrates that a lower frequency VNA combined with a mixer can be used to realize an effective and affordable calibrated mm-Wave VSA, to acquire modulated signals with multi-GHz bandwidth.

9:25-9:45

C-5 Student

Millimeter-Wave Implementation of Phased Array Emulation from Wideband Load-Pull Envelope Measurements

Mattia Mengozzi (University of Bologna); Alberto Maria Angelotti (University of Bologna); Alberto Santarelli (University of Bologna); Paolo Mezzanotte (University of Perugia); Gian Piero Gibiino (University of Bologna)*

A measurement-based emulation procedure for phased arrays is implemented at millimeter-wave frequencies. By exploiting wideband active load-pull, it allows for the evaluation of the loading conditions and linearity performance of the power amplifier (PA) as operated in the array, without the need to manufacture the array itself. The technique is validated by emulating an ideal 1x4 linear array with variable coupling and an EM-simulated 2x2 patch array for an off-the-shelf PA.

9:45-10:10

Coffee Break & Exhibition

Joel Dunsmore (ARFTG Exhibition Chair)

Plenary Session

10:10-10:50
ARFTG

ARFTG Plenary Talk The convergence of Advanced Models and Measurements for Virtual Prototyping Success

Larry Dunleavy (Modelithics, Inc.)

The electronic design automation (EDA) industry has become mature with time, frequency non-linear, electromagnetic and multi-domain simulation capabilities that are beyond anything envisioned a few decades ago. EDA advances are still being demanded and becoming available. An example is practical multi-physics simulations that promise to facilitate circuit, electromagnetic and thermal simulation needs in the same platform with a single 3D model description. The goal of all this capability is to predict, and optimize before building anything, future measured" real-world" behavior of a physical system or circuit with a virtual model, or digital twin of that system or circuit. The congruence of future measured behavior of a physical prototype, or product, to virtual prototype simulated behavior depends as much on the EDA tool capabilities as on the appropriateness and accuracy of the models used to represent the components within. Development of such models can take many forms depending on the type of component and type of simulations the models are to be used for. However, in most cases, accurate component-level measurements are essential for model development and/or model validation. In the end, virtual prototyping success comes down to intelligent use of accurate measurements at every stage of the process from model development and validation to closing the loop on the final measured behavior of the designed product. This talk will give an up-to-date summary of best practice RF/Microwave/mm-wave modeling strategies that include a range of different model types, and strategies, and how measurements are used in the process. Also to be discussed are examples of virtual prototyping success, where the ability to predict future linear, non-linear, noise and EM coupling effects is shown to be not only possible, but increasingly available to designers worldwide!

Dr. Larry Dunleavy co-founded Modelithics, Inc. in 2001, to provide improved modeling solutions and high-quality microwave and millimeter-wave measurement services for RF and microwave designers. He also is a Professor within USF's Department of Electrical Engineering, where he has been a faculty member since 1990. He is the Co-Director of the Center for Wireless and Microwave Information Systems (The WAMI Center). His teaching and research interests embrace all aspects of RF & Microwave circuit design, measurements, and modeling. In 1991 he enjoyed a summer research appointment at the Air Force Research Facility at Hanscom Field, MA. In 1997- 98 he spent a sabbatical year with the Noise Metrology Laboratory of the National Institute of Standards in Boulder, CO. Dr. Dunleavy also served as the General Chair and Co-chair of the 2014 IEEE MTT-S IMS held in Tampa Florida. Prior to joining USF, in the period from 1982 to 1990, he worked for E-Systems Company and Hughes Aircraft as an RF & Microwave design and test engineer. Dr. Dunleavy received the B.S.E.E. degree from Michigan Technological University in 1982 and the M.S.E.E. and Ph.D. degrees in 1984 and 1988, respectively, from the University of Michigan. He was a Howard Hughes Doctoral Fellow. Dr. Dunleavy is a Senior Member of IEEE and is active in the IEEE MTT Society and a Lifetime Member of the Automatic RF Techniques Group (ARFTG) and a founding member and serves on the Executive Committee for the IEEE WAMICON Conference held annually in Florida each year.

RWW-1

RWW Plenary Talk The Final Frontier – Using Si/SiGe Technology in Space Systems

John D. Cressler (Georgia Tech)

Space has been aptly called the “final frontier” (thank you, Star Trek!). The application needs of the global space and aerospace communities are predictably many and varied, ranging from a diverse set of communications and imaging satellites, to the GPS constellation, to microwave and millimeter-wave (mmW) remote sensing to support weather forecasting and climate science, to exploration of other worlds, which include: the mighty James Webb Space Telescope (probing the origins of the universe), the shadowed polar craters of the Moon (where water ice resides), Mars surface (colonization?), and Europa (the search for extraterrestrial life in the water ocean beneath the 10 km ice cap). While classically, orbital satellites were massive, tough to launch, and extremely expensive (a few $Bs), the current (and rapidly accelerating) trend has swung decidedly towards using relatively low-cost (a few $M) and easy to launch constellations of single or multi-U CubeSats (1U = 10x10x10 cm3) to cost-effectively address the plethora of emerging needs. These days, this has been increasingly supported by commercial space ventures (e.g., SpaceX, BlueOrigin et al., vs. the old gang—NASA and DoD), which are proliferating rapidly. As appealing as space is for visioning fun new science and slick applications, it remains a decidedly unfriendly place to visit. Space is the quintessential “extreme environment,” bathed in intense radiation from both our Sun (high energy electrons and protons trapped by the Earth’s magnetosphere in radiation belts) and the cosmos (GeV energy galactic cosmic rays from supernovae). By way of level setting, a satellite in the most benign Earth orbit, Low Earth Orbit (LEO – 160-1000 km up from the surface), experiences 100,000 rad of ionizing radiation dose over mission life. In comparison, 500 rad will kill a person! That is, we are asking a lot of our electronics in such systems, and given the extreme cost constraints of launch weight, adding a few inches of lead shielding is not the ideal solution! In addition, it is mighty chilly in space (2.73 K = -455°F, the cosmic background), and when the sunlight shines on you, it gets uncomfortably warm, very quickly (e.g., on the surface of the Moon, from -180°C to +120°C from darkness to light, within a few moments). Yep, space is a tough place to do business. As I have long argued, Si/SiGe HBT BiCMOS technology provides a unique solution for many of the needs of these emerging space systems, including: 1) extreme levels of performance (multi-hundred GHz) with the SiGe HBT and high integration levels with on-board CMOS, for realizing compelling system functionality/unit volume, at low cost; 2) the rapid improvement of all electronic circuit relevant performance metrics with cooling, with operational capability down into the mK quantum regime (SiGe HBTs love chilly weather!); 3) the ability to operate robustly up to 150-200°C, with modest performance loss; 4) the ability to operate robustly over wide temperature ranges (in principle from mK to 150-200°C); 5) built-in robustness to multi-Mrad total ionizing dose radiation; and 6) built-in heavy ion induced latchup immunity (read: those pesky GeV cosmic rays). Long ago (1990s), the notion of creating a low-cost Si-based electronic + photonic integrated circuit (EPIC) “superchip” was envisioned (R. Soref), which brought together advanced SiGe HBTs (analog, RF-mmW), CMOS (digital), and Si integrated photonics (with the possible exception of a laser, which could be flipped onto the die worse case). In essence, EPICs are a low-cost, high-yielding, reliable, highly integrated Si platform for putting electrons and light into the same conversation! Clearly this represents a paradigm shift to business as usual. Now, with even more compelling system functionality/unit volume, at low cost. Such an EPIC superchip could in principle satisfy all-comers-of-new-needs. While photonics has long been used in space (think solar cells, imagers), EPICs are new to that space game, but possess great potential for the emergent needs in this new vision of CubeSat/SmallSat driven space systems, including, thing like: LIDAR (spacecraft-to-spacecraft positioning); deep space and within-constellation optical communications (huge data rate improvement); and on-spacecraft high bandwidth data transport (think data center in the sky for instruments that spew out tons of data that need to get back home quickly). This field of EPICs in space is only a few years old, but already much has been learned, and results look very encouraging. In this plenary address, I will highlight the current status and the future trends of using Si/SiGe electronic and photonics in space systems.

