101st ARFTG Microwave Measurement Conference

CHALLENGES IN COMPLEX MEASUREMENT ENVIRONMENTS

June 16th, 2023

San Diego, CA USA

Conference Program

Rev. 1.2 June 4, 2023

Table of Contents

ARFTG Sponsors

ARFTG-101th Executive Committee would like to thank our sponsors for their great and valued support of the conference and the ARFTG organization.

Gold Sponsor

MPI CORPORATION

qorvo
all around you

Silver Sponsors

Anritsu
envision:ensure

COPPER MOUNTAIN™ TECHNOLOGIES

KEYSIGHT TECHNOLOGIES

VDI

Welcome to ARFTG-101st Conference

As Chair of the 101st ARFTG Microwave Measurement Symposium, which is co-located with the International Microwave Week, I would like to extend my warm welcome to all of our attendees, speakers, sponsors and the organizing team. All the people involved in the organization have worked hard to provide everyone with an interesting technical program and a carefully designed event. The topic of this ARFTG is "Challenges in Complex Measurement Environments" which will provide interesting and inspiring talks on how RF measurement techniques are copying with the continuously changing and ever more complex real life environments. Moreover, the program includes also many other topics of interest to the measurement and metrology community.

Along with the conference, we have two workshops in conjunction with the IMS program (namely WSM and WMC) and two users' forums (NVNA and On-Wafer).

It is also a pleasure to chair the 101st ARFTG conference together with my colleague Jeffrey Jargon. The ARFTG started as a network analyzer user-group in September 1972, which was called "ANA-ATE", for Automatic Network Analyzer – Automatic Test Equipment. It adopted the Automatic Radio Frequency Techniques Group (ARFTG) name in 1974.

Today, ARFTG is devoted to both cutting-edge and practical measurements in RF, communications, microwaves, millimeter-waves, and related fields. ARFTG gives you the opportunity to meet with the people that developed many of the measurement techniques that you use today.

I look forward to seeing you in sunny San Diego to enjoy the renowned in-person interaction that is the hallmark of the ARFTG community. I hope that you will enjoy the presentations and find them enriching. Finally, I would like to thank our sponsors, exhibiters, and all the members of the conference steering committee for their work and support in preparing this conference.

Marco Spirito, General Chair 101st ARFTG

Marco Spirito
General Chair
TU Delft

Jeffrey Jargon
General co-Chair
NIST

Jon Martens
TPC Chair
Anritsu

Dennis Lewis
TPC co-Chair
Boeing

Program at a Glance

SUNDAY 11 JUNE 2023	MONDAY 12 JUNE 2023	TUE/WED 13/14 JUNE 2023	THURSDAY 15 JUNE 2023	FRIDAY 16 JUNE 2023
8:00 – 17:20 **Workshop WSM Advances in Microwave and mm-Wave Wideband Measurements for Radar and Communications Applications** Room: 31C	8:00 – 17:20 **Workshop WMD Device Thermal Noise Metrology: Needs, Challenges and Opportunities** Room: 29D	No Activities	15:00 – 16:30 **NVNA Users' Forum** Room: 32A 16:30 – 18:00 **On-Wafer User's Forum** Room: 32A	8:00 – 8:40 **Keynote: Measurement Challenges and Novel Approaches to Modern Antenna Measurements in Complex Environments Using UAVs and Multi-Axis Robots** 8:40 – 9:40 **Session A Over-the-Air Measurement Topics** 10:40 – 12:00 **Session B Modulated and Spectral Analysis** 13:20 – 14:40 **Doug Rytting Memorial Session C Advanced Linear Network Analysis** 15:30 – 17:10 **Session D Non-Linear, Large-Signal VNA Techniques**

Sunday, June 11th, 8:00 – 17:20

WSM. ARFTG co-Sponsored IMS-2023 Workshop

Room: 31C

8:00 — 17:20

Advances in Microwave and mm-Wave Wideband Measurements for Radar and Communications Applications Users Forum

Organizers: Gian Piero Gibiino (University of Bologna), Nicholas C. Miller (AFRL)

Wideband measurement and characterization techniques at microwave and mm-wave frequencies are becoming increasingly demanding to satisfy the specifications of the ever-evolving communications and radar industry. This workshop presents recent research and technology advancements from industry, research centers, and academia, by discussing relevant performance metrics and their experimental evaluation across different hardware platforms. Advanced characterization techniques are presented for transistors, power amplifiers, and beamformers, encompassing over-the-air testing, linearity, load-pull, and calibration of precision radar. The first half of the workshop is dedicated to state-of-the-art wideband device characterization techniques and load-pull. The second half of the workshop is focused on beamformers and over-the-air characterization techniques and standards. Both the morning and afternoon sessions of this workshop will end with open interactive discussions useful to outline future trends and research on these topics.

