2017 Microwave Week Workshop Proposal Form

Joint IMS and ARFTG Workshop Proposal

Section 1

Proposed Workshop Title: "Novel 5G Applications of Nonlinear Vector Network Analyzer for Broadband Modulation and Millimeter Wave Characterization."

Half-day or full-day workshop: Full-day

Workshop Organizer(s):

1. Name (corresponding organizer): Patrick Roblin
   Affiliation: The Ohio State University
   MTT-S Affiliation: Joint IMS/ARFTG workshop committee
   email: roblin.1@osu.edu
2. Name: J. Apolinar Reynoso-Hernandez
   Affiliation: CICESE
   MTT-S Affiliation: MTT-1 Committee Member and Past Chair; IMS TPRC
   email: apolinar@cicese.mx

Conference the Workshop is Associated with (choose at least one):

IMS X **RFIC** **ARFTG** X

Section 2

WORKSHOP ABSTRACT (provide a succinct description in ~ 300 words)

The world's thirst for communication keeps on increasing as users are attracted to new broadband services for accessing data on the cloud, video-conferencing, and streaming videos using various user equipment's. This growing demand for higher data rates (>=6 Gpbs) is motivating vigorous research activities world-wide on the development of wideband and multiband systems above and below 6 GHz. The fifth generation (5G) of wireless standards (Rel-14 due in 2017) are being developed for cellular communication by 3GPP to directly address these issues.

This workshop will focus on new 5G applications of nonlinear vector network analyzers (NVNAs) including:

(1) Vector signal analysis for measuring with a high dynamic range, modulated signals with very large bandwidth (multiple GHz).

(2) The characterization of millimeter transistors which includes the impact of large-signal cyclo-stationary memory effects in CW mm-wave small-signal response.

(3) Newly supportive phase references and phase-calibration techniques for NVNAs permitting the full characterization of RF PAs under various wideband and multiband excitations.

With the development of these novel measurement techniques, new challenges in behavioral & circuit modeling of devices for broadband modulated multi-harmonic excitations must also be addressed. This includes characterizing and modeling the mutual coupling between the elements of the massive MIMO active antenna array and the associated dynamic load modulation it induces.

Also the mixed-signal instrumentation and measurement approaches needed to characterize software defined radio and digital radio front ends for the new 5G communication paradigm will be presented together with the application of D-parameters to mixed-signal integrated solutions for 5G.

This workshop will bring together some of the leading world experts in the field to present both these novel measurement techniques and associated emerging behavioral modeling techniques.

Speakers/Contributors:

- Jean Pierre Teyssier, Keysight Technologies, USA
- Dominique Schreurs and Gustavo Avolio, K.U. Louvain, Belgium
  Antonio Raffo, University of Ferrara, Italy
- Jon Martens, Anritsu, USA
- Yichi Zhang, National Institute of Metrology, China
- Patrick Roblin, The Ohio State University, USA
  Meenakshi Rawat, IIT, Roorkee, India
- Jan Verspecht, Keysight Technologies, USA
- Edouard Ngoya, XLIM, France
- Jose Carlos Pedro, Univ. of Aveiro, Portugal
- Nuno Borges Carvalho, Univ. of Aveiro, Portugal

Is this proposal endorsed by an IMS Technical Committee? Yes

If yes, provide the Committee Number(s): MTT-1, MTT-11 (In Review)

MTT-1 Computer-Aided Design Technical Committee (Pending)

Chair: Prof. Peter Aaen (p.aaen@surrey.ac.uk)

MTT11 Microwave and Millimeter-Wave Solid State Devices Technical Committee

Chair: Dr. Jon Martens (Jon.Martens@anritsu.com)

WORKSHOP JUSTIFICATION (Briefly describe the importance of this topic and its relevance to the MTT community**)**

New measurement applications of NVNAs have emerged, extending their use to the ultra-wide-bandwidth and/or millimeter wave for 5G applications.

