

# A Power Reconfigurable High-Efficiency X-Band Power Amplifier MMIC Using the Load Modulated Balanced Amplifier Technique

J. R. Powell, D. J. Sheppard, R. Quaglia<sup>✉</sup>, Member, IEEE, and S. C.ripps, Life Fellow, IEEE

**Abstract**—The load modulated balanced amplifier (LMBA) technique uses a control signal, injected at the output coupler, to modulate the impedance of the balanced amplifier transistors. A 14.1-W X-band LMBA is reported, integrating for the first time the balanced, driver, and control signal amplifiers in a single microwave monolithic integrated circuit. Load modulation and bias settings are used to demonstrate that high circuit efficiency can be achieved as the LMBA is adjusted for operation in three RF-power regimes; 1.5, 5.6, and 14.1 W for a constant input power of 22 dBm. Power-added efficiencies above 37% are observed in all power regimes from 8 to 9 GHz under saturated conditions.

**Index Terms**—Balanced power amplifier, Doherty, gallium nitride (GaN), load modulation, microwave monolithic integrated circuit (MMIC).

## I. INTRODUCTION

**P**OWER amplifier efficiency is a critical parameter for all applications. Maintaining efficiency as the output-power requirement changes has been the subject of many inventions and papers. The Doherty technique [1], [2] has been widely adopted for its backed-off efficiency characteristic. Recently, a new technique, the load modulated balanced amplifier (LMBA) has been proposed and demonstrated [3]. In this technique, the output impedance seen by the transistors of a balanced amplifier is modulated using a control signal power (CSP) injected at the isolated port of the output coupler. It was shown in [2] that CSP power is recovered at the output.

Demonstrations of the LMBA technique have to date been confined to hybrid technologies and with a single-stage amplifier. The first published implementation [3] at 0.8–2 GHz yielded 60%–78% and 51%–67% drain efficiencies (DEs) at 42-dBm peak power and at 6-dB output-power back off (OPBO), respectively. A further hybrid LMBA [4] operated from 4.5 to 7.5 GHz with 39-dBm peak power and 47%–77% DE. In [3], it was demonstrated that using two drain bias states and three CSP power levels allows DE above 60%

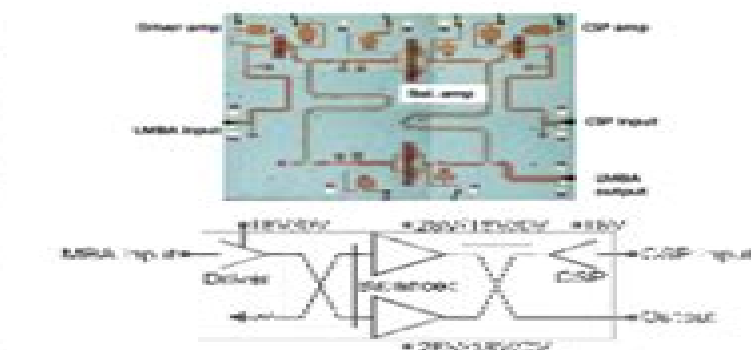


Fig. 1. Photograph of the LMBA MMIC fabricated using GaN 0.25- $\mu$ m gate technology at WIP Semiconductors ( $4 \times 3.55$  mm<sup>2</sup>), and block diagram representing the several integrated functions in the LMBA.

to be maintained at > 8 dB OPBO over regions of the band of operation. An extension of this letter [5] has employed a power splitter and on-board phase shifter network to allow a single input to be used in contrast to the separated CSP inputs in [3] and [4]. In this letter, an X-band LMBA in microwave monolithic integrated circuit (MMIC) technology is demonstrated for the first time. This MMIC was designed for specific applications which require discrete, rather than continuous, switched power levels with maximum efficiency.

## II. DESIGN

The LMBA MMIC incorporates a balanced amplifier pair, a driver amplifier, and a CSP amplifier, as shown in Fig. 1. The design objective was to demonstrate that load modulation could be employed to enable the amplifier to maintain efficiency at three discrete output power states; 14.1, 5.6, and 1.5 W by using various bias voltage states. The design strategy was to configure the balanced amplifier circuit for peak efficiency at a drain voltage of 18 V and use the LMBA function to reconfigure the balanced amplifier output match when the balanced amplifier drain voltage is varied. In this way, the added power from the CSP will contribute to the overall higher power when the drain is increased to 28 V.

