90th ARFTG Microwave Measurement Symposium: Abstracts

November 30 and December 1, 2017, Boulder Colorado

Session A: Keynote Talk & On-Wafer Measurements Part 1

Session Chair: Jon Martens, Anritsu

ThA-1

KEYNOTE: Wireless Technology – Game-Changing Solutions of Integration

0810-0850

Ke Wu, Poly-Grames Research Center, Department of Electrical Engineering, Polytechnique Montreal, Quebec, Canada

Recent research and development of hardware architectures and technologies over MHz-through-THz frequency range have generated a significant momentum for future wireless applications. This leap forward is being propelled by the organic fusion of multiple functions and the scalable integration of multiple technologies through heterogeneous materials and innovative processes. This presentation begins with the overview of fundamental wireless functionalities. Emerging advances in multifunction, multimaterial, multilayer and multiband wireless technologies are reviewed. Technological roadmap is highlighted with reference to enabling and building technological elements, ranging from current and emerging compound materials to evolving and beyond CMOS, and from developing substrate integrations to future electromagnetic techniques. The talk also provides a brief tour of the state-of-the-art wireless devices, antennas, circuits and systems in connection with integration issues. Challenging issues and future directions of wireless technology and hardware characterization including 5G and beyond are discussed.

ThA-2

An Intra-Laboratory Investigation of On-Wafer Measurement Reproducibility at Millimeter-Wave Frequencies

0850-0910

Roland G Clarke[1], Chong Li[2], and Nick Ridler[3]

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Understanding the relative contribution of contact repeatability and overall reproducibility for on-wafer measurements provides useful insight into the significance of measurement comparisons. We report on an intra-laboratory investigation into contact repeatability and the variation that may be anticipated when measurements are reproduced in different laboratories using different equipment. We pay particular attention to the dispersion in measurement results arising from the use of on-wafer and off-wafer calibration. Experimental results are reported for measurements in the frequency range 140 GHz to 220 GHz, together with preliminary estimates of the repeatability limits for this type of measurement.

ThA-3

110 GHz On-Wafer Measurement Comparison on Alumina Substrate

0850-0910

Thorsten Probst[1], Ralf Doerner[2], Matthias Ohlrogge[3], Roger Lozar[3], and Uwe Arz[1]

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This paper reports on initial results of a three party on-wafer measurement comparison carried out on a custom-made alumina calibration substrate in the frequency range up to 110 GHz. The correction of the vector network analyzer measurement is done with the highly accurate multiline TRL (mTRL) calibration. The focus of the investigation is on the influence of the measurement system, the probe geometry and operator skills. The results of the calibrations are presented and the influence on selected devices under tests (DUT) are evaluated for different measurement configurations.

Session B: Panel of Future RF Instrumentation

Session Moderator: Dylan Williams, NIST

Session C: Novel Application Areas for RF and Microwave Measurements

Session Chair: Jeff Jargon, NIST

ThC-1

INVITED: Rydberg Atom Electric-Field Metrology

1320-1400

Josh A. Gordon, Matthew T. Simons, and Christopher L. Holloway, NIST, Boulder, United States

In the past several years much progress has been made in atom-based sensing of radio- frequency (RF) electric-fields. In particular, a relatively new technique for converting an RF field amplitude into an optical frequency response in a gas of atoms has shown much promise. A primary goal is to realize an atomic standard measurement of RF fields that is intrinsically calibrated and directly linked to the SI. Such a measurement consists of a gas of room temperature alkali atoms such as Rubidium (Rb) and Cesium (Cs) contained in a glass vapor cell which are optically excited to Rydberg states. While in the Rydberg state the atoms act as nano-sized antenna which will respond favorably to RF fields. The atomic structure of these atoms produces a very rich resonance response across a large frequency range from hundreds of MHz and approaching 1 THz. In this technique, the atoms act as a transducer mapping RF field strength to an optical frequency shift. The RF field strength is thus obtained directly from the optical spectrum of the atoms. We discuss the theory behind this technique and present several measurements. Measurements demonstrating the broad tunability of this technique as well as far-field antenna and near-field coplanar waveguide modes are made. We also present a recently developed quantum electric-field probe based on this Rydberg atom technique, which is constructed from a fiber optically coupled micro vapor cell.

