MITSUBISHI ELECTRIC RESEARCH LABORATORIES
http://www.merl.com

A 40-dBm High Voltage Broadband GaN Class-J Power Amplifier for PoE Micro-Basestations

Ma, R.; Goswami, S.; Yamanaka, K.; Komatsuzaki, Y.; Ohta, A.

TR2013-045 June 2013

Abstract

A broadband, efficient and linear RF power amplifier for 4G multi-standard micro-basestations is presented. With an optimized Class-J matching network and a new commercially available high voltage 10W GaN HEMT, output power around 40.5dBm is measured across 1.65-2.70GHz with 55-72% drain efficiency at 1-dB compression point under CW stimulus. Using a 20MHz modulated test signal at 2.5GHz with 9.5dB PAPR, high average efficiency of 48% was measured at 35.9dBm average output power, with ACPR better than -30dBc. To the author's best knowledge, this is the first Class-J prototype operating at 47V, enabling power over ethernet applications without any external voltage regulation, thereby further reducing bill of materials and improving the overall system efficiency.

IEEE International Microwave Symposium (IMS)

A 40-dBm High Voltage Broadband GaN Class-J Power Amplifier for PoE Micro-Basestations

Rui Ma[1], Sushmit Goswami[1, 2], Koji Yamanaka[3], Yuji Komatsuzaki[3], and Akira Ohta[4]

[1]Mitsubishi Electric Research Laboratories, Cambridge, MA, USA, rma@merl.com

[2]Massachusetts Institute of Technology (MIT), Cambridge, MA, USA

[3]Mitsubishi Electric Corporation, Information Technology R&D Center, Kamakura, Japan

[4]Mitsubishi Electric Corporation, High Frequency & Optical Device Works, Itami, Japan

Abstract — A broadband, efficient and linear RF power amplifier for 4G multi-standard micro-basestations is presented. With an optimized Class-J matching network and a new commercially available high voltage 10W GaN HEMT, output power around 40.5dBm is measured across 1.65-2.70GHz with 55-72% drain efficiency at 1-dB compression point under CW stimulus. Using a 20MHz modulated test signal at 2.5GHz with 9.5dB PAPR, high average efficiency of 48% was measured at 35.9dBm average output power, with ACPR better than -30dBc. To the author's best knowledge, this is the first Class-J prototype operating at 47V, enabling power over ethernet applications without any external voltage regulation, thereby further reducing bill of materials and improving the overall system efficiency.

Index Terms — Power amplifier, Gallium Nitride HEMT, Multi-standard, Transmitter, Power over Ethernet (PoE).

I. Introduction

The goal of ubiquitous connectivity has led to a proliferation of wireless standards. New standards like LTE include dozens of bands, spread over a multi-octave frequency range from 0.4-3.8GHz [1]. Traditional one-radio-per-band architectures are severely ineffective from a cost and form-factor standpoints. Thus, there is an urgent need to evolve towards minimalistic broadband solutions without sacrificing performance. In addition, the evolution of modern cellular infrastructure is clearly towards a more heterogeneous topology. With a continuing effort to improve coverage in an environment of scarce spectrum, off-load to smaller cells e.g. micro-basestations, pico- and femto-cells is becoming increasingly important. These systems are essentially miniature basestations, radiating between 1 and 10W of peak RF power, with a direct backhaul connection via Ethernet. The most efficient way to power such systems is via Power over Ethernet (PoE plus), as is common with WiFi access points, and some outdoor high capacity microwave radios.

This work introduces a broadband efficient RF power amplifier (PA) suitable for 4G micro-basestations. To meet the need of multi-standard wideband operation, an optimized design based on the recently reported Class-J continuum principle is adopted [2]. The design goal is to achieve nearly constant output power and high efficiency over 1GHz bandwidth centered around 2GHz. To enable direct biasing from the available PoE rail of 44-57V, a GaN HEMT from Mitsubishi Electric (MGF0840G) targeted at high voltage operation is selected. The prototyped 10W power amplifier has for the first time successfully demonstrated that the state-of-the-art high voltage GaN device is able to operate at 47V sustaining the harmful high peak voltage while offering good linearity and high average efficiency above 1GHz bandwidth.

The paper is organized as follows: Section II outlines the design procedure of the amplifier, solving the challenges faced in achieving simultaneously high operational bandwidth and efficiency. Section III details the measurement results on the fabricated prototype. Finally, Section IV presents the key conclusions and future work.