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## **Compact Highly Integrated X Band Power Amplifier Using:**

**RF Power Semiconductor Generator Application in Heating and Energy Utilization** Satoshi Horikoshi, Nick Serpone, 2020-03-26 This is a specialized book for researchers and technicians of universities and companies who are interested in the fundamentals of RF power semiconductors their applications and market penetration Looking around we see that products using vacuum tube technology are disappearing For example branch tube TVs have changed to liquid crystal TVs and fluorescent light have turned into LED The switch from vacuum tube technology to semiconductor technology has progressed remarkably At the same time high precision functionalization miniaturization and energy saving have advanced On the other hand there is a magnetron which is a vacuum tube device for generating microwaves However even this vacuum tube technology has come to be replaced by RF power semiconductor technology In the last few years the price of semiconductors has dropped sharply and its application to microwave heating and energy fields will proceed In some fields the transition from magnetron microwave oscillator to semiconductor microwave oscillator has already begun From now on this development will progress remarkably Although there are several technical books on electrical systems that explain RF power semiconductors there are no books yet based on users viewpoints on actual microwave heating and energy fields In particular none have been written about exact usage and practical cases to answer questions such as What are the advantages and disadvantages of RF power semiconductor oscillator What kind of field can be used and the difficulty of the market and application Based on these issues this book explains the RF power semiconductors from the user's point of view by covering a very wide range of fields      *Switchmode RF and Microwave Power Amplifiers* Andrei Grebennikov, Marc J. Franco, 2021-03-19 Switchmode RF and Microwave Power Amplifiers Third Edition is an essential reference book on developing RF and microwave switchmode power amplifiers The book combines theoretical discussions with practical examples allowing readers to design high efficiency RF and microwave power amplifiers on different types of bipolar and field effect transistors design any type of high efficiency switchmode power amplifiers operating in Class D or E at lower frequencies and in Class E or F and their subclasses at microwave frequencies with specified output power also providing techniques on how to design multiband and broadband Doherty amplifiers using different bandwidth extension techniques and implementation technologies This book provides the necessary information to understand the theory and practical implementation of load network design techniques based on lumped and transmission line elements It brings a unique focus on switchmode RF and microwave power amplifiers that are widely used in cellular wireless satellite and radar communication systems which offer major power consumption savings Provides a complete history of high efficiency Class E and Class F techniques Presents a new chapter on Class E with shunt capacitance and shunt filter to simplify the design of high efficiency power amplifier with broader frequency bandwidths Covers different Doherty architectures including integrated and monolithic implementations which are and will be used in modern communication systems to save power

consumption and to reduce size and costs Includes extended coverage of multiband and broadband Doherty amplifiers with different frequency ranges and output powers using different bandwidth extension techniques Balances theory with practical implementation avoiding a cookbook approach and enabling engineers to develop better designs including hybrid integrated and monolithic implementations *The Engineering Index Annual*, 1992 Since its creation in 1884 Engineering Index has covered virtually every major engineering innovation from around the world It serves as the historical record of virtually every major engineering innovation of the 20th century Recent content is a vital resource for current awareness new production information technological forecasting and competitive intelligence The world's most comprehensive interdisciplinary engineering database Engineering Index contains over 10.7 million records Each year over 500,000 new abstracts are added from over 5,000 scholarly journals trade magazines and conference proceedings Coverage spans over 175 engineering disciplines from over 80 countries Updated weekly [Applications in Electronics Pervading Industry, Environment and Society](#) Alessandro De Gloria, 2015-08-07 This book provides a thorough overview of cutting edge research on electronics applications relevant to industry the environment and society at large A wide spectrum of application domains are covered from automotive to space and from health to security and special attention is devoted to the use of embedded devices and sensors for imaging communication and control The book is based on the 2014 APPLEPIES Conference held in Rome which brought together researchers and stakeholders to consider the most significant current trends in the field of applied electronics and to debate visions for the future Areas covered by the conference included information communication technology biotechnology and biomedical imaging space secure clean and efficient energy the environment and smart green and integrated transport As electronics technology continues to develop apace constantly meeting previously unthinkable targets further attention needs to be directed toward the electronics applications and the development of systems that facilitate human activities This book written by industrial and academic professionals will hopefully contribute in this endeavor [Broadband RF and Microwave Amplifiers](#) Andrei Grebennikov, Narendra Kumar, Binboga S. Yarman, 2017-07-12 Broadband RF and Microwave Amplifiers provides extensive coverage of broadband radio frequency RF and microwave power amplifier design including well known historical and recent novel schematic configurations theoretical approaches circuit simulation results and practical implementation strategies The text begins by introducing two port networks to illustrate the behavior of linear and nonlinear circuits explaining the basic principles of power amplifier design and discussing impedance matching and broadband power amplifier design using lumped and distributed parameters The book then Shows how dissipative or lossy gain compensation matching circuits can offer an important trade off between power gain reflection coefficient and operating frequency bandwidth Describes the design of broadband RF and microwave amplifiers using real frequency techniques RFTs supplying numerous examples based on the MATLAB programming process Examines Class E power amplifiers Doherty amplifiers low noise amplifiers microwave gallium arsenide field effect transistor

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