Monday, June 12th, 8:00 – 17:20

WMD. ARFTG co-Sponsored IMS-2023 Workshop

Room: 29D

8:00 — 17:20

Device Thermal Noise Metrology: Needs, Challenges and Opportunities

Organizers: Leonard Hayden (Qorvo), Tom McKay (GLOBALFOUNDRIES)

Availability of high-volume, extremely low-noise transistor VLSI technologies with minimum noise figures as low as 0.2dB (Te, min 14K) at Cellular, WiFi and SATCOM frequencies challenge existing noise metrology practice. State-of-the-art device noise metrology systems are unable to provide system architects and technology developers the ability to clearly discern performance of one device technology over another at these low noise levels. Recent investments by the EU and the US governments in semiconductor manufacturing including RF, microwave and mm-wave applications underscore the need and opportunity for further public-private collaboration in this area. This workshop begins with the motivation for extremely low minimum noise figure technology from applications such as LEO SATCOM and remote sensing, followed by technology developers' experience with existing metrology practice, culminating with discussions on ways forward from commercial vendors and NIST.

Thursday, June 15th, 15:00 – 18:30

	NVNA Users Forum **Room: 32AB**
15:00 — **15:05**	Welcome Patrick Roblin (The Ohio State University) and Apolinar Reynoso Hernandez (CICESE, Ensenada)
15:05 — **15:25**	Round table introduction of the attendees
15:25 — **15:50**	VNA-Based Characterization of Frequency Multipliers and Frequency Multiplier-based Transmitters Ahmed Ben Ayed and Slim Boumaiza (Department of Electrical and Computer Engineering, Antennas, Microwaves and Wave Optics Emerging Radio Systems Group)
15:50 — **16:00**	Discussion Moderators: Patrick Roblin (The Ohio State University, USA) and Apolinar Reynoso Hernandez (CICESE, Ensenada, Mexico)
16:00 — **16:15**	Broadband EVM Measurement for VSGs using a VNA-based Technique Gian Piero Gibiino, Alberto Maria Angelotti (University of Bologna)
16:15 — **16:25**	Discussion Moderators: Patrick Roblin (The Ohio State University) and Apolinar Reynoso Hernandez (CICESE, Ensenada)
16:25 — **16:30**	Farewell

	On-Wafer Users Forum **Room: 32AB**
16:30 — **16:35**	Welcome Macro Spirito (Delf University of Technology), Jon Martens (Anritsu), Andrej Rumiantsev (MPI Corporation), Gia Ngoc Phung (PTB)
16:35 — **16:55**	Traceability for On-wafer S-parameter Measurements Uwe Arz (PTB)
16:55 — **17:05**	Discussion Moderator: Andrej Rumiantsev (MPI Corporation), Gia Ngoc Phung (PTB)
17:05 — **17:15**	On Probe-Tip Calibration Reference Impedance Lucas Nyssens (UCL)
17:05 — **17:30**	Discussion Moderator: Andrej Rumiantsev (MPI Corporation), Gia Ngoc Phung (PTB)
	Joint On-Wafer and THZ Measurement Topics
17:30 — **17:40**	Automated & Nanorobotics Millimeter-Wave On-Wafer Probe Station Kamel Haddadi (University of Lille)
17:40 — **17:55**	Discussion Moderator: Andrej Rumiantsev (MPI Corporation), Gia Ngoc Phung (PTB)
17:55 — **18:25**	Beyond 110 GHz: Research and Activity at NIST Jim Booth (NIST) (with discussion and Q&A)
18:25 — **18:30**	Farewell

Friday, June 16th, 7:55 – 17:10

Conference Opening

7:55 — 8:00

Welcome to the 100th ARFTG Conference

Conference Co-Chairs: Marco Spirito and Jeffrey Jargon
TPC Co-Chairs: Jon Martens and Dennis Lewis

8:00 — 8:40

Keynote: Measurement Challenges and Novel Approaches to Modern Antenna Measurements in Complex Environments Using UAVs and Multi-Axis Robots

Stuart Gregson (Next Phase Measurements)

Session A: Over-the-Air Measurement Topics

Session Chair: Dennis Lewis (Boeing)

8:40 — 9:00

A1

Practical Verification of Over-the-Air Measurements and Correlation across Measurement Setups

Thomas Deckert (NI)*; Okay Schierhorn (NI); Harsh Nitharwal (NI); Jan Fromme (NI)

Recent years have seen a more widespread use of over-the-air (OTA) measurement techniques to characterize active antennas, especially at mm-wave frequencies. Because the level of integration of circuit components with the passive radiating elements increases, more OTA-type measurements need to be made without increasing the cost of test. Test engineers are challenged by issues of repeatability, mechanical positioning, and movement. It can be difficult and time consuming to correlate results across different measurement setups. In our contribution, we put together practical steps to verify OTA measurement results and show their utility with example measurement data marking typically achievable results

