Oral Presentation Room TBD 0800 Friday, May 27, 2016
Session: Fr1-A
5G Measurements Chair: Kate Remley, Co-Chair: John Wood

Fr1-A-1 **Measurements for Emerging Communications Technologies**
0800-0840 ***M. Pierpoint, Keysight Technologies, Inc, Santa Rosa, United States***
Abstract Later

Fr1-A-2 **Emulation of Array Coupling Influence on RF Power Amplifiers in a Measurement Setup**
0840-0900 ***D. Nopchinda, K. Buisman, Chalmers University of Technology, Gothenburg, Sweden***
A new method for emulating coupling effects in a measurements setup is presented. This method is based on an iterative procedure, where a signal is injected towards the output of the power amplifier, based on the output signal of the power amplifier measured in the previous iteration. Thus any coupling can be emulated by injecting an appropriately scaled signal. Emulation results are presented for a 6 W GaN amplifier. The results are verified using two identical amplifiers connected by a fixed attenuator.

Fr1-A-3 **Comparison of Timebase Interpolation Methods for Traceable, Wideband mm-Wave Communication Signals**
0900-0920 ***R. D. Horansky, D. C. Ribeiro, K. A. Remley, P. D. Hale, C. Wang, D. F. Williams, NIST, Boulder, United States***
An integral part of processing a signal from a calibrated, equivalent-time sampling oscilloscope is accurately determining sampling times and then interpolating the resulting irregularly-spaced time grid to create a uniform time spacing. In this paper, we present simulations and measurements to determine the effect of the interpolation choice on the fidelity of a modulated signal. We judge the effect by calculating the error-vector-magnitude of the resultant signal from each interpolation.

Poster Presentation Room TBD 0930 Friday, May 27, 2016
Session: Fr1-P
Poster Session Chair: Ron Ginley

Fr1-P-1 **Wideband RF Characterization Setup with High Dynamic Range Low Frequency Measurement Capabilities**
0930-1020 ***S. Gustafsson, C. Fager, K. Buisman, M. Thorsell, Chalmers University of Technology, Gothenburg, Sweden***
In this paper, a wideband RF characterization setup with low-frequency (LF) measurement capabilities is presented. Simultaneous LF and RF measurements enable studies of trapping phenomena, thermal effects and other LF-related nonlinear distortion in microwave devices using realistic wideband RF stimuli. The setup is capable of measuring up to 4 GHz through the RF path,

and from DC to 125 MHz through the LF path. A study is made on how device linearity is affected by the choice of power supply unit (PSU). LF measurements reveal significant differences in baseband termination in the PSUs, consequently affecting the linearity of the measured RF output spectrum.

Fr1-P-2 Electrical Characterization of Waveguide Shim and Uncertainty Analysis

0930-1020 ***J. Kim, J. Kang, T. Kang, J. Park, Korea Research Institute of Standards and Science, Daejeon, Republic of Korea***

In this paper we propose a method to characterize waveguide shims, which are being used in almost all calibration kits for waveguide connectors and also used as impedance standard in Thru-Reflect-Line (TRL) calibration, for their length and aperture width and height. Also given are preliminary uncertainty analyses for the electrical characterization of the length, actually the phase shift through the shim, for two calibration methods for the Vector Network Analyzer (VNA).

Fr1-P-3 See-Through-Wall Life Sensing Using Mobile Doppler Radar

0930-1020 ***A. Rahman, E. Yavari, X. Gao, J. Xu, V. Lubecke, O. Lubecke, University of Hawaii at Manoa, Honolulu, United States***

A see-through-the-wall (STTW) life sign detection from a mobile platform has been studied. Ultrasonic sensors were used for motion artifact detection. An adaptive algorithm was implemented to validate the techniques for motion compensation when using a mobile life sign radar

Fr1-P-4 Connection Torque Consideration for Waveguide Flange at Millimeter-wave and Terahertz Frequencies

0930-1020 ***M. Horibe, AIST, Tsukuba, Japan***

Connection torque of waveguide flange is one of major impact factor of measurement reproducibility in the range of millimeter-wave and terahertz frequencies. Generally, connection of waveguide flange is made by four screws specified in the MIL-DTL-3922/67C (UG-387). However, different values of connection torques are specified and used in the each society and industry. There is no existing specification for connection torque. In addition, the four screws connection have to spend time to make a connection/disconnection for waveguide flange, then the measurement stability for long time was concerned due to stability performance of vector network analyzer frequency extension module. The new connection clamp for waveguide connection have been proposed as a solution to make connection quickly. This paper investigates a connection feature and its torque value to make good connection repeatability.

