84th ARFTG Microwave Measurement Conference

ARFTG 84th WORKSHOP

The New Frontiers for Microwave Measurements

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Boulder, Colorado

St Julien Hotel

84th ARFTG
Topic: *High Efficiency Microwave Power Amplifiers*
December 5th, 2014, Boulder, Colorado
www.arftg.org

Workshop Title: "*High Efficiency Microwave Power Amplifiers: Design & Characterization*"

Workshop Organizers:

Name : Zoya Popovic and Patrick Roblin
Affiliation: University of Colorado, Colorado and The Ohio State University, Ohio
Email: roblin.1@osu.edu

Workshop Description:

As wireless communication keeps expanding with the development of spectrum efficient wide bandwidth modulation schemes, new challenges are arising for the development of power-efficiency RF power amplifiers capable of handling high peak to average power ratio. This workshop will review new advanced techniques which have recently emerged for the design, nonlinear characterization and linearization of such power efficient and broadband RF power amplifiers.

Schedule (Friday, December 5th, 2014):

- 13:20 – 13:25: Welcome
- 13:25 – 14:15: Zoya Popovic
- 14:15 – 15:05: Charles Campbell
- 15:05 – 15:20: Coffee break
- 15:20 – 16:10: Guillaume Bigny
- 16:10 – 17:00: Patrick Roblin

1. Speaker's Name: Zoya Popovic, Thibault Reverand, David Sardin, Mike Litchfield, Scott Schafer, Andrew Zai

Confirmed: Yes

Affiliation: Colorado University

Presentation Title:

Design and measurements of high-efficiency PAs for high PAR signals

Email: Zoya.Popovic@Colorado.EDU

Abstract:

High-efficiency power amplifiers are typically designed for peak efficiency at high input power level, while the efficiency drops at lower input power levels. The trend in communication signals, however, is to increase the peak-to-average power ratio (PAPR) in order to use the spectrum more efficiently. This implies a reduction in PA efficiency averaged over time. There are several transmitter architectures that have been implemented to solve this problem, including the Doherty architecture, currently adopted in base-station transmitters. Other architectures include supply-modulated (ET) and outphasing transmitters, which are being introduced currently in handsets. In addition, there is interest in new spectrally-confined radar waveforms with amplitude modulated pulses which also have high PAR.

In this talk, we will discuss various MMIC PA designs with 3 to 10W output power and peak PAE greater than 60% at X-band using the TriQuint 150-nm GaN on SiC process, including PAs for supply modulation, outphasing PAs and Doherty PAs. The latter two architectures exhibit load modulation, and the talk will present internal measurements of load modulation in several X-band outphasing configurations. Furthermore, a detailed discussion of supply-modulated X-band transmitters with MMIC GaN dynamic bias supplies with be presented, along with the simulation and measurement challenges for this type of transmitter.

Bio:

Professor Zoya Popović received the Dipl.Ing. degree from the University of Belgrade, Serbia, Yugoslavia, in 1985, and the Ph.D. degree from the California Institute of Technology, Pasadena, in 1990. Since 1990, she has been with the University of Colorado at Boulder, where she is currently a Distinguished Professor and holds the Hudson Moore Jr. Chair in the department of Electrical, Computer and Energy Engineering. In 2001, she was a Visiting Professor with the Technical University of Munich, Munich, Germany. Since 1991, she has graduated 40 Ph.D. students. Her research interests include high-efficiency, low-noise, and broadband microwave and millimeter-wave circuits, quasi-optical millimeter-wave techniques for imaging, smart and multibeam antenna arrays, intelligent RF front ends, and wireless powering for batteryless sensors. Prof. Popovic was the recipient of the 1993 and 2006 Microwave Prizes presented by the IEEE Microwave Theory and Techniques Society (IEEE MTT-S) for the best journal papers, and received the 1996 URSI IssacKoga Gold Medal. In 1997, Eta Kappa Nu students chose her as a Professor of the Year. She was the recipient of a 2000 Humboldt Research Award for Senior U.S. Scientists from the German Alexander von Humboldt Stiftung. She was elected a Foreign Member of the Serbian Academy of Sciences and Arts in 2006. She was also the recipient of the 2001 Hewlett-Packard(HP)/American Society for Engineering Education(ASEE) Terman Medal for combined teaching and research excellence.

1. **Speaker's Name:** Charles Campbell	**Confirmed:** Yes

Affiliation: TriQuint Semiconductor, Dallas, Fort Worth Area

Presentation Title:

MMIC Power Amplifier Design, What Mom Didn't Tell you.

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Abstract:

Power amplifier design is a subject that has been covered extensively in published literature. Ironically, it may be one the least covered topics when it comes to actual power amplifier design and implementation. There are a number of aspects and details that are inadequately covered, glossed over or simply (and probably intentionally) ignored by existing references. Many of these points can render a design inoperable if not properly considered in the modeling, simulation or characterization phase of the overall amplifier development process. Modern monolithic implementations, i.e. MMICs, presents opportunities to greatly reduce size and cost while improving power amplifier performance. MMICs however are also replete with potential issues and hazards that can trip-up even the most experienced designers. In this workshop chapter select MMIC design, test and modeling issues along with potential solutions will be described and discussed.

