TARGET
TOP AMPLIFIER RESEARCH GROUPS IN A EUROPEAN TEAM

Course description: **Microwave Power Amplifier Design**

Modules:

1. Power Amplifier Fundamentals
2. Non-Linear Characterisation and Modelling Techniques
3. Non-Linear Analysis Methods
4. Power Amplifier Design Techniques Overview
5. High Efficiency Power Amplifier Design
6. Combining Techniques
7. Thermal and Packaging Issues
8. Linearisation Issues in a Power Amplifier
9. Foundry Realisation and Design Rules
10. Power Amplifier Design Examples

Audience:

This course is designed for engineers working in the field of microwave electronics.
It provides both a comprehensive preliminary overview of power amplifier designs and a deep insight of high efficiency microwave amplifiers.

Preliminary Knowledge:

Microwave electronic fundamentals

Our presenters:

Thomas J. Brazil, Anding Zhu (University College of Dublin, Ireland)
Angel Mediavilla, Tomas Fernandez Ibañez (Universidad de Cantabria, Spain)
Josè Carlos Pedro, Nuno Borges Carvalho (Instituto de Telecomunicacoes, Portugal)
Paolo Colantonio, Franco Giannini, Ernesto Limiti (University of Rome Tor Vergata, Italy)
Giovanni Ghione, Simona Donati Guerrieri, Marco Pirola (Politecnico di Torino, Italy)
Máirtín O'Droma (University of Limerick, Ireland)
Eduard Bertran (Universitat Politecnica de Catalunya, Spain)
Joaquin Portilla (Universidad del Pais Vasco, Spain)
Michael Gadringer (Technische Universität Wien, Austria)
Klaus Beilenhoff, Eric Leclerc (United Monolithic Semiconductor, France)

TARGET is a Network of Excellence under the 6th Framework programme of the European Commission

Module 1 - Power Amplifier Fundamentals

Power amplifier design is the crucial concern in many microwave systems. Its performances in fact fix the overall power consumption, the size and weight of the entire unit. Regardless of the specific application, the minimisation of the dissipated power by the active devices must be attained at the highest output power levels, hence imposing a tight specification on the PA efficiency that becomes the major challenge of the design.

In this introductory module the fundamental concepts involved in a power amplifier design are presented.

The fundamental characteristics and design parameters, together with the major system specifications influencing the amplifier designer's choices are discussed. The gain compression and efficiency features of a power stage are examined together with an overview of design power limiting mechanisms.

Finally, due to the large signal operating condition and the active device inherent non linear behaviour, the linearity issues are focused. The fundamental non linear amplifier characteristics and design parameters, like IP3, C/I, ACPR, etc., are defined and an overview of intermodulation issues are presented.

Presenter: Thomas J. Brazil
Alternative:
Anding Zhu
Duration: 1 hour

Module 2 – Non-Linear Characterisation and Modelling Techniques

In the design of a power amplifier, the availability of a suitable active device non linear model become mandatory to a accurate design, especially if simulation tools have to be adopted to design MMIC circuits.

In this module the techniques to extract both linear and non linear active device models are focused, according to different device technologies adopted.

Useful criteria about how to choose a suitable non linear model are discussed and clarified.
The device characterisation and measurement procedures adopted to infer both linear and non linear models are presented. The low frequency dispersion effects and methods to extract non linear model with accurate intermodulation prediction are discussed.

The procedure to implement a non linear model in a commercial CAD (MWO, ADS) is presented by using exemplifying cases.

Presenter: Angel Mediavilla
Alternative:
Tomas Fernandez Ibañez
Duration: 1 hour

Module 3 - Non-Linear Analysis Methods

Computer-Aided Design Tools have experienced a dramatic improvement both in performances and simulation capabilities. Such improvement is due both to the increase in computing speed and hardware progress both in workstations and PCs, and in the assessment of appropriate analysis techniques.

Modern CAD tools include in fact linear and non linear simulation capabilities, coupled with electromagnetic field solvers, layout generation and system simulation capabilities. For the analysis and design of power amplifier circuits obviously the non linear simulation capabilities are indeed necessary, due to the inherent non linear behaviour of the active devices employed in a power stage.

The non linear simulation approaches may be based on time-domain techniques, mixed time-frequency-domain techniques (harmonic Balance), fully frequency-domain algorithms or Volterra-series approaches.