Fr1-P-5 Accurate interface conductivity measurement technique for a copper-clad dielectric substrate using a substrate sandwiched dielectric rod resonator

0930-1020 ***T. Shimizu, Y. Kogami, Utsunomiya University, Utsunomiya, Japan***

Copper-clad dielectric substrates are commonly used in microwave and millimeter wave planar circuits. Generally, an adhesive surface of a copper foil is roughened to increase peel strength from a substrate. It is known that the interface conductivity is different from the surface conductivity. Therefore, measurement techniques of the interface conductivity of copper-clad dielectric substrates are required. In this paper, a novel resonant analysis on the basis of the mode matching method for a dielectric rod sandwiched between copper-clad dielectric substrates is presented for

evaluating the interface conductivity of the copper-clad dielectric substrates. Furthermore, the usefulness of the proposed technique on the basis of the mode matching method are verified numerically and experimentally.

Fr1-P-6 RF Wafer Probing with Improved Contact Repeatability Using Nanometer Positioning

0930-1020 ***K. Daffé1, G. Dambrine1, F. Von Kleist-Retzow2, K. Haddadi1, 1IEMN - University of Lille, Villeneuve d'ascq, France, 2University Oldenburg, Oldenburg, Germany***

This paper presents an improved technique for monitoring and controlling the contact condition of on-wafer RF probes with nanometer accuracy to enhance the measurement repeatability. The set-up consists of a vector network analyzer, a modified probe station with a planar calibration substrate aligned under microwave GSG probe through a closed-loop nanopositioner and a camera system. A fully one-port SOL calibration is performed in the frequency range 0.05-50 GHz. A repeatability study based on standard deviations of the measured data considering both conventional and proposed approaches is described. From these experimental results, the improvement of the technique proposed is achieved by properly monitoring the strain and deformation of the probe inherent to the contact with the substrate.

Fr1-P-7 On the Definition of Reference Planes in Probe-level Calibrations

0930-1020 ***L. Galatro1, F. Mubarak2,1, M. Spirito1, 1Delft University of Technology, Delft, Netherlands, 2Van Swinden Laboratorium (VSL), Delft, Netherlands***

In this contribution we analyze the definition of reference planes in probe-level calibrations. The removal of the probe type from the calibration definition is presented first analyzing the transition discontinuities and defining to which extent they have to be incorporated in the calibration error terms. Subsequently a commercial calibration, which is defined specific to a probe topology, is considered and its frequency dependent standard response are computed accurately via a 3D EM simulator. These probe independent standard definitions are then used to compare the accuracy achieved on the same structures, (i.e., CPW lines of different lengths) from two different probe topologies. Finally, the data from both probes are compared, using a worst bound metric, to the data achieved when using the probe specific calibration data showing an accuracy improvement for the probe independent approach, validating the improved identification of the reference plane proposed here.

Fr1-P-8 A study of the reference impedance influence on a TRL calibration

0930-1020 ***K. Kuhlmann, Physikalisch-Technische Bundesanstalt - PTB, Braunschweig, Germany***

In coaxial systems typically beadless air lines are applied as line standards for a high precision TRL calibration of a vector network analyzer. This paper describes the influence of the characteristic impedance of the line standards on the quality of a TRL calibration. The dependency of the air line impedance on the dimensional and material properties is presented and the influence on the measurement results of selected devices under tests is evaluated.

Fr1-P-9 RF-to-DC and Backscatter Load Modulator Characterization

0930-1020 ***M. Jordão, R. Correia, D. Ribeiro, P. Cruz, N. B. Carvalho, Instituto de Telecomunicações, Aveiro, Portugal***

The main objective of this paper is to develop a RF-DC and a load modulation backscatter calibrated characterization platform. With the now proposed solution the variation of the input load impedance of RF-DC converters will be characterized versus frequency and input power. Moreover the same will be made for the RF-DC conversion efficiency, allowing an improved design optimization. Besides that backscatter load modulation integrated circuits will also be characterized, this is strategic in the \gls{rfid} design community in order to optimize \gls{rfid} circuit parameters that are key for improved designs.