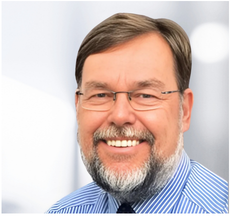
John D. Cressler received his PhD from Columbia University in 1990. He is currently Regents Professor, Schlumberger Chair Professor in Electronics, and the Ken Byers Teaching Fellow in Science and Religion, in the School of Electrical and Computer Engineering at Georgia Tech. His research interests center on SiGe electronic and photonic devices, circuits, and systems. He and his team have published over 800 scientific papers in these areas, and he has graduated 72 PhD students over his 32-year academic career. He has published a number of books, both non-fiction and historical fiction, and he has received a number of awards for both his teaching and research.

RWW-2

RWW Plenary Talk From Niche to Dominance - Si/SiGe in Integrated Microwave Electronics

Hermann Schumacher (Ulm University)

Si/SiGe frontend ICs played a crucial role in making wireless systems in the upper microwave and millimeter-wave range a common sight in civilian, even consumer, systems, such as active satellite antennas for low-earth orbit satellite systems, automotive radars, or high-speed communication links in 5G and emerging 6G standards. Getting there has not been easy. Silicon, after all, has a rather mediocre electron mobility compared to III-V semiconductor families, and a truly semi-insulating substrate suitable for planar transmission line passives is hard to achieve. Starting as early as 1965 (T.M. Hyltin), Silicon was investigated as a potential competitor for GaAs as a semiconductor substrate for microwaves. Early in the 1980s, advances in the technology of Si IMPATT devices breathed new life into microwave electronics on Si. But by and large, monolithic microwave integrated circuits (MMICs) remained firmly in the GaAs camp. Starting in the late 1990s, this changed when the Si microwave IC community realized that the path forward was not to be found in imitating GaAs design approaches. The problem with lossy Si substrates was mitigated by thin-film microstrip lines. With the Si/SiGe heterojunction bipolar transistor an active device emerged which rivaled, and later surpassed, III-V high electron mobility transistors in transit frequency and maximum frequency of oscillation. The advantage of using Silicon for micro- and millimeter-wave ICs is, at least initially, not in its lower substrate cost. Given the comparatively small technological changes introduced by Si/SiGe HBTs to existing and mature BiCMOS processes, Si-based MMICs very quickly increased in complexity. Once commercial markets evolved, the ability to fabricate Si-MMICs on large wafer diameters rapidly brought cost down. The underlying Si processes offered mixed-signal and digital add-ons unavailable in III-V competitors, reducing the packaging complexity. Concentrated passives, including on-chip transformers, replaced transmission line elements, leading to very substantial area reduction. Even micro-electro-mechanical switches (MEMS) can be integrated on chip, including the necessary DC-DC converters for electrostatic actuation. While at RF, MEMS did not catch on as initially expected, their time may still come as we move further up in frequency. The IEEE Topical Meetings on Silicon Monolithic Integrated Circuits in RF Systems (SiRF), whose 25th installment we celebrate in 2025, have been an excellent yardstick of this field's progress over the years, while still providing room for other device concepts, such as SiGe MODFETs, graphene MODFETs, or carbon nanotube transistors. Results from SiRF's proceedings will be used to outline a short history of Si-based micro- and millimeter-wave electronics, augmented with earlier results which may help to understand where we came from, and why Si/SiGe BiCMOS was such a disruptive change. The presentation will conclude with a look ahead, continuously aware that "predictions are very hard, especially about the future", an aphorism attributed to Yogi Berra, Albert Einstein, but uttered by neither.



Hermann Schumacher received is Diploma in Electrical Engineering in 1982, and his Doctorate in Engineering (Dr.-Ing., with highest distinction) in 1986, both from RWTH Aachen University. In 1986, he joined Bell Communications Research in Red Bank, NJ, USA, researching compound semiconductor devices for optoelectronic integration of high-speed fiberoptic applications. Among other things, he was involved in early work on InP/InGaAs heterojunction bipolar transistors (HBTs).

In 1990, he joined Ulm University, Ulm, Germany. There, he and his research group worked on Si/SiGe HBTs (initially with the Daimler Research Center in Ulm), and, increasingly, microwave and millimeter-wave integrated circuits. From 2000 until 2016, he led the Competence Center on Integrated Circuits in Communications, a public-private partnership. Investigated applications ranged from short-range ultra-wideband radars for vital sign detection and security systems to complex frontend ICs for active electronically scanned satellite antennas.

From 2011 until 2022, Professor Schumacher developed and directed the School of Advanced Professional Studies, the continuing education unit of Ulm University.