VNAs with spectrum analyzer capabilities have recently become available. Ultra-fast NVNAs with a vector-signal-analyzer (VSA) feature which acquires with multi-GHz bandwidth signals with high dynamic-ranges are now within reach.

NVNA calibration also remains a critical topic for wideband (multi-GHz) receivers. New approaches based on signal-synthesis are becoming available from equipment providers. In addition novel phase-reference and phase-calibration techniques for NVNA measurements have been demonstrated by various metrology groups to facilitate the characterization of RF PAs under various wideband excitations.

For 5G nonlinear devices there is currently no NVNA capable of acquiring harmonics above 67 GHz. Yet millimeter wave devices are strongly affected by large-signal memory effects. By simultaneously performing small-signal mm-wave measurements and large-signal RF measurements of the large-signal operating point (LSOP), one can fully account for the impact of the large-signal cyclo-stationary memory effects upon the CW mm-wave small-signal response of 5G devices.

Measurements experts working on 5G will benefit from being introduced to these new measurement techniques. Also new behavioral modeling techniques are also emerging to address the memory effects observed in device when excited by the broadband modulated signals anticipated for 5G. Several talks addressing these challenges using different approaches are scheduled. These talks will be preceded by a review of the state-of-the-art in behavioral modeling and linearization for broadband and multi-band DPD.

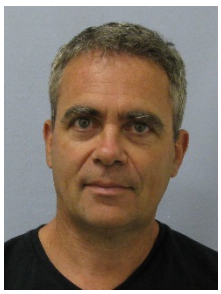
Figuring among the impairments impacting 5G systems is the mutual coupling between the elements of the massive MIMO active antenna array. One talk will discuss the characterization and modeling of the associated load-pulling effect.

Modeling nonlinearities in 5G is not limited to analog blocks. The final talk will introduce system designers to the D-parameters recently proposed to characterize non-linear mixed-signal components (ADC, DAC) in 5G wireless systems.

Section 3: LIST OF SPEAKERS

1. Speaker's Name: Jean Pierre Teyssier	**Confirmed:** YES
Affiliation: Keysight Technologies	
Presentation Title: NVNA for Accurate DUT Measurements with Wideband Repetitive Modulated Signals	
Email: jean-pierre_teyssier@keysight.com	

Brief Bio:



Jean-Pierre Teyssier was born in Brive, France, in 1963. He received the Master and Ph.D. degrees from Limoges University, France, in 1990 and 1994, respectively. From 1995 to 2012, he has been a Researcher and Professor with the XLIM Laboratory at University of Limoges, and he has been co-founder of the VTD (Verspecht Teyssier DeGroote) startup company in 2007. He is now a research engineer with Keysight Technologies. His main research interests include RF nonlinear measurements, designs of time-domain and pulsed network measurement systems, embedded software for bench equipment, bench control, and modeling software. He is currently the main engineer for the multi-port Spectrum Analyzer feature of the Keysight Technologies PNA-X network analyzer.
Since 2001, Jean-Pierre Teyssier is a regular contributor for ARFTG and IMS papers, and since 2007, he is a member of ARFTG ExCom and co-chair of the NVNA user's forum.

Lecture Summary:

Taking together the NonLinear Vector Network Analyzer and the Spectrum Analyzer capabilities of a modern network analyzer makes available very accurate vector (IQ) measurements of wideband modulated test signals. As the active DUT (can be power amplifier or frequency converter devices) input and output waves are measured coherently within a calibrated network environment, new insights exhibiting the DUT stimulus/response under modulated signals are demonstrated.