II. Circuit Design

Efficient and broadband RF PAs based on the proposed Class-J concept [2] and the more recently reported extended continuous Class-F have demonstrated high efficiency around GHz bandwidth in the cellular bands [3]. The operation principles of such continuum-mode RF PAs have been explicitly explained in the previous publications [2-3]. With relatively simple matching topologies providing complex impedances at fundamental and harmonics (up to 2nd harmonic for Class-J and 4th harmonic for continuous Class-F operation), the strictly required constant short/open load conditions have been mitigated, which are the main limitations for the traditional harmonic-tuned power amplifier to achieve wider bandwidth and high efficiency.

However, higher peak voltage of $v(\theta)$ than that of conventional harmonic-tuned efficient PA will be caused at output terminal as described in equation (1), which is a generalized expression of normalized voltage in a typical continuum-mode of high order [2]. This is mainly attributed to the reactive terminations [2-3]. Higher peak voltage can go beyond 3 times the supply voltage, as shown in Fig. 1. Consequently, it has been limited in practice to increase the supply voltage in this kind of continuum-mode PA operation to gain better performance.

$$v(\theta) = 1 - \cos\theta + (a/2)\sin\theta - \alpha\sin 2\theta + (\alpha/2)\sin 3\theta \qquad (1)$$

So far, mostly reported continuum-mode power amplifiers using GaN HEMT have been designed with supply voltage below 30V [2-3].

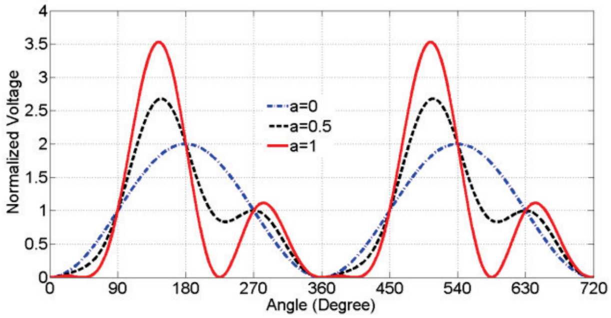

Fig. 1. Theoretical output voltage waveforms for continuum-mode amplifier (for simplicity a ≥ 0 shown only) defined by equation (1).

The Class-J PA in this work has been designed with a recent commercially available 10W GaN HEMT suitable for a supply voltage of 47V demonstrating that state-of-the-art GaN HEMT technology has the capability of operating in high voltage Class-J mode with very promising performance. The main design procedures are described as follows:

A. Load-pull Simulation

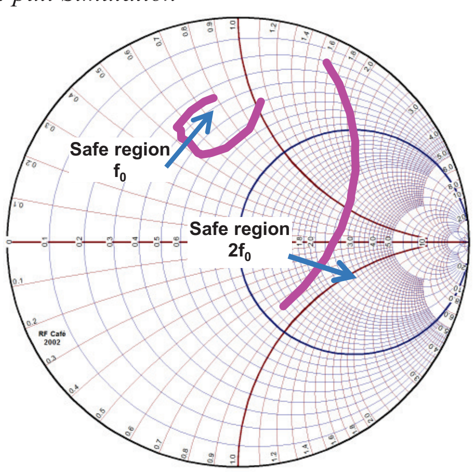

Fig. 2. Simulated load-pull contours of the safe regions of fundamental and second harmonic (1.5-2.7GHz, Z_0= 50Ω).

Based on the nonlinear large signal model of the packaged device, load-pull simulations in ADS (Advanced Design System) have been performed to determine the optimum termination conditions for obtaining high drain efficiency (>50%) over the frequency range from 1.5-2.7GHz for both the fundamental and second harmonics. The targeted output power was 40.5dBm (around P_{1dB} at 2GHz center frequency, with DC static bias point: V_{DS}=47V, I_{DS}=90mA). The results in Fig. 2 are referred to the external packaged device plane-A (see Fig. 3). These results can be used as an initial guideline for designing the impedance matching topology. It can be seen that R_{opt} of the packaged part is around 28Ω and complex impedances are distributed in a quite concentrated region over the aforementioned wide frequency range, implying the good broadband matching feasibility.

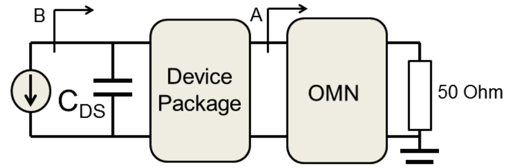

Fig. 3. Impedance reference plan illustration.