ThC-2

Measurement of Sub-Degree Angular Carbon Fiber Tow Misalignment

1400-1420

William C. Wilson[1], Jason P. Moore[1], and Hunter McCraw[2]

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NASA is investigating the use of carbon fiber tow steering to tune aeroelastic characteristics in advanced composite structures. In support of that effort, NASA is also investigating methods of measuring the angle of carbon fiber tows as they are placed. This work presents the results of using microwave reflectometry in the ~2 GHz region to measure carbon fiber tow angles at 0.1° resolution.

ThC-3

Demonstration of RF Impedance Matching Techniques or Near-Field Scanning Microwave Microscopy Based on Atomic Force Microscopy

1420-1440

Masahiro Horibe, Iku Hirano, National Institute of Advanced Industrial Science and Technology (AIST), Tsukuba, Japan

We have demonstrated a near-field scanning microwave microscopy (SMM) based on an atomic force microscopy (AFM) with mechanical impedance tuning techniques and interferometric circuits in order to precise measurement for characteristics of various material under test (MUT). Recent commercial SMM system has fixed impedance matching circuit in commercial product and some types of interferometer structures in prototype or laboratory level system. All system is useful for operator without knowledge of microwave measurements, but they have some limitation of measurement range for material characteristics, i.e. conductivity, permittivity and permeability. It is expected that various characteristics of materials can be measured with the same accuracy by the impedance tuning technique.

Session D: Calibration, Verification, and De-embedding

Session Chair: Jim Booth, NIST

ThD-1

Qualitative Multidimensional Calibration Comparison

1600-1620

Aric W. Sanders, Ron Ginley, Richard Chamberlin, Jasper Drisko, Christian Long, and Nathan Orloff, NIST, Boulder, Colorado, USA

We present a technique for the visual comparison of any two vector network analyzer calibrations. This method visualizes the comparative action of the calibrations for multiple complex scattering parameters relative to the calibrated measurement plane. This method is independent of the calibration model. This comparative visualization of the two calibrations facilitates quick assessment of different calibration and error models, guides the choice of verification standards for later comparison, creates an easy way to monitor instrument stability over time, and can help guide the development of new on wafer calibration schemes.

ThD-2

Establishing Traceability for SOLT Calibration Kits

1620-1640

Ron Ginley, NIST, Boulder, Colorado, USA

Establishing traceability for a measurement is very important so that the results of the measurement can be used in a common framework for comparisons and understanding. The standard source of traceability for Short-Open-Load-Thru (SOLT) calibrations has been through empirical models and is tenuous at best. Additionally, the uncertainties do not contain any information about cross-frequency correlations. This work describes a technique for establishing traceability for SOLT calibration kits with fully correlated uncertainties. The calibrations performed using calibration kits evaluated with this new approach are traceable back to dimensional standards. This paper describes the new technique and shows the results of measurements based on this technique.

ThD-3

How to Extract Distributed Circuit Parameters from the Scattering Parameters of a Transmission Line

1640-1700

Nate Orloff, NIST, Boulder, Colorado, USA

Distributed circuit parameters parameterize the transmission and reflection off a given transmission line in terms of a distributed resistance, inductance, capacitance, and conductance, which are per unit length frequency dependent quantities. While there are analytical models for extracting the distributed circuit parameters, these models are discontinuous as a function of frequency when the phases of the transmission or reflection approach π or $-\pi$. Here, we develop a nonlinear least-square regression algorithm that accurately extracts the distributed circuit parameters. Compared to existing approaches and finite element models, our algorithm successfully extracts the distributed circuit parameters as a function of frequency; all while being less sensitive to these phase conditions. Such an algorithm is useful for understanding how to deembed transmission lines, and how to extract electrical properties of the materials used in a circuit.

Session E: On-Wafer Measurements Part 2

Session Chair: Leonard Hayden, Qorvo

FrE-1

INVITED: Characterization of fluid permittivity to 110 GHz by microwave microfluidics

0830-0910

Chris J. Long[1], Nathan D. Orloff[1], Cully Little[1,2], Xiao Ma[1,3], Angela Stelson[1], Jasper Drisko[1], Isaac E. Hanemann[1,2], Ami Thakrar[1,4], Jordi Mateu[1,5,6], Jim Hwang[3], and Jim Booth[1], [1]NIST, Boulder, Colorado, USA, [2]University of Colorado, Boulder, USA, [3]Lehigh University, Bethlehem, Pennsylvania, USA, [4]University of California, Berkeley, USA [5]Universitat Politecnica de Catalunya, Barcelona, Spain [6]Centre Tecnologic de Telecomunicacions de Catalunya, Barcelona, Spain