2. Speaker's Name: Prof. Dominique Schreurs, Dr. Gustavo Avolio, Prof. Antonio Raffo	**Confirmed:** YES
Affiliation: K.U. Leuven, Belgium	
Presentation Title: Dynamic-bias Measurements for Microwave and mm-Wave Transistor Characterization: A Step Further	
Email: dominique.schreurs@kuleuven.be	

Brief Bio:

Dominique Schreurs (S'90–M'97–SM'02-Fellow) received the M.Sc. degree in electronic engineering and Ph.D. degree from the University of Leuven (KU Leuven), Belgium. She is now a Full Professor with KU Leuven. She has been a Visiting Scientist with Agilent Technologies, ETH Zürich, and the National Institute of Standards and Technology (NIST). Her main research interests concern the (non)linear characterization and modeling of active microwave devices, and (non)linear circuit design for telecommunications and biomedical applications. Prof. Schreurs is serving on the AdCom of the MTT Society. She is an IEEE Fellow, past MTT-S Distinguished Microwave Lecturer and presently also editor of IEEE Trans. Microwave Theory and Techniques. She serves as Vice-President on the Executive Committee of the ARFTG organization, and was general chair of the 2007 and 2012 Spring ARFTG Conference. Prof. Schreurs was co-chair of the European Microwave Conference (EuMC) in 2008.

Gustavo Avolio was born in Cosenza, Italy, in 1982. He received the MSc. in electronic engineering from the University of Calabria, Italy, in 2006. In 2012 he obtained the Ph.D. in electronic engineering from KU Leuven, Belgium. He is currently a post-doctoral researcher supported by FWO Vlaanderen, Belgium. In 2013 and 2014 he has been a visiting scientist at the National Institute of Standards and Technology (NIST) in Boulder, USA. Since 2009 he has often been a visiting scientist at the University of Ferrara, Italy. His research work focuses on large-signal measurements and nonlinear modeling of advanced microwave devices.

Lecture Summary:

The talk focuses on the recently introduced dynamic-bias measurement technique for transistor characterization at microwave and mm-wave frequencies. We will discuss various measurement set-ups to perform dynamic-bias measurements and show how to use these measurements in the modeling phase. Furthermore we will introduce dynamic-bias S-parameters, which can be directly derived from dynamic-bias measurements and represent a natural extension of classical multi-bias S-parameters. In particular, we will show how these parameters allows one to obtain a more effective characterization of low- and high-frequency dispersive effects.

3. Speaker's Name: Jon Martens	**Confirmed:** YES
Affiliation: Anritsu Company	
Presentation Title: Millimeter-Wave Multi-GHz-IF Receivers: Linearity and Correction Considerations	
Email: Jon.Martens@anritsu.com	

Brief Bio:

J. Martens has been with Anritsu since 1995 working on measurement systems architectures, algorithm development and mm-wave circuit design. He is currently the president of the measurements group ARFTG and a former associate editor for the Transactions on Microwave Theory and Techniques.

Lecture Summary:

Receiver performance can sometimes be a limiting issue in mm-wave, wide modulation bandwidth systems. The higher and wider IF frequencies can present some unique linearity and correction challenges particularly in variable gain and A/D conversion areas. This talk will explore some of the more subtle linearity and distortion issues at multi-GHz IFs, how they can be characterized, and sometimes mitigated or corrected.

4. Speaker's Name: Dr. Yichi Zhang	**Confirmed:** YES

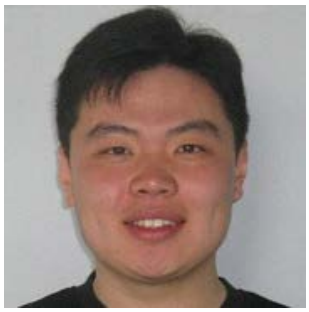
Affiliation: National Institute of Metrology, Beijing,China

Presentation Title:

Dense-spectral-grid Multi-band NVNA Measurement for Characterizing RF PA Inter-modulation and Harmonic Nonlinearities.

Email: zhangyichi@nim.ac.cn

Brief Bio:



Yichi ZHANG received the Ph.D. degree in the Harbin Institute of Technology, Harbin, China, in 2013. He is currently with the RF Parameter Laboratory, Division of Electronics and Information Technology, National Institute of Metrology, Beijing, China. His current research interests include the RF phase measurement, complex modulated signal characterization, calibration techniques and uncertainty analysis of the NVNA, and the measurement-based nonlinear behavioral modeling.