B. Matching Network Design and Optimization

On the basis of the load-pull simulation, the output matching network (OMN) has been synthesized and optimized to achieve the targeted impedance terminations over the whole frequency band falling in the safe region, as shown in Fig. 2 and Fig. 4(i). During the optimization procedure, transformed impedances at fundamental and second harmonic with regard to reference plane-B are observed (after de-embedding using the device model), to ensure the optimum PA operation.

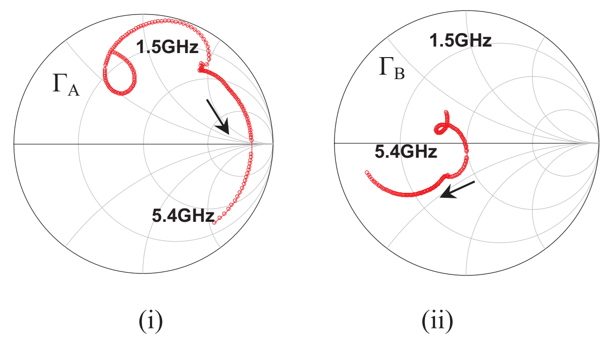

Fig. 4. Transformed impedance at: (i) Package reference plane-A; (ii) Intrinsic current generator plane-B from 1.5-5.4GHz (Z_0=R_{opt}).

Class-J operation conditions are fulfilled by the designed OMN after optimization (two shorted-shunt stubs and high-Q air core inductor in the drain bias path as well as by-pass capacitors), offering inductive reactance for the fundamental frequency and capacitive reactance for the second harmonics.

Note that due attention has been given during optimization of OMN to avoid falling into the "clipping region" to minimize the nonlinear distortion. It is observed that optimizing the second harmonic termination improves efficiency substantially. Fabricated PA using Rogers 4350B (h=0.508mm, ε_r=3.66, t=18μm) substrate is shown in Fig. 5.

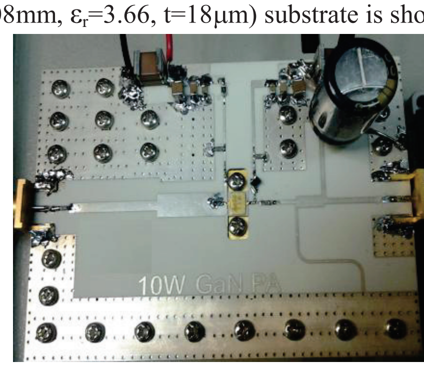

Fig. 5. Fabricated 10W high voltage GaN power amplifier.

III. MEASUREMENT

Both continuous-wave (CW) and modulated signal tests are performed on the PA prototype. For CW measurements, the input power of 27.2dBm is set, obtaining P_{out} of 40.5dBm (at P_{1dB}) in mid-band and then held constant for the frequency sweep to demonstrate the broad operational bandwidth.

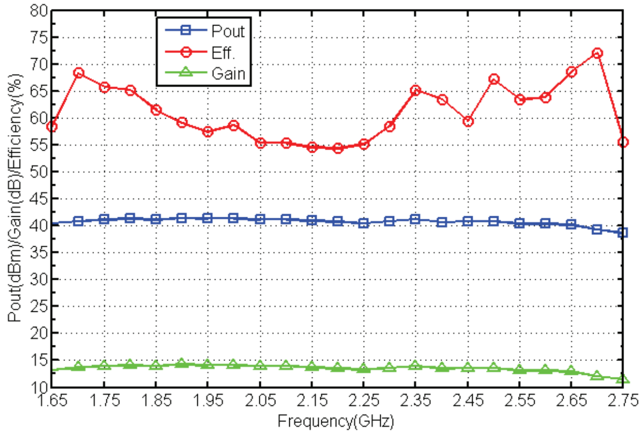

Fig. 6. Measured output power, drain efficiency, and gain under CW frequency swept from 1.65GHz-2.75GHz at P_{in} of 27.2dBm.

At static bias point of V_{DS} = 47V, I_{DS} = 90mA (deep Class-AB), CW test results show that measured drain efficiency is above 55% from 1.65-2.70GHz (peak efficiency of 72% at 2.7GHz), and output power is 40.5±1dBm.