9:00 — 9:20

A2

Robot-Based Multi-Purpose Measurement Platform for 6G Communications

Woohyun Chung (Korea Research Institute of Standards and Science)*; Chihyun Cho (KRISS); Jae-Yong Kwon (KRISS)

A robot-based multi-purpose measurement platform for sub-THz measurements is presented. This platform is composed of a pair of precision robot arms on a metric optical breadboard for precise alignment. The robot arm is capable of controlling its coordinates within a few tens of micrometers, with rotation angles of less than 0.1 degrees. At sub-THz frequencies, the platform itself acts as a semi-anechoic chamber. In this paper, each robot arm was equipped with a sub-THz frequency extender with a horn antenna for scattering parameter

measurements with a vector network analyzer. To demonstrate the capabilities of the platform, we present measurement results of the free-space loss, antenna pattern, and communication channel characteristics, specifically the power delay profile and angle of arrival, as examples.

9:20 — 9:40

A3

Dynamic Range by Design in OTA EVM measurements

Paritosh Manurkar (CU Boulder)*; Dan Kuester (NIST); Joshua M Kast (Colorado School of Mines); Rob Horansky (NIST)

We present an experimental approach to design an over-the-air (OTA) millimeter-wave system for measuring error vector magnitude (EVM) with associated uncertainties that include correlations and nonlinearities. Our approach uses a variable waveguide attenuator at the output of a modulated-signal source at 44 GHz and provides traceable measurements on a calibrated equivalent-time sampling oscilloscope. The conductor-based EVM measurements and associated uncertainties presented here serve as a baseline for the eventual OTA-based EVM. We also discuss a noise based EVM estimation technique as a simple tool for planning OTA EVM measurements, but without a complete knowledge of measurement uncertainties.

9:40 — 10:40

Break

Exhibition and Interactive Forum

Interactive Forum

Session Chair: Jeffrey Jargon, NIST

9:40 — 15:30

P1

A 3D FW-EM Simulation-Based PSOD Method for Characterizing On-Wafer Devices Compensating for Short Pattern Error

Yunsang Shin (Seoul National University)*; Sangwook Nam (Seoul National University)

The commonly employed pad-short-open de-embedding (PSOD) method extracts on-wafer device-under-test (DUT) characteristics by measuring the pad, short, and open patterns. However, when the previous PSOD method is applied to extract the complex DUT characteristics in high-frequency and broadband measurements, there is a problem in extraction accuracy owing to errors that occur in the short pattern. Therefore, we propose a novel PSOD method that improves accuracy by compensating for errors from short patterns using three-dimensional (3D) full-wave electromagnetic (FW-EM) simulations. In applying the proposed method to extract calculable rectangular conductors, we confirm that the extraction accuracy improved by up to 32.1% compared with that of the existing method.

9:40 — 15:30

P2

Design of Optimal Length for Waveguide Offset Shorts in D-band based on Uncertainty Analysis

Chihyun Cho (KRISS)*; Jae-Yong Kwon (KRISS)

Recently we established a D-band waveguide impedance standard. However, since it is very inefficient to use a primary standard for routine calibration service, here we design another offset shorts calibration kit. The optimal length of the offset shorts was set so that the

uncertainty with respect to 1-port calibrations was the smallest when calibrating the DUT using the designed offset short. To meet this goal, we developed a novel design process to propagate the uncertainty of our primary standard to the uncertainty of the designed offset shorts, and then re-propagate to the uncertainty of the DUT to be calibrated. Then, to find the optimal length, the uncertainty of the DUT was made as small as possible by using a global optimization algorithm. We designed three offsets; in this case, the uncertainty was about 2 dB when the DUT had a reflection coefficient of -20 dB, and had an uncertainty of about 0.35 dB for the reflection coefficient of 0 dB. The proposed method can easily design a calibration kit composed of an arbitrary number of offset shorts and a calibration kit using reference standards with arbitrary reflection coefficients, such as load or mismatch.

9:40 — 15:30

P3

Implementing Direct RF Sampling at Sub-Nyquist Rate for Error Vector Magnitude Measurements

Xifeng Lu (NIST)*; Paritosh Manurkar (NIST); Dazhen Gu (NIST); Dan Kuester (NIST); Rob Horansky (NIST)

We investigate an under-sampling method for error vector magnitude (EVM) measurements. The approach is to simulate the demodulation of the time-domain waveform with both conventional oversampling and sub-Nyquist sampling methods. The dominant increase in EVM from sub-Nyquist sampling compared to oversampling is due to noise aliased from higher-order Nyquist zones. Simulations quantify this behavior by comparing the additive white noise response of under- and over-sampling receivers. We also examined the jitter effects in the simulation and found that additive noise dominates the degradation in EVM changes for the root mean square (RMS) jitter no more than 1 ps. As the Nyquist rate becomes more and more difficult to reach in the high-frequency communication, the sub-Nyquist sampling method provides an alternative by use of a sophisticated yet agile digital processing algorithm.