Lecture Summary:

The content might be described as "Under large-signal modulated excitations, RF PAs show significant inter-modulation and harmonic nonlinearities at the same time. In order to characterize the actual PA behavior in real life, the multi-harmonic modulated PA input/output waves have to be entirely and correctly measured. In the presentation, newly proposed phase reference and phase calibration techniques are introduced and discussed, based on which the NVNA test-bed could be developed for the full characterization of RF PAs under various wideband excitations. Moreover, other potential techniques and non-mature ideas under development are shared for discussion.

5. Speaker's Name: Prof. Patrick Roblin and Prof. Meenakshi Rawat	**Confirmed:** YES

Affiliation: The Ohio State University, USA

Presentation Title:

Review of Broadband Behavioral Modeling and Linearization Techniques for 5G

Email: roblin.1@osu.edu

Brief Bio:

Patrick Roblin was born in Paris, France, in September 1958. He received the *Maîtrise en Physique* degree from the Louis Pasteur University, Strasbourg, France, in 1980, and the D.Sc. degree in electrical engineering from Washington University, St. Louis, MO, in 1984. In 1984, he joined the Department of Electrical and Computer Engineering at The Ohio State University (OSU), Columbus, OH where he is currently a Professor.

His present research interests include the measurement, modeling, design and linearization of non-linear RF devices and circuits such as power-amplifiers, oscillators and modulators. He authored and co-authored two textbooks published by Cambridge University Press. He is the founder of the Non-Linear RF research lab at OSU and has developed at OSU two educational RF/microwave laboratories and associated curriculum for training both undergraduate and graduate students. He is currently serving as a *distinguished microwave lecture*r for IEEE MTT.

Meenakshi Rawat (M'09) received the B.Tech. degree in electrical engineering from the Govind Ballabh Pant University of Agriculture and Technology, Uttarakhand, India, in 2006, and the M.Sc. and Ph.D. degrees in electrical and computer engineering from the University of Calgary, Calgary, AB, Canada, in 2012. From September 2012 to June 2013, she was a PostDoctoral Research Fellow with the University of Calgary. From July 2013 to June 2014, she was a Post-Doctoral Project Researcher/Scientist with the Ohio State University. She is currently an Assistant Professor with the Indian Institute of Technology (IIT), Roorkee, Uttarakhand, India. Dr. Rawat was workshop co-chair for ARFTG-82 and session co-chair for MMwave and THz Designs for iMARC 2014, Bangalore, India. She was part of the Calgary group that won Overall Championship and Best Design Prize of the 3rd Annual Smart Radio Challenge, Wireless Innovation Forum. She was also the three-time recipient of the Research Production Award of the University of Calgary and Best Poster Award of the 82nd and 83rd Automatic RF Techniques Group (ARFTG) Conference in 2013 and 2014.

Lecture Summary:

The behavioral models used for the representation of CW and modulated multi-harmonic data will be reviewed in this lecture. This will include the general *multi-harmonic Volterra functions* for CW periodic nonlinear RF excitations, the X-parameter/S-function *approximations* for mildly nonlinear RF excitations and their extension for broadband modulated multi-harmonic signals.

Next this lecture will consider the characterization and mitigation of the impairments associated with the PA nonlinearities in SDR systems when the same power amplifier is used for the amplification of concurrent multiple-band signals (carrier aggregation). Both predistortion and feedforward approaches for modulated harmonic cancelation will also be presented.

Finally this review will conclude with a discussion on nonlinear impairments in MIMO systems and advanced configurations for self-testing and adaptation which might be called up on for their mitigation.

6. Speaker's Name: Dr. Jan Verspecht	**Confirmed:** YES

Affiliation: Keysight Technologies, Inc., USA

Presentation Title:

Robust Digital Predistortion Method Based on Dynamic X-parameters

Email: jan_verspecht@keysight.com

Brief Bio:

Jan Verspecht received the electrical engineering and Ph.D. degrees from the Vrije Universiteit Brussel (VUB), Brussels, Belgium, in 1990 and 1995, respectively.

