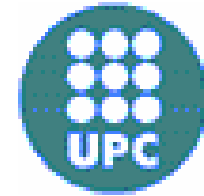




**T A R G E T**

TOP AMPLIFIER RESEARCH GROUPS  
IN A EUROPEAN TEAM



# 3<sup>rd</sup> TARGET Summer School

**“Linear Power Amplifier Design & Wireless Systems”**

*24 - 27 July, 2006*

Escola Politecnica Superior de Castelldefels (EPSC)  
Universitat Politècnica de Catalunya (UPC)

# PROGRAM

<b>Monday, 24</b>	
<b>08:30-09:00</b>	<b>Registration</b>
<b>09:00-09:30</b>	<b>Welcome, Opening</b>
<b>9:30:10:30</b>	<b>Wireless systems: Digital modulations</b> Luis Alonso, <i>UPC</i>
<b>10.30-10:50</b>	<b>COFFEE BREAK</b>
<b>10:50-12:00</b>	<b>Wireless systems: Media access: CDMA, OFDM</b> Luis Alonso, <i>UPC</i>
<b>12.00 – 13.00</b>	<b>TX &amp; RX Block Diagram: Evaluation at system level. PART I</b> Silvia Ruiz, <i>UPC</i>
<b>13:00-14:30</b>	<b>LUNCH</b>
<b>14:30-15:30</b>	<b>TX &amp; RX Block Diagram: Evaluation at system level. PART II</b> Silvia Ruiz, <i>UPC</i>
<b>15:30-15:50</b>	<b>COFFEE BREAK</b>
<b>15:50:17:50</b>	<b>PA Design Fundamentals</b> Markus Mayer, <i>Technische Universität Wien</i> + Simona Donati <i>Politecnico di Torino</i>

<b>Tuesday, 25</b>	
<b>09:00-10:10</b>	<b>High efficient power amplifiers</b> Ingo Dettmann, <i>Universität Stuttgart</i>
<b>10:10-11.20</b>	<b>Advanced topics in power amplifiers design</b> Paolo Colantonio, <i>Università di Roma "Tor Vergata"</i>
<b>11.20-11.40</b>	<b>COFFEE BREAK</b>
<b>11.40-13:00</b>	<b>Circuit Level Linearisation: An Overview</b> Angel Mediavilla - José Angel Garcia <i>Universidad de Cantabria</i>
<b>13:00-14:30</b>	<b>LUNCH</b>
<b>14:30:17:00</b>	<b>MODEL EXTRACTION (Practical session: ADS oriented)</b> Maciej Myslinski + Manuel Yarleque <i>Katholieke Universiteit Leuven</i>
<b>-TBD-</b>	<b>Reception</b>

<b>Wednesday, 26</b>	
<b>09:00-10:30</b>	<b>System Level Linearisation: Overview</b> Mairtin O'Droma <i>University of Limerick</i>
<b>10.30-10:50</b>	COFFEE BREAK
<b>10:50-12:00</b>	<b>Digital Predistorters</b> Pere L. Gilabert, <i>UPC</i>
<b>12.00 – 13.00</b>	<b>Feed-Forward linearizers</b> Michael Gadringer <i>Technische Universität Wien</i>
<b>13:00-14:30</b>	LUNCH
<b>14:30:18:00</b>	<b>TUTORIAL ON PA BEHAVIOURAL MODELLING:  (Practical session: MATLAB oriented)</b> J.C..Pedro , <i>IT Aveiro</i> D. Silveira, <i>TU Wien</i>

TIME	<b>Thursday, 27</b>
<b>08:00-10:10</b>	<b>MMIC (PA implementation)</b> Hermann Schumacher <i>Universität Ulm</i> + Maurizio Pagani <i>ERICSSON</i>
<b>10.10-10.30</b>	COFFEE BREAK
<b>10.30-11:40</b>	<b>DSP-FPGA based linearizers  (Implementation issues)</b> Gabriel Montoro, <i>UPC</i>
<b>11.40 – 13.00</b>	<b>PA implementation issues (component level)</b> Holger Arthabe. <i>Technische Universität Wien</i>
<b>13:00-14:30</b>	LUNCH
<b>14:30:17:00</b>	<b>TUTORIAL ON BASIC PA MEASUREMENTS  (Practical session: LABORATORY)</b> Jordi Berenguer <i>UPC</i>

