Automatic RF Techniques Group

91st ARFTG Microwave Measurement Conference

Loews Hotel, Philadelphia, PA

TECHNICAL AGENDA

Friday, June 15

Welcome to 91st ARFTG Conference

8:00 AM 8:10 AM *Dominique Schreurs, ARFTG President and General Chair; Andrej Rumiantsev, TPC Chair*

Session A - Characterization Challenges of Modulated Signal Metrics

Session Chair: Andrej Rumiantsev

KEYNOTE: The Toughest RF Measurements in 5G

8:10 AM 8:50 AM *Roger Nichols, Keysight*

A-1

Impact of Phase Calibration on EVM Measurement Quality

8:50 AM 9:10 AM *Diogo Ribeiro, Instituto de Telecomunicacoes; Dylan Williams, NIST; Richard Chamberlin, NIST; Nuno Borges Carvalho, Universidade de Aveiro*

In this paper, the calibrated measurement of wideband modulated signals by mixer-based large-signal network analyzers (LSNAs) will be evaluated, with a focus on the impact of the phase calibration in the measured error vector magnitude (EVM). The uncertainties of the EVMrms results will also be analyzed.

A-2

Importance of Preserving Correlations in Error-Vector-Magnitude Uncertainty

9:10 AM 9:30 AM *Benjamin F. Jamroz, NIST; Dylan F. Williams, NIST; Kate A. Remley, NIST; Robert D. Horansky, NIST;*

Correlations are an important consideration in the uncertainty analysis of high-frequency electronic systems. We introduce a method to scramble the correlations of a correlated uncertainty analysis and develop a software tool to do this as part of the NIST Microwave Uncertainty Framework. We then compare the results of a correlated uncertainty analysis and the scrambled analysis in estimating the uncertainty in Error-Vector-Magnitude of a modulated signal. This comparison shows that preserving correlations in uncertainties is critical to accurately assessing system performance and uncertainty.

A-3 **Optimizing the Signal-to-Noise and Distortion Ratio of a GaN LNA using Dynamic Bias**

9:30 AM 9:50 AM *Lowisa Hanning, Chalmers University of Technology; Johan Bremer, Chalmers University of Technology; Marie Ström, Saab AB; Niklas Billström, Saab AB; Thomas Eriksson, Chalmers University of Technology; Mattias Thorsell, Chalmers University of Technology*

This paper shows how the signal-to-noise and distortion ratio (SNDR) for low noise amplifiers (LNA) can be derived from the commonly specified parameters noise figure, gain, third order output intercept point and 1 dB compression point. The parameters dependency of the biasing of the amplifier are also incorporated which enables the possibility to study how SNDR can be optimized for different operating conditions by dynamically change the gate- and drain voltage. An experimental verification shows that improvements in SNDR can be achieved by selecting gate and drain voltage of the LNA according to the level of the input signal power.

9:50 AM 10:40 AM **Break – Exhibits and Interactive Forum**

Session B - Large-Signal Measurement of Wireless Infrastructure Building Blocks

Session Chair: Peter Aaen

B-1 **Extracting Improved Figures of Merit for Characterizing Nonlinear Devices using Multisine Excitation Signals**

10:40 AM 11:00 AM *Evi Van Nechel, Vrije Universiteit Brussel; Yves Rolain, Vrije Universiteit Brussels; John Lataire, Vrije Universiteit Brussels*

This paper proposes a technique for extracting multiple measurement-based figures of merit with a single measurement taken from 1 measurement setup. Separate estimates of the linear term, the noise term and the in-band and out-of-band nonlinear distortion allow to calculate the signal-to-noise and distortion ratio, noise power ratio, adjacent channel leakage power ratio, etc. Those are extracted in least squares sense for a class of modulated excitation signals resembling real communication signals like LTE. The proposed method allows to split the linear dynamics from the nonlinear distortion, resulting in improved measures that are closer to the actual definitions of these figures of merit. Experimental results validate the proposed technique.

