Automatic RF Techniques Group

86th ARFTG Microwave Measurement Conference

Georgia Tech Hotel and Conference Center, Atlanta, GA

TECHNICAL AGENDA

Thursday, December 3, 2015

0800 to 0810 **Welcome**

ARFTG Vice-President: Jon Martens, Anritsu
Conference Co-Chair and TPC Chair: Joe Gering, Qorvo

0810 to 0950 **Session A: RF/Microwave Applications to Bioengineering / Biomedicine**

Session Chair: James Booth, NIST

A-1 Microwaves in Biomedical Science — A Path Forward (INVITED)

0810-0850 W. D. Hunt, Georgia Institute of Technology, Atlanta, United States

In this talk we will begin with an overview of biosensing techniques which are currently being used for clinical and research purposes in biomedical science. Among these are ELISA, surface plasmon resonance, QCM (acoustic) and integrated optics. The so-called "gold standard" is ELISA (enzyme-linked immunosorbent assay) is an optical technique in which, for example, a target molecule (antigen) binds to a surface, followed by an antibody which then binds to the antigen that then binds to an enzyme or an antibody, to which a flurophore is linked. The complex then generates an optical response when excited optically. An approach that would make Rube Goldberg quite proud.

There are substantial shortcomings of all of these approaches which will be discussed in some detail in the talk. Among the shortcomings of these various immunoassay techniques (i.e. use an antibody) techniques are the following:

- performance, i.e. specificity, is highly dependent on the antibody quality, immobilization, etc.
- the sensor modalities record a perturbation to a physical characteristic of the surface—this perturbation may only partly be due to the antibody-antigen interaction
- very few of these techniques give one a picture of the before-during-and after of a biomolecular event.

Microwave spectroscopy of biological molecules will no doubt be fraught with its own challenges and imperfections as it moves forward but in this talk we wish to examine the tantalizing possibilities. A group in Spain led by J. L. Alonso of the Universidad de Valladolid has for a number of years performed a series of tantalizing experiments in which they have measured the microwave spectra of biologically relevant small molecules. Of particular interest is that the microwave spectra are markedly and measurably different for chiral forms (i.e. left and right hand) of the same molecule. Chirality is a critical aspect of biomolecules. A microwave spectroscopy approach would have a great advantage over other sensing modalities in that no antibodies would be required and Rube Goldberg will be in the rear view mirror. The microwave spectra, if performed properly, would allow one to focus on the interaction itself and perhaps be independent of other physical perturbations which are difficult to sort out. A clear problem with collecting these microwave spectra is that when the molecules are not in a gaseous state, the collisions with other molecules broadens the spectral peaks, thereby obscuring the spectral uniqueness. If this rather substantial hurdle can be overcome, perhaps microwave spectroscopy may be used to monitor biomolecular recognition events before-during and after. The GHz range frequencies of the spectra would indicate that they may perhaps be followed well over the time period of molecular events. The progression of these interactions in time are at the present time unseen by biomolecular science.

A-2 Sensor-on-CMOS Dielectric Characterization Using Temperature Modulation

0850-0910 J. Chien, A. M. Niknejad, University of California, Berkeley, Berkeley, United States

In this paper, on-chip temperature modulation is applied in a CMOS-based dielectric sensor for the determination of sample temperature coefficients in a microfluidic setting. System uncertainties are taken into account by a multi-step calibration with the use of on-chip metal-based switched-capacitors. Using de-ionized water as reference, the temperature coefficients of saline and methanol-water mixture are extracted at 17.5 GHz with temperature spanning from 32 ~ 37 ºC.

