# Preface

For some years now an immense growth and variety of wireless communication systems has been bringing very welcome benefits to our daily lives immersed as they are in the complexities of ever more intricately integrated global village. All indications are that this extensive growth and radical transformation of radiocommunication systems will continue. It has come about largely through the introduction of novel digital modulation formats on the back of VLSI-DSP technology development, together with the rapid progress, and reduced size and cost, in monolithic microwave integrated circuits (MMICs) and the underlying progress in the supporting technologies of device physics, device modelling, circuit theory and modelling, and circuit and system behavioural modelling. Research progress in all these technologies is crucial for ongoing development of wireless communications and systems, especially low cost, high bandwidth and power efficiencies, technically sound and stable MMIC solutions operating from microwave through to millimetre wave (mm-wave) MMICs, i.e. 100GHz and more, which are destined for the commercial consumer end-user market. This book focuses on research related to one of the key transmitter components, the high power microwave and mm-wave power amplifiers and specifically on research aspects and progress in relation to characterisation and modelling for their linearisation.

Reasons for linearisation may be summarised as in the following. Complex modulation signals which are attractive because of their bandwidth efficiency and resistance to multipath distortion are usually characterised by a complex and strongly varying envelope, measured by such parameters as crest factor and peak to average power ratio (PAPR). Such signals require stringently linear transmission channels both to maintain modulation fidelity and avoid the generation of out-of-band intermodulation products, harmonics and other spurious signals deleterious to communications in adjacent channels.

For this linearity requirement, the most critical component is the transmitter's final stage power amplifier. In transceivers these power amplifiers are by far the greatest energy consumers. For present day cellular handheld wireless devices some 70%, and more, of the battery energy goes into the transmit power amplifier. Thus every percentage increase in power added efficiency (PAE) translates to more than a 0.7% increase in talktime (battery recharge interval, BRI). For base stations and wireless access points every percentage increase in PAE translates into a percentage power saving and into saving on cooling costs (as power lost through inefficiency is usually dissipated in heat). This, in the context for instance of a national cellular network, can accumulate to quite considerable savings. Unfortunately the improvement in PAE of power amplifiers comes at the expense of loss of linearity.

Naturally then, both scientific and industrial communities are dedicating significant research and development resources towards seeking and optimising solutions which aim to resolve these competing linearity and energy efficiency requirements. Largely these solutions amount to the addition of power amplifier linearising structures, internally to the amplifier itself at a circuit level, or externally at a system level, or a combination of both. There are many linearisation schemes based on a few key principles such as feedback, feedforward and predistortion. None can be considered as the definitive linearisation solution. Their optimality depends on the specific application conditions, such as output power requirement, bandwidth, operating frequency, signal structure, modulation fidelity, adjacent channel power ratio (ACPR) requirements, power efficiency, thermal management attributes, adaptivity, stability, cost/ benefit issues and so forth. In all cases, without exception, achieving the desired power amplifier stage performance is only possible thanks to an appropriate understanding of the power amplifier behaviour, from a device, circuit or a system perspective, and thereby effecting suitable control of that behaviour.

This is the context and motivation for writing a book on “Characterization and Modelling Approaches for Advanced Linearisation Techniques”. Our goal is to bring together some of the most representative research lines in the field, and this we do thanks to contributions from leading authorities in the field.

The compilation of the book has benefited enormously from the European Union’s Network of Excellence “Top Amplifier Research Groups in a European Team”, TARGET, (EU-FP6-IST-2004-507893, www.target-net.org). Being funded within the Sixth Framework Programme of the European Commission, it integrates the microwave and mm-wave solid state power amplifier research efforts of 47 regular and 16 associated groups from both academia and industry. While this book is not a comprehensive reflection of the RF power amplifier and power amplifier linearisation research work being carried out by partners within TARGET, the selection of work presented here by authors does nonetheless reflect important ongoing research in advanced linearisation characterisation and modelling within TARGET at this particular time.

The unsuspected complexity of the nonlinear distortion measurement problem is thoroughly examined in the first chapter by Nuno Borges Carvalho of the Universidade de Aveiro, Portugal. He presents a careful study of behaviour, and measurement techniques and expectations, when the power amplifier is subjected to different excitation signals from single tone to multi-sines. The design of an excitation signal for multi-sines characterisation is also addressed. The ideas here are complemented well in a later chapter by Dominque Schreurs, Catholic University of Leuven and Kate Remley, National Institute of Standards, where they investigate RF behavioural modelling using multi-sine excitations.