While the former algorithms, derived from widely diffused SPICE-like approaches and adapted to deal with microwave problems are mainly adopted for transient analysis, the latter are adopted for the steady state analysis of the circuit.

Moreover, while Volterra-based approaches find their natural application to circuits exhibiting mild non linearities and specifically to the analysis of power amplifier linearity, the working horse of all commercial non linear CAD software is indeed the HB technique. Such approach has been extended from the piecewise formulation to include nasty non linear problems, such as the non linear noise analysis, forced autonomous circuits and input signals with complex modulation schemes. In the latter case, especially important for the analysis of PA performances in actual operating conditions in communication systems, envelope-based approaches and multi-tone ones are adopted, demonstrating excellent simulation capabilities and numerical efficiency.

In this module, the basic formulation of the non linear analysis methods is discussed by using simple example to compare the different approaches.

Presenter: Josè Carlos Pedro
Alternative:
Nuno Borges Carvalho
Duration: 2 hours
Please Note: This is an optional module.

Module 4 – Power Amplifier Design Techniques Overview

The realisation of a power stage is based on a suitable design of active device input and output matching networks.

While small-signal amplifier design is based on well-established techniques (S-Parameter approach), in the design of a power amplifier non linear concepts must be adopted, due to the active device large signal operating condition, resulting in the "Load-Line Matching Condition". In fact, the power limiting mechanisms in active devices reside in their inherent physical constraints. Such limitations pose an upper limit to the maximum swings that output current and voltage may experience, reflecting in a corresponding limit to the device output power.

Moreover, the growing demand for portable apparatuses, whose main characteristic is battery duration and overall size, translates naturally into a low power electronic system. Since the power amplifier in the transmitter section represents clearly the main source of supply power consumption, such feature is directly transferred to its specifications. The power amplifier designer is therefore in front of a difficult trade-off among the contrasting goals of high transmitted power, low power consumption and, for many telecommunication systems, linear operation.

Since the achievable performances of microwave power amplifiers are mainly limited by the active device parameters and operating conditions, the selection and implementation of an appropriate design methodology, leading to the solution of several design problems, is the crucial point in the design of a power stage.

In this module, the commonly used approaches for the design of power amplifiers, peculiar of the microwave and millimetre wave frequency range, are reviewed and discussed.

The power amplifier design guidelines are focused, comparing measurement-based techniques with CAD-based approaches, and stressing their relative strength and weakness. Simplified techniques are also discussed, particularly addressed to the preliminary evaluation of power capabilities of a given device, for a power budget exercise, and to gather physical insight into the power generating mechanisms.

Finally, the harmonic tuning strategies for high efficiency power amplifier design are outlined, together with their basic application rules.

Presenter: Ernesto Limiti
Alternative:
Paolo Colantonio
Duration: 2 hours
Please Note: It is recommended to book Module 4 in combination with Module 1.

Module 5 – High Efficiency Power Amplifier Design

Wireless network operators main requests are operational costs reduction and, at the same time, system capabilities increase. In particular, deployment of smaller base stations, featured by higher flexibility, efficiency and lower cost, becomes one of the system suppliers main goals. In this scenario, power amplifiers play a key role, becoming crucial elements of transmitter units in many microwave systems, including mobile phone applications, satellite payloads, microwave transponders, and many others.

Usual PA design approaches seek high power efficiency coupled with suitable gain and output power levels. The former is required to improve battery lifetime and to ease thermal management, thus reducing operating cost, while the latter specifications are needed to reduce the number of amplifier stages together with unit size and weight, thus decreasing manufacturing costs. Such requirements are contrasting ones, therefore demanding a design compromise on achievable performances.

To increase the amplifier efficiency performances, a proper selection of bias point and voltage and/or current waveform shaping become mandatory. For RF application, the best design solutions become the Class E and Class F approaches.

For microwave applications other design strategies have been proposed, in particular for narrow-band applications, based on harmonic tuning design strategies.

In this module, a comprehensive theory of high efficiency power amplifiers design criteria is presented. Starting from simple power balance considerations, extended to encompass the general problem of power amplifier design, traditional Class E and F design strategies are reviewed. Novel harmonic tuning strategies are presented and a comparison is carried out. Useful design criteria are inferred for the design of input and output networks of high efficiency / high frequency power amplifiers.

Finally, for each design strategy an hybrid or a monolithic amplifier example is presented.

Presenter: Franco Giannini
Alternative:
Paolo Colantonio
Duration: 2 hours
Please note: It is recommended to book Module 5 in combination with Modules 1 and 4.