9:40 — 15:30

P4

Evaluating Correlation Between Measurement Samples in Reverberation Chambers Using Clustering

Carnot L Nogueira (NIST)*; Kate Remley (NIST); Rob Horansky (NIST)

Traditionally, in reverberation chambers (RC) measurement autocorrelation or correlation-matrix methods have been applied to evaluate measurement correlation. In this article, we introduce the use of clustering based on correlative distance to group correlated measurements. We apply the method to measurements taken in an RC using one and two paddles to stir the electromagnetic fields and applying decreasing angular steps between consecutive paddles' positions. The results – using varying correlation threshold values – demonstrate that the method calculates the number of effective samples and allows discerning outliers, i.e., uncorrelated measurements, and clusters of correlated measurements. This calculation method, if verified, will allow non-sequential stir sequence design and, thereby, reduce testing time.

9:40 — 15:30

P5

VNA-Based Large-Signal Drain-Modulated Power Amplifier Measurement Setup With Digital Pre-Distortion

Rob Vissers (Chalmers University of Technology)*; Christian Fager (Chalmers University of Technology); Gregor Lasser (Chalmers University of Technology)

In this work a Vector Network Analyzer (VNA)-based large-signal drain-modulated measurement setup with simultaneous input and output signal extraction and Digitial Pre-Distortion (DPD) for Power Amplifier (PA) characterization is discussed. The proposed architecture is capable of handling coherent wideband modulated signaling with a calibrated reference plane down to the tip of the wafer probes, making it resilient to component changes outside the VNA directional couplers like signal generators and pre-amplifiers. Furthermore, a laboratory-grade drain modulator circuit with current sensing is proposed, being re-configurable for both Gallium Nitride (GaN) and Gallium Arsenide (GaAs) voltage ranges. Modulated measurements with a 500 MHz bandwidth have been performed on a two-way power-combined Doherty PA designed in 22 nm FD-SOI, resulting in an improvement of the Adjacent Channel Power Ratio (ACPR) of 10.7 dB and an improvement of the RMS Error Vector Magnitude (EVM) of 8.5% after DPD.

9:40 — 15:30

P6

Over-the-Air Characterization of mmW Near-Field Channels

Yagmur Ozturk (The Ohio State University)*; Niru Nahar (Ohio State University); Kubilay Sertel (Ohio State University)

We propose a near-field channel characterization method for millimeter wave full-duplex, or simultaneous transmit-receive systems for high-data-rate, point-to-point wireless connectivity. We discuss the unique challenges in designing and evaluating full-duplex near-field wireless links stemming from near-field interactions of the radiators in close proximity of each other, leading to a link budget that is significantly different from the conventional far-field criteria such as Friis' transmission formula. Among these challenges are multiple reflections between the near-zone wireless nodes that lead to pulse spread, and cross-talk between transmit and receive antennas on the same node that lead to significant interference. As such, effective over-the-air characterization of near-zone mmW full-duplex links require new methods and instrumentation. Here, we propose an exemplary automated characterization system where the relative positions of the antennas can be precisely varied in three dimensions. We demonstrate the methodology using differentially fed patch antennas designed for 57-64GHz band, and a 4-port vector network analyzer (VNA) for S-parameter measurements. A 4-port Thru-Reflect-Line calibration is used for calibrated channel and cross-talk measurements between nodes. We demonstrate the performance and efficacy of this exemplary mmW proximity communication link using the proposed setup and illustrate the subtleties in evaluating and validating such a wireless system.

9:40 — 15:30

P7

NPR assessment without multi-tone phase randomization

Ricardo Figueiredo (University of Aveiro)*; Nuno Borges Carvalho (Instituto de Telecomunicacoes)

This work presents a fast method to assess the noise power ratio (NPR) of a radio-frequency system under multi-tone excitation. To assess NPR, this technique does not need to average

multiple output power spectral density measurements obtained with different realizations of the random phase multi-tone test signal. The true NPR is obtained from a single computation.

