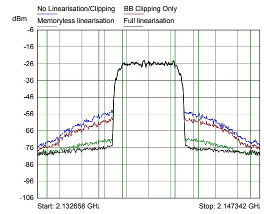

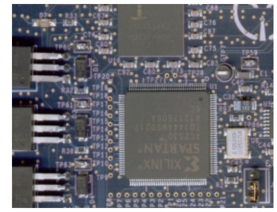

Linearised RF Power Amplifier Systems - Theory and Design

23rd to 27th April 2007, Cambridge, UK.

Venue: Kaetsu Centre, New Hall,
University of Cambridge, England

TUTORS

Dr. Steve C Cripps, *Hywave Associates*

Dr Chris Potter, *Cambridge RF Ltd.*

TECHNOLOGY FOCUS

RF Transmitter linearity has become a topic of intensive research worldwide in the wireless communication era. The combination of fixed, narrow frequency bandwidth allocations and the growing demands for information throughput for rapidly evolving consumer wireless products has resulted in the implementation of RF modulation schemes, which have low tolerance for system non-linearity. This is in contrast to first generation wireless products, which used more traditional modulation schemes - such as OQPSK, GMSK.

These older systems were originally conceived with a primary goal of being tolerant of some moderate peak envelope clipping of the RF signal. Third generation, 3G-systems, have been forced to discard this concession to the RF designer, in the interests of much higher channel and signal bandwidth capacity.

The use of analog and digital techniques for linearisation of the transmitter, and especially the final power amplifier stage, has become not just desirable, but a key element in the success of 3G wireless products.

SUMMARY

Introduction to Linearised PA Systems • Role of Linearisation, Review of Modulation Systems and Standards • Review of PA Techniques • Class A, AB, Class D,E,F, Kahn, Chireix, Doherty • Power Amplifier Linearity • Power and Volterra Series, AM-AM, AM-PM, Volterra Series Extraction, IM, Spectral Re-growth, Envelope Simulation, IM Asymmetry and Memory Effects • Predistortion Techniques , Basic Theory, Analog Predistortion •Digital Predistortion, Theory , Practice and Simulation, • Feedback Techniques • RF Feedback, Envelope Feedback, Cartesian and Vector Feedback • Feedforward • Feedforward Loop Analysis, EPA Power Tradeoffs, Adaption Issues, CAD Simulations • RF Component Design for Linearised Systems • Detectors, Vector Modulators, RF to DC Converters

COURSE OBJECTIVES

The objective of this course is to provide an up-to-date review of linearisation techniques for RF power amplifiers in wireless communications systems. This updated and extended course places a new emphasis on digital predistortion techniques, which are expected gradually to replace many of the existing analog methods over the new few years.

Applications for all kinds of wireless systems are intended, and although there will be an emphasis on cellular base stations, other application areas such mobiles and satellite systems will be included.

This course places an emphasis on the analysis and a priori design of PA linearisers, in addition to the CAD simulation of practical devices and systems.

Various CAD tools will be used to illustrate the performance of practical designs.

WHO SHOULD ATTEND

PA Designers
PA designers at all levels will find this course an excellent update to their current knowledge and an opportunity to meet and discuss with others working in the same area.

System Level Engineers
Engineers who specify and use RF components, including PAs, in system design will obtain an understanding of what is possible, at what cost and system level tradeoff.

DSP Engineers
The growing role of DSP in RF PA systems is clear, and this course would serve as a good background for DSP designers who are, or are about to, become involved in the design of linearisation systems for RF PAs.

New Hall is a modern college within the University of Cambridge, which offers excellent facilities for learning in buildings that have won various architectural awards. Our courses are delivered in the Teaching Room of the Kaetsu Centre. Course fees include morning and afternoon refreshments and lunch served in the remarkable 'Dome' dining hall.

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COURSE CONTENT

Day 1. The first day is mainly a review of PA design and non-linear PA effects. Classical PA modes (A, AB, B) will be briefly reviewed. The efficiency enhancement possibilities proposed by Khan, Chireix, and Doherty will be reviewed briefly. Different modulation schemes and specification standards will be reviewed, so that the linearity and efficiency requirements from each can be determined.