12:00-13:30

Awards Lunch

David Blackham (ARFTG Awards)

SESSION D: On-Wafer Measurements and Calibration

13:30-13:55

D-1

INVITED Impact of Uncertainty and Non-Idealities in On-Wafer Multiline TRL Calibration on Broadband GaN HEMT Modeling

Jason Shell (Michigan State University); Jerome Cheron (NIST); Edward Gebara (Michigan State University); Matthew Hodek (Michigan State University); Nicholas Miller (Michigan State University)*

This paper analyzes the effect of broadband S-Parameter measurement uncertainty on small-signal modeling of millimeter-wave gallium nitride (GaN) high electron mobility transistors (HEMTs). Measurements from 0.5 – 110 GHz of two GaN HEMTs with different gate lengths are analyzed. An approach to quantifying the effect of measurement uncertainty on small-signal modeling is applied to the GaN HEMTs. The results indicate a strong dependence of the intrinsic model parameters to measurement uncertainty.

Nicholas C. Miller (Senior Member, IEEE) received the B.S., M.S., and Ph.D. degrees in electrical and computer engineering from Michigan State University, East Lansing, MI, USA, in 2013, 2015, and 2017, respectively. He was an Electronics Engineer at the Air Force Research Laboratory from 2017 to 2023. In 2023, he joined the Faculty of the Electrical and Computer Engineering Department, Michigan State University, as an Assistant Professor. His current research interests include linear and nonlinear mm-wave characterization of on-wafer transistors and integrated circuits, physics-based compact modeling of compound semiconductor transistors, and technology computer-aided design modeling of wide and ultrawide bandgap semiconductor transistors. Dr. Miller is currently a Young Professional Member of the IEEE MTT TC-3 Microwave Measurements Committee. He was a recipient of the IEEE AP-S Predoctoral Research Award in 2013, the U.S. DoD Science, Mathematics, and Research for Transformation (SMART) Scholarship in 2014, the IEEE Dayton Section Harrell V. Nobel Award in 2019 for physics-based device modeling, the Best Conference Paper Award at the 21st IEEE Wireless and Microwave Technology Conference (WAMICON) in 2021, the Best Presentation Award at the IEEE MTT-S Young Professional Workshop on Optimization and Modeling of Active Devices in 2022, and the AFRL Early Career Award in 2023.

13:55-14:15

D-2

Modal TRL De-Embedding of Symmetric Differential Transmission Lines with Proper Reference Impedance Matrix Transformations

Shuhei Amakawa (Hiroshima University)*; Takeshi Yoshida (Hiroshima University); Michael Gadringer (Graz University of Technology); Wolfgnag Bösch (Graz University of Technology)

Theory of mode transformation is presented for S-matrices and their associated reference impedances. It is shown that when an S-matrix is mode-transformed, the associated reference impedance matrix must also be transformed commensurately. Modal thru-reflect-line (TRL) de-embedding of 4-port symmetric differential transmission lines (TLs) is presented by way of example. It is shown that reference impedance matrices may become nondiagonal, which goes beyond the scope of the assumption made by the conventional S-parameter theory. The mode transformation theory is validated by using synthesized data via applying 2-port TRL and calibration comparison (for characteristic impedance estimation) to the two eigenmodes, followed by inverse mode transformation and renormalization transformation back to the single-ended nodal representation. Measurement data for differential TLs with GSGSG pads on a 65-nm CMOS chip are also presented.

14:15-14:35

D-3

Investigation of Probe Pitch Influence on On-Wafer Multiline TRL Calibrations up to 110 GHz

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

Recently, much progress has been made in the traceability of on-wafer measurements of planar devices on coplanar calibration substrates. However, reliable uncertainties for on-wafer S-parameters can only be given for a specific combination of substrate material, planar transmission line and probes, and only if single-mode propagation is ensured. This condition limits the use of uncertainties for probes with different dimensions. Therefore, this paper presents a systematic investigation of the influence of probe pitches on selected devices under test. The effects of probe pitch in conjunction with the influence of neighbourhood effects are investigated via simulations up to 110 GHz and compared with measurement results of example DUTs with expanded uncertainties at a coverage probability of 95 % (k=2).

14:35-14:55

D-4

Method of Estimating RF Probe-Tip Calibration Reproducibility Budget on Commercial Calibration Substrates

Andrej Rumiantsev (mpi) (MPI Corporation)*; Ralf Doerner (Ferdinand-Braun-Institut (FBH))

The paper presents a method for estimating the reproducibility budget for RF probe-tip calibration on commercial calibration substrates, a critical factor for achieving reliable wafer-level measurements. This approach isolates calibration errors associated with standard location and probe contact repeatability, enabling more consistent cross-system data comparisons even with varying VNAs and probe models. The proposed method simplifies the application of calibration uncertainty propagation tools for wafer-level experiments and highlights the value of location-dependent error estimation. Furthermore, we illustrate how the estimated calibration reproducibility error budgets can be used for reporting the measurement results of a passive verification device.

14:55-15:35

Coffee Break, Interactive Forum & Exhibition

Joel Dunsmore (ARFTG Exhibition Chair)

15:35-15:55
E-1 Student

Evaluation of On-Wafer Noise Parameter Measurement Techniques at Cryogenic Temperatures

James Kelly (University of Glasgow)*; Jing Wang (University of Glasgow); Afesomeh Ofiare (University of Glasgow); Chong Li (University of Glasgow); Nick Ridler (National Physical Laboratory)

In this paper, we highlight the current techniques for on-wafer noise parameter measurements under cryogenic conditions, and demonstrate their benefits and limitations. We first compared two noise parameter measurement systems at room temperature: one using the internal tuner of the network analyzer; and the other using an external tuner. We then used the internal tuner of the network analyzer for characterizing a GaN high electron mobility transistor at temperatures down to 78 K. The aim of this process was to identify which factors need addressing to improve the accuracy and precision of on-wafer noise parameter measurements at cryogenic temperatures. Stable noise data is reported up to 16 GHz; the minimum noise figure increased with both temperature and frequency, as expected. Predictions are also made for problems that may occur at lower temperatures, such as 4 K and mK.

15:55-16:15
E-2 Student

Time-Domain Noise Characterization of LNAs: Validation, Trade-offs, and Analytical Insights

Yin Zeng (Chalmers University of Technology)*, Jörgen Stenarson (Chalmers University of Technology), Peter Sobis (Chalmers University of Technology), Jan Grahn(Chalmers University of Technology)

We present a direct method for time-domain noise characterization of transient-state LNAs with ns-level resolution. We validate noise measurements using a time-domain method by comparing them with corresponding NFA-based data at a static reference bias. The trade-off between characterized noise variance and time resolution is investigated. A comprehensive analytical expression linking measured noise variance to noise source temperature and LNA static noise performance is derived. This provides insight for efficient and accurate measurements of transient noise and gain in noise-sensitive time-dividing systems.