Module 6 – Combining Techniques

A power amplifier is a system component aimed to increase the power level of the signal at its input up to a suitable and predefined level. For this purpose, several active device technologies have been developed or enhanced in order to increase power density. However, the maximum power achievable from a single device usually is not sufficient to completely fulfil system requirements, thus power combining techniques become mandatory.

In this module the basic combining structures are analysed, comparing their performances and frequency limitations.

Presenter: Giovanni Ghione
Alternative:
Marco Pirola
Duration: 1 hour

Module 7 – Thermal and Packaging Issues

A power amplifier is a system component aimed to increase the power level of the signal at its input up to a suitable and predefined level. For this purpose, several active device technologies have been developed or enhanced in order to increase power density. However, increasing the power level density, an increase of devices' temperature (heat) is expected. Since the active devices have a finite thermal impedances, the heat generation raises the devices above ambient temperature. But the active device parameters are functions of their temperature. Therefore moderate increases in temperature decrease device gain and power, while large increases in temperature compromise the device reliability. This means that the temperature of the active devices must be managed carefully.

In this module the basic theory of device thermal modelling are outlined, starting from physical principle and deriving electro-thermal models able to quantify thermal drift on High Power Amplifiers. Finally several thermal management solution are discussed, together with suitable packaging strategies.

Presenter: Giovanni Ghione
Alternative:
Simona Donati Guerrieri
Duration: 1 hour

Module 8 – Linearisation Issues in a Power Amplifier

A power amplifier is a system component whose main task is to increase the power level of the signal at its input up to a predefined level. This characteristic on one hand forces the selection of the active devices composing the power amplifier on the basis of their output power capabilities; on the other hand, in order to fully exploit such capabilities, the devices are typically operated under large-signal regimes, forcing the exploration of non-linear operating regions. A PA is therefore a non-linear system component, whose large-signal operating conditions often lead to detrimental effects on the output signal, resulting the generation of harmonics, intermodulation products and other spurious signals, and a distorted replica of the input signal.

Such non linear phenomena become crucial in power stages of present wireless communication systems. Transmitters with ever increased transmit power levels need to operate in improved power efficient modes, while not degrading the quality of signal itself.

Moreover, with complex modulation approaches being adopted to increase spectral efficiency linear transmission is crucial, the role of linearisation is vital in PA's forced to work in large signal conditions, with signals characterised by large envelope fluctuations.

Adjacent channel effects of a non linear PA behaviour may be represented by a spectrum alteration, in particular by spectral regrowth phenomena, which can be deleterious to information transmitted on adjacent channels, and in loss of modulation fidelity for signals in those channels.

Approaching the issue largely at a system behavioural level, in this module the measurements and parameters adopted to quantify the distortion generated in a non linear system and in particular in power stages are discussed. The main schemes and techniques that can be adopted to increase linearity and efficiency, such as predistortion, feedback, feedforward, Doherty, EER, etc. will be presented.

Presenter: Mairtin O'Droma
Alternatives:
Eduard Bertran
Joaquin Portillo
Michael Gadringer
Duration: 2 hours

Module 9 – Foundry Realisation and Design Rules

Microwave power amplifier system applications span over a broad range of areas, among which telecommunications, radar, electronic warfare, heating, medical microwave imaging represent a few examples. The large differences in system applications are reflected back into the technologies adopted for the realisation of the power amplifier active module.
In this module the RF and microwave transistor technologies actually adopted for the design of power stages are discussed.

The foundry design process is outlined together with the main design rules to be respected.
Finally, the complete process, from a foundry point of view, for the design of a power amplifier is presented.

Presenter: Klaus Beilenhoff
Alternative:
Eric Leclerc
Duration: 1 hour

Module 10 - Power Amplifier Design Examples

In order to complete the course on microwave power amplifier, practical design examples are presented in this module.

Starting form the active device characteristics and amplifier requirements, the design procedure is step by step outlined by using commercial CAD tools. The bias solutions are discussed together with useful single device stabilization techniques, and the adopted non linear design strategy is outlined to obtain a preliminary amplifier electrical schematic design. Then the layout generation process is presented both for hybrid and monolithic realisations.

For combined structures, the even/odd oscillation issues are discussed, showing useful analysis techniques and design solutions.

Presenter: Paolo Colantonio
Alternative:
Ernesto Limiti
Duration: 2 hours