**SCIENTIFIC ORGANIZATION: Eduard Bertran, UPC**

# Wireless systems: Digital Modulations

*(Luis Alonso, UPC)*

- Digital Communications
  - Advantages
  - Implementation Issues
  - General block diagram of a Digital Communication System
- Baseband Transmission
  - Digital Transmission, SNR, ISI, Nyquist Pulse Generation, time and frequency characteristics
  - Reception: Filtering and detection
- Passband digital modulations
  - M-ASK
  - M-PSK: BPSK, QPSK, O-QPSK, MSK, GMSK, Differential Coding
  - M-FSK: MSK, GMSK
  - M-QAM

## Wireless systems. Media access: CDMA, OFDM

- CDMA
  - Definition, types, advantages, drawbacks
  - Transmission and reception
  - Implementation Issues
    - Power Control
    - Synchronisation
    - Code sequences generation
  - BER analysis for PN sequence transmission
- OFDM
  - Definition, advantages, drawbacks
  - Transmission and reception
  - Implementation Issues
    - Multipath effect
    - Guard interval and cyclic extension

# TX & RX Block Diagram: Evaluation at system level

*(Silvia Ruiz, UPC)*

This lecture, split in two parts each one of 1 hour, will focus on the whole evaluation of a general communication's system at the system level. This covers from the effects of some subsystems impairments, such as jitter or noise, and the output sensitivity to these effects, as well as some quality parameters, more close the user's perception (data-rate, signal strength, BER,...).

1.- The Radio channel

2.- Block-diagram characterization

- Transmitter
- Receiver
- Channel

3.- Degradations / impairments: Kinds of noise, noise minimisations, interferences, distortions, power loss ...

4.- Output sensitivities.

5.- Quality parameters (QoS, SNR, Pe, BER, reliability, latency, capacity: data-rate vs. data throughput, ...)

# PA Design Fundamentals

(Markus Mayer, TUW; Simona Donati, POLITO)

Part 1	Part 2
<ul style="list-style-type: none"><li>• PA Basics<ul style="list-style-type: none"><li>○ Motivation</li><li>○ Limits<ul style="list-style-type: none"><li>▪ DC-IV, Load Matching</li><li>▪ Introduction to Load Pulling</li><li>▪ Technology - Equivalent Circuit</li><li>▪ Examples</li></ul></li></ul></li><li>• PA Operating Classes<ul style="list-style-type: none"><li>○ Class A-C<ul style="list-style-type: none"><li>▪ Conduction Angle</li></ul></li><li>○ Switching Classes</li><li>○ Harmonic Controlled PA</li></ul></li><li>• Linearity Aspects<ul style="list-style-type: none"><li>○ Sources of Nonlinearities</li><li>○ Measures of Nonlinearities</li><li>○ Linearity vs. Operating Classes</li><li>○ DC and 2nd harmonic zone</li><li>○ Sweet Spots</li></ul></li><li>• Stability issues<ul style="list-style-type: none"><li>○ Stability basics</li><li>○ Low/high frequency instabilities</li></ul></li><li>• Biasing Techniques<ul style="list-style-type: none"><li>○ Common Biasing Circuits</li></ul></li></ul>	<ul style="list-style-type: none"><li>• Power Amplifier Architectures<ul style="list-style-type: none"><li>○ Motivation and Intro</li><li>○ Wilkinson combiner</li><li>○ Balanced configuration</li><li>○ Push-Pull</li><li>○ Spatial combining</li><li>○ Interstage Matching</li></ul></li><li>• Broadband PAs<ul style="list-style-type: none"><li>○ Broadband Matching<ul style="list-style-type: none"><li>▪ Network Synthesis</li><li>▪ Balanced Amplifiers</li></ul></li><li>○ Distributed Amplifier</li></ul></li><li>• Enhancing Techniques (short overview)<ul style="list-style-type: none"><li>○ Efficiency Boosting Techniques</li><li>○ Linearity Improvement Techniques</li></ul></li></ul>

# High efficient power amplifiers

*(Ingo Dettmann, Universität Stuttgart)*

- Introduction
  - \* Why high efficient PAs?
  - \* Linearity vs. Efficiency
- Amplifier Classes
  - \* Linear Classes
  - \* Switching Mode classes
- Efficiency Improvement Techniques
  - \* How to improve Efficiency?
- PA Architecture for Efficiency Improvement
  - \* Doherty PA
  - \* Chireix PA
  - \* Supply Modulation
  - \* Kahn Architecture
  - \* Class S PA
- Conclusion

## Advanced topics in power amplifiers design

*(Paolo Colantonio, Univ. Roma TOR VERGATA)*

- Multi-band, multi-standard Power Amplifier Design
- Practical results

# **Circuit Level Linearisation: An Overview**

*(Angel Mediavilla, José A. García, Univ. de Cantabria)*

## 1. Introduction

- Why linearising at circuit or device level?
- The need for a precise control over the device nonlinear characteristics

## 2. Active devices.

- Role of the nonlinearities' derivatives on device IMD behaviour.
- Experimental characterization and distortion modelling concepts.
- Bias and load conditions for amplifier linearity optimisation.
- Memory effects.