16:15-16:35
E-3 Student

Characterization of In-plane Polarization Domains in 2D SnSe by Scanning Microwave Microscopy

Yawei Zhang (Cornell University)*; Xiaopeng Wang (Cornell University); James Hwang (Cornell University); Nannan Mao (Massachusetts Institute of Technology); Peng Wu (Massachusetts Institute of Technology); Jing Kong (Massachusetts Institute of Technology)

Scanning microwave microscopy (SMM) allows nanoscale characterization of two-dimensional (2D) tin selenide (SnSe) polarization domain structure and resistance. This study examines SnSe flakes up to 15-nm thick, synthesized by low-pressure physical vapor deposition and transferred onto a silicon substrate. The SMM uncovers lateral polarization domains not detected by optical microscopy or atomic force microscopy. The SMM determines the resistivity of the domain interior is approximately 0.02 Ω·m, which is much higher than the resistivity of the domain boundaries. This observation agrees with current-voltage measurement of devices fabricated on 2D SnSe. This work demonstrates SMM's efficacy for non-destructive, in situ monitoring of 2D materials and devices.

16:35-16:55

E-4

Broadband Characterization of Flexible Conductor-Dielectric Composites

Luckshitha Suriyasena Liyanage (University of Colombo); Nathan Orloff (NIST); Nicholas Jungwirth (NIST); Sarah Evans (Colorado School of Mines); Christian Long (NIST); Angela Stelson (NIST); Jacob Pawlik (NIST); James Booth (NIST)*

Broadband measurements are important for characterizing a wide range of materials for communications applications at microwave and mm-wave frequencies. Here we report on broadband measurements of the effective permittivity of conductor-dielectric flexible composite materials over the frequency range 0.05 - 67 GHz. The materials under test are comprised of silver nanoparticles dispersed in an elastomer host material (polydimethylsiloxane) with variable volume fraction from 0.75% - 5.8%. Broadband calibration and de-embedding techniques are applied, along with finite-element simulations, to determine the complex effective permittivity for four different silver nanoparticle volume fractions from the measured scattering parameters. The resulting effective permittivity is well described by Maxwell-Garnett mixing formula, and the material coefficients extracted from fits include the conductivity, permittivity, and shape factor of the silver nanoparticle inclusions. Our analysis shows that as the filling fraction increases, the permittivity and conductivity of the inclusions increase dramatically, while the shape factor decreases. This results in much higher-than-expected enhancement of the effective permittivity for a range of volume fractions, which is likely due to aggregation or agglomeration of conducting particles in clusters with high interfacial polarizations.

17:00

End of the ARFTG-104 Conference

Interactive Forum Session

P-1

Application of Dual-Mode Ruby Dielectric Resonator for Characterization of Copper Foils in High-Frequency Circuits

Lukasz Nowicki (QWED Sp. z o. o.)*; Tomasz Nalecz (QWED Sp. z o. o.); Malgorzata Celuch (QWED Sp. z o. o.); Thomas Devahif (Circuit Foil); Janusz Rudnicki (QWED Sp. z o. o.)

Achieving high electrical performance in mmWave PCBs often compromises copper foil reliability. This study introduces a novel measurement approach using Ruby Dielectric Resonators (RuDR) operating at 13 GHz and 21 GHz to assess copper foil conductivity without substrate interference. By focusing on direct loss measurements, these resonators provide accurate data on the effects of surface roughness on foil performance, crucial for 5G applications. The RuDR resonator, used in this study, highlights a decreasing exponential relationship between conductivity and surface roughness, confirming the significance of surface texture. The findings guide the development of high-performance materials for next-generation mmWave technologies.

P-2 Student

Impact of Deep Memory in Identification of Quasi-Identical RF Power Amplifiers using Digital Post Distortion

Nicholas Ellis (Ohio State University)*; Patrick Roblin (Ohio State University); James Gaudreau (Ohio State University); Joel Johnson (Ohio State University); Justin Kuric (Ohio State University); Christopher Ball (Ohio State University); Richard Ridgway (Ohio State University)

Quasi-identical power amplifiers (PA) can be differentiated through the unique nonlinearities that are inherent to each individual PA. It was recently demonstrated that digital post distortion (DPoD) applied to the measured output data facilitates this PA identification. In this paper, a generalized cubic spline basis (GCSB) with selective deep memory is used to perform an enhanced DPoD. It is experimentally verified that the use of deep memory in the GCSB model can not only increase the performance of DPoD but also greatly magnify the differences observed in the normalized mean squared error (NMSE) of the linearized PA output signal relative to the reference input signal. This new technique can thus be used to reliably differentiate between two quasi-identical power amplifiers from the same device's manufacturer.

P-3

Broadband RF Characterization Test Setup for Millimeter Wave Applications

David Sardin (Qorvo)*; Jason Zhang (Qorvo)

This paper presents a versatile test setup configuration capable of reporting broadband large signal on-wafer characterization data over various frequency bands and up to 110 GHz. Millimeter wave characterization is often frequency band limited and requires various test hardware to be swapped when frequency focus evolves. Exploring various frequency bands is therefore time consuming as well as prone to measurement uncertainties addition when new measurement errors are introduced during the next calibration event. The presented coaxial test bench configuration allows measuring both small and large signal performance without the necessity to reconfigure the test hardware nor recalibrate the test bench. This work provides a descriptive overview of the test setup and discusses application by reporting measurement data of an E-band GaN power amplifier. Index Terms — W-band, millimeter wave, E-band, power amplifiers, 5G, GaN.

P-4 Student

Techniques for Characterizing Dual-Input Outphasing Power Amplifiers

Dominic Mikrut (Ohio State University)*; Yuhan Zheng (Ohio State University); Patrick Roblin (Ohio State University); Shane Smith (SenseICs); Josh Coffey (SenseICs); Ramy Tantawy (SenseICs)

The aim of this paper is to compare the usage of two different testbeds to characterize dual-input outphasing PAs which are becoming more prevalent. One testbed relies on the use of a legacy two-port nonlinear vector network analyzer (NVNA) and the second testbed relies on a four-port vector network analyzer (VNA). Two different dual-input outphasing PAs were characterized under CW conditions using the NVNA and VNA testbeds, respectively. The required procedures for each testbed for characterizing these dual-input outphasing PAs are presented and their relative merits discussed.