A-3 Broadband Single-Cell Detection with a Coplanar Series Gap

0910-0930 X. Ma, X. Du, C. Multari, Y. Ning, C. Palego, X. Luo, V. Gholizadeh, X. Cheng, J. C. Hwang, Lehigh University, Bethlehem, United States

Based on a coplanar waveguide with a series gap in conjunction with dielectrophoresis trapping, consecutive S-parameter measurements between 0.5 and 20 GHz were quickly performed with and without a Jurkat cell trapped to compensate for a relatively noisy and unstable background. This allowed the small cytoplasm capacitance, on the order of 10 fF, to be reliably extracted. The extracted cytoplasm capacitance is within a factor of 2 of the previously reported value but is believed to be more accurate. The present technique can complement previously developed microwave and RF techniques in characterizing the capacitances and resistances of plasma and membrane for complete characterization of the electrical properties of a simple cell.

A-4 Optimized Matching of an Implantable Medical Device Antenna in Different Tissue Medium Using Load Pull Measurements

0930-0950 P. Li, L. Zhang, F. Liu, J. Amely-Velez, St. Jude Medical, Sylmar, United States

RF communication with implantable medical devices (IMD) such as a pacemaker experience unique challenges due to the operating conditions within a human body. This includes added body losses caused by the different tissue compositions where material properties range from εr=58 (muscle) to εr=5.58 (fat). In order to achieve maximum throughput for a 402MHz RF signal, it is important to have minimum mismatch losses between the RF front end of a device and the embedded antenna. This paper presents a method to optimize the matching with various tissues using load pull analysis with a prototype implantable medical device as an example. By using automated impedance tuners, an optimum impedance point was found, improving the mismatch loss by as much as 3dB compared to a design with no consideration given to tissue variation.

0950 to 1120 **Break – Exhibits and Interactive Forum**

Session Chair: Ken Wong, Keysight

P-1 Uncertainty Analysis in Coplanar Waveguide with Unscented Transformation

A. A. Savin[1], V. G. Guba[2], O. N. Bykova[2], [1]Tomsk State University of Control Systems and Radioelectronics, Tomsk, Russian Federation, [2]NPK TAIR, a subsidiary of Copper Mountain Technologies, Tomsk, Russian Federation

In this paper results of uncertainty analysis of coplanar waveguides (CPWs) parameters are shown in the presence of ambiguities in line geometry and material properties. Calculations are performed with unscented transformation (UT). Error bounds calculated with UT are compared with the results of Monte-Carlo simulation.

P-2 Comparison Analysis of VNA Residual Errors Estimation Algorithms with Time Domain Separation

A. A. Savin[1], V. G. Guba[2], O. N. Bykova[2], [1]Tomsk State University of Control Systems and Radioelectronics, Tomsk, Russian Federation, [2]NPK TAIR, a subsidiary of Copper Mountain Technologies, Tomsk, Russian Federation

In the paper results of algorithms' comparison which are utilized for determination of vector network analyzer (VNA) residual parameters are described. Separation of parameters in time domain is the basis for the algorithms. The algorithms based on unscented Kalman filter, least mean square technique and conventional time domain filtering are reviewed. Experimental results are achieved in coplanar waveguide environment in frequency range up to 70 GHz using two airlines with different length.

P-3 Impedance Standard Substrate Fabricated by Screen Printing Technology

M. Horibe, R. Sakamaki, AIST, Tsukuba, Japan

The paper proposes new fabrication process for an Impedance Standard Substrate (ISS) for on-wafer measurements at microwave and millimeter-wave frequencies. Screen printing technology has provided coplanar waveguides (CPW) lines with low transmission loss and high precision contact repeatability at millimeter-wave frequency up to 110 GHz. The paper demonstrate capability of the screen printed CPW as an ISS for on-wafer measurements. Standard lines with seven different lengths were designed and fabricated by screen printing technology. In the paper, Multiline Thru-Reflect-Line (TRL) calibration was performed by using ISSs fabricated by both screen printing and conventional pleated technologies. Regarding calibration capability validation, contact repeatability performance was first tested, then, verification devices were measured. According to comparison results, results obtained by calibration of screen printing ISS are almost the same as results measured based on conventional ISS tech