9:40 — 15:30

P8

Validity of Room-temperature Calibration for On-wafer Measurements up to 220 GHz, 125 °C, and 48 h

Tianze Li (Cornell University)*; Lei Li (Cornell University); James C. M. Hwang (Cornell University)

At-temperature calibration is not only inconvenient, but also complicated by the temperature dependence of impedance standards. This paper examines the validity of a room-temperature calibration for on-wafer measurements from 70 kHz to 220 GHz, from 25 °C to 125 °C, and up to 48 h. The results indicate that the room-temperature calibration is applicable up to 125 °C provided errors up to 0.5 dB in magnitude and 5° in phase are tolerable. Consistent with previous reports up to 110 GHz, the present errors are mainly caused by the time-dependent system drift instead of the temperature dependence of impedance standards. For unknown reasons, the system proven to be stable at room temperature drifts significantly at elevated temperatures. This makes elevated-temperature measurements challenging because presently it takes approximately three hours for the system to stabilize at a new temperature. Therefore, in the near term, efforts should be concentrated on making the system stabilize faster, rather than correcting for the temperature dependence of impedance standards.

9:40 — 15:30

P9

Characterization of a Compact Wideband Microwave Metasurface Lens for Cryogenic Applications

Ali Al-Moathin (U. Glasgow); Mingyan Zhong (U. Glasgow); Qusay Al-Taai (U. Glasgow); Yunan Jiang (U. Glasgow); Michael Farage (U. Glasgow); Jalil ur Rehman Kazim (U. Glasgow); Muhammad Zulfiqar Ali (Oxford Instr.); Fatemeh Nikbakhtnasrabadi (U. Glasgow); Megan Powell (U. Strathclyde); Prince Khatri (U. Strathclyde); Manoj Stanley (NPL); Alessandro Rossi (U. Strathclyde);(NPL); Hadi Heidari (U. Glasgow); Muhammad Ali Imran (U. Glasgow); Qammer H. Abbasi (U. Glasgow); Nick M. Ridler (NPL); Martin Weides (U. Glasgow); Chong Li (U. Glasgow)*

In this paper, we present characterization of a compact flat microwave lens operating between 6 GHz and 14 GHz using a near field scanning system. An X-band horn antenna and open-end rectangular waveguide were used as an illumination source and probe, respectively. |S21| is measured as the probe antenna moves on a plane orthogonal to the optical axis vertically and horizontally. The lens is made of a metasurface layer that is sandwiched by two layers of cross-oriented gratings. The overall dimension of the lens is 10 cm in diameter and 0.57 cm in thickness. The measurement results show that the lens's focal lens is 8 cm, and the beamwidth (full width at half maximum (FWHM)) is 3.5 cm. A transmission efficiency of over 90% and a cross-polarization gain of 25 dB were achieved over the entire bandwidth. The measurement results at room temperature are in good agreements with numerical simulations. The proposed lens will be used in a cryogenic environment e.g. dilution refrigerators for quantum computing systems. More results at cryogenic temperature e.g. below 30 K will be shown at the conference.

9:40 — 15:30

P10

In-Situ Measurement of Transmitter Antenna Input Current Using a Software-Defined Radio

Austin S Egbert (Baylor University); Adam C Goad (Baylor University); Samuel M Haug (Baylor University); Charles Baylis (Baylor University)*; Benjamin Kirk (Army Research Laboratory); Anthony Martone (Army Research Laboratory); Robert J. Marks II (Baylor University)

In phased-array transmitters, array calibration is often used to correct for the magnitude and phase changes of voltage waves from the signal sources to the antennas in the different array elements. Inserting a reconfigurable impedance tuner between the power amplifier and the antenna in each element allows the range to be maximized upon changes in operating frequency or scan angle. However, tuning the impedance causes an undesirable real-time change in the magnitude and phase of the element transmission parameters. Proper assessment of this real-time change is needed to use equalization and impedance tuning to maintain the array pattern. Specifically, the antenna input currents must be monitored, and the antenna input currents can be used with the known antenna patterns to calculate the array transmission pattern. Measurement assessment of the antenna input current for impedance-tuning operations is demonstrated using a dual-directional coupler with a software-defined radio voltage measurement input. This is a practically implemented version of the approach that shows a path forward to system implementation of this “on the fly” transmitter calibration approach for arrays containing reconfigurable circuits, or for use in adjusting traditional array calibrations during operation.

Session B: Modulated and Spectral Analysis

Session Chair: Dominique Schreurs (KU Leuven)

10:40 — 11:00

B1

A Measurement-Referenced Error Vector Magnitude for Counterfeit Cellular Device Detection

Améya S Ramadurgakar (NIST)*; Kate Remley (NIST); Dylan Williams (NIST); Jacob Rezac (NIST); Melinda Piket-May (University of Colorado Boulder); Rob Horansky (NIST)

Standard formulations of error vector magnitude compare a wireless device’s symbol constellation to an ideal reference constellation. In this work, we utilize the residual error vector magnitude, which uses measurements of a wireless device.

to define a reference constellation. We apply this formulation to the problem of identifying a device’s manufacturer from over-the-air measurements of the wireless device and show that the residual error vector magnitude outperforms standard error vector magnitude formulation in this task.