Source and load pull technology for the characterisation of nonlinear behaviour of power amplifiers under different load condition and the verification of large signal computer models is the subject of Holger Arthaber, Markus Mayer and Gottfried Magerl research presented in chapter 2. Specifically, approaches to circumvent the impact on measurement results due to harmonic components are presented. Ways to implement variable loads, required for source/load pull setups, are dealt with and the important issues such as de-embedding and calibration are discussed. Examples of active and passive harmonic load pull setups together with measurement are used to underpin the discussion.

When a lineariser is added to ameliorate the nonlinear effects of a power amplifier it is important to be able to relate the improvements gained to the degree of linearisation achieved. A new measure of the degree of linearisation is introduced and carefully defined by Máirtín O’Droma of the University of Limerick, Ireland with his colleagues there, Nana Mgebrishvili, Yiming Lei and Anthony Goacher, and with Eduard Bertran of the Technical University of Catalonia (UPC) and Bernd Bunz of the University of Kassel, Germany. Naming it ‘percentage linearisation’ (PL) they show how it can be related to the improvement in modulation fidelity and ACPR, illustrating this with examples using IEEE 802.11a and UWC-136 air-interfaces. Such a measure can be used to set lineariser operating requirements to yield designer reductions in power amplifier backoff, and hence increases in PAE, while still satisfying mandatory behavioural specifications for a given air-interface. In this it can be most useful in the cost/benefit analysis when considering the introduction of certain linearisation schemes in specific circumstances.

In chapter 4 Christian Fager of the Microwave Electronics Laboratory, Chalmers University, Sweden, develops analytical methodology for the prediction of intermodulation distortion (IMD) in practical power amplifiers (PAs). How the analysis enables measured IMD behaviour to be directly related to the nonlinear features in the device characteristics is demonstrated. These methods, while perhaps not yielding the highest degree of accuracy, nonetheless can provide important insights into what mechanisms dominate in producing the IMD measured and thus, also, how it can be minimised. Use of this increased understanding to make some device-level linearity improving techniques, primarily with the use of appropriate bias and load conditions, is presented by José García and his colleagues at the University of Cantabria, Spain, in chapter 5. The possibility of designing highly efficient distortion generators, to be employed in simple device-based linearisation schemes is also addressed. Both concepts are proposed as real alternatives for low cost applications.

Dominque Schreurs of the Catholic University of Leuven, Belgium and Kate Remley of National Institute of Standards, U.S.A. show in chapter 6 that the use of multi-sine excitations, as approximations of complex modulated signals, can render the large-signal power amplifier behavioural modelling more efficient from the point of view of both experimental design and data handling, and this without loss of accuracy. This work complements that of Carvalho's in chapter one. In addition, as modulated excitations can reveal slow-memory effects present in the device, they describe how these can be incorporated in the behavioural modelling description.

Completing this book are two chapters dedicated to specific analysis techniques for circuit level linearisation and the introduction of modern elements of control theory in the lineariser design. The former are addressed by Joaquín Portilla and Juan-Mari Collantes of the University of the Basque Country, Bilbao, Spain in chapter 7. They set out how circuit level linearisation techniques offer excellent characteristics in terms of simplicity, efficiency, reproducibility and the possibility of a high level of MMIC integration. Success in the design of circuit level linearisers strongly relies on the use of appropriate and high-performance analysis tools. Two methodologies presented to help designers in this context are Volterra series analysis and large signal stability analysis. The former is applied to improve the understanding of the different intermodulation distortion contributions taking place in a bipolar amplifier with diode predistortion lineariser. The latter is proposed to help in diminishing the risk of parametric oscillations in feedback linearisation structures. Overall they show that the techniques offer a competitive strategy in diverse applications for power amplifier nonlinearity distortion reduction.

The use of modern H-infinity control theory in design of RF power amplifier linearisers is addressed by Gabriel Montoro of the Technical University of Catalonia (UPC), Spain, together with his colleagues there Eduard Bertran, Pere L Gilabert, and Jordi Berenguer, and with Máirtín O'Droma of the University of Limerick. An alternative Cartesian feedback lineariser based on the application of the H-infinity robust control theory is developed. Applying it to some practical problems, they show that this new design methodology permits accomplishing stringent linearity requirements while overall system efficiency and stability are preserved. Results and advantages are compared with the classical Cartesian feedback.

We could not end this brief note, without our most sincere gratitude to all those who have helped us in this task. We acknowledge the invaluable support provided by TARGET Network of Excellence, especially the continued encouragement received from its Steering Committee. Especially we would like to thank all the authors that have kindly accepted

contributing to this book, through whose tremendous efforts it has been possible to cover a wide variety of issues while keeping a common objective.

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