P-4 **Withdrawn**

P-5 **Joint Self-Heating and RF Large Signal Characterization**

F. J. Martinez-Rodriguez[1,2], P. Roblin[1], J. I. Martinez-Lopez[2], [1]The Ohio State University, Columbus, United States, [2]Universidad Nacional Autónoma de México, Coyoacan, Mexico

Self-heating affects the RF performance of power transistors and must therefore be characterized for accurate device modeling. This paper presents an active loadpull (ALP) testbed which performs continuous wave measurements with the LSNA for arbitrary loads and substrate temperatures while jointly measuring the device die temperatures with an infrared sensor. Measurements are performed for a 15 W GaN HEMTs for 15, 25, 35 and 45 C substrate temperatures. The thermal resistance is extracted from the dissipated power and temperature data for fundamental loads spanning the entire Smith Chart. The quasi linear relation between the dissipated power and the device temperature increase measured for all loads verifies that a physical temperature is measured. The expected correlation between the dissipated power, output power and device temperature is also evidenced. This ALP testbed provides thus a wealth of joint loadpull, thermal and loadline data which should facilitate the extraction of an electrothermal device model directly from large-signal RF measurements.

1120 to 1200 **Session B: Characterization of Flexible Substrates**

Session Chair: Mitch Wallis, NIST

B-1 **Microwave Characterization of Ink-Jet Printed CPW on PET Substrates**

1120-1140

A. Sahu[1], V. Devabhaktuni[1], A. Lewandowski[2], P. Barmuta[2], T. M. Walllis[3], M. Shkunov[4], P. H. Aaen[4], [1]University of Toledo, Toledo, United States, [2]Warsaw university of Technology, Nowowiejska, Poland, [3]NIST, Boulder, United States, [4]University of Surrey, Guildford, United Kingdom

This paper characterizes coplanar waveguide (CPW) lines formed by ink-jet printed technology on flexible polyethylene terephthalate (PET) substrates. The reel-to-reel printing process uses inkjet printing as a precursor for 2µm copper plating, which allows significantly lowered resistances as compared to traditional inks. A multiline TRL calibration technique has been used to characterize the propagation constant and reflection coefficient of the CPW lines. It is shown that the fabricated samples have contact repeatability, permitting redundant multiline calibrations

B-2 **Measurement Methods for the Permittivity of Thin Sheet Dielectric Materials**

1140-1200

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

This paper presents a new method for the determination of the complex permittivity of thin sheet dielectric materials that are flexible and elastic. Instead of the traditional method to install a doughnut shape sample in the transverse plane used in transmission line methods, most widely used methods for broadband permittivity measurements, a thin sheet sample is installed onto the outer conductor of the coaxial transmission line. The proposed method has much large sensitivity compared to the traditional one and is a broadband technique useful for thin sheet materials. Measurement results and comparison with other approaches agree very well, particularly at high frequency range.

1200 to 1300 **Lunch**

1300 to 1320 **ARFTG Business Meeting**

1320 to 1440 **Session C: Nonlinear Measurements, Modeling, and Linearization**
Session Chair: Dominique Schreurs, K. U. Leuven

C-1 Frequency-scalable nonlinear behavioral transistor model from single frequency X-parameter measurements based on time-reversal transformation properties (INVITED)

1320-1400 D. E. Root[1], R. M. Biernacki[1], M. Marcu[1], M. Koh[2], P. J. Tasker[2], [1]Keysight Technologies, Santa Rosa, United States, [2]Cardiff University, Cardiff, United Kingdom

This paper presents a powerful new method that takes large-signal transistor X-parameter data at a single fundamental frequency and generates from them a frequency-scalable nonlinear simulation model. The method is based on a novel orthogonal identification (direct extraction) of current source and charge source contributions to the spectrally rich port currents under large-signal conditions done entirely in the frequency domain. Explicit decomposition formulae are derived in terms of sensitivity functions at pairs of large-signal operating points related to one-another by time-reversal transformation. The method is applied and validated with respect to a pHEMT transistor, where it is demonstrated that the scalable model can predict the nonlinear performance of the transistor over several orders of magnitude in frequency, all from measured X-parameters at a single fundamental frequency.