11:00 — 11:20

B2

Spectral Purity Evaluation of VNA Frequency Extenders to Enable Electronic Software-Based Power Control

Carmine De Martino (Delft University of Technology)*; Juan Bueno Lopez (Delft University of Technology); Marco Spirito (TU Delft)

In this paper, we present an experimental strategy to analyze the harmonic content of mm-wave frequency extenders using the VNA (absolute) power calibration step, without requiring spectrum analyzers and/or separate downconverters. The spectral purity of the upconverted band of the extenders is a key requirement to enable entirely software-based power control required for the accurate analysis of an (active) device under test.

The proposed approach is based on the complementary response provided by the calorimeter-based power meter (i.e. VDI PM5) capable of integrating the entire spectral content of the waveguide band, in respect to the extreme frequency selectivity of the narrow-band mixer-based downconverter of the VNA. This complementary integration bandwidth response allows to compare the two results at each input drive level (at the power calibration setup, in-situ) and link the difference to the increased harmonic content contribution, with respect to the spectral content value at the saturation drive level, i.e. nominal manufacturer specified. The paper presents tests carried out in the WR10 (75-110 GHz) and WR6 band (110-170 GHz). The WR10 resulted in a harmonic contribution on the total output power of a maximum of 0.3 dB down to -33 dBc power back off from saturation level, and less than 1 dB down to -38 dBc while in WR6 the same parameter is less than 1 dB over the entire frequency band excluding the lower frequency points.

11:20 — 11:40

B3

Pulsed Sub-THz Wideband Vector Component Analysis

Jean-Pierre Teyssier (Keysight Technologies)*; Joel Dunsmore (Keysight Technologies); Johan Ericsson (Keysight Technologies); Sam Kusano (Keysight Technologies, Inc.); Nizar Messaoudi (Keysight Technologies, University of Waterloo)

Pulsed Sub-THz active component testing is enabled for wideband repetitive test signals within a VNA instrument. A coherent stroboscopic approach on top of a timestamp phase stitching technique allows access to the measured amplitudes and phases of the test signal tones for arbitrary modulation bandwidth at sub-THz carrier frequency. Time domain IQ data is then available at DUT ports and used to perform demodulation.

11:40 — 12:00

B4

Accurately Applying Wideband Modulated Signals to a DUT Using an Extended VSG-VSA Setup

Frans Verbeyst (NI)*; Pawel Barmuta (NI); Marc Vanden Bossche (NI); Markus Rullmann (NI)

Starting from a classical Vector Signal Generator – Vector Signal Analyzer (VSG – VSA) configuration, this paper explains how to extend the setup using proper hardware and software to enforce a desired wideband periodic modulated input signal at the Device Under Test (DUT). Using a relatively simple and straightforward algorithm, this paper shows that it is possible to compensate for both linear and nonlinear distortions as part of the generation and as part of the (non)linear interaction at the input of the DUT. This approach does not rely on compact test signals in order to apply spectral digital predistortion (DPD) to the parent signal. Instead, the correction can be extracted and applied on-the-fly and in-situ using a 3GPP-compliant signal while the DUT is connected.

12:00 — 13:20

Awards Luncheon

Session C: Doug Rytting Memorial Session. Advanced Linear Network Analysis

Session Chair: Rusty Myers, Keysight Technologies

13:20 — 13:40

C1

Memorial for Doug Rytting

Marc Vanden Boscche, NI

13:40 — 14:00

C2

D-Band Characterization of a Commercial High-Resistivity Silicon Calibration Substrate

Gia Ngoc Phung (Physikalische Technische Bundesanstalt)*; Hyunji Koo (KRISS); chihyun cho (KRISS); JAE-YONG KWON (KRISS); Uwe Arz (Physikalisch-Technische Bundesanstalt (PTB))

Silicon (Si) is one of the most important materials used in many RF applications. On-wafer characterization of Si-based devices, components and circuits is widely adopted. Recent investigations have been devoted to the study of parasitic

probe and neighborhood effects in commercial alumina-based calibration substrates. However, these parasitic effects have not been thoroughly investigated for commercial silicon-based calibration substrates. Therefore, this paper presents a detailed study of a commercial high-resistivity silicon (HRSi) calibration substrate. The neighborhood effect in conjunction with probe influences is investigated up to D-band frequencies.

14:00 — 14:20

C3

Dielectric Spectroscopy of Liquids by De-embedding Two-Port Measurements

Seyede Maede Chavoshi (KU Leuven)*; Matko Martinic (KU Leuven); Helene Ponsaerts (KU Leuven); Maya Van Dijck (KU Leuven); Bart Nauwelaers (KU Leuven); Tomislav Markovic (University of Zagreb); Dominique Schreurs (University of Leuven)

In this article, we present a calibration approach for a microwave sensor aimed for dielectric spectroscopy of liquids. The sensor consists of a T-junction terminated with an interdigitated electrodes (IDE) structure. Therefore, the calibration technique involves de-embedding a 3-port network (i.e., the T-junction) by using only three known materials.