B-2

A Fully Calibrated NVNA Set-up for Linearity Characterization of RF Power Devices using Unequally Spaced Multi-Tone Signal Through IM3 & IM5 Measurements

11:00 AM 11:20 AM *Vincent Gillet, Xlim; Jean-Pierre Teyssier, Keysight Technologies; Michel Prigent, XLIM; Raymond Quéré, XLIM*

This paper presents an innovative experimental method and its associated test bench for assessing the in- band linearity degradation of radiofrequency and microwave power devices, suitable both for on-wafer and connectorized characterization. The Unequally Spaced Multi-Tone (USMT) signal is a tailored signal which presents flexible characteristics depending on the number of pilot tones (e.g. Peak to average radio, IQ enveloppe, and Radiofrequency bandwidth). It behaves like a complex modulation signal with particularity to have a complete separation of pilot tones, IM3 and IM5 and it was used for linearity measurements. The method has been used up to 28 MHz RF Bandwidth on a VNA with the spectrum option (PNA-L from Keysight Technologies). In only one acquisition, simultaneous criteria are evaluated, like output power, gain, Power Added Efficiency (PAE), in-band degradation such as Carrier to Intermodulation ratio (C/I) induced by the device, by measuring the USMT signal.

B-3

A Robust and Reliable Behavioral Model of High Power GaN HEMTS for RF Doherty Amplifier Application

11:20 AM 11:40 AM *Lotfi Ayari, AMCAD ENGINEERING; Alain Xiong, AMCAD ENGINEERING; Christophe Maziere, AMCAD ENGINEERING; Zacharia Ouardirhi, AMCAD ENGINEERING; Tony Gasseling, AMCAD ENGINEERING*

The aim of this work is to improve the black-box transistor's model behavior when used for Doherty Power Amplifier (DPA) designs. A methodology is proposed to reinforce the model's robustness when the transistor sees a dynamic load impedance modulation. In comparison with previous works, this modeling approach uses a specific load impedance pattern needed for the model extraction. In addition, the choice of the nonlinear descrip-tion order is optimized to reinforce the model convergence capa-bilities. A 10 W GaN Packaged Transistor operating in AB and C classes has been measured with a Nonlinear Vector Network Analyzer (NVNA) based Load Pull setup. These measurements have been used to extract seamlessly the models. Finally, different DPA architectures have been simulated in order to prove the model validity, reliability and robustness.

B-4

Wideband Test Bench Dedicated to Behavioral Modeling of Non Linear RF Blocks with Frequency Transposition and Memory

11:40 AM 12:00 PM Christophe Maziere, AMCAD ENGINEERING; Wissam Waabe, AMCAD ENGINEERING; Zacharia Ouardirhi, AMCAD ENGINEERING; Tony Gasseling, AMCAD ENGINEERING

This paper presents a measurement scenario for the behavioral modeling of RF blocks exhibit memory effects, mismatch and frequency transposition. The measurement principle is based on the use of a regular VNA setup and is applied here for the characterization and modeling of a Down-converter chain. The validation process of such a methodology is carried out with an experimental set-up based on transceiver architecture. It has been experimentally demonstrated that this measurement principle allows accurate model identification by performing a simple set of measurements. Extracted model proves the ability to provide a good prediction for complex communication signals

12:00 AM 1:30 PM **Awards Luncheon**

Session C - It's all about Calibration and Measurements for 5G

Session Chair: Jon Martens

C-1

Electro-Optic Near Field Imaging of High-Power RF/Microwave Transistors in Plastic Packages

1:30 PM 1:50 PM

Jonas Urbonas, University of Surrey; Frederik Vanaverbeke, NXP Semiconductors; Kevin Kim, NXP Semiconductors; Peter H. Aaen1, University of Surrey

In this paper, through-plastic vector E-field measurements of an LDMOS transistor in an over-molded plastic package are presented. The measurement system uses a commercially-available electro-optic system connected to an NVNA with a comb generator to non-invasively measure the phase-coherent multi-harmonic E-fields. The device is measured in a load-pull measurement system, which is used to present optimal source and load impedances to the transistor during the multi-harmonic E-field measurements. All three E-field components are measured at the fundamental (2.2 GHz) and two harmonics at P1dB = 53.2 dBm.