C-2 Automatic Feed-Forward Cancellation of Modulated Harmonic

1400-1420 H. Yu[1], V. Ratnasamy[1], P. Roblin[1], M. Rawat[2], C. Xie[3], [1]The Ohio State University, Columbus, United States, [2]Indian Institute of Technology, Roorkee, India, [3]Rockwell Collins, Cedar Rapids, United States

This paper presents an algorithm for the simultaneous linearization and cancellation of modulated harmonics of broadband power amplifiers (PA). The algorithm relies on a joint system identification of the nonlinearity, memory effects and group delay of both the main and harmonic cancellation channels using a recently reported cubic spline basis. The filter-less cancellation of the modulated harmonics uses both the method of predistortion and feedforward while the synchronized PA linearization relies solely on digital predistortion. Experimental verification with a broadband PA yields a reduction of 31 dB of the third harmonic to 59 dBc below the main channel. Simultaneously the linearization provides -40 dB NMSE and 49.5 and 50 dBc ACPR at the fundamental frequency.

C-3 Enhanced PHD Model Extraction by Improving Harmonic Response Superposition During Extraction

1420-1440 D. T. Bespalko, S. Boumaiza, Emerging Radio Systems Group, Waterloo, Canada

A Poly-Harmonic Distortion (PHD) model extraction procedure is proposed to improve the model accuracy for unmatched, broadband RF transistors by minimizing multi-harmonic signal reflections within the measurement system. As a result, the fictitious need for higher-order models is avoided by minimizing the order of the nonlinear measurement system used to extract the model. Under strongly nonlinear conditions the accuracy of the PHD model is improved by 5dB, in terms of Normalized Mean-Squared Error (NMSE), averaging less than 1% time-domain output power error.

1440 to 1445 **ARFTG Business Meeting Wrap-Up**

1445 to 1600 **Break – Exhibits and Continuation of the Interactive Forum**
Session Chair: Ken Wong, Keysight

1600 to 1700 **Session D: Novel Measurement Techniques and Applications**
Session Chair: Leonard Hayden, Qorvo

D-1 Towards Faster, Swept, Time-Coherent Transient Network Analyzer Measurements

1600-1620 J. Martens, E. Vayner, J. Tu, Anritsu, Morgan Hill, United States

Time- and phase-coherent swept network analyzer measurements are increasingly important for everything from harmonic waveform reconstruction needs in power amplifier analysis to transient pulse response problems in radar and phased array applications and generic memory effect analysis in device characterization. Classically, there have been several solutions to these problems but these have often been slow or have required sometimes complex reference-generation schemes to enable phase recovery. By employing a wide-IF digitizer in a sampling receiver along with a somewhat novel triggering/marking scheme, it is possible to perform synchronous measurements during a frequency or power sweep at 10s of us sweep rates and keeping phase data on unratioed wave quantities. This configuration is demonstrated with a waveform reconstruction experiment and with sensitive swept transient DUT measurements delineating thermal response differences of more than 1.5 dB and 15 degrees.

D-2 Hurdles to On-Wafer Harmonic Measurements

1620-1640 K. J. Muhonen, Qorvo, Greensboro, United States

With the ever increasing need for spectrum in the mobile phones, specs are tougher for spurious emissions. Harmonics can fall into bands that are used for other services so prior evaluation of those harmonics is critical in product development. An on-wafer harmonic bench is used for fast evaluation of material and designs without having to build a final product to know what the harmonic performance will be. Harmonic measurements are not new; but high power, (4 watts) on-wafer harmonic measurements present hurdles that have not been solved. Low passive intermodulation (PIM) components, probe selection, connector selection and bench configuration all play into building a measurement system with low enough system noise to be able to evaluate the state-of-the-art technologies for mobile applications.

