ZHANCANG WANG

HIGH-EFFICIENCY LOAD MODULATION POWER AMPLIFIERS FOR WIRELESS COMMUNICATIONS

This cutting-edge resource presents a complete and systematic overview of the practical design considerations of radio frequency (RF) high-efficiency load modulation power amplifiers (PA) for modern wireless communications for 4G and beyond. It covers design approaches for passive and active load modulation operation, as well as hybrid methods with dynamic supply modulation and digital signal processing algorithms required for efficiency enhancement.

Passive load impedance tuner design, dynamic load modulation PA, active load modulation PA, Doherty PA, and Chireix PA design for efficient enhancement are explained. Readers find practical guidance in bandwidth extension, including video bandwidth enhancement techniques, broadband and concurrent multiband dynamic load amplifiers, topology selection, design procedures, and network output.

"The book is well planned with topics flowing well from the introductory chapter reviewing modulation scheme history and trends in wireless communications, through a solid theoretical understanding of various load modulation approaches. This book is recommended for those who want a full introduction and understanding of the topic through to more experienced engineers that require convenient reference material."
– Raymond S. Pengelly, *Retired, Fellow of the IEEE, Fellow of the IET*

Zhancang Wang is a senior RF specialist for Ericsson and the owner of Amplifier Frontier Research (AFR) group, driving open discussions of cutting-edge amplifier technologies. He earned his master of electrical engineering degree from Beijing University of Technology, China.

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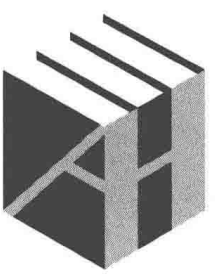
Zhancang Wang



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High-Efficiency Load Modulation Power Amplifiers for Wireless Communications

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Preface

The motivation for this book came about for the following reasons. First, the eightieth birthday anniversaries of both Doherty and Chireix radio frequency (RF) power amplifiers (PA) are barely over, but I would like use this book to honor Mr. Doherty and Mr. Chireix. Second, the book is an essential and complementary companion to my first book, *Envelope Tracking Power Amplifiers for Wireless Communications* (Artech House, 2014), which focused specifically on supply modulation RF PA techniques. The goal of this book is to introduce cutting-edge load modulation RF PAs for next-generation wireless communication standards. As we know, for the purpose of improving energy efficiency of RF PAs under high peak-to-average-power ratio (PAPR) stimulus, supply modulation schemes such as envelope tracking (ET) are promising but are not the only candidates for efficiency enhancement. The load modulation PA family, including both passive and active load modulation schemes, actually dominates and became very competitive rivals to ET PAs. Although many types have been around for a long time, such as Doherty and Chireix schemes stemming from the 1930s, some new types, such as dynamic load modulation (DLM) and asymmetrical multilevel outphasing (AMO) techniques, are fairly young. Furthermore, with the evolution of Doherty and Chireix, some emerging variants, especially digital Doherty and digital Chireix, are rarely elaborated on in existing books. Therefore, to enrich the knowledge tree of modern load modulation PAs, a comprehensive analysis of them can be found in this book.

Load modulation PA techniques were first developed 80 years ago to handle the excessive energy consumption of high-power amplitude modulation (AM) broadcast radio transmitters. Since constant amplitude frequency modulation (FM) techniques displaced AM in the 1950s—the same fate that displaced supply modulation PAs—load modulation PAs became marginalized and irrelevant to engineering practice, where they languished as an academic curiosity. However, the increasing PAPRs of modern communication signals with advanced digital modulation schemes have reinvigorated load modulation techniques to achieve considerable energy saving in broadband digital transmitters. With Doherty taking the lead, which was accepted early on for common use, more and more commercial load modulation PAs have been developed for the fifth generation (5G).