Fr1-P-11 Measurement of Terahertz Detector Responsivity Using an Optical Time Domain Spectrometer

0930-1020 ***F. d. Brito-Filho1,2, 1Univesity of Sao Paulo, Sao Paulo, Brazil, 2Federal University of Semiarid Region, Caraubas, Brazil***

This paper presents a technique to measure terahertz detector responsivity using an optical terahertz time domain spectrometer. The detectors are based on ballistic MOSFET behaviour at terahertz frequency and were designed and fabricated using a 180 nanometer CMOS process with a detector-antenna co-design methodology assisted by high-frequency IC design tools and EM simulators. The tests were performed using an adapted THz-TDS setup in order to measure detector responsivity. Results shows that measured responsivity is closed to simulated ones.

Fr1-P-12 Supply-Terminal 40 MHz BW Characterization of Impedance-like Nonlinear Functions for Envelope Tracking PAs

0930-1020 ***G. Gibiino1,2, J. Couvidat3, G. Avolio2, D. Schreurs2, A. Santarelli1, 1University of Bologna, Bologna, Italy, 2KU Leuven, Leuven, Belgium, 3University of Limoges, Limoges, France***

We present an approach for the dynamic characterization of the non-idealities arising in envelope tracking (ET) systems when either the radio-frequency (RF) power amplifier (PA) or the supply modulator (SM) are driven into nonlinear operation. Impedance-like nonlinear functions, derived through a modified Volterra formulation, are here introduced and measured at the supply terminal over 40 MHz bandwidth (BW), allowing better predictions of the dynamic voltage and current at the SM-PA interface.

Fr1-P-13 Calibration of a Real-Time Load-Pull System Using the Generalized Theory of the TRM Technique

0930-1020 ***M. A. Pulido-Gaytan1, J. A. Reynoso-Hernandez1, M. d. Maya-Sanchez1, J. R. Loo-Yau2, 1CICESE Research Center, Ensenada, Mexico, 2Cinvestav, Guadalajara, Mexico***

The thru-reflect-match (TRM) calibration technique uses as calibration structures a thru, a pair of highly reflecting loads and two loads of impedance close to the measuring system impedance (Z0). In practice, the loads used as match standard may be nonsymmetrical and of impedance different from Z0. By using the ABCD-parameters matrix formalism, in this paper the calibration of a load-pull system is carried out by using a generalized theory of the TRM technique, allowing the use of nonsymmetrical loads of arbitrary impedance. The impact of ignoring the asymmetry and frequency-

dependent impedance of the loads used as match standard on the determination of the load-pull contours of constant output power is investigated.

Fr1-P-14 Microwave Characterization of Flexible Plastic Substrates Using Printed Electronics

0930-1020 ***M. Haghzadeh, C. Armiento, A. Akyurtlu, University of Massachusetts Lowell, Lowell, United States***

This work describes the development of a wide-band RF measurement technique using printed test structures for characterizing the complex dielectric properties of flexible substrates at RF and microwave frequencies. This novel method is based on a single probe measurement using two concentric circular capacitors with different gap sizes that can be additively manufactured on the dielectric film under test. Three types of common, commercially-available substrates for flexible electronics were characterized: Polyimide (Kapton), Liquid Crystalline Polymer (LCP), and Polyethylene Terephthalate (PET). Their dielectric constant and loss tangent were measured from 50MHz up to 20GHz, and were compared to the data available from substrate vendors.

Fr1-P-15 Characterization of Integrated GaN Power Switches using Pulsed-IV and Time Domain Measurements.

0930-1020 ***A. T. Pereira, A. Parker, M. Heimlich, N. Weste, Macquarie University, Sydney, Australia***

This paper reports the investigation of RF GaN HEMTs as integrated power switches in high frequency, high efficiency switching topologies. GaN HEMTs suffer from trap phenomena which degrades the performance of the HEMT when used as power switches. Pulsed IV characterization revealed upto 50% reduction in the theoretically available output power, at pulse frequency of 500 KHz and quiescent switch voltage of 60V. Transient measurements of a MMIC switching circuit with integrated drivers fabricated in the same process delivered an output power of 5.8 W at a switching frequency of 100 MHz and drain voltage of 30V.