C-2

Wideband Dynamic Drain Current Measurements with a Galvanically Isolated Probe Targeting Supply-Modulated RF Power Amplifiers for 5G Infrastructure

1:50 PM 2:10 PM

Nikolai Wolff, Ferdinand-Braun-Institut, Leibniz-Institut für Höchstfrequenztechnik; Thomas Hoffmann, Ferdinand-Braun-Institut, Leibniz-Institut für Höchstfrequenztechnik; Wolfgang Heinrich, Ferdinand-Braun-Institut; Olof Bengtsson, Ferdinand-Braun-Institut, Leibniz-Institut für Höchstfrequenztechnik

Supply modulation of RF power amplifiers (PA) is a powerful efficiency enhancement technique. For optimization of the RF PA and the supply modulator the dynamic low frequency drain current is of high interest but measurements are difficult due to the large voltage variations at the PA drain bias supply ter-invasive technique is preferred to the use of bulky directional couplers. A Sensor based on a shunt resistor is a favorable choice, but complicated by the extremely large common-mode voltage. In this paper a measurement technique based on reflection measurements of an active reflector element using an interferometer based on a Doppler radar is investigated. The system allows for very wideband current measurements with high common-mode rejection and low parasitic loading of the shunt resistor. Thereby, the method has the potential to meet the requirements for the extreme wide bandwidth signals used in the future telecommunication infrastructure for 5G.

C-3 **Efficient Linearization of a RF Transmitter under 5G Waveforms Through Iterated Ridge Regression**

2:10 PM 2:30 PM *Juan Becerra, University of Seville; Abraham Pérez-Hernández, University of Seville; María J. Madero-Ayora, University of Seville; Carlos Crespo-Cadenas, University of Seville*

This work presents a novel method for the digital predistortion of power amplifiers (PAs) based on sparse behavioral models. The iterated Ridge regression is adapted to work in the Volterra series framework. Experiments driven on a test bench based on a GaN PA driven by a 15-MHz filter bank multicarrier (FBMC) signal were conducted in order to validate the algorithm. Experimental results in a digital predistortion scenario and the comparison with the orthogonal matching pursuit highlight the enhancement of this pruning method.

C-4 **A New Calibration Method for Achieving High Insertion-Loss Measurements with a Vector Network Analyzer**

2:30 PM 2:50 PM *Jeff Jargon, NIST; Dylan Williams, NIST*

We present a new calibration method for achieving high insertion-loss measurements with a vector network analyzer (VNA). The method requires a characterized attenuator and other additional hardware, including an amplifier, an isolator, two directional couplers, and two attenuators. With this setup, we measure wave-parameters rather than scattering-parameters. This technique enables us to shift the dynamic range of our measurements while decreasing uncertainties due to the noise floor of the VNA. With hardware available in our laboratory, we can measure values of insertion-loss up to 150 dB.

2:50 PM 3:40 PM **Break – Exhibits and Interactive Forum**

Session D - But don't miss mm-Waves and Beyond

Session Chair: Leonard Hayden

D-1 **Experimental Study on Crosstalk Reduction between Integrated Inductors up to Millimeter-Wave Regime**

3:40 PM 4:00 PM *Vadim Issakov, Infineon Technologies AG; Andreas Werthof, Infineon Technologies AG; Johanens Rimmelspacher, University of Erlangen-Nuremberg; Robert Weigel, University of Erlangen-Nuremberg; Angelika Geiselbrechtinger, Infineon Technologies AG*

Amount of inductors in SoCs is increasing with the growing complexity of the chips. Driven on one hand by integration of 5G transceivers, yet on the other hand by chip area reduction, inductors need to be placed densely. This causes interferences coupled via inductors. This paper presents an experimental study on coupling between on-chip inductors and investigation of various crosstalk reduction techniques for highly integrated SoCs up to mm-wave frequencies. We compare different orientations of 8-shaped inductors and discuss a rotated version of the 8-shape coil, which provides an additional improvement of 10 dB over the entire frequency range. Two-port measurements of coupled inductors connected single-endedly are performed up to 145 GHz. Additionally, 4-port measurements are done up to 70 GHz. We propose analyzing the crosstalk mechanisms by converting the measured S-parameters into the mixed-mode representation. Test structures were realized in 28 nm bulk CMOS technology node.