## 3. Device and circuit level linearization techniques

- Device-based implementation of system level topologies
- Derivative superposition.
- Bias and load adaptation.

## 4. Integrating device and circuit solutions with single radiators and arrays.

- Integrated active amplifying antennas
- Spatial control of the IMD radiated field

## 5. Conclusions

# MODEL EXTRACTION

## (Practical session: ADS oriented)

*(Maciej Myslinski, Manuel Yarleque, Katholieke Universiteit Leuven)*

### 1. Goal

Demonstrate extraction, implementation and verification procedure of measurement-based large-signal model on two practical examples:

- 1.1. Angelov large-signal model of HEMT transistor,
- 1.2. Large-signal time-domain black-box model of RF amplifier.

### 2. Description

During the semi-interactive session we will present how to apply ADS in extraction, implementation and verification process of two different modeling methods. First approach will be related to a large-signal model extracted from S-parameters and DC measurements applied to HEMT transistor predestined for RF medium PA design. As the second method we will present a large-signal model extracted from Large-Signal Network Analyzer (LSNA) time-domain measurements applied to the existing RF buffer amplifier. In both cases a minimum theoretical knowledge will be given, only to justify required actions in the modeling procedures. The focus will be on the practical aspects of the procedures and the related problems awaiting engineers.

### 3. Outline

- 3.1. Angelov large-signal model of HEMT transistor
  - Introduction and presentation of the modeling method, } More Theory
  - Outline of the modeling procedure, }
  - Cold FETs conditions,
  - Equivalent Circuit of extrinsic parasitics,
  - 4-port techniques for extrinsic parasitics,
  - HEMT transistor intrinsic extraction for large signal model; Optimization.
- 3.2. Large-signal time-domain black-box model of RF amplifier
  - Introduction and presentation of the modeling method, } More Theory
  - Outline of the modeling procedure, }
  - Experiment design,
  - LSNA measurements,
  - Data processing and construction of time-domain waveforms,
  - Choice of the set of independent variables,
  - Derivation of I/O functional relationship - Neural Network,
  - Neural Network implementation in ADS,
  - Simulation using single-tone, two-tone, multisine and digitally modulated signal measurement results,
  - Conclusions.

# System Level Linearisation: Overview

*(Máirtín O'Droma, Univ. of Limerick)*

- Introduction
- Problem statement, Linearity vs. power efficiency
- Circuit and system level linearisation.
- Power amplifiers modelling and characterisation
  - Linearisation at System Level
    - Linearisers aiming at avoiding distortion
      - Power back-off tuning (not strictly a lineariser)
      - LINC/CALLUM
      - EE&R (Envelope Elimination and Restoration)
      - Predistortion (analogue or digital; signal or data; base-band or RF)
    - Linearisers aiming at reducing distortion
      - Feedback (and its variants: RF, envelope, Cartesian, polar)
      - Predistortion
      - Feedforward
- Some comparative results
- Benchmarking and Evaluating Linearisation Benefits

# Digital Predistorters

*(Pere L. Gilabert, UPC)*

## ▶ INTRODUCTION

- Predistortion Fundamentals
- Analogue & Digital Predistortion
- Signal and Data Predistortion

## ▶ PREDISTORTION MODELS

- AM/AM AM/PM static compensation
- Power Amplifier Dynamic Models:
  - Volterra
  - Hammerstein
  - Wiener

## ▶ IDENTIFICATION

- Direct and Indirect Learning approaches
- Estimation Algorithms. Restrictions

## ▶ IMPLEMENTATION

- Look-up Tables
- Polar, Mapping or Complex Gain Predistorters

## ▶ EXAMPLES

- Linearity performance with Digital Predistortion Linearization
- Issues related to Power Amplifier memory effects

## ▶ CONCLUSION

# Feed-Forward linearizers

*(Michael Gadringer, TUW)*

- Introduction:

The classical feedforward (FF) setup:

- Structure
- Basic functional principle
- Behavior of cancellation loops
- Amplifier distortion extraction using a cancellation loop
- FF Amplifier power budget
- Comparison to other amplifier concepts (LINC, EER, ...)