P-5 Student

Ultra-wideband Multi-line Calibration by Microstrip and Coplanar Impedance Standards on the Same GaAs Chip

Tianze Li (Cornell University)*; Lei Li (Cornell University); James Hwang (Cornell University)

Calibration accuracy and stability have not been well studied above 100 GHz. This paper presents a comprehensive evaluation of multiline through-reflect-line (MTRL) calibration across an ultrawide bandwidth of 1-220 GHz using microstrip and coplanar impedance standards on the same GaAs chip. For the selection of impedance standards, different combinations of line lengths are evaluated in terms of normalized standard deviation and mean absolute error. The results show that increasing the number of lines significantly enhances accuracy and stability. This study affords valuable insights into the robustness of MTRL calibration across different impedance standards and offers practical guidance for ultra-wideband calibration.

P-6 Student

Optimization of a Near-Field Measurement System Based on Mechanically Modulated Scattering

Yu Huang (University of Wisconsin-Madison)*; Alan Bettermann (University of Wisconsin-Madison); Daniel van der Weide (University of Wisconsin)

We build and optimize a prototype near-field mapping system that uses mechanically modulated scattering, focusing on standing wave suppression and probe design. We observe effects of standing waves in the apparatus, identify their root causes, then limit electric field distortions in the measured results. The validity of the system is benchmarked by measuring the magnitude and phase of the normal electric field radiated by a terminated microstrip line and comparing with the simulation.

P-7

Human Free Automated Recalibration for Drift Compensation and Over Multiple Temperatures On-Wafer Autonomous RF Measurements

Pranav Shrivastava (FormFactor GmbH)*

The Autonomous RF measurement assistant, a combination of programmable positioners, a precise digital microscopy system and advanced pattern recognition algorithms, enables fully autonomous, hands-free calibrations and measurements of RF devices over multiple temperatures. Autonomous RF is used to manage the entire test flow for thermal and ambient testing. This includes the full automated calibration, monitoring to prevent measurement drift, adjustment of probe spacing to account for growth and adjust probing geometries to deal with devices of different layout. In this work, the use of this approach with regard to doing MLTRL calibrations instead both off and on wafer. This work also shows interaction between WinCal, python and analytical approach to evaluate the calibration repeatability. Performance Analyzer discuss the repeatability and the probe placement for the unattended long duration RF measurements.

ARFTG Workshop

Wednesday, January 22nd | Morning Session

Testing, Modeling and Linearization of Nonlinear RF/microwave Devices and Circuits

8:00-8:45
W-1

Definition of NPR, EVM, and EVM-like criterion for use in linear distortion, nonlinear distortion and noise characterization

Jacques Sombrin (CNES, France)

NPR, EVM, and EVM-like criterion can be defined in the same way by using cross-correlation to discriminate between ideal signal and noise or distortion. After removing the ideal signal from the distorted and noisy signal, it is possible to interpret the residual noise or distortion to obtain data on the equipment in the transmission link and in some cases to improve its operation. Some well known degradations are caused by nonlinear transfer curves of amplifiers, additive noise, phase noise of local oscillators, phase and amplitude imbalance of quadrature modulators and demodulators, frequency response of filters, ... One final goal is to optimize the energy consumed to transmit each bit of information in a given noisy channel.

Jacques Sombrin received his engineering degrees from Ecole Polytechnique (Paris) in 1969 and Ecole Nationale Supérieure des Télécommunications (Paris) in1974. He is a life member of IEEE, emeritus member of SEE and member of EuMA. He was awarded the EuMA Career Award in 2015. Microwave Engineer in CNES (the French Space Agency) from 1974, more recently Senior Expert and Assistant Director for Radio Frequencies, in charge of radio frequency research program and roadmaps until 2010. He participated in satellite projects and has been responsible for microwave equipment development (TWT, TWTA, filters...), for microwave instruments and payloads, for space telecom systems architecture and performance. Since 2011, he is a Consulting Engineer and a researcher in TéSA (Aeronautics and Space Telecommunications laboratory in Toulouse). His current research interests include: • Model and simulation of amplifiers nonlinearity in telecommunication satellites and their linearization. • Telecommunication systems NPR and EVM characterization, efficiency, and optimization of capacity/power consumption compromise. • Multipactor effect, microwave breakdown and passive intermodulation products.

8:45-9:30

W-2

Advances in Characterization and Linearization of RF Power Amplifiers for Modulated Applications

Gian Piero Gibiino (University of Bologna, Italy)

This presentation addresses recent research on the characterization and linearization of RF power amplifiers (PAs) targeting modulated operation, with a primary emphasis on Gallium Nitride PAs for space and communications applications. Wideband active load-pull techniques are employed to evaluate the tradeoff between linearity and efficiency at the device level. The talk also presents a case study on a dual-input MMIC Doherty PA operating at 24 GHz, where optimization techniques are used to automatically adjust bias and input splitting to improve efficiency while maintaining linearity for high-PAPR modulated signals.

Gian Piero Gibiino received a dual Ph.D. degree from the University of Bologna, Bologna, Italy, and KU Leuven, Leuven, Belgium, in 2016. That same year, he was a visiting researcher at Keysight Technologies, Aalborg, Denmark. He is currently an Assistant Professor at the University of Bologna, where he conducts research in the fields of microwave measurements and nonlinear modeling. Dr. Gibiino is also an Affiliate Member of the MTT-S Design Automation and Microwave Measurements Technical Committees.

9:30 – 10:15

W-3

Physics-Based Nonlinear Modeling of GaN HEMTs using the ASM-HEMT and Fermi Kinetics Transport

Nicholas Miller (Michigan State University)

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 the various applications and properties of the GaN transistors. This talk will focus on the recent developments of nonlinear modeling of GaN HEMTs using the ASM-HEMT and the Fermi kinetics transport TCAD solver.

Nicholas C. Miller (Senior Member, IEEE) received the B.S., M.S., and Ph.D. degrees in electrical and computer engineering from Michigan State University, East Lansing, MI, USA in 2013, 2015, and 2017, respectively. He was an electronics engineer at the Air Force Research Laboratory from 2017 to 2023. In 2023, he joined the faculty of the Electrical and Computer Engineering Department at Michigan State University as an assistant professor. He is currently a young professional member of the IEEE MTT TC-3 microwave measurements committee. His current research interests include linear and nonlinear mm-wave characterization of on-wafer transistors and integrated circuits, physics-based compact modeling of compound semiconductor transistors, and technology computer aided design modeling of wide and ultrawide bandgap semiconductor transistors. Dr. Miller was the recipient of the IEEE AP-S pre-doctoral research Award in 2013, U.S. DoD science, mathematics, and research for transformation (SMART) scholarship in 2014, IEEE Dayton Section Harrell V. Nobel Award in 2019 for physics-based device modeling, Best Conference Paper Award at the 21st IEEE Wireless and Microwave Technology Conference (WAMICON) in 2021, the Best Presentation Award at the IEEE MTT-S Young Professional Workshop on Optimization and Modeling of Active Devices in 2022, and the AFRL Early Career Award in 2023.