D-2 **MM-wave Partial Information De-embedding: Errors and Sensitivities**

4:00 PM 4:20 PM *Jon Martens, Anritsu*

De-embedding methods making significant structural assumptions have become popular in recent years, particularly in PC board and cable assembly spaces, because of the relative immunity to repeatability and standards availability problems at the DUT plane. Some of the same issues occur in mm-wave fixtures where repeatability can be even more of a challenge. The intrinsic errors, repeatability behavior and configuration sensitivities of one such method, based on phase localization of structures in the fixture using reflection data alone, are studied in this work with examples in the WR-10 and WR-2.2 bands. For some classes of fixtures, the repeatability immunity and standards sensitivity can be orders of magnitude better than with classical methods while showing similar sensitivities to first tier calibration issues. The absolute errors can, however, be substantial for certain distributions of mismatch within the fixture.

D-3 **On the Impact of Radiation Losses in TRL Calibrations**

4:20 PM 4:40 PM *Marco Spirito, Delft University of Technology; Carmine De Martino, Delft University of Technology; Luca Galatro, Delft University of Technology*

In this contribution we analyze the impact of radiation losses due to multimode propagations in (single medium) calibration substrates. The impact of the complex modelling of the loss mechanism due to radiation mode is applied to the specific case of TRL on-wafer calibrations for mm-wave operation. A quantitative analysis based on 3D EM simulation is performed to provide guidelines on the material to be used as the calibration substrate, the backside conditions, and the accuracy that can then be expected.

D-4

Direct mm-Wave On-Wafer Power Calibration Employing CMOS as a Transfer Device

4:40 PM 5:00 PM

Carmine De Martino, Delft University of Technology; Eduard Malotaux, Delft University of Technology; Luca Galatro, Delft University of Technology; Marco Spirito, Delft University of Technology

In this paper we present a measurement procedure and required hardware to realize absolute power calibration in on-wafer VNA-based mm-wave setups, without requiring disconnection. The approach uses a 28nm CMOS n-channel MOSFET as the power calibration transfer device, providing sufficient responsivity up to 325GHz. The square law conversion from mm-wave to DC output of the CMOS device is employed to achieve a direct on-wafer calibration. The use of the calibration transfer device allows for a zero-movement calibration procedure of a mm-wave measurement setup thereby reducing errors originating from cable movements, while also reducing the required time in comparison to the standard, calorimeter based, approaches. The proposed calibration method is benchmarked against the procedure using instrumentation power meters in WR3 showing that using the calibration transfer device become possible to have decent calibration performance but with significantly less effort and time.

Session P - Interactive Forum

Session Chair: J. Apolinar Reynoso-Hernandez, Patrick Roblin

P-1

Accuracy Improvement of On-wafer Measurement at Millimeter-wave Frequency by a Full-automatic RF probe-tip Alignment Technique

9:50 AM 3:40 PM

Ryo Sakamaki, National institute of Advanced Industrial Science and Technology; Masahiro Horibe, AIST

P-2

Determination of the Line Characteristic Impedance Using Calibration Comparison

9:50 AM 3:40 PM

Manuel Pulido-Gaytán, CICESE; J. Apolinar Reynoso-Hernandez, CICESE; Andres Zárate- de Landa, CICESE; José Raul Loo-Yau, Centro de Investigación y de Estudios Avanzados del I.P.N (CINVESTAV); María del Carmen Maya-Sanchez, Centro de Investigación Científica y de Educación Superior de Ensenada (CICESE)

P-3

On the Importance of Calibration Standards Definitions for On-Wafer Measurements up to 110 GHz

9:50 AM 3:40 PM

Thorsten Probst, Physikalisch-Technische Bundesanstalt (PTB); Sherko Zinal, PTB; Ralf Doerner, Ferdinand-Braun-Institut (FBH); Uwe Arz, Physikalisch-Technische Bundesanstalt (PTB)

P-4

Improving Wafer-Level Calibration Consistency with TMRR Calibration Method

9:50 AM 3:40 PM

Andrej Rumiantsev, MPI Corporation; Tony Fu, MPI Corporation; Ralf Doerner, Ferdinand-Braun-Institut (FBH)

P-5 **15-Term Self-Calibration without an Ideal THRU- or LINE-Standard**

9:50 AM 3:40 PM *Sebastian Wagner, Hochschule Augsburg - University of Applied Sciences; Reinhard Stolle, Hochschule Augsburg - University of Applied Sciences*