Fr1-P-16 Maximizing the Benefit of Existing Equipment for Nonlinear and Communication Measurements

0930-1020 ***D. A. Humphreys1,4, A. Raffo2, G. Bosi2,3, G. Vannini2, D. Schreurs3, K. N. Gebremicael4, 1National Physical Laboratory, Teddington, United Kingdom, 2University of Ferrara, Ferrara , Italy, 3KU Leuven, Leuven, Belgium, 4University of Bristol, Bristol, United Kingdom***

The Nonlinear Vector Network Analyzer (NVNA) is the workhorse for nonlinear measurements. Also, during the development of new communications systems, such as 5G, dedicated test equipment is not available. Sampling and real-time oscilloscopes offer a lower cost alternative to the NVNA but require error corrections to improve their accuracy. NPL, NIST and other NMIs have advanced this area and we summarize these corrections and their limitations, with examples, and set out guidance rules to maximize the accuracy of the results.

Room: Oral Presentation Room TBD 1020 Friday, May 27, 2016

Session: Fr1-B

Linear Calibration and Measurement Techniques Chair: Jon Martens, Co-Chair: Andrej Rumiantsev

Fr1-B-1 **Traceable High Impedance Calibration Standards**

1020-1040 ***M. Haase1, K. Hoffmann1, M. Hudlicka2, 1Czech technical university in Prague, Prague, Czech Republic, 2Czech Metrology Institute, Prague, Czech Republic***

The paper deals with S-parameters characterization process of newly developed and fabricated high impedance calibration standards, based on APC-7 microwave connectors, suitable for extreme impedances measurement. It evaluates all critical factors playing significant role in the process including dimension and material characterization and used fabrication technology. A combination of the electromagnetic simulator ANSYS HFSS and precise traceable microwave measurements is used for their final characterization and evaluation of the uncertainty. Finally, some technological solutions which could further improve the characterization uncertainty are proposed.

Fr1-B-2 **Traceable Calibration with 1.0 mm Coaxial Standards**

1040-1100 ***J. Hoffmann, M. Wollensack, J. Ruefenacht, D. Stalder, M. Zeier, Federal Institute of Metrology METAS, Bern-Wabern, Switzerland***

We present an SI traceable calibration of a vector network analyzer with 1.0 mm connectors. A cooling setup and a special fixture are developed for the used frequency extenders. This and the modeling of the offset short standards yield results which are physically plausible and have up to 5 times lower uncertainties than existing calibrations for 1.0 mm connectors.

Fr1-B-3 **Developing Models for Type-N Coaxial VNA Calibration Kits within the NIST Microwave Uncertainty Framework**

1100-1120 ***J. A. Jargon, D. F. Williams, P. D. Hale, NIST, Boulder, United States***

We developed models for Type N coaxial vector network analyzer (VNA) calibration kits within the NIST Microwave Uncertainty Framework. First, we created physical models of commercially-available standards that support multiline thru-reflect-line (TRL) and open-short-load-thru (OSLT) calibrations, and included error mechanisms in each of the standards' constituent parameters that were utilized in the NIST Microwave Uncertainty Framework to propagate uncertainties. Next, we created a measurement-based model of a commercial electronic calibration unit (ECU) by characterizing the scattering parameters of its internal states with a multiline TRL calibration. Finally, we calibrated a network analyzer using the three calibration methods, and compared measurements, including uncertainties, made on a number of verification devices. We show that the three calibrations agreed to within their respective uncertainties.

Fr1-B-4 **Multimode Analysis of a One-Port Dual Ridged Waveguide Probe**

1120-1140 ***M. W. Hyde, M. J. Havrilla, Air Force Institute of Technology, Dayton, United States***

Multimode analysis of a one-port, i.e., single, dual ridged waveguide probe is presented. This work significantly extends previous dual ridged waveguide probe research in which only the

dominant mode was considered. The theoretical analysis of the dual ridged waveguide probe with higher-order modes is presented and discussed. Experimental results of a magnetic shielding material are presented to investigate the effect of higher-order modes on dual ridged waveguide probe characterization results.