Microfluidics have a wide variety of applications including medical diagnostics, pharmacological manufacturing, and high-throughput chemistry. The advantages of microfluidics include access to small fluid volumes and the possibility to integrate many different types of measurements, including optical, thermal, and electrical measurements. Electrical measurements are particularly important in impedance spectroscopy, DNA protein analysis, and manufacturing quality control. However, for many fluids it is not possible to probe electrical properties at low frequencies (up to ~ 1 GHz) due to screening of the electric field by mobile ions in solution, motivating measurements at higher frequencies. Here we review our groups recent progress in combining on-wafer microwave metrology with microfluidics. We focus primarily on broadband measurements (10 kHz to 110 GHz) of microfluidic structures on top of coplanar waveguides. We discuss methods for deembedding on-wafer and packaged microfluidic devices, modeling of electrical double layer effects, and extraction of quantitative fluid dielectric properties. Advances in these areas are rapidly approaching a point where label-free, high-throughput, broadband, non-destructive measurements of nanoliter fluid volumes can be performed by microwave microfluidics in a turn-key system.

FrE-2

Coplanar Waveguide for Dielectric Material Measurements at Frequencies from 140 GHz to 200 GHz

0910-0930

Xiue Bao[1], Song Liu[2], Ilja Ocket[1,3], Juncheng Bao[1], Dries Kil[1], Shengkang Zhang[2], Chunyue Cheng[2], Keming Feng[2], Bob Puers[1], Dominique Schreurs[1], and Bart Nauwelaers[1], [1]KU Leuven, Belgium, [2]Beijing Institute of Radio Metrology and Measurement, Beijing, China, [3]Interuniversity Microelectronics Center (IMEC), Heverlee, Belgium

This paper presents a single line coplanar waveguide (CPW) based technique for dielectric spectroscopy on solid and liquid materials under test (MUT) in G-band (140 GHz-220 GHz). Using a conformal mapping technique (CMT), the minimum required MUT thickness is derived, and the relations between the propagation constant of the CPW line and the material's permittivity are presented. A single CPW line that is integrated with an SU-8 microfluidic channel is employed for characterization of solid SU-8 and de-ionized water. The measurement results show good agreement with previously reported data obtained through other techniques.

FrE-3

Establishing Traceability for On-Wafer S-Parameter Measurements of Membrane Technology Devices up to 110 GHz

0930-0950

Uwe Arz[1], Sherko Zinal[1], Thorsten Probst[1], Gerd Hechtfischer[2], Franz-Josef Schmückle[3], and Wolfgang Heinrich[3], [1]Physikalische-Technische Bundenanstalt (PTB), Braunschweig, Germany, [2]Rohde & Schwarz, GmbH & Co. München, Germany, [3]Ferdinand-Braun Institut, Leibniz-Institut für Höchstfrequenztechnik, Berlin, Germany

In this paper we report on progress towards establishing traceability for fully calibrated on-wafer measurements of planar devices built in membrane technology. For the first time, we present a comprehensive uncertainty budget for on-wafer S-parameter measurements, including instrumentation errors, connector repeatability and calibration standard uncertainties. Preliminary results are shown for three typical devices.

Session F: Non-Linear Measurements

Session Chair: Dominique Schreurs, KU Leuven

FrF-1

Characterization of Transmission Lines with Nonlinear Dielectric Materials

1100-1120

Aaron M. Hagerstrom, NIST, Boulder, Colorado, USA

Nonlinear transmission lines are interesting for two broad reasons: first, they have several direct device applications (i.e. harmonic generation, and phase shifters), and second, they provide a way to characterize nonlinear materials at \si{mm}-wave frequencies. In either case, circuit modeling is challenging because nonlinear waveguides are described by a nonlinear wave equation. In this paper, we focus on characterizing the nonlinear mixing products generated by coplanar waveguides on a strongly nonlinear ferroelectric Barium Strontium Titanate film. We develop a perturbative solution to the nonlinear wave equation, and validate our model by using a nonlinear vector network analyzer (NVNA) measure the nonlinear mixing products. Our approach is useful for predicting spurious signals generated by nonlinear mixing in devices with nonlinear dielectrics, and predicting the performance of nonlinear devices like harmonic generators.