Day 2 begins with a study of PA non-linear effects, and behavioural modeling techniques will then be considered. This treatment will include the fitting of higher order polynomial models to measured PA characteristics, and the problem of IM asymmetry and memory effects. The rest of the day will be devoted to predistortion methods. Predistortion has become the most important developing linearisation technique in recent times due to the availability of faster DSP hardware. Nevertheless, analog predistortion still has value in some applications and it is also dealt with here. Basic predistortion theory, using polynomial series, will be presented.

Day 3 focusses on digital predistortion methods, applied either at the PA input, or as is becoming more standard practice, at the DSP signal synthesis system level. Tradeoffs between algorithmic, or LUT (Look-Up Table) implementations will be discussed. Memory effect correction will be described. Issues such as predistortion bandwidth, sampling rates, digital precision, for different specifications and standards will be given quantitative treatment. Illustrations using non-linear CAD simulations will be presented. Adaption issues and methodology are discussed. The requirement for power control and its impact on the system design is also assessed.

Day 4 will begin with a treatment of feedback techniques. The main emphasis will be on so-called indirect feedback techniques. The most familiar of these, the Cartesian and Polar Loop will be reviewed, but the vector loop will also be emphasised due to its possibilities as a stand-alone amplifier, rather than a transmitter, technique. Some quantitative and CAD analysis will be performed to illustrate the tradeoffs between baseband gain, bandwidth, stability, and linearisation effectiveness. Some novel approaches to vector PA feedback will be introduced, which may in the future lead feedback methods back into the forefront in linearised PA systems when newer RF transistor technologies become available.

Day 4 continues with feedforward, which in commercially available products still remains the mainstream linearisation technique. The feedforward loop will be analysed quantitatively in order to characterise the important tradeoffs between system performance and efficiency. The impact of different types of PA non-linearity on the feedforward system will be discussed. Tracking requirements, adaption, and error PA requirements will also be analysed quantitatively. A CAD simulator will be used to demonstrate some of the theoretical analysis, using both simple 2-carrier and also multicarrier signal environments. Some important variations on the basic feedforward loop will be discussed, including the so-called "digital feedforward" method, which is analogous to the digital derivative of analogue predistortion. The advantages and disadvantages of the two "DSP-era" PA linearisation techniques will be reviewed.

Day 5 considers practical implementation of linearised power amplifiers. First, the digital components of a predistortion system are discussed. This includes a review of currently available hardware, and considers the decision-making process in the selection of suitable parts for the predistorter. Next the theory and design of several microwave subsystem components are described, which are required in any linearisation scheme. This will include a more extensive analysis of various kinds of detectors, with the tradeoffs between speed and precision, and different detector technologies. Vector modulators will also be discussed. Finally, the intriguing concept of converting "wasted" RF energy back into useful DC supply will be reviewed and analysed as a possible efficiency enhancement technique.

ABOUT YOUR TUTORS

CRIPPS, Steve C, Hywave Associates, Somerset, UK.

Dr Cripps obtained his Ph.D. degree from Cambridge University, England. He worked for Plessey Research on GaAsFET hybrid circuit development. Later he joined Watkins-Johnson's solid state division, Palo Alto, CA, and has held Engineering and Management positions at WJ, Loral, and Celeritek. During this period, he designed the industry's first 2-8 Ghz and 6-18 Ghz 1 watt solid state amplifiers, and in 1983 published a technique for microwave power amplifier design, which has become widely adopted in the industry. In 1990 Dr. Cripps became an independent consultant and was active in a variety of commercial RF product developments, including the design of several cellular telephone power amplifier MMIC products. In 1996 he returned to England, where his consulting activities continue to be focused in the RF power amplifier area.

POTTER, Christopher, Cambridge RF Ltd., Cambridge UK.

Dr. Potter is presently a consultant with Cambridge RF Ltd. in Cambridge UK. Since 1998, he has been involved with linear PA designs for terminals and cellular infrastructure. His main research interests are in the field of adaptive linearisation. He is also active in RF system designs for terminals and cellular infrastructure, and tools for automation of the RF design process.

Dr. Potter received the B.Sc. degree in Electronics in 1983 from the University of York, England and the Ph.D. degree in 1987 from the University of London, England. From 1983 to 1995, he designed a variety of microwave and RF test equipment at Marconi Instruments. From 1995 to 2002, he worked at Tality UK on RF architectures and product designs for GSM, EDGE, Bluetooth, 802.11a/b and WCDMA.