Bio:

Charles F. Campbell received B.S.E.E., M.S.E.E. and Ph.D. degrees from Iowa State University in 1988, 1991 and 1993 respectively. From 1993 to 1998 he was with Texas Instruments, Dallas, TX where he was involved with microwave module design and MMIC development. Since 1998 he has been with various divisions of TriQuint Semiconductor where he has held positions of Design Team leader, Design Engineering Director and most recently, Engineering Senior Fellow. A Fellow of the IEEE, has served on the Editorial Board for IEEE Transactions on Microwave Theory and Techniques, Technical Program Committee for the Compound Semiconductor Integrated Circuits Symposium, and the IEEE Microwave Prize selection committee. He has authored or co-authored 45 journal and conference papers, and authored an on-line book chapter on MMIC power amplifier design.

1. Speaker's Name: Guillaume Bigny | **Confirmed:** Yes

Affiliation: Infineon Technologies

Presentation Title:

Design and characterization requirements of RF high power and high efficiency amplifiers: challenges and Infineon Technologies' vision

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Abstract:

With the wireless communication demand continuing to expand, the requirements on the infrastructure components such as the RF power amplifiers are increasing; the needs for complex modulations, wider bandwidth and higher frequencies with higher linearity and higher efficiency are pushing the RF boundaries and performance of the RF power amplifiers to the limits. Not only has the design of these amplifiers become more challenging but also the characterization and linearization techniques.

As the technologies improve, amplifiers gaining benefit from harmonic frequency content, such as Class- F, are getting more common and the classic characterization methods have then to evolve. Although the classic, passive load-pull approach keeps improving, the active harmonic load-pull solutions bring a lot of benefits such as waveform engineering. As GaN technology becomes more popular, competing with LDMOS for higher efficiency at higher frequency, harmonic content, linearity and memory effects have emerged as the highest significant challenges and need to be considered during the design and characterization phases.

This contribution will present Infineon Technologies' vision and approach to address the challenge of high efficiency and high bandwidth at higher frequency while improving the time to market cycle time and maintaining high quality standards for a challenging cost-driven market.

Bio:

Guillaume Bigny was born in France in 1971. He received the Bachelor Degree in Telecommunications in 1995 and the Masters Degree in Microwaves and Micro-Electronics Engineering from the University of Sciences and Technologies, Lille, France, in 1997. Following graduation he designed K-band transmitters with Alcatel, France. From 2000 to 2010, he held various positions with Freescale Semiconductor in France and in the US where he focused on LDMOS RF power amplifier design such as discrete amplifiers, multi-stage RFIC for base station infrastructures applications, GaN Doherty and digital gate bias modulation systems. In 2010 he moved to TriQuint Semiconductor as Applications Manager supporting High Voltage HBT power amplifiers. Since 2012, he holds the position of Technology Development Manager with Infineon Technologies, working on LDMOS and GaN technologies for high power RF amplifiers and characterization techniques such as passive and active harmonic load-pull solutions.

1. **Speaker's Name:** Patrick Roblin	**Confirmed:** Yes

Affiliation: The Ohio State University

Presentation Title:

Designing high efficiency Doherty and Chireix power amplifiers using an *Embedding Device Model*

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Abstract:

Amplifiers based on multiple transistors/amplifiers such as the Doherty, Chireix/Outphasing are being used to realize amplifiers with high efficiency at high power backoff. These techniques rely on various form of load modulation to maintain the high efficiency over a wide range of power. The Doherty and Chireix theory is usually introduced using ideal memoryless transistor or amplifier models. Much optimization effort or load-pull search is then taking place to make these amplifying schemes work with real transistors and amplifiers (class B, C, E or F) which exhibit high-frequency memory effects due to the nonlinear transistor capacitances and the linear device and package parasitics. On the contrary with the model-based embedding PA design technique, the PA design starts with the intrinsic RF IV characteristics of the transistor. Resistive parasitics can be included if harmonic injection is not targeted. The multi-transistor PA is then first designed using the intrinsic IV for each transistor to achieve the desired Doherty (or Chireix) operation. The intrinsic voltage and current waveforms are then projected to the package planes using the nonlinear embedding device model. This projection determines in a single simulation the required waveforms at the package reference planes which sustain the desired intrinsic transistor operation. A loss-less multi-harmonic matching network can then be synthesized to reproject the multi-harmonic complex loads required at the package planes back to the ideal resistive loads required at the Doherty (or Chireix at specific input power levels) combiner. Practical design examples for both the Doherty and the Chireix amplifier (unpublished) will be presented to show how using this systematic PA design procedure the design is performed without using time-consuming optimizations or load-pull searches.

Bio:

Patrick Roblin was born in Paris, France, in September 1958. He received the *Maitrise de 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 is 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. He has developed at OSU two educational RF/microwave laboratories and associated curriculum for training both undergraduate and graduate students.