FrF-2

Load-Pull Measurement for Device-Technology Comparison

1120-1140

Leonard Hayden and Sonja Nedeljkovic, Qorvo, Inc., Hillsboro, Oregon, USA

Enabling understanding of device physics mechanisms when optimizing HBT device design requires careful comparison of experiments with differences that are small compared to absolute measurement accuracy. An on-wafer approach has been developed that minimizes measurement variables allowing best sensitivity for comparison. Linearity is evaluated for tuned load conditions using a single-tone power-swept Nonlinear Vector Network Analyzer (NVNA) measurement and ACP and EVM estimates are calculated. This approach is effective despite insensitivity to thermal, trapping, and base-band impedance effects which are either considered separately or are irrelevant to the device design.

Session P: Posters

Session Chair: Mitch Wallis, NIST

Thursday, 0930-1100 and 1440-1600

ThP-1

Kicking the Tires of the NIST Microwave Uncertainty Framework – Part 2

Ron Ginley, NIST, Boulder, Colorado, USA

Traceability of a measurement requires two parts. An unbroken chain of measurements and uncertainties for each link of the chain. The NIST Microwave Uncertainty Framework (MUF) can provide both the required parts for a single link in the chain or for multiple links. In Part 1 of this work [1] the scattering-parameter measurement results

determined by the MUF were compared to the established technique used at NIST. In this Part 2, the comparison of the uncertainties calculated with the different approaches will be discussed.

ThP-2

Development of a Verification Technique for On-wafer Noise Figure Measurement Systems

Aihua Wu[1], Chen Liu[1], Chong Li[2], Jing Sun[1], and Yibang Wang[1]

[1] Hebei Semiconductor Research Institute, Shijiazhuang, China, [2] University of Glasgow, UK

We present the development of a verification technique for on-wafer noise figure (NF) measurement systems. As the key element of the technique, a verification device consisting of a mismatched attenuator and a low noise amplifier (LNA) has been developed. The attenuator and the LNA are on two separate chips and joined using a gold bondwire. The verification procedure based on the device was developed and tested on an on-wafer vector network analyzer system with a noise measurement option across the frequency range from 2 GHz to 20 GHz. It has also been found that the bondwire contributes to negligible effect on the system when NF is high e.g. 3 dB but slightly higher when NF is smaller e.g. 1 dB.

ThP-3

G-band Reflectivity Results of Conical Blackbody for Radiometer Calibration

Derek A. Houtz and Dazhen Gu, NIST, Boulder, Colorado, USA

Two hollow conical cavities have been developed and built for the National Institute of Standards and Technology (NIST) for use as radiometric brightness temperature sources, or blackbodies. According to Kirchoff's reciprocity relation, a good absorber is a good emitter, and a blackbody aims to maximize emissivity. Thus, we desire low reflectivity to approximate an ideal blackbody. We present new results of the reflectivity of the smaller conical blackbody in G-band between 130 GHz and 230 GHz. We found monostatic reflectivity, or return loss, no larger than -45 dB at critical remote sensing bands near 165 GHz, 183 GHz, and 229 GHz. We found that use of a thin closed-cell polyethylene insulation layer has a larger-than-predicted impact on reflectivity in G-band. We suggest some modifications to improve performance with the polyethylene and discuss current and future investigations related to the blackbody's electromagnetic performance.

ThP-4

Quantifying Variance Components for Repeated Scattering Parameter Measurements

Amanda Koepke and Jeff Jargon, NIST, Boulder, Colorado, USA

We quantify random uncertainties for scattering-parameters repeatedly measured with a vector network analyzer (VNA), focusing on variations due to multiple calibrations, disconnects, and repeat measurements. We describe a two-stage nested design, which allows us to model the random effects, and present results for a series of coaxial measurements performed by making use of an open-short-load-thru (OSLT) calibration kit with Type-N connectors.

ThP-5

Background Measurement of System Nonlinearity Using Spread-Spectrum Methods

Adam Wichman and Lawrence Larson, Brown University, Providence, Rhode Island, USA

We demonstrate a time-domain, spread-spectrum measurement technique for lowpass Volterra coefficients for weakly nonlinear RF systems. Robust estimates of the coefficients are obtained at nonlinear test signal amplitudes well below the operating signal level during normal system operation, demonstrating that the technique can be used as a ``background" nonlinearity measurement approach.