The sensor is calibrated for 1-2 GHz frequency range using three samples of ethanol/water mixtures with 20%, 50%, and 80% ethanol content, respectively, and the permittivity extraction approach is validated using four different samples. The retrieved complex permittivity results in a 1.8% and 6.4% average relative error for the real and imaginary parts compared to coaxial probe measurements for all samples, which shows the great performance of the proposed calibration technique.

14:20 — 14:40

C4

Verification of Reference Impedance from Common On-Wafer Calibrations on Commercial Calibration Substrates

Lucas Nyssens (Université catholique de Louvain)*; Martin Rack (Université catholique de Louvain); Romain Tuytaerts (Université catholique de Louvain); Dimitri Lederer (Université catholique de Louvain); Jean-Pierre Raskin (Université catholique de Louvain)

This paper compares the reference impedance (Zref) of common on-wafer calibrations (SOLT, LRRM, multi-line TRL) on a commercial calibration substrate. First, a method to extract Zref of a calibration, based on the calibration comparison technique, is presented. Its application shows that lumped-standard calibrations have comparable Zref up to ~40-50 GHz but require accurate lumped standards characterization, and LRRM Zref is demonstrated to be particularly sensitive to probe misplacement on Thru and Load standards. It therefore confirms mTRL as reference calibration. However, measurements of two commercial calibration substrates have shown that even mTRL Zref suffers from systematic errors linked to violation of the assumptions G' = 0 and frequency-independent C' line terms used to compute the line characteristic impedance.

14:40 — 15:30

Break

Exhibition and Interactive Forum

Session D: Non-Linear, Large-Signal VNA Techniques

Session Chair: Patrick Roblin, The Ohio State University

15:30 — 15:50

D1

VNA-Based Characterization of Frequency Multipliers Phase-Distortions Under Continuous-Wave and Modulated Signal Excitation

Mahitab Eladwy (University of Waterloo)*; Ahmed Ben Ayed (University of Waterloo); Slim Boumaiza (University of Waterloo,Canada)

This paper proposes vector network analyzer (VNA)-based measurement techniques for complementary characterization of phase distortion in frequency multipliers under both continuous-wave (CW) and modulated signal excitation. Specifically, a nonlinear VNA-based technique that uses a comb-generator as a phase reference to measure phase distortion in frequency multipliers under CW excitation is presented. Additionally, a new correlation-based method is proposed for measuring phase distortion in frequency multipliers under modulation signal stimuli without resorting to a phase reference. These measurement techniques were applied to characterize the phase distortions exhibited by a 45-nm SOI CMOS stacked push-push frequency doubler operating around 60 GHz.

15:50 — 16:10

D2

Modulated-Input Control and Linearization of a Multi-Port Millimeter-Wave PA by VNA-based Calibrated Wideband Measurements

Mattia Mengozzi (University of Bologna)*; Gian Piero Gibiino (University di Bologna); Alberto Maria Angelotti (University of Bologna); Christoph Schulze (Ferdinand-Braun-Institut); Olof

Bengtsson (Ferdinand-Braun-Institut, Leibniz-Institut für Höchstfrequenztechnik); Corrado Florian (University of Bologna); Alberto Santarelli (University of Bologna)

An on-wafer multiport measurement system based on a VNA is exploited in order to perform the wideband characterization and linearization of a dual input Doherty PA at millimeter-wave frequencies. By leveraging on the error-corrected wideband waves, an algorithm is proposed in order to realize modulated signal control across a 600-MHz bandwidth at the DUT on-wafer plane, eventually allowing to impose a user-defined emulated splitting ratio on the dual input. The linearization performance of such an emulated PA configuration is finally evaluated.

16:10 — 16:30

D3

A Rigorous Analysis of the Random Noise in Reflection Coefficients Synthesized via Mixed-Signal Active Tuners

Faisal Mubarak (VSL)*; Marco Spirito (TU Delft); Fabio Munoz (VSL)

In this contribution, we present a rigorous analysis based on uncertainty propagation techniques to estimate the random variation of the controlled reflection coefficient in mixed-signal load-pull test benches. A digital-to-analog converter is commonly used in these test benches to generate the baseband signal required to synthesize the high-frequency, user-defined injected wave. To study the random noise of the injected wave, which can be mapped to the noise of the controlled reflection coefficient, we employ Jacobian sensitivity functions between the baseband signal and the RF one. First, the baseband integrated rms noise of the up-converter is evaluated, and then the upconverted noise is determined via the derived transfer function. Finally, experimental results to validate the uncertainty control bound of the synthesized reflection coefficients are presented, highlighting a full coverage of the measured reflection coefficients.

