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A 4-W Doherty Power Amplifier in GaN MMIC Technology for 15-GHz Applications / Quaglia, Roberto; Camarchia, Vittorio; Jorge, Julian Moreno Rubio; Pirola, Marco; Ghione, Giovanni. - In: IEEE MICROWAVE AND WIRELESS COMPONENTS LETTERS. - ISSN 1531-1309. - STAMPA. - 27:4(2017), pp. 365-367. [10.1109/LMWC.2017.2678440]

*Availability:*

This version is available at: 11583/2668206 since: 2018-02-12T13:31:44Z

*Publisher:*

IEEE

*Published*

DOI:10.1109/LMWC.2017.2678440

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# A 4-W Doherty Power Amplifier in GaN MMIC Technology for 15-GHz Applications

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**Abstract**—This letter presents an integrated Doherty power amplifier (PA) in 0.25- $\mu\text{m}$  GaN on SiC process. Designed for 15-GHz point-to-point radios, the PA exhibits an output power of  $36 \pm 0.5$  dBm between 13.7 and 15.3 GHz, while at 14.6 GHz, it shows a 6-dB output back-off efficiency higher than 28%. Modulated signal measurements applying digital predistortion demonstrate the compatibility of the amplifier with point-to-point radio requirements. To the best of our knowledge, this PA has the highest back-off efficiency for the 15-GHz band, and is the first GaN Doherty in the Ku-band.

**Index