From 1990 until 1999 he was a Research Engineer with the Hewlett-Packard Company. From 1999 until 2002 he became a Technical Leader with Agilent Technologies. In 2003 he founded the consulting company Jan Verspecht b.v.b.a.. In 2008 he co-founded the company Verspecht-Teyssier-DeGroote s.a.s. (VTD), where he was responsible for business development. In 2012 VTD was acquired by Agilent Technologies, now Keysight Technologies, where he now holds the position of Master Research Engineer.

He is a pioneer of and key contributor to the development of Nonlinear Vector Network Analyzer (NVNA) technology. In 1996 he invented X-parameters. He holds 11 patents and he has authored and co-authored the book entitled "X-parameters", over 40 conference papers and 12 refereed journal papers. His research interests include the large-signal characterization and behavioral modeling of RF and microwave components.

Dr. Verspecht is the recipient of the 2002 ARFTG Technology Award and the 2009 Best IMS Oral Presentation Award. In 2007 Dr. Verspecht was elevated to the grade of IEEE Fellow by the IEEE Board of Directors.

Lecture Summary:

We present a digital pre-distortion (DPD) method based on dynamic X-parameters. We first explain how long term memory effects can be modelled by dynamic X-parameters. Next we show how a dynamic X-parameter model can be inverted in order to generate a robust DPD method. The resulting DPD is more robust than existing DPD techniques as it works well for a wide range of modulation bandwidths and signal amplitude distributions.

7. Speaker's Name: Prof. Edouard Ngoya, D. Gapillout, S. Mons, C. Mazière, K. El-Akhdar	**Confirmed:** YES

Affiliation: XLIM, University of Limoges, France

Presentation Title:

Challenges for Nonlinear Memory Characterization and Modeling in Broadband PA Applications

Email: edouard.ngoya@xlim.fr

Brief Bio:

Edouard Ngoya received a PhD degree in Electronics from the University of Limoges in 1988. He worked as R&D engineer with CAROLINE and RACAL-REDAC in 1988 and 1989. In 1990 he joined the French Centre National de la Recherche Scientifique (CNRS) as a senior researcher at XLIM-University of Limoges. He has initiated key circuit simulation and modeling techniques like the so-called envelope-transient analysis, and contributed to the development of several EDA tools for nonlinear RF and microwave circuits. He co-founded Xpedion Design Systems in 1997 and is author of the GoldenGate™ RFIC simulation tool by Keysight Technologies. He is currently consultant with Cadence Design Systems on RF simulation technology. Dr. Ngoya has supervised two dozens of PhD and post-doctoral works, and authored/co-authored more than 100 articles and conference papers on the subject of circuit simulation and modeling. His current domains of interest include full-chip RFIC simulation techniques, analog system bloc-level modeling, PA linearization techniques and RF system simulation.

Lecture Summary:

The continuous growth of data rate requirements in modern wireless communications leads to more-and-more complex and wideband modulation signals that need to be processed by the transmit power amplifier with high fidelity at the lowest power consumption. These are making design, characterization and modeling of the power amplifier very challenging due to the combination of wide variability of the signal time statistics, high dynamic range and very large bandwidth. The presentation will summarize some recent advances on the behavioral modeling methodologies of the nonlinear memory of power amplifiers.

8. Speaker's Name: José C. Pedro, Filipe E. Barradas and Telmo R. Cunha	**Confirmed:** YES

Affiliation: Universidade de Aveiro, Portugal

Presentation Title:

NVNA Measurements for 5G Active Antenna Array Behavioral Modeling

Email: jcpedro@ua.pt

Brief Bio:

José C. Pedro received the diploma (1985), doctoral (1993) and habilitation (2002) degrees in electrical engineering, from University of Aveiro, Portugal, where he is currently a Professor. His scientific interests include active device modeling and the analysis and design of various nonlinear microwave circuits. He is the leading author of the book Intermodulation Distortion in Microwave and Wireless Circuits and has authored or co-authored more than 200 papers in international journals and symposia beyond the many presentations given in related workshops. He was an Associate Editor for the IEEE MTT Transactions and is a reviewer for the MTT-IMS and the EuMC. Prof. Pedro has served his university department as the Coordinator of the Scientific Council and as the Department Head.