10:15 - 10:30

Coffee Break

10:30 – 11:15
W-4

Load Modulated Balanced Amplifier: Design and Operation

Taylor Barton, Yaqub Mahsud (University of Colorado Boulder)

The load modulated balanced amplifier architecture for efficiency enhancement has received a lot of recent attention in the literature, with a variety of drive strategies (e.g., LMBA vs S-LMBA) and design techniques proposed. In this talk, we will present the LMBA design space and give design examples comparing the effects of different strategies on efficiency, linearity, and bandwidth. The hardware examples will focus primarily on MMIC implementations of the LMBA architecture.

Prof. Taylor Barton is an Associate Professor in the Department of Electrical, Computer, and Energy Engineering at the University of Colorado Boulder. She received her degrees including the Sc.D from the Massachusetts Institute of Technology in the department of Electrical Engineering and Computer Science. Her research group specializes in efficiency enhancement techniques and nonlinear circuit design for RF and microwave power amplifiers. Prof. Barton has received the AFSOR YIP and NSF CAREER awards and received the IEEE MTT-S Outstanding Young Engineer Award in 2023.
Yaqub Mahsud received the B.S degree in Engineering from Harvey Mudd College in 2021, and the M.S. degree in electrical engineering from the University of Colorado Boulder in 2024, where he is currently pursuing the Ph.D. degree in the RF Power and Analog Lab. His research interests include efficient, linear, and broadband power amplifier architectures.

11:15 – 12:00
W-5

Advancements and Challenges in Testing, Modeling, and Linearization of LSMA Transmitters for 5G/6G: From GHz to Sub-THz

Slim Boumaiza (University of Waterloo)

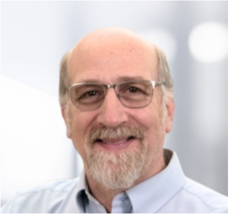
As 5G technology rapidly advances and 6G looms on the horizon, the need for innovation in the testing, modeling, and linearization of large-scale multiple antenna (LSMA) transmitters has never been greater. This talk will explore key challenges in predicting and addressing the nonlinear behavior of LSMA transmitters, emphasizing the role of co-simulation frameworks in advancing design and testing methodologies. We will explore critical questions, including: • Should LSMA transmitter demonstrators be developed for proof-of-concept validation at the component level, such as for power amplifiers? • Is over-the-air (OTA) testing in far-field or near-field environments essential, or can augmenting connectorized systems strike a balance between accuracy, cost, and time? • Are current linearization techniques sufficient to handle LSMA nonlinearity under varying conditions like precoding and dynamic resource block allocation? The talk will then provide a brief introduction to the state of testing, modeling, and linearization methods for sub-6 GHz (FR1) digital beamforming transmitters, before shifting focus to recent progress in millimeter-wave (mmWave) RF beamforming transmitters in FR2 bands. Finally, the talk will delve into the unique challenges facing the testing, modeling and linearization at the component and system levels at FR3 and sub-THz frequencies and will explore strategies to overcome them. By presenting the latest innovations and discussing future directions, attendees will gain valuable insights into optimizing LSMA transmitter technology for the 5G/6G communication systems.

Slim Boumaiza received his B.Eng. in electrical engineering from the École Nationale d'Ingénieurs de Tunis in 1997, and his M.S. and Ph.D. from École Polytechnique de Montréal in 1999 and 2004 respectively. He is a professor at the University of Waterloo, heading the Emerging Radio System Research Group in the Department of Electrical and Computer Engineering. He has extensive experience in developing high-performance and energy-efficient wireless transmitters for 3G/4G/5G and satellite communications. His expertise includes characterizing, modeling, and designing microwave and millimeter wave circuits, high-efficiency power amplifiers, linearization techniques, mixed RF/digital signal processing, and beamforming radio transceivers. He has received Early Researcher Award from Ontario Research Fund, NSERC Accelerator and Synergy awards and has published over 90 journal articles and 145 conference papers.

12:00 End of ARFTG Workshop

ARFTG ExCom Elections

Candidate Biographies

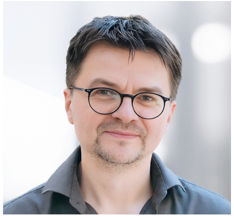


Joel Dunsmore (Keysight Technologies, USA) is a Keysight R&D Fellow working at the Santa Rosa Site. He received his Ph.D. from Leeds University in 2004. He was a principal contributor to PNA family of network analyzers, with recent work in non-linear test, including differential devices, and mixer measurements, as well as modulated and spectrum measurements. He has received 36 patents and authored the "Handbook of Microwave Component Measurements, 2nd Edition (John Wiley, 2020)", and has the YouTube Channel @DrJoelVNA. He has been a member of ARFTG ExCom for 6 years, has been general chair of one ARFTG conference and Technical Program Chair of another, and is the ongoing ARFTG Conference Exhibits Chairperson.

Dennis Lewis (Boeing, USA) received his BS EE degree with honors from Henry Cogswell College and his MS degree in Physics from the University of Washington. He has worked at Boeing for 35 years and is recognized as a Technical Fellow, leading the enterprise antenna measurement capability for Boeing Test and Evaluation. Dennis holds twelve patents and is the recipient of the 2013 & 2015 Boeing Special Invention Award. He is a senior member of the IEEE and several of its technical societies including the Microwave Theory and Techniques Society (MTT-S), the Antennas and Propagation Society and the Electromagnetic Compatibility (EMC) Society. He actively contributes to these societies as a member of the IEEE MTT-S subcommittee 3 on microwave measurements and as a Board Member and a past Distinguished Lecturer for the EMC Society. He is a Senior Member and served as Vice President on the Board of Directors for the Antenna Measurements Techniques Association (AMTA) and chaired its annual symposium in 2012 & 2023. As a past faculty member at North Seattle College, Dennis developed and taught a course on The Fundamentals of Measurement Science. He is also a past chair and serves on the Technical Advisory Committee. His current technical interests include aerospace applications of reverberation chamber test techniques as well as microwave and antenna measurement systems and uncertainties.