Fr1-B-5 AMC pin waveguide flange for screw redundant millimeter and submillimeter measurements

1140-1200 ***S. Rahiminejad, E. Pucci, V. Vassilev, S. Haasl, P. Kildal, P. Enoksson, Chalmers University of Technology, Gothenburg, Sweden***

Measurements with waveguide flanges at frequencies above 100 GHz have a considerable issue with leakage due to problems with achieving good electrical contact between the opposite flanges. The higher the frequency, the higher is the requirement for full contact. However, by using an artificial magnetic conducting (AMC) flange on one side of the interface, full electric contact is not needed between the two joining flanges. The AMC is realized as a pin-surface creating an artificial magnetic conductive surface, and the leakage is stopped by a parallel-plate stopband like in gap waveguides. This paper describes how these modified flanges can be used for screw redundant millimeter and sub-millimeter measurements.

Room: Oral Presentation Room TBD 1300 Friday, May 27, 2016

Session: Fr1-C

Nonlinear Characterization and Modeling Chair: Patrick Roblin, Co-Chair: Earl McCune

Fr1-C-1 Mixed-Signal, Mixed-Mode and Mixed-Domain Characterization approaches for Emerging Wireless Technologies

1300-1330 ***N. B. Carvalho, Universidade de Aveiro, Aveiro, Portugal***

Emerging Wireless Technologies have an impact on microwave characterization technologies: the changes in paradigm from analog to digital and from RF to DC have a strong impact on the way nonlinear microwave characterization is seen. Behavioral characterization and modelling becomes a fundamental tool in complex systems, where the combination of analog, digital, RF and DC play a strong role in these characterization schemes. In this talk a general overview of these technologies is presented, focusing on Software Defined Radio front-end characterization and on RF-DC converters for Wireless Power Transmission, and despite apparent differences, the characterization will be presented as an integrated view on how to model and how to characterize those components from a behavioral point of view. Examples on Analog to Digital Converters (ADCs) and Digital to Analog Converters (DACs) in Digital Pre-distortion (DPD) systems, and Wireless Power Transmission RF-DC converters will be presented.

Fr1-C-2 Importance and Measurement of Phase-Stiffness in RF Switching Amplifiers

1330-1350 ***D. Babic, E. McCune, W. Godycki, Q. Diduck, D. Kirkpatrick, Eridan Communications, Inc., Santa Clara, United States***

Phase-stiffness is a measure of the ability of an RF power amplifier to tolerate disturbance injected into its output. Phase-stiffness of conventional (linear) RF power amplifiers used in phased-array radar results from inserting circulators and isolators on their output as they cannot tolerate typical disturbances arising from antenna mismatch and signals arriving from mutual coupling of array elements. We show that the output stage of a RF switching amplifier employing a single AlGaN/GaN HEMT loaded with an inductor exhibits high tolerance to external signal disturbance at the carrier frequency. This RF amplifier architecture shows promise for use in phase-array radar and active antenna array transmit/receive modules as this may operate without isolators.

Fr1-C-3 Computationally Efficient Coefficient Estimator used in Memory-Based Digital Predistortion (DPD) Models

1350-1410 ***R. N. Braithwaite, Consultant, Orange, United States***

Computationally efficient estimation of digital predistortion (DPD) coefficients for memory polynomial, gain polynomial, and pruned Volterra series models is proposed. In all three cases, the basis waveforms within the estimator are specified in the frequency domain as a function of memoryless waveforms and delay operators, thereby reducing the number of FFTs needed and allowing the tap spacing to be a fraction of a sample. The gain polynomial and pruned Volterra series cases are approximations that are sufficiently accurate for a closed loop estimator to converge to a desired steady-state.