Prof. Pedro is a MTT-S Distinguished Microwave Lecturer. He received the Marconi Young Scientist Award in 1993 and the 2000 Institution of Electrical Engineers (IEE) Measurement Prize. In 2007 he was elected Fellow of the IEEE for his contributions to the nonlinear distortion analysis of microwave devices and circuits and in 2015 he was received the European Microwave Prize. In 2016 he was awarded the IEEE MTT-S Distinguished Educator Award.

Lecture Summary:

Massive MIMO, MMIMO, systems for 5-G wireless networks pose new problems to nonlinear transmitter modeling and its extraction. Contrary to conventional transmitters where the output amplifier drives a fixed load, mutual coupling between the elements of the MMIMO active antenna array is seen by the interacting power amplifiers, PAs, as a form of dynamic load modulation. Therefore, the fixed load condition, which is one of the strongest underlying assumptions in the traditional low-pass equivalent transmitter behavioral models, can no longer hold, and a single-input/dual-output formulation, for the nonlinear dynamic PAs, followed by a multi-input/multi-output network, representing the linear and dynamic radiation sub-system, must be adopted.

The present talk addresses this new transmitter behavioral model formulation and the nonlinear vector network analyzer systems required to extract them. Various possible behavioral model formulations are reviewed in terms of complexity and accuracy while their corresponding measurements systems will be discussed in terms of both the required hardware measurement set-ups and modulated stimuli.

9. Speaker's Name: Nuno Borges Carvalho	**Confirmed:** YES

Affiliation: Universidade de Aveiro, Portugal

Presentation Title:

Enabling 5G digital Communications using D-Parameters

Email: nbcarvalho@ua.pt

Brief Bio:

Nuno Borges Carvalho (S'97–M'00–SM'05-F'15) was born in Luanda, Angola, in 1972. He received the Diploma and Doctoral degrees in electronics and telecommunications engineering from the University of Aveiro, Aveiro, Portugal, in 1995 and 2000, respectively.

He is currently a Full Professor and a Senior Research Scientist with the Institute of Telecommunications, University of Aveiro and an IEEE Fellow. He coauthored Intermodulation in Microwave and Wireless Circuits (Artech House, 2003), Microwave and Wireless Measurement Techniques (Cambridge University Press, 2013) and White Space Communication Technologies (Cambridge University Press, 2014). He has been a reviewer and author of over 200 papers in magazines and conferences. He is associate editor of the IEEE Transactions on Microwave Theory and Techniques, IEEE Microwave Magazine and Cambridge Wireless Power Transfer Journal.

He is the co-inventor of four patents. His main research interests include software-defined radio front-ends, wireless power transmission, nonlinear distortion analysis in microwave/wireless circuits and systems, and measurement of nonlinear phenomena. He has recently been involved in the design of dedicated radios and systems for newly emerging wireless technologies.

Dr. Borges Carvalho is the co-chair of the IEEE MTT-20 Technical Committee and the past-chair of the IEEE Portuguese Section and MTT-11, he also belong to the technical commitees, MTT-11, MTT-20 and MTT-26. He is also the chair of the URSI-Portugal Metrology Group. He was the recipient of the 1995 University of Aveiro and the Portuguese Engineering Association Prize for the best 1995 student at the University of Aveiro, the 1998 Student Paper Competition (Third Place) of the IEEE Microwave Theory and Techniques Society (IEEE MTT-S) International Microwave Symposium (IMS), and the 2000 IEE Measurement Prize.

Lecture Summary:

In this talk mixed-signal instrumentation and measurement approaches will be presented to characterize software defined radio and digital radio front ends for the new 5G communication paradigm. The talk will present the main drawbacks, the calibration procedures and the framework to apply D-parameters to mixed-signal integrated solutions for 5G.

Some practical examples will be showed including the application of this approach to digital pre-distortion approaches.