- Design of a linear and efficient feedforward amplifier

- Feedforward output signal decomposition
- Enhanced control of a FF setup
- Implementation issues for the suggested control concept into a FF amplifier

# TUTORIAL ON PA BEHAVIOURAL MODELLING

(First part: *José Carlos Pedro, Instituto de Telecomunicações*)

## 1. Introduction

- 1.1 – Moving from the conventional equivalent circuit modelling approach to the behavioural modelling strategy.
- 1.2 – Physical modelling versus behavioural modelling. Why do we need behavioural models of RF PAs?

## 2. General Distortion Performance of Microwave PAs

- 2.1 – Sources of nonlinear distortion in a RF PA.
- 2.2 – Nonlinearity and PA memory effects. Linear and nonlinear memory. Why is the nonlinear behaviour of a PA dynamic if its linear characteristics can be linear?

## 3. Basics on System Identification Theory

- 3.1 – Basic theoretical tools on nonlinear system identification theory. Static and dynamic nonlinear operators.
- 3.2 – Polynomial and neural network approximations. Polynomial filters and time-delay artificial neural networks.
- 3.3 – Local and global models. The compromise between approximation accuracy and easiness of parameter extraction.

## 4. Nonlinear Behavioural Modelling of Microwave PAs

- 4.1 – Complex envelope low-pass equivalent and modulated RF band-pass PA behavioural models.
- 4.2 – Static models and dynamic models.
- 4.3 – Models addressing linear memory and models capable of representing nonlinear memory.
- 4.4 – Formal approaches to PA behavioural modelling: Volterra filters and time-delay artificial neural networks.
- 4.5 – Selected examples of proposed nonlinear dynamic behavioural models of RF PAs

## 5. Nonlinear Measurements for Model Extraction

- 5.1 – Notions of signal space coverage and behavioural model extraction.
- 5.2 – Time-domain versus frequency-domain measurements.

## 6. Conclusions

# (Second part: *Daniel Silveira, TUW*). MATLAB oriented

### Validation

- Common figures of merit used: NMSE, VAF, Distortion EVM

### Linear estimation

- LS estimation
- Correlation based methods
- Adaptive Filter signal estimation
  - LMS
  - RLS
- Frequency response estimation
- Pseudo-inverse estimation

### Nonlinear estimation

### Memoryless models estimation

- Saleh models
- Polynom LS estimation
  - Orthogonal Polynoms: Chebyshev, Hermite

### Models with memory estimation

- Block structured models
  - Linear-Nonlinear (Wiener), Nonlinear-Linear (Hammerstein), Linear-Nonlinear-Linear (Wiener-Hammerstein)
  - Relationship to Volterra series
- Iterative procedures
  - Newton
  - Gauss-Newton, Levenberg-Marquardt

## MMIC (PA implementation)

*Hermann Schumacher*  
*Universität Ulm*

- Introduction to SiGe-based design of millimeter-wave ICs, with examples ranging from 24 GHz to 80 GHz, including their practical implementation.
- Design restrictions introduced by the substrate material substrate losses and by the HBT structure itself (e.g. low breakdown voltages).
- Challenges of multifunctional ICs.

*Maurizio Pagani*  
*ERICSSON*

- MMIC PA implementation issues:
- guideline for the design of MMIC PA
- design flow productivity and bottlenecks
- Some design challenges:

Reliability, modelling, manufacturability, packaging and system integration.

## **DSP-FPGA based linearizers (Implementation issues)**

*(Gabriel Montoro, UPC)*

- 1.- Introduction: What we need to implement a digital predistorter?. Subsystems and devices.
- 2.- AD and DA conversion: Sampling and subsampling. IF sampling. Converters technology.
- 3.- Digital processors: DSP's and FPGA's. Classification and comparison.
- 4.- Specific IC for implementing predistorters.

## **PA implementation issues (component level)**

*(Holger Arthabe, TUW)*

Passive components parasitics,

Lumped and distributed elements

Different realizations of a impedance. Thin film technology ,high-Q spiral inductors.

Effects of transistor mounting (focusing on bond wire effects, heat sinking, adhesive mounting, ...)

Bias-networks.

Design example of a thin film 10W SSPA for DAB.

# TUTORIAL ON BASIC PA MEASUREMENTS

*(Jordi Berenguer, UPC)*

- 1) Introduction to the RF instrumentation:
  - a) The spectrum analyzer
  - b) The vector network analyzer
  - c) The vector signal generators
  - d) The noise figure meter
  - e) Power meters
  - f) Cautions and best practices.
  
- 2) Linearity measurements in PA's
  - a) Scalar and vector measurements
  - b) Noise measurements
  - c) The calibration process
  
- 3) Non-linear measurements in PA's
  - a) Compression
  - b) Intermodulation