Fr1-C-4 Novel design features for the improvement of linearity in filter structures for PIM measurements

1410-1430 ***M. B. Grassl, G. Kaiser, Spinner GmbH, Feldkirchen-Westerham, Germany***

In recent years, passive intermodulation (PIM) has become increasingly critical in modern mobile communication systems due to a more dense allocation of the available spectrum. Thus, the requirements on components for such systems have increased as well. As a consequence, problems arose for PIM measurements as the residual PIM of the measurement devices has not improved significantly over the same time. In this paper we present some new design features for filter structures used in PIM measurement devices that make residual PIM levels possible which are low enough to test modern mobile communication infrastructure components.

Room: Oral Presentation Room TBD 1510 Friday, May 27, 2016

Session: Fr1-D

Measurement Uncertainty and Nonlinear Measurements, Chair: Leonard Hayden, Co-Chair: Gustavo Avolio

Fr1-D-1 **Investigating Correlations in Frequency-Domain S-Parameter Measurements**

1510-1530 ***U. Arz, PTB, Braunschweig, Germany***

This paper presents a simple and straightforward method to explore correlations between S-parameter data in the frequency domain. In contrast to existing methods like e.g. uncertainty ellipses, which can only provide information at one given frequency, the new method can visualize correlations between measurement data at different frequency points over the entire measurement bandwidth. The procedure is illustrated using typical results from coaxial S-parameter measurements.

Fr1-D-2 **Verification of a Foundry-Developed Transistor Model Including Measurement Uncertainty**

1530-1550 ***D. Williams1, W. Zhao1, R. A. Chamberlin1, J. Cheron1, M. Urteaga2, 1National Institute of Standards and Technology, Boulder, United States, 2Teledyne Scientific, Thousand Oaks, United States***

We verify a foundry model for state-of-the-art 250 nm heterojunction bipolar transistors with large-signal measurements. We demonstrate the propagation of correlated measurement uncertainties through the verification process, and use them to quantify the differences we observe in the measurements and models.

Fr1-D-3 **Impact of Microwave Measurement Uncertainty on the Nonlinear Embedding Procedure**

1550-1610 ***G. Bosi2,1, A. Raffo1, G. Avolio2, D. Schreurs2, D. A. Humphreys3, 1University of Ferrara, Ferrara, Italy, 2KU Leuven, Leuven, Belgium, 3National Physical Laboratory, Teddington, United Kingdom***

We analyze the uncertainty contribution of the nonlinear embedding design technique in transposing the low-frequency data to microwave frequencies. Uncertainty analysis is performed with the NIST Microwave Uncertainty Framework and is applied to a GaAs pHEMT device.

Fr1-D-4 **Simultaneous Measurement of Optical and RF Behavior under CW and Pulsed Fully Active Harmonic Load-Pull**

1610-1630 ***M. A. Casbon1, T. Brazzini2, P. J. Tasker1, M. Uren2, M. Kuball2, 1Cardiff University, Cardiff, United Kingdom, 2Bristol University, Bristol, United Kingdom***

Here we present a system capable of simultaneous measurements of the RF and optical behavior of on-wafer devices, permitting the complete range of Fully Active Harmonic Load-Pull techniques to be employed while either observing optical phenomena such as Electroluminescence, or applying optical stimuli for trapping investigations. Full access to the backside of the wafer is achieved, allowing measurements on devices with source coupled field plates or air bridges, which normally obscure the gate region. Electroluminescence can be observed with an ultra-low light camera or a spectrometer. The test device was a GaN on silicon carbide HFET.

Fr1-D-5 W-Band Passive Load Pull System for On-Wafer Characterization of High Power Density N-polar GaN Devices Based on Output Match and Drive Power Requirements vs. Gate Width

1630-1650 ***M. Guidry, S. Wienecke, B. Romanczyk, X. Zheng, H. Li, E. Ahmadi, K. Hestroffer, S. Keller, U. K. Mishra, University of California, Santa Barbara, United States***

A W-band on-wafer passive load pull system, constructed for the characterization of high power density N-polar GaN devices, is presented. N-Polar GaN's large RF voltage swing enables high power densities but also increases the power match impedance which must be synthesized with the limited on-wafer tuning range. Increasing test cell gate width to decrease impedance increases the system's drive power requirement. The tradeoff between these is analyzed, showing that a passive load pull system can characterize a wide range of devices. This is demonstrated with measured data from a N-polar GaN device exhibiting 4.1 W/mm power density at 94 GHz.