16:30 — 16:50

D4

First Comparison of Active and Passive Load Pull at W-Band

Christopher Clymore (University of California, Santa Barbara)*; Matthew Guidry (UCSB); Emre Akso (UCSB); Henry Collins (UCSB); Wenjian Liu (UCSB); Christian Wurm (UCSB); Nirupam Hatui (UCSB); Umesh Mishra (UCSB)

GaN W-band devices have shown remarkable power performances using passive load pull measurements. However, as the device peripheries increase to provide higher power from a single cell, the available matching range from passive load pull becomes a greater limiting factor. Switching to active load pull, the matching range can cover the entire Smith chart, given sufficient drive power. In this work, the design of a high-power W-band on-wafer active load pull is shown, along with some of the configuration choices and associated tradeoffs in system performance and flexibility. N-polar GaN HEMT devices were measured in this setup and a passive load pull system to compare and qualify the new active load pull system configuration.

16:50 — 17:10

D5

Mini-Rump Session: High Frequency Measurement in 2030. What Will be Discussed?

Moderator: Leonard Hayden (Qorvo)

17:10 **End of Conference**

See you again at ARFTG-102nd Conference!

102nd ARFTG Microwave Measurement Conference

Software Architectures and Automation of Microwave Measurement Methods and Systems

San Antonio, TX, US, January 21-24, 2024

www.arftg.org

Conference Chairs
chairs@arftg.org

Andrej Rumiantsev, MPI
Joe Gering, Qorvo

TPC Chairs
tpc@arftg.org

Dennis Lewis, Boeing
Jeffrey Jargon, NIST

Executive Committee

President: *David Blackham*
Vice-President: *Rusty Myers*
Secretary: *Patrick Roblin*
Treasurer: *Jon Martens*

Education, Short Course:
J. Apolinar Reynoso-Hernández
Awards, Membership:
Jean-Pierre Teyssier
Sponsorship: *Joe Gering*
Website: *Andrej Rumiantsev*
Advertising and Publicity:
Dennis Lewis
MTT Liasson:
Dominique Schreurs
Exhibits: exhibits@arftg.org
Joel Dunsmore
Forums: forums@arftg.org
Gia Ngoc Phung
Communication e-Publicity:
Jeffrey Jargon
Publications: *Marco Spirito*
Workshops: *Mauro Marchetti*

ExCom Members' Affiliation
ARFTG ExCom Roster

CALL FOR PAPERS

The theme for the 102nd ARFTG Conference is *"Software Architectures and Automation of Microwave Measurement Methods and Systems"*. As with previous ARFTG-winter events, ARFTG-102nd is co-located with the IEEE Radio & Wireless Week 2024. Through the course of ARFTG's history, software and automation of microwave measurements have progressed tremendously: from the first simple automated network measurements to complex software-defined instrumentation and open-source integrated EDA tools. We encourage the submission of original papers demonstrating innovative approaches to tackle measurement challenges inherently linked to the high explosion of diverse applications based on EM waves. Suggested topics include but are not limited to:

- *Software, machine learning methods and AI application, open-source tools for automation in modern microwave measurements*
- *De-embedding, calibration, and characterization techniques*
- *Characterization of material properties and biological samples*
- *On-wafer characterization*
- *Millimeter-wave antenna and OTA testing*

Topics always of interest including:

- *RF/digital mixed-signal measurement and calibration*
- *Nonlinear / large-signal measurement and modeling techniques*
- *Terahertz measurement techniques*
- *Other recent developments in metrology incl. measurement uncertainty*

Deadlines

September 8, 2023	Paper summary due in PDF format.
October 6, 2023	Paper acceptance and classification will be communicated.
November 3, 2023	Publication-ready paper is due in PDF format.

Instructions for Authors

Contributed papers will be presented as 20-minute talks or in an interactive poster session. The final version of the papers will be published in the conference proceedings, and will be submitted as well to IEEE Xplore, provided it has been presented during the conference.

We request that authors submit a 4-page summary paper with supporting figures of both experimental setups and measurement results to enable evaluations of the novelty of the work. More details and submission instructions can be found at:

http://www.arftg.org/index.php/upcoming-conference/author-instructions.

Exhibit & Sponsorship

The 102nd ARFTG Microwave Measurement Symposium also offers an outstanding exhibition and sponsorship opportunity. Please contact our Exhibits and Sponsorship Chairs (exhibits@arftg.org, sponsorship@arftg.org) directly for further information

IEEE ARFTG RWW MTT-S

For more information on the next ARFTG-102nd Conference, visit the conference web page.