Proposal for a full-day workshop at IMS 2017

Title:

“New developments in microwave measurements for planar circuits and components”

Abstract:

High-frequency on-wafer measurement techniques are fundamental prerequisites for many applications in science, engineering and metrology. While reliable planar measurements up to millimetre-wave frequencies are becoming more and more state-of-the-art, the traceability in an industrial characterisation process, planar S-parameter measurements of nano-devices and the extension to frequencies beyond 100 GHz are still open topics to the scientific and industrial community. Therefore the aim of this workshop is to provide an overview of these current research areas and to present future directions in the field of planar on-wafer measurements.

The first part of this workshop is therefore related to the fundamental question of how to achieve traceability in planar on-wafer measurements. More specifically, this means we will discuss the characterization and verification process of different error mechanisms in a planar on-wafer environment.

The second part of the workshop is linked to the measurement of nano-electronic devices. Since these components are rapidly finding their way into the field of millimetre and sub-millimetre wave frequencies, we are facing even more the difficulty of how to perform reliable RF measurements on such devices. This includes issues such as the impedance mismatch problem or the challenge of probing at nanoscale dimensions.

Besides the complexity regarding the measurement of nano-devices, reliable on-wafer measurements at sub-millimetre frequencies are nowadays getting increasingly important. At these high frequencies one faces the problem of crosstalk phenomena and excitation of higher order modes. These relevant topics together with future thoughts on how to solve them shall be covered in the third part of this workshop.

To summarize the workshop and get a broad feedback on potential future topics we will initiate a round table discussion at the end. At this point everybody will have the opportunity to interact with the speakers more closely than in the short discussions after each talk.

List of speakers and planed time schedule:

Time	Speaker	Title of the talk
8:00 – 8:10	**Welcome Workshop attendees**	
8:10 – 8:50	Uwe Arz	PlanarCal - A European project on planar S-parameter measurements
8:50 – 9:30	Dylan Williams	Traceability for large-signal on-wafer measurements
9:30 – 10:00	**Coffee Break**	
10:00 – 10:40	Johannes Hoffmann	On-Wafer Measurements with VNA Tools II
10:40 – 11:20	Masahiro Horibe	Precision and Reproducible On-Wafer Measurement at Millimeter-wave and THz frequency
11:20 – 12:00	Andrej Rumiantsev	Wafer-level calibration, measurement and measurement uncertainties at the mm-wave frequency range
12:00 – 13:30	**Lunch**	
13:30 – 14:10	Mitch Wallis	On-wafer characterization of nano-electronic devices and nanomaterials
14:10 – 14:40	Kamel Haddadi	1-110 GHz near-field scanning microwave microscope combined with a scanning electron microscope
14:40 - 15:10	Matthias Ohlrogge	Benefits and obstacles of planar on-wafer measurements at submillimeter frequencies
15:10 – 15:40	**Coffee Break**	
15:40 – 16:10	Marco Spirito	Design, characterization and evaluation of TRL calibration kits integrated using silicon based technologies
16:10 – 16:40	Gerald Gold	Modeling Conductor Surface Roughness
16:40 – 17:00	**Summary and round table discussion of the workshop**	

Talk 1:

Speaker:

Uwe Arz (S'97-M'02-SM'09) received the Dipl.-Ing. degree in electrical engineering in 1994 and the Ph.D. degree (summa cum laude) in 2001, both from the University of Hannover, Hannover, Germany. In 2001 he served as a postdoctoral research associate at the National Institute of Standards and Technology in Boulder, Colorado. In 2002 he then joined the Physikalisch-Technische Bundesanstalt (PTB) in Braunschweig, Germany, where he develops metrology for on-wafer measurements. He is currently head of the Working Group Fundamentals of Scattering Parameter Measurements at PTB and leads the European EMPIR project PlanarCal as coordinator.

Title:

“PlanarCal - A European project on planar S-parameter measurements”

Abstract:

This talk will present an overview of the European project PlanarCal, which is funded from the European Metrology Programme for Innovation and Research (EMPIR). The overall aim of the project is to enable the traceable measurement and electrical characterisation of integrated planar circuits and components from radio-frequency (RF) to sub-mm frequencies. This will allow industry to characterise components and devices for eventual use in high-speed and microwave applications (e.g. wireless communications, automotive radar and medical sensing) with known measurement uncertainties.

Talk 2:

Speaker:

Dylan F. Williams received a Ph.D. in Electrical Engineering from the University of California, Berkeley in 1986. He joined the Electromagnetic Fields Division of the National Institute of Standards and Technology in 1989 where he develops electrical waveform and microwave metrology. He has published over 100 technical papers, is a Fellow of the IEEE, is the recipient of the 2013 IEEE Joseph F. Keithley Award, and served as Editor of the IEEE Transactions on Microwave Theory and Techniques. He is currently President Elect of the IEEE Microwave Theory and Techniques Society.