Power sweep using CW signal has been measured at several frequencies at the same bias point mentioned before. Representative results at 2.5GHz are shown in Fig. 7. Output power of 41.2dBm (around P_{2dB}) is obtained with peak drain efficiency of 68.3%. Notably, high efficiency (above 50%) is still obtained even at 5.5dB back off region.

To benchmark PA linearity, a modulated test signal with 20MHz signal bandwidth centered at 2.5GHz (PAPR of 9.5dB) was used as the stimulus. The measured output spectrum is shown in Fig. 8. ACPR1 of -30dBc and ACPR2 of -40dBc at 20MHz and 40MHz offset were obtained without using any linearization, respectively. Furthermore, the lower and upper spectrums show good symmetry, indicating the minimum memory effect and good potential for linearization. Attractively, a high average efficiency of 48% even with such

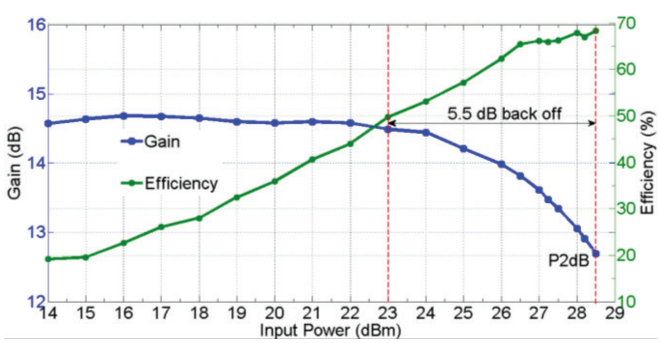

Fig. 7. Measured gain and efficiency with CW signal at 2.5GHz.

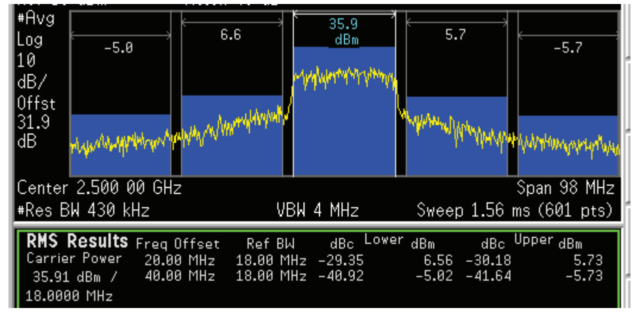

Fig. 8. Output spectrum of 20MHz modulated test signal at 2.5GHz (average Pin of 22.5dBm and average efficiency of 48%).

broadband high PAPR signal was obtained with average output power of 35.9dBm. To summarize, we achieve superior performance in terms of bandwidth, linearity and efficiency for the implemented 47V Class-J PA.

IV. CONCLUSIONS

A broadband and highly efficient RFPA for multi-standard micro-basestations is presented. A high-voltage GaN HEMT device rated for a supply voltage of 47V is used for the first time, to enable direct operation of the PA from the PoE rail without any external power management. With an optimized matching network design using the Class-J impedance continuum, output power of 40.5±1dBm with a drain efficiency of 55-72% was achieved from 1.65-2.70GHz. This demonstrated frequency bandwidth would be able to cover a large number of FDD and TDD cellular bands of 4G LTE spectrum. The RFPA prototype also shows better than -30dBc with ACPR1 with 20MHz wideband modulated signals, which can be improved by another 15-20dBc in future work using linearization techniques. Demonstration of other advanced continuum-mode PAs such like extended continuous class-F^{-1} with high voltage GaN will be shown in the future work.

ACKNOLEDGEMENT

The authors would like to thank C. Duan, P. Orlik, K. H. Teo, J. Barnwell, K. Parsons and J. Zhang of Mitsubishi Electric Research Labs for the discussions and support.

REFERENCES

[1] 3GPP, UMTS; Base Station (BS) radio transmission and reception (FDD), TS25.104 version 11.3.0 Release 11, Oct. 2012.

[2] Wright, J. Lees, P. Tasker, J. Benedikt, S. C. Cripps, "A Methodology for Realizing High Efficiency Class-J in a Linear and Broadband PA," IEEE Trans. Microwave Theory & Tech, Dec. 2009.

[3] N. Tuffy, L. Guan, A. Zhu, and T. Brazil, "A Simplified Broadband Design Methodology for Linearized High Efficiency Continuous Class-F Power Amplifiers," IEEE Trans. Microwave Theory & Tech, June 2012.