D-3 A compact measurement set-up for envelope-tracking RF PAs with calibrated sensing of baseband V/I at the supply terminal.

1640-1700 G. Gibiino[1,2], J. Couvidat[1,3], G. Pailloncy[4], M. Vanden Bossche[4], A. Ghiotto[3], D. Schreurs[1], [1]KU Leuven, Leuven, Belgium, [2]University of Bologna, Bologna, Italy, [3]University of Bordeaux, Talence, France, [4]National Instruments, Zaventem, Belgium

This paper presents a compact set-up to perform automated measurements of RF PAs under envelope-tracking (ET) operation. In addition to RF signal generation and acquisition, it allows calibrated measurements of the baseband voltage and current at the supply terminal with up to 40 MHz bandwidth, enabling instantaneous efficiency measurements. The presented set-up is used to extract two different shaping tables, and to test ET operation with a 5 MHz WCDMA and a 20 MHz LTE signals at 838 MHz. The used devices are an InGaP/Silicon RF power amplifier (PA) from Skyworks and a high voltage extra fast complementary bipolar (XFCB) power modulator (PM) from Analog Devices.

0800 to 0920 **Session E: Millimeter-Wave and Terahertz Measurements and Calibration**

Session Chair: Dave Blackham, Keysight

E-1 Continuing Challenge of Improving Measurement Accuracy in Terahertz Vector Network Analyzers - The Taming of "Terahertz Vector Network Analyzers" (INVITED)

0800-0840 M. Horibe, National Institute of Advanced Industrial Science and Technology (AIST) - National Metrology Institute of Japan (NMIJ), Tsukuba, Japan

Metrological traceability is required for testing and spurious emission management. Even if above 110 GHz frequency, metrological traceability is universally important, however the system set-up and calibration method are as important as the metrology standards due to high cost and low stability / reproducibility for the measurement system and standards as compared to those in the microwave frequency range. In recent years, operation frequency of commercial vector network analyzers (VNA) reaches currently up to 1.6 THz.

Key priorities for improvement of VNA measurement accuracy are waveguide interface performance, operation conditions, hardware set-up, calibration standards and methods. Then, measurement traceability and uncertainty, further verification process, including measurement comparison, are absolutely necessary for quality of measurements.

Details of priorities for improvement of VNA measurement accuracy are as follows:

- Waveguide Flange: Connection repeatability, Standardization,
- Operation conditions: Connection clump (tool), Connection torque, Air floating connection plat form,
- Hardware set-up: System noise, Cable effect on phase measurements, linearity evaluation,
- Calibration standards and methods: Thru-Reflect-Line and offset shorts, Oversized and undersized waveguide aperture,
- Metrological traceability
- Uncertainty analysis
- Verification and Measurement comparison

The presentation introduces all key priority together with latest research achievements, then gives recommendation for accurate VNA measurement in Terahertz.

E-2 Performance assessment of VNA calibration schemes for millimeter-wave and submillimeter-wave frequencies, using the 33 GHz – 50 GHz band

0840-0900 K. Drazil, A. Pavlis, M. Hudlicka, Czech Metrology Institute, Prague, Czech Republic

In this article vector network analyzer (VNA) calibration schemes suitable for traceable scattering parameter measurements in rectangular waveguides at millimeter-wave and submillimeter-wave frequencies are compared with well-established techniques being used at lower frequencies. Comparison measurements were performed in the frequency band 33 GHz – 50 GHz.

E-3 An IQ-Steering Technique for Amplitude and Phase Control of mm-Wave Signals

0900-0920 M. Spirito[1], A. Visweswaran[2,1], C. de Martino[1], [1]Delft University of Technology, Delft, Netherlands, [2]IMEC, Leuven, Belgium

In this contribution we present a custom test-bench capable to deliver amplitude and phase controllable mm-wave signals to an on-wafer environment. The setup employs IQ up-conversion with high resolution DACs to modulate both amplitude and phases of n coherent LO signals. Amplification and multiplication stages are then added to shift the signal into the mm-wave range (i.e., 30GHz to 40GHz). A pre-distortion and calibration technique is developed in order to achieve accurate amplitude and phase control at the wafer probe level.