Daily Schedule

Monday 9.30-12.30, 13.30-17.00

Part 1 – Introduction
- Role of PA Linearisation in Modern Communications Systems

Part 2 – RF Power Amplifiers Review
- Basic RF transistor model
- Quasi-Linear modes; Class A, Class AB,Class B; Efficiency and Linearity
- High Efficiency Modes; Class C, Class D,Class F, Class E
- Doherty PA
- LINC techniques

Part 3 – Review of Modulation Formats
- Principles of Digital Modulation
- Modulation Measurements relating to transmitters and PAs

Part 4 – Review of Regulatory Specifications for PAs
- GSM-EDGE, 3GPP, IS-95, CDMA2000; IQ constellation, time-domain and frequency-domain characteristics.
- EVM, ACLR, PCDE performance requirements
- Modulation amplitude probability distributions; peak to average ratio

Tuesday 9.00-12.30, 13.30-17.00

Part 5 – Nonlinear Properties of RF PAs
- PA non-linearity
- AM-AM and AM-PM
- Power Series and 2-carrier analysis
- • Volterra Series and Behavioural modelling
- Memory effects and IM asymmetry
- Dynamic Thermal Effects

Part 6 - Analog Predistortion
- Introduction and PD theory
- Simple analog PDs
- Polynomial PD analysis
- Cubers and Polynomial Synthesisers
- Second degree Signal Injection

Wednesday 9.00-12.30, 13.30-17.00

Part 7 – Digital Predistortion
- Digital Predistortion Architectures, including Multi-carrier
- Bandwidth, Clock Rate and Precision Issues
- LUT and Algorithmic Approach
- Memory Effect Modelling
- Adaption Issues
- Power Control

Hands-on Demonstration of Digital Predistortion
- Linearisation of a power amplifier
- Demodulation and analysis using spectrum and vector signal analysers

Thursday 9.00-12.30, 13.30-17.00

Part 8 Feedback Techniques
- Direct Feedback
- Envelope Feedback: Introduction & concept
- Envelope Feedback Methods
- Envelope Feedback Analysis
- Vector Envelope Feedback

Part 9 – Feedforward
- Introduction
- 3rd order analysis
- Tracking and error amp issues
- "EZ_FEED" Simulation
- LDMOS CAD design example
- Feedforward gain/phase tracking techniques

Friday 9.00-12.30, 13.30-16.00

Part 10 - DSP and DPD hardware
- Introduction to DSP and DPD hardware
- DSP, FPGA, ASIC technology
- ADC and DAC technology
- Practical DPD Architectures; Multi-carrier, Adaption, Power Control
- Lineariser Software Development

Part 11 – RF Sensing and Control
- Detectors and Sensors
- • Amplitude and Phase Modulators

Part 12 – Conclusions

Course Registration And Information

You may either make a preliminary registration (with no financial commitment) or firm registration on our website www.cambridgeRF.com/courses, or if you prefer, complete the form below and return by post or fax to:

Diane Potter, Cambridge RF Ltd., 10 Teversham Road, Fulbourn, Cambridge, United Kingdom CB1 5EB

Fax: +44 (0)870 7061487 Telephone: +44 (0)1223 700497 E-mail: courses@cambridgeRF.com

Linearised RF Power Amplifier Systems - Theory and Design 23rd to 27th April 2007

Title	First name			Family name
Company				Department
Address				City
Postcode	Country			Email
Course Fee				The course fee includes tuition, course documents, lunches and break refreshments. Accommodation is not included in this price but we can arrange it for you or send you information. New Hall offers en-suite rooms which we can book for you (cost is £63+VAT per night inc full English breakfast). Many local hotels and guest houses are also available.
Standard price	@£1,900 each	☐	£	
Early registration price (firm registration received 6 weeks before course start)	@£1,700 each	☐	£	
Student / academic rate (for 2 or more students)	@£850 each	☐	£	
Discounted prices	+VAT @ 17.5%		£	
Please contact us to ask about discounts for 2 or more delegates	TOTAL		£	
Invoicing Information				
Address to send invoice				
Attention to			Email	
Purchase order number			Company VAT number (EU only)	

Cancellation Policy: In case of cancellation, the fee will be refunded, less a 15% administration charge, if cancellation is made in writing no later than 2 weeks before course start. Full course fee will be charged after that date. Substitutions can be made any time before course start.

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