

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

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**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

POWER 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%

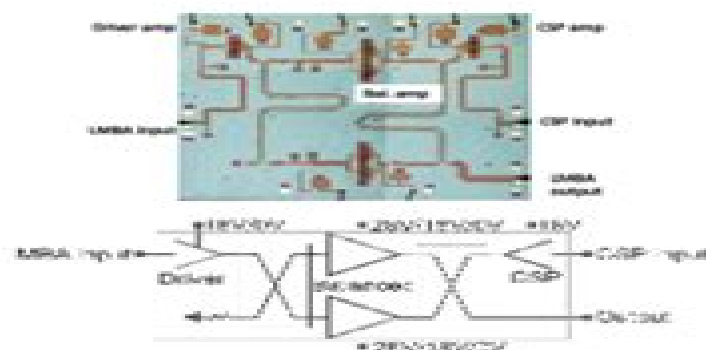


Fig. 1. Photograph of the LMBA MMIC fabricated using GaN 0.25- $\mu$ m gate technology at WIP Semiconductors ( $4 \times 3.55$  mm<sup>2</sup>), and block diagram representing the several integrated functions in the LMBA.

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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