0920 to 1040 **Break – Exhibits**

1040 to 1200 **Session F: Calibration and Verification**

Session Chair: Jon Martens, Anritsu

F-1 The Impact of Knowing the Impedance of the Lines Used in the TRL Calibration on the Load-Pull Characterization of Power Transistors

1040-1100 M. A. Pulido-Gaytan[1], J. A. Reynoso-Hernandez[1], M. C. Maya-Sanchez[1], J. R. Loo-Yau[2], [1]Cicese, Ensenada, Mexico, [2]Cinvestav, Zapopan, Mexico

In this paper, the impact of knowing the impedance of the lines used in the TRL calibration (Z) on the load-pull (LP) characterization of power transistors is assessed. Relevant parameters, such as input impedance (ZIN), load impedance (ZLD) and large-signal gain are considered. By using the ABCD-parameters matrix formalism in the calibration of the LP measurement setup, closed form expressions for evaluating the impact of knowing Z on the calculation of these parameters are presented. It is demonstrated that knowing Z is of paramount importance in the calculation of ZIN and ZLD. Regarding the gain, it is demonstrated that while the voltage and current gains do not depend on the knowledge of Z, the gain expressed as the ratio of the transmitted to incident waves does.

F-2 Improved SOLT/RSOL Planar Calibration via EM Modelling and Reduced Spread Resistive Layers

1100-1120 M. Spirito[1], L. Galatro[1], G. Lorito[2], T. Zoumpoulidis[2], F. Mubarak[3,1], [1]Delft University of Technology, Delft, Netherlands, [2]Iszgro diodes, Delft, Netherlands, [3]Van Swinden Laboratorium , Delft, Netherlands

In this contribution we analyze the improvement on the quality of planar SOLT calibration when employing fullwave EM simulation to extract the models of the standards. Moreover, a technology based on integrated circuit fabrication process will be evaluated for the realization of high-resolution and low spread calibration kits implemented on fused silica.

F-3 Calibration/Verification Standards for Measurement of Extremely High Impedances

1120-1140 M. Haase, K. Hoffmann, Czech Technical University in Prague, Prague, Czech Republic

The paper concerns the design of calibration/verification standards suitable for a system developed to be capable of measuring extreme impedances. Values of standard impedances cover the range from 5 kΩ to approx. 200 kΩ. The paper focuses on selecting a structure compatible with an APC-7 connector and its optimization taking into account also the presence of higher order modes and technology demands. CST Microwave Studio (CST) is used for simulations. S-parameters of the final structure are verified by means of an independent 3D simulator ANSYS HFSS (HFSS).

F-4 Evaluation and Modeling of Measurement Resolution of A Vector Network Analyzer for Extreme Impedance Measurements

1140-1200 F. Mubarak[1,2], R. Romano[2], M. Spirito[2], [1]Van Swinden Laboratorium (VSL), Delft, Netherlands, [2]Delft University of Technology, Delft, Netherlands

A broadband S-parameter measurement system for extreme impedance measurements is proposed and analyzed in terms of its accuracy. Measurement speed and system resolution at extreme impedance values is comparable to that of a conventional Vector Network Analyzer performance achieved for 50 Ω device measurements. A dedicated one-port calibration method is modeled in a circuit simulator environment and implemented for the proposed system. Compared to the 0.05 % measurement resolution in extreme impedance measurements using a state-of-art 50 Ω VNA, an almost fifty times lower 0.001 % resolution is achieved with the proposed VNA system utilizing an interferometric principle, with active compensation of reflected waves.

1200 to 1320 **Lunch**