Title:

“Traceability for large-signal on-wafer measurements”

Abstract:

The National Institute of Standards and Technology has put together a traceability path for large-signal on-wafer measurements that starts with on-wafer measurements and extends all the way through circuit design and simulation. We will discuss this entire traceability path. We will begin with the fundamental linear part of the calibration, which focuses on on-wafer impedance and scattering-parameter measurements. Then we will turn to the amplitude and phase aspects of the calibrations. We will discuss how these uncertainties can be propagated through the device modeling process, and how we can add process variations to the results. Finally, we will discuss the creation of models that capture not only the impact of measurement uncertainty and process variation in the model development process, but touch on how these can be seamlessly implemented in ADS and other circuit simulation tools.

Talk 3:

Speaker:

Johannes Hoffmann received the Dipl. Ing. degree in electrical engineering from the University of Stuttgart, Stuttgart, Germany, in 2005, the Ing. degree from the Ecole Nationale Superieure des Telecommunications (ENST), Paris, France, in 2005, in the course of a double diploma program. In 2009 he received the Ph.D. degree from ETH Zurich, Zurich, Switzerland. He is currently with the Laboratory for RF & MW of the Federal Institute of Metrology METAS, Switzerland. His research interests are in general measurements which involve microwaves, uncertainty calculation and numerical modeling.

Title:

“On-Waver Measurements with VNA Tools II”

Abstract:

Depending on the application there are a multitude of calibration algorithms (SOLT, TRL, LRL, LRM.) which are applied to on-wafer measurements. Additionally there are many uncertainty contributors (contact repeatability, drift of the VNA, cross-talk,.) which have to be considered for estimating measurement uncertainty. VNA Tools is a free software which can be used to calibrate on-wafer measurement data and which propagates the uncertainties to the final result. Starting from the experimental characterization of uncertainty sources up to the final result with error budget, all steps are shown in an exemplary on wafer calibration.

Talk 4:

Speaker:

Masahiro Horibe received the Ph.D. degree in quantum engineering from Nagoya University, Nagoya, Japan, in 2001. He was received Japan Society for the Promotion Science Postdoctoral Fellowship during 1999-2001. In 2001, he joined Fujitsu Limited, Kanagawa, Japan. During 2001-2003, he worked in Superconductivity Research Laboratory, International Superconductivity Technology Center, Tokyo, Japan. In 2003, he worked carbon-nanotube applications in Fujitsu Laboratories Ltd.. Currently, he is a group leader of Electromagnetic Measurement Group, Research Institute of Physical Measurements, National Metrology Institute of Japan, National Institute of Advanced Industrial Science and Technology, Tsukuba, Japan. He works on the research and development of the national metrology standards of scattering parameters and material characterization in the RF, microwave, millimeter-wave, and terahertz frequency ranges. His interests are material characterization for nano-electronics materials, flexible electronics application, characterization for power electronics devices, i.e. SiC and GaN.

Dr. Horibe is a Japan national committee chair of the IEC TC46 and SC46F, co-chair of IEC TC 113 WG3 Japanese committee, members of the IEEE, ARFTG, IEEE MTT-11 technical committee, the URSI Commission A, the IEEE P287, 1765, 1770 and 1785 standard working groups. He is also the ISO/IEC17025 Assessor for the International Accreditation Japan.

Title:

“Precision and Reproducible On-Wafer Measurement at Millimeter-wave and THz frequency”

Abstract:

On-wafer probing technology have widely been demanded at millimeter-wave and Terahertz frequencies. However in order to make precision and reproducible measurements, all other aspects of the measurement techniques must be considered. This talk will present the probe contact algorism and wafer-level calibration aspects in order to precision and reproducible wafer-level VNA measurements that can be achieved.

Talk 5:

Speaker:

Andrej Rumiantsev was born in Minsk, Belarus in 1972. He received the Diploma-Engineer degree (with highest honors) in Telecommunication systems from the Belarusian State University of Informatics and Radio Electronics (BSUIR), Minsk, Belarus, and the Dr.-Ing. Degree (with summa cum laude) in Electrical Engineering from Brandenburg University of Technology (BTU) Cottbus, Germany, in 1994 and 2014, respectively.

From 1997 to 2001, he served as a research and teaching assistant in the Department of Telecommunication Systems at the BSUIR. From 2001 to 2013, he held various engineering and engineering management positions at SUSS MicroTec Test Systems (from January 2010 Cascade Microtech). He significantly contributed to the development of the SUSS' RF wafer probe, the |Z| Probe, wafer-level calibration standards, calibration software and probe systems. At Cascade Microtech, he held the position of Product Marketing Manager of Device Characterization for Modeling and Process Development. In March 2013, he joined Ulrich L. Rohde Chair for RF and Microwave Techniques at Brandenburg University of Technologies (BTU), Cottbus, Germany. Dr. Rumiantsev is currently with MPI Corporation, holding a position of Director of RF Technologies of the Advanced Semiconductor Test Division. His research interests include RF calibration and wafer-level measurement techniques for advanced semiconductor devices.