Patrick Roblin (The Ohio State University (OSU), USA) received the Maîtrise de Physics degree from the Louis Pasteur University, Strasbourg, France, in 1980, and the M.S. and D.Sc. degrees in electrical engineering from Washington University, St. Louis, MO, in 1982 and 1984, respectively. In 1984, he joined the Department of Electrical Engineering, at the Ohio State University (OSU), Columbus, OH, where is currently a professor. At OSU, he developed two educational RF/microwave laboratories and associated curriculum and founded the Non-Linear RF research lab. His research interests include the measurement, modeling, design and linearization of non-linear RF devices and circuits. He authored and co-authored three textbooks: two with Cambridge University Press and one with Springer. From 2016 to 2018 he served as Distinguished Microwave Lecturer for IEEE-MTT. He is currently serving as vice-president of ARFTG and as co-chair of the MTT Technical Committee TC3 on Microwave Measurements.

Back to TOC



Andrej Rumiantsev (MPI Corporation, Taiwan) received his Diploma-Engineer degree (with highest honors) in Telecommunication Systems from the Belarusian State University of Informatics and Radioelectronics (BSUIR) in Minsk, Belarus, in 1994, and his Dr.-Ing. degree (summa cum laude) in Electrical Engineering from Brandenburg University of Technology (BTU) Cottbus, Germany, in 2014. Since 2001, he has worked in engineering, product management, and marketing for leading companies in RF technologies, contributing to innovations in RF wafer probes, calibration standards, software, and probe systems. He is currently the Director of RF Technologies at MPI Corporation. Dr. Rumiantsev actively contributes to the field as a member of the IEEE MTT-3 Microwave Measurements Committee, Chair of the IEEE MTT-S P2822 Working Group, and ExCom member of ARFTG. He holds multiple patents in wafer-level RF calibration and measurement techniques, and his doctoral thesis received the “Best Dissertation of 2014” award at BTU.

Why I’m Running for Re-Election. My journey with ARFTG started 20 years ago, at ARFTG-63, where I published my first ARFTG paper. Since then, ARFTG has become an irreplaceable part of my professional career, both as a conference and as a community. I had the honor of being part of the organizing committee for the ARFTG On-Wafer Users’ Forum, which we launched at ARFTG-88. Over the years, this forum has grown into an integral part of the ARFTG community, fostering valuable discussions and advancements in wafer-level measurements. At the upcoming ARFTG-104th Symposium, we will celebrate the 20th On-Wafer Users’ Forum—a milestone that highlights the forum’s impact and longevity. I have contributed to organizing multiple ARFTG conferences and symposia, serving several times as General Chair and Technical Program Chair. I also played a key role in recent rebranding ARFTG and creating the new look and feel of our documents and website, which I currently manage. In recognition of my long-term service, I was granted ARFTG Life Member status, an honor that reinforces my commitment to this community. If re-elected, I’ll continue working to expand ARFTG’s impact, and I’m excited about what we can achieve together to keep ARFTG at the forefront of our field.

Dominique Schreurs (KU Leuven, Belgium) has been involved with ARFTG since the previous millennium. She attended her first ARFTG conference as a PhD student in 1996, and has attended most ARFTG conferences since, resulting in receiving the ARFTG Life Member status in 2013. She organized the very first workshop at a Fall ARFTG Symposium in 2001 and has been (co)organiser and speaker in various ARFTG workshops over the years. She was one of the co-initiators of the NVNA Users’ Forum in 2002 and is still acting as its advisor. Dominique got elected to the ARFTG Executive Committee in 2003 and has assumed various ExCom positions over the years (Workshop Chair, Education Chair, Technical Coordination, Secretary, Nominations, Awards, MTT-S Liaison, ...), including ARFTG President in 2018-2019. Dominique is acting frequently as a reviewer on the ARFTG TPC, and was TPC chair of 2002 Fall ARFTG, 2016 Spring ARFTG, and 2023 Winter ARFTG. She was General Chair of the Spring ARFTG conferences in 2007, 2012, 2018, and 2024. She was also an instructor at the ARFTG Short Course numerous times. In daily life, Dominique is a full professor at KU Leuven in Belgium. Belgium is the birthplace of the early NVNA prototypes (called LSNA at the time), and therefore it is natural that her research embarked on nonlinear microwave measurements. In recent years, her students have been working on topics such as experiment design, measurement uncertainty, measurement-based modelling of devices, dielectric spectroscopy measurements, MIMO antenna characterisation,... to name a few. Her research is documented in about 900 publications (books, journal papers, and conference contributions), among which a substantial number were presented at ARFTG conferences. When Dominique was a post-doc, she performed scientific stays at Agilent Technologies (now Keysight Technologies) in Santa Rosa, CA, and NIST in Boulder, CO. As a professor, she performed a sabbatical at NIST and also has been sending her PhD students over there. Dominique is highly motivated to continue serving the ARFTG community. As ARFTG Past President and ARFTG Life Member, she can leverage on her longstanding experience in her future contributions on ExCom.

James Skinner (National Physical Laboratory (NPL), UK) is a microwave metrologist at the UK’s National Physical Laboratory (NPL). His expertise is in VNA calibration and S-parameter metrology for coaxial and waveguide media. In his role at NPL, he has been responsible for maintaining the UK primary standards for RF impedance since 2016. Since 2020, he has authored and co-authored over 30 scientific publications on metrology research from kHz to THz frequencies, covering topics including sub-THz waveguides, cryogenic measurements for quantum computing, time-domain metrology, on-wafer measurements and novel calibration technologies. He was awarded a first class Masters degree in Electronic Engineering from Queen Mary University London in 2016, and is currently studying a PhD in Microwave Engineering at Imperial College London. He currently serves as secretary for the IEEE P1785 working group for waveguide standards above 110 GHz, and is looking to bring his passion and enthusiasm for metrology to the role of ARFTG ExCom member.