It had been a challenge for me to figure out how to organize a book with so many load modulation PA techniques. Telling the history, categorizing them by passive or active, analog or digital, bandwidth and efficiency trade-offs, and new or old had been considered. Finally, after a history and background introduction, this

book describes load modulation PAs from passive to active types. Next, design considerations for bandwidth and efficiency are illustrated. For types such as Doherty and Chireix, the main variants that evolved are addressed after a short introduction of the classic theory, which can be found in the literature. This book explores the topic from the basic principles of load modulation PA techniques through their application scenarios, including dynamic load modulation (DLM), active load modulation such as Doherty and Chireix PA designs, and load modulation PA design for both broadband and efficiency enhancement. In addition, the book covers the evolution of load modulation PA, especially digital signal processing design techniques and applications for wireless communication purposes.

The book can be used by graduate students, researchers, and design engineers in microwave and wireless design areas. It is assumed that readers have already acquired a basic knowledge of RF and microwave circuit design. A solid background in RF PA design theory and basic communication concepts is required. The book may also be used as a textbook for a graduate course on highly efficient RF power amplification design and measurement.

Chapter 1 reviews the modulation scheme history and trends in wireless communications. The long evolution from analog modulation to digital modulation, the change of signal characters and its impacts to efficiency RF power amplification are comprehensively presented. Usually, RF/microwave engineers do not consider much of this evolution, but we show the whole picture, explaining the difficulty in handling power amplification with high efficiency. The key architectures to meet the challenges are introduced, including bias modulation PAs, load modulation PAs, and their hybrids. Actually, bias modulation and load modulation currently dominate both academic research and commercial utilization. The comparison of those two rivals is elaborated as well to explore their advantages and disadvantages in design and applications. Finally, the basic theory and classification of load modulation PAs are presented in detail..

Chapter 2 is dedicated to passive impedance tuner design approaches adopted in developing dynamic load modulation (DLM) PA systems. The chapter is divided inot discussions on the semiconductor technologies used and network topologies beginning with microwave varactors and high-performance varactor stack techniques and moving to impedance tuner structure and their measurement methodologies.

Chapter 3 is dedicated to the introduction of a young load modulation PA type as dynamic load modulation, which was proposed by F. H. Raab around 2000. The chapter explains the theory of the principle of dynamic load PA techniques. It also discusses microwave varactor techniques, the key component of dynamic load PAs. General bandwidth and linearity metrics applied in dynamic load PA technique are then discussed and practical instances of DLM with various nonlinear PA types are explained in detail. The chapter also provides extensive DLM details with various power levels along with their respective advantages and limitations. Subsequently, various dynamic load PAs are examined according to different classes of power amplifiers for comparisons.

Chapter 4 provides extensive details on active load modulation (ALM) techniques and design considerations. It starts with a general architectures introduction of Doherty and Chireix PAs. Next, an efficiency-linearity-gain trade-off is analyzed as a key design consideration for active load modulation. To enable the practice of engineering implementations, both passive and active designs of active load

modulation PAs are discussed separately. Adequate details have been included for the design of related ALM PAs.

Chapter 5 presents design techniques of load modulation for efficiency enhancement and issues related to the implementation of these techniques are discussed. This process begins with development of harmonic termination for peak power efficiency boosting. Uneven, multiway, and multistage Doherty PAs are discussed by classification of topologies from simple to complex. The dynamic bias modulation scheme of ALM PAs is also studied in this chapter. Because Chireix and outphasing techniques have been illustrated in Zhang and Larson's *Design of Linear RF Outphasing Power Amplifiers* (Artech House, 2003), only an introduction and some highlights will be covered in this book for simplicity. More details about Chireix efficiency enhancement can be found in the literature.

Chapter 6 deals with the trade-off issues involved in load modulation PA designs, with a focus on bandwidth. To enhance bandwidth, typically direct broadband and multiband solutions are addressed. Multiple aspects that were discussed previously to help design a load modulation for either direct broadband or multiple band are now discussed in detail. Several matching techniques and RF PA topologies adopted in load modulation design for high bandwidth are also explained in detail.

Chapter 7 presents the evolution of classical load modulation PA topologies to meet the new challenges. Inverted Doherty PA, serial type Doherty PA, digital Doherty/Chireix PA, multilevel LINC, and AMO are introduced. Thereafter, related design techniques and considerations are categorized and explained in detail for evolutional solution selection. An inverted Doherty PA design example is also illustrated for better understanding in engineering practice.

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