Dr. Rumiantsev is a member of the IEEE MTT-11 Microwave Measurements Committee and the ExCom member of Automatic RF Techniques Group (ARFTG). He is the past Chair of the Modeling and Simulation Sub-Committee and the ExCom member of IEEE Bipolar/BiCMOS Circuits and Technology Meeting (BCTM). He holds several patents in the area of wafer-level RF calibration and measurements techniques. Dr. Rumiantsev received the ARFTG-71th Best Interactive Forum Paper Award. His doctoral thesis was awarded as "Best Dissertation of 2014 at Brandenburg University of Technologies".

Title:

"Wafer-level calibration, measurement and measurement uncertainties at the mm-wave frequency range"

Abstract:

Wafer-level S-parameter measurement at mm-wave and sub-mm wave frequencies plays a crucial role in the model development and IC design verification and debug of advanced semiconductor technologies. Accurate calibration of the entire wafer-level measurement system to the RF probe tip end or to the intrinsic device terminals is a critical success factor for extracting trustable device model parameters and characterizing true performance of a MMIC.

This presentation will start with the basics of S-parameter measurement and calibration techniques at the wafer-level. Special attention will be paid to how to choose the right calibration method for specific measurement application needs. Definition of the calibration reference plane and the measurement reference impedance of a calibrated system will be reviewed as well. Finally, the potential sources of calibration residual errors will be analyzed. Practical examples will be given on how to minimize the impact of such errors on the measurement accuracy of a calibrated probe system.

Talk 6:

Speaker:

T. Mitch Wallis received his B.S. degree in physics from the Georgia Institute of Technology in 1996 and his M.S. and Ph. D. degrees in physics from Cornell University in 2000 and 2003, respectively. Since 2003, he has been at the National Institute of Standards and Technology in Boulder, CO. He was a National Research Council postdoctoral fellow at NIST and is now a staff physicist. His research interests include nanoscale imaging, high-frequency scanning probe microscopy and other metrology for radio frequency nanoscale electronics. He is the current chair of the MTT technical committee on RF Nanotechnology. He is co-author of a forthcoming book on Measurement Techniques for Radio Frequency Nanoelectronics.

Title:

“On-wafer characterization of nano-electronic devices and nanomaterials”

Abstract:

The ongoing miniaturization of electronic devices has led to the discovery of new nanomaterials and new phenomena at the nanoscale. In turn, this has led to the design, fabrication, and development of RF nanoelectronic devices that incorporate nanoscale elements or nanomaterials, such as carbon nanotubes, semiconducting nanowires, or graphene. Reliable, accurate, on-wafer measurements of such devices are critical to their optimization and commercialization. To this end, a full framework, including measurement, modeling, and validation, has been developed for on-wafer characterization of RF nanoelectronics. The calibration approach is based on the on-wafer, multiline thru-reflect-line technique. Further, this framework addresses the inherent impedance mismatch between RF nanoelectronic devices and commercial test equipment. Finally, circuit and finite-element models are used to extract circuit and material parameters for the devices.

Talk 7:

Speaker:

K. Haddadi received the MSc degree and the Ph.D. degree from the University of Lille 1, France, in 2003 and 2007, respectively. He is currently an Associate Professor at the University of Lille 1 and the Institute of electronics, de Microelectronics and Nanotechnology (IEMN), Villeneuve d'Ascq, France. His research interests are in the areas of microwave and millimeter-wave instrumentation, characterization and modeling of devices and materials, design of multi-port RF systems for metrology and communications and high-frequency characterization of nanometer devices.

Title:

"1-110 GHz near-field scanning microwave microscope combined with a scanning electron microscope"

Abstract:

Nanotechnology emerges from the physical, chemical, biological and engineering sciences, where novel tools and techniques are developed to probe and manipulate single atoms and molecules. In particular, the introduction of near-field scanning microwave microscopy tools have pioneered many applications, notably including mapping and quantitative measurement of complex impedances of nano-devices and electromagnetic properties of materials. In this frame, a unique scanning

1-110 GHz scanning microwave microscope built inside a scanning electron microscope is developed. The system can produces simultaneously complex impedance, atomic force microscopy and scanning electron microscopy images providing novel and unique equipment featuring unprecedented capabilities for tackling the frontiers between spatial resolution and frequency domain.