Xiaobang Shang (Senior Member, IEEE, National Physical Laboratory (NPL), UK) received his BEng (First Class) in Electronic and Communication Engineering in 2008 and his PhD in Microwave Engineering in 2011 from the University of Birmingham, UK. In 2017 he joined the National Physical Laboratory (NPL, UK) as a Senior Scientist, and was promoted to a Principal Scientist in 2023. His current research interests are on-wafer measurements (at room temperature and cryogenic temperatures), material characterizations, calibration, and de-embedding. Dr. Shang was the Coordinator for EMPIR TEMMT project (2019 – 2022), a large-scale European Union metrology project involving 19 partners globally. He has authored or co-authored over 120 articles on microwave measurements and microwave circuits. He is a member of IEEE MTT-S TC-3 and TC-21, an Associate Editor for IEEE Microwave and Wireless Technology Letters (2020-2024), and a Visiting Professor at the University of Manchester. He represents Group 4 countries on the EuMA General Assembly (2022–2024) and is selected by EuMA as the General TPC Chair for EuMW 2026. Dr. Shang was the recipient of several prestigious awards including the IEEE MTT-S Outstanding Young Engineer Award in 2025, the Roberto Sorrentino Prize in 2022, the IEEE MTT-S Tatsuo Itoh Award in 2017, and the ARFTG Roger Pollard Microwave Measurement Student Fellowship in 2009. He looks forward to volunteering for the ARFTG community and contributing to its activities.

See you Again at the ARFTG-105th Conference!

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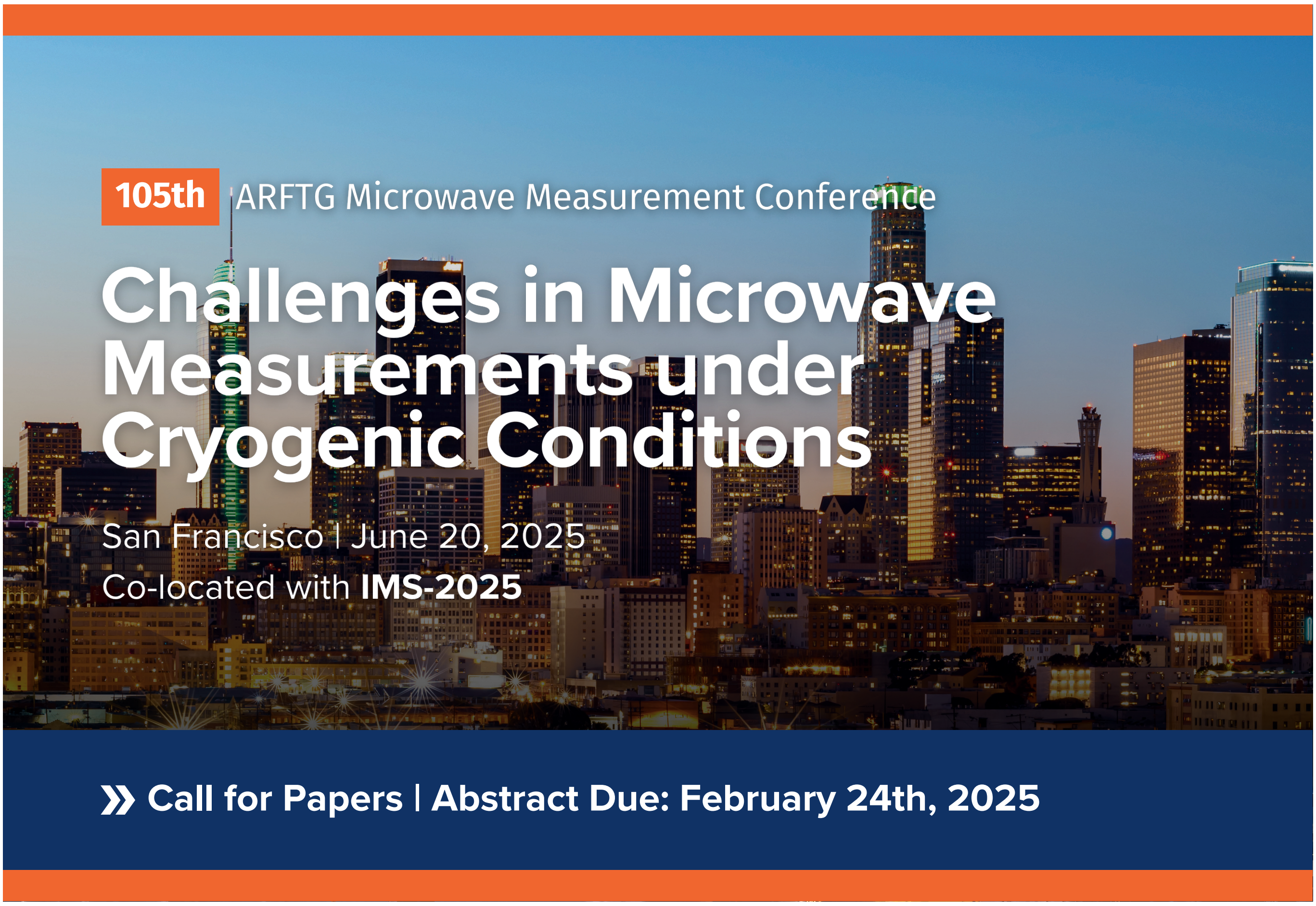
IEEE MTT-S



Suggested topics include, but are not limited to:

- Measurement & calibration to support quantum computing circuits/systems
- Noise measurement under cryogenic conditions
- Free space calibration and measurements in confined cryogenic environments
- Calibrations and measurements on devices and systems in space
- Other innovative measurements in quantum technologies

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105th ARFTG Microwave Measurement Conference

CALL FOR PAPERS

The theme for the 105th ARFTG Conference (co-located with IMS-2025) is "Challenges in Microwave Measurements under Cryogenic Conditions". We encourage the submission of original papers demonstrating innovative measurement approaches to support the development of quantum computing systems and other applications operating under cryogenic temperatures. Contributions exploring all areas of RF, microwave, and sub-THz measurements are welcome. Suggested topics include, but are not limited to:

- Measurement & calibration to support quantum computing circuits/systems
- Noise measurement under cryogenic conditions
- Free space calibration and measurements in confined cryogenic environments
- Calibrations and measurements on devices and systems in space
- Other innovative measurements in quantum technologies

Topics always of interest include:

- RF/digital mixed-signal measurement and calibration
- On-wafer calibration and measurements
- Characterization of material properties
- Other recent developments in metrology incl. measurement uncertainty

DEADLINES

February 24, 2025	**Abstract Submission Due**
March 21, 2025	Paper acceptance and classification notification
April 18, 2025	Publication-ready paper is due in PDF format

INSTRUCTIONS FOR AUTHORS

Authors are strongly encouraged to use the template on that webpage to prepare both initial paper and final paper submissions.

We request that authors submit an initial paper (4 pages or less) 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 in IEEE Xplore, provided it has been presented at the conference.

More details can be found on the ARFTG website:
https://arftg.org/author-instruction

Version: 2.1: December 23, 2024

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Dominique Schreurs
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