P-6 **Moisture Effect on the Characteristics of Cellulosic Material Made RF Lines.**

9:50 AM 3:40 PM *Cyril Guers, Université de Savoie & Université Grenoble Alpes; F. Garet, Université de Savoie, P. Xavier, Université Grenoble Alpes; P. Huber, Centre Technique du Papier; G. Depres, Arjowiggins Rives; P. Artillan, Université de Savoie; T.P. Vuong, Université Grenoble Alpes*

P-7 **Permeability Measurements of Thin Sheet Materials and Uncertainty Analysis**

9:50 AM 3:40 PM *JeongHwan Kim, KRISS*

P-8 **Frequency Dependence Measurement Technique of the Interface Conductivity using a Dielectric Rod Resonator Sandwiched Between Copper-Clad Dielectric Substrates**

9:50 AM 3:40 PM *Takashi Shimizu, Utsunomiya University; Yusaku Hirano, Utsunomiya University; Yoshinori Kogami, Utsunomiya University*

P-9 **Material Parameters Extraction of Printed Circuits and Semiconductor Substrates Using Wideband Reflection Measurements**

9:50 AM 3:40 PM *Aleksandr A. Savin, Tomsk State University of Control Systems and Radio Electronics; Vladimir G. Guba, Copper Mountain Technologies; Aleksandr A. Ladur, NPK TAIR; Olesia N. Bykova, NPK TAIR; Eugeny A. Shutov, Tomsk State University of Control Systems and Radio Electronics; Feodor I. Sheyerman, Tomsk State University of Control Systems and Radio Electronics; Brian Walker, Copper Mountain Technologies;*

P-10 **Active Antenna Array Characterization for Massive MIMO 5G Scenarios**

9:50 AM 3:40 PM *Marina Jordao, Instituto de Telecomunicacoes; Daniel Belo, Instituto de Telecomunicacoes; Nuno Borges Carvalho, Instituto de Telecomunicacoes*

P-11 **Digitally Assisted Wideband Compensation of Parallel RF Signal Paths in a Transmitter**

9:50 AM 3:40 PM *Prasidh Ramabadran, National University of Ireland, Maynooth; Sidath Madhuwantha, National University of Ireland, Maynooth; Pavel Afanasyev, National University of Ireland, Maynooth; Ronan Farrell, National University of Ireland, Maynooth; Lazaro Marco, Ampleon; John Dooley, National University of Ireland, Maynooth*

P-12 **Swept-Frequency Square-Wave Generation for Phase-Reference in Mixer-Based Instruments**

9:50 AM 3:40 PM *Diogo Ribeiro, Instituto de Telecomunicacoes; Nuno Borges Carvalho, Instituto de Telecomunicacoes*

P-13 **Quantitative Measurement in Scanning Microwave Microscopy**

9:50 AM 3:40 PM *Masahiro Horibe, AIST; Seitaro Kon, AIST; Iku Hirano, AIST*

P-14 **Low-Cost, Wideband Multiport Reflectometer in Single-Layer Structure for Accurate High VSWR Measurement**

9:50 AM 3:40 PM *Florian Dietrich, RWTH Aachen University; Muh-Dey Wei, RWTH Aachen University; Renato Negra, RWTH Aachen University*

P-15 **On the Effective Modeling of the Test-Set Non-linearity**

9:50 AM 3:40 PM *Thoalfukar Husseini, Cardiff University; Syed M. H. Syed Anera, Cardiff University; Azam Al-rawachy, Cardiff University; James Bell, Cardiff University; Paul J Tasker, Cardiff University; Johannes Benedikt, Cardiff University*

P-16 **UV Thermal Imaging of RF GaN Devices with GaN Resistor Validation**

9:50 AM 3:40 PM *Dustin Kendig, Microsanj; Georges Pavlidis, Georgia Institute of Technology; Samuel Graham, Georgia Institute of Technology; Justin Reiter, Analog Devices; Michael Gurr, Raytheon Corporation; David Altman, Raytheon Corporation; Stephen Huerster, Raytheon Corporation; Ali Shakouri, Purdue University*

5:00 PM **Closing Notes. End of ARFTG-91st Conference**

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