Talk 8:

Speaker:

Matthias Ohlrogge was born in 1986. He received the Master of Science in microsystems engineering as well as the Ph.D. degree from the Albert Ludwigs University of Freiburg, Freiburg, Germany, in 2012 and 2016 respectively. In December 2012, he joined the Device Modeling Group, at the Fraunhofer institute for applied solid state physics in Freiburg. His current research interests are the development and characterization of millimeter and sub-millimeter-wave GaAs devices and calibration techniques.

Title:

“Benefits and obstacles of planar on-wafer measurements at submillimeter frequencies”

Abstract:

In the last few years electronic devices increased their corner frequencies tremendously, on the one hand due to material optimizations and on the other hand due to the ongoing miniaturization in device size. Especially the miniaturization of device size resulting in an increase of the corner frequencies leads to parasitic effects like fringing or coupling that have an influence on the device behavior even at lower frequencies and therefore have to be well described in the modelling process. In this talk we will show, that specifically the stability prediction of devices models, even at low frequencies, can be much improved, when we consider the above stated high frequency effects.

Nevertheless the precise characterization of these effects needs reliable on-wafer measurements at sub-millimeter frequencies, which is of course not straight forward achievable with a classical design of the on-wafer access- and test structures. Therefore this talk will additionally look at obstacles that occur during the planar on-wafer measurement for the device characterization at sub-millimeter frequencies. At the end we will present some interesting new approaches that are going to improve the main problems of device characterization at sub-millimeter frequencies.

Talk 9:

Speaker:

Marco Spirito (S'01-M'08) received the M.Sc. degree (cum laude) in electrical engineering from the University of Naples "Federico II," Naples, Italy, in 2000, and the Ph.D. degree from the Delft University of Technology, Delft, The Netherlands, in 2006. In April 2008 he joined the Electronics Research Laboratory at the Delft University of Technology where he is an Associate Professor since April 2013. In 2010 he was one of the co-founders of Anteverta-MW, a company specialized in measurement instrumentations, which was sold in 2015 to Maury Microwaves.

His research interests include the development of advanced passive components and building blocks operating in the millimeter and sub-millimeter frequency ranges and the development of characterization setups and calibration techniques for millimeter and sub-millimeter waves.

Dr. Spirito was the recipient of the Best Student Paper Award for his contribution to the 2002 IEEE Bipolar/BiCMOS Circuits and Technology Meeting (BCTM) he received the IEEE MTT Society Microwave Prize in 2008, was a co-recipient of the best student paper award at IEEE RFIC 2011, and the GAAS Association Student Fellowship in 2012.

Title:

"Design, characterization and evaluation of TRL calibration kits integrated using silicon based technologies"

Abstract:

With the continuous up-scaling of the maximum operation frequency of commercially available integration technologies, mm-wave circuits are entering real-life applications, such as automotive radar and high data rate wireless and wired links.

In order to foster these device improvements and increase the penetration of mm-wave applications in the commercial world, the availability of accurate measurement techniques, for low-cost, large-volume technology platforms, is becoming a key requirement.

However, the need to design accurate calibration kits in the same medium as that of the DUT, due to the error arising from calibration transfer at mm-waves, is colliding with complexities and stringent design rules encountered when integrating components is silicon technologies.

In this presentation, an overview of all currently employed techniques for defining the parameters required by TRL calibrations are presented, highlighting advantages and drawbacks of the available approaches. Design guides to implement high precision TRL kits up to the sub-mm-wave range are given. The main drawbacks in terms of propagation of un-wanted modes and improper coupling through the probe to pad transition are also analyzed. Finally, the evaluation of the quality achieved by calibration kits integrated on commercially available silicon technology is presented.

Talk 10:

Speaker:

Gerald Gold graduated in Mechatronics at the Friedrich-Alexander University Erlangen-Nürnberg (FAU), Germany, in 2009 and received his Dr. Eng. degree from the Institute of Microwaves and Photonics at FAU, in 2016 and is there currently a member of the research staff.

His main research interests are material characterization, loss mechanisms at microwave frequencies and automated RF-measurements.

Title:

“Modeling Conductor Surface Roughness”

Abstract:

This talk covers essential aspects of modeling surface roughness for microwave applications based on underlying physics. At first, surface roughness metrology and commonly used roughness parameters are described. Existing models and their limitations are discussed before the recently proposed Gradient Model is introduced. To this purpose, the modeling approach, the derivation from Maxwell‘s equations, model predictions and their experimental verification are shown.

Then a corresponding surface impedance concept is derived, which allows for easy application of the Gradient Model with 3D field solvers or analytical models. Therewith obtained simulation results illustrate roughness impact on loss and phase delay in typical transmission lines.

Comparison to measurement results up to 100GHz show, that the Gradient Model accurately predicts these quantities for rough conductor surfaces. Furthermore the impact from imperfect surfaces on planar CPW calibration standards is shown.