88th ARFTG Microwave Measurement Conference

ARFTG 88th WORKSHOP

PA Design Techniques for Future Wireless Systems

December 9th, 2016

Austin, Texas

88th ARFTG PA Microwave Measurement Conference
December 9th, 2016, Austin, Texas
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Workshop Title: *"PA Design Techniques for Future Wireless Systems"*

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

Workshop Description:
As wireless communication keeps expanding with the development of 5G wireless communication system, new challenges are arising for the development of power-efficiency RF power amplifiers for high-peak-to-average power-ratio, broadband, and mm-wave applications. This workshop will review new advanced techniques which have been introduced to meet these challenges.

Schedule (Friday, December 9th, 2016):

- 13:15 – 13:20: Welcome
- 13:20 – 14:00: Taylor Barton

Outphasing Power Amplifiers: Analysis, Design, and Measurement

- 14:00 – 14:40: Patrick Roblin

Optimization of Doherty and Chireix PAs over their degrees of freedom using an *Embedding Device Model*

- 14:40 – 15:20 Morten Olavsbråten

Efficiency and linearity issues in design of efficient wideband PA's based on class F/inverse F

- 15:20 – 15:35: Coffee break
- 15:35 – 16:15: Michael Roberg

Qorvo GaN MMIC Power Amplifiers for Radar, EW and Communication System Applications

- 16:15 – 16:55: Karun Rawat

Bandwidth enhancement of load modulation techniques in Power amplifiers for upcoming wireless communication

- 16:55 – 17:35: Zoya Popovic

Improving PA efficiency for high PAR signals using supply modulation

Speaker's Name: Prof. Taylor Barton	**Confirmed:** Yes

Affiliation: Colorado University, Boulder

Presentation Title:
Outphasing Power Amplifiers: Analysis, Design, and Measurement

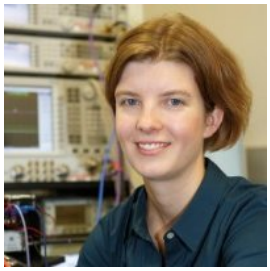
Email: taylor.w.barton@colorado.edu

Abstract:

Outphasing amplifier architectures control output power using relative phase control of efficient branch PAs, offering the potential for (narrowband) linear amplification with high efficiency over a wide range of output powers. The advantage of this approach is in the operating mode of the constituent branch PAs, which can be realized as efficient saturated or switched-mode PAs. Conventional outphasing techniques, however, have several design challenges relating to both the power combining network and treatment of the input signal. This talk will present an overview of classic outphasing techniques, including systems based on isolating and lossless power combining, and then will describe recent research including improving wide-range back-off efficiency and system complexity.

Bio:

Dr. Taylor Barton is an Assistant Professor in the Department of Electrical, Computer, and Energy Engineering at the University of Colorado Boulder. Prior to joining CU Boulder in 2016, she was an Assistant Professor at The University of Texas at Dallas for two years, and a post-doctoral associate in the Microsystems Technology Laboratories at MIT. Dr. Barton received her Sc.B., M.Eng., E.E., and Sc.D degrees from MIT's EECS department. Her research interests include efficiency-enhancement techniques in RF and microwave circuits.



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

Affiliation: The Ohio State University

Presentation Title:
Optimization of Doherty and Chireix power amplifiers over their degrees of freedom using an *Embedding Device Model*

Email: roblin.1@osu.edu

Abstract:

Amplifiers based on multiple transistors/amplifiers such as the Doherty, Chireix PAs enables to realize amplifiers with high efficiency for signals with high peak to average power ratios. These techniques rely on load modulation to obtain a high efficiency at both peak and backoff. 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/amplifiers 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. An automatic design procedure is further implemented which permits the designer to sweep the PA design degrees of freedom to select the desired optimal Doherty or Chireix operation. The intrinsic voltage and current waveforms are then projected to the package planes using the nonlinear embedding device model to determine the required load and source networks which sustains the targeted intrinsic transistors' operation. Practical design examples for both the Doherty and Chireix amplifiers will be presented to show how this procedure streamlines the co-design of the Doherty/Chireix combiners and PAs.

Bio:

Patrick Roblin 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. He is currently serving for three years as a distinguished microwave lecturer for IEEE-MTT.

Speaker's Name: Morten Olavsbraaten | **Confirmed:** Yes

Affiliation: Norwegian University of Science and Technology (NTNU), Trondheim, Norway

Presentation Title: Efficiency and linearity issues in design of efficient wideband PA's based on class F/F^{-1}

Email: morten.olavsbraten@iet.ntnu.no

Abstract:

Design of efficient wideband Power Amplifiers is a challenge. There exist several methods to get the efficiency in a broadband setting. Lately, applying properties of class J and different variations of this, is one way of achieving this. This presentation will show examples of how to make a wideband PA out of classical class F, inverse class F and an easy simple method using Load Pull (the latter do not require access to internal currents and voltages of the transistor). The issues that occurs when the bandwidths increase above 0.5 octave and 1 octave in harmonically tuned amplifiers, will be addressed. Is there a way of deciding when to use class F or inverse class F in a broadband design? The other problem in a broadband PA is linearity, when the signal bandwidths is wide. The wider the signal bandwidth, the harder it is to do i.e. digital Predistortion. Then, other techniques, like gate tracking, will give some linearity benefits. The principal of a gate tracking method will be shown.

Bio:

Morten Olavsbråten received his M.Sc. degree in electrical engineering from the Norwegian Institute of Technology (NTH) in 1993, and his Ph.D. degree in electrical engineering from the Norwegian University of Science and Technology (NTNU) in 2003. He has been employed as a fulltime Associate Professor at Department of Electronics and Telecommunications, Norwegian University of Science and Technology, NTNU, since 2003. He was the head of the Radio Systems Group at the department from 2009 to 2015. His teaching experience covers more than five different courses at graduate and undergraduate level, including circuit design, radio systems, microwave integrated circuits and nonlinear microwave components. He has supervised, on average, 2 PhD candidates and 5 Master candidates, each year. Morten Olavsbråten's research interests spans several fields of RF and Microwaves, such as Transistor modelling, Power Amplifier modelling and design, microwave measurements techniques including time domain waveform measurements. He has been manager for several research projects funded by NFR (Norwegian Research Counsil), NoE TARGET, and Cost 0803 RFCSET, at the department.

Speaker's Name: Michael Roberg	**Confirmed:** Yes

Affiliation: Qorvo

Presentation Title: Qorvo GaN MMIC Power Amplifiers for Radar, EW and Communication System Applications

Email: Michael.Roberg@qorvo.com

Abstract:

This talk will present an overview of several Qorvo GaN MMIC power amplifiers designed for radar, EW and communication system applications. Design considerations for each system application will be discussed within the context of the presented MMICs. The typical design flow for a MMIC power amplifier will be presented. Desired characteristics of non-linear models supporting MMIC PA design will be discussed, with the goal of better aligning device measurements and models with design goals.

Bio:

Dr. Michael Roberg received the B.S. degree in electrical engineering from Bucknell University, Lewisburg, PA in 2003, the M.S.E.E. degree from the University of Pennsylvania, in 2006, and the Ph.D. degree from the University of Colorado at Boulder in 2012. From 2003 to 2009, he was an engineer at Lockheed Martin-MS2 in Moorestown, NJ working on advanced phased array radar systems. He currently works for Qorvo in the Infrastructure and Defense Products business unit as a MMIC design engineer, senior member technical staff. His current research interests include microwave power amplifier theory and design, and high efficiency radar and communication system transmitters. He is also interested in high efficiency microwave power rectifiers.

Speaker's Name: Karun Rawat	**Confirmed:** Yes

Affiliation: I.I.T. Roorkee, India

Presentation Title: Bandwidth enhancement of load modulation techniques in Power amplifiers for upcoming wireless communication

Email: karunrawat@gmail.com

Abstract:

To accommodate the increasing demand of data rate in modern wireless communication, the use of spectral efficient modulation schemes and multiple accesses techniques are essential. This results in signals with high crest factor, which are handled inefficiently with conventional power amplifiers operating at average power level backed-off from saturation. Thus, the schemes such as load modulation are often used which allows power amplifiers to operate efficiently even at back-off. However, for data rate of the order of Gbps in 5G wireless communication, the typical channel bandwidth requirement may grow up to 500 MHz or beyond. Therefore, the bandwidth enhancement of load modulation techniques is becoming essential for upcoming wireless communication. In particular, carrier aggregation, where, overall aggregated bandwidth can be achieved by inter/intra-band concurrent transmission requires multi-band/broad-band power amplification schemes. This talk discusses the design strategy for multi-band/broad-band Doherty power amplifier as a solution for average efficiency enhancement at back off. This also includes recent trends in multi-stage broad-band/multi-band design techniques for Doherty PA with enhanced back-off. In addition, the idea of switching concurrent multiple bands of Doherty power amplifiers at different frequencies along with reconfigurable back-offs is also presented as new solution for concurrent multi-band operation.

Bio:

Karun Rawat has received his PhD. degree in electrical engineering from University of Calgary, Canada in 2012, where he worked as a student research assistant and later Post-doctoral research fellow under the research grant of iCORE and CRC chair, Alberta, Canada. He is currently Assistant Professor in department of Electronics and Communication at Indian Institute of Technology Roorkee, India. Prior to this, he was Assistant Professor in Centre for Applied Research in Electronics, Indian Institute of Technology Delhi from 2013-2014 and scientist in the Space Applications Center, Indian Space Research Organization Ahmedabad, from 2003–2007. His area of research is RF power amplifier and transceiver design. His research has resulted in more than 43 publications in journals and conferences and one published book. He has given several IEEE talks in India as well as abroad including workshops in power amplifiers at IEEE IMaRC 2014-2015 and IEEE APMC 2015. Dr. Rawat has been reviewer of several IEEE transactions. Dr. Rawat has received research production award for three consecutive years from 2009-2011 during his PhD. He also received best design prize in 3rd Annual Smart Radio Challenge in 2010. He is also member of the editorial board of Wiley journal in RF and Microwave Computer Aided Engineering (RFMiCAE). He has also been associated with advisory committee of several RF industries, national scientific labs and universities for brainstorming and research initiatives.

Speaker's Name: Zoya Popovic	**Confirmed:** Yes

Affiliation: University of Colorado, Boulder

Presentation Title: Improving PA efficiency for high PAPR signals using supply modulation

Email: Zoya.Popovic@Colorado.edu

Abstract:

Supply modulation can be used to increase average efficiency of microwave power amplifiers in a number of transmitter architectures for broadband high peak-to-average (PAR) signals. This talk presents an overview of MMIC PAs and dynamic supplies integrated in the same Qorvo 150-nm GaN on SiC process with depletion-mode only HEMTs. Envelope-tracking, Doherty, LINC and Chireix MMIC power amplifiers designed for carrier frequencies in X-band are shown. The dynamic supplies include fast switching Buck converters with integrated drivers, a 4-level supply, a 3-bit power DAC and a 4.5GHz dc-dc converter. Approaches for high-bandwidth (>250MHz) and high PAR (>10dB) communication signals are discussed, along with an approach for amplitude modulated radar pulse signals with spectral confinment. Challenges in maintaining high efficiency and linearity of next-generation broadband and multi-band transmitters are highlighted.

Bio:

Zoya Popovic is a Distinguished Professor and the Hudson Moore Jr. Endowed Chair of Electrical Engineering at the University of Colorado. She obtained her Dipl.Ing. degree at the University of Belgrade, Serbia, and her Ph.D. at Caltech. In 2001/03 and 2014, she was a Visiting Professor with the Technical University of Munich, Germany and ISAE in Toulouse, France, respectively. She has graduated 52 PhDs and currently advises 15 doctoral students in various areas of microwave engineering. She is a Fellow of the IEEE and the recipient of two IEEE MTT Microwave Prizes for best journal papers, the White House NSF Presidential Faculty Fellow award, the URSI Issac Koga Gold Medal, the ASEE/HP Terman Medal and the German Humboldt Research Award. She was named IEEE MTT Distinguished Educator in 2013 and the University of Colorado Distinguished Research Lecturer in 2015. She has a husband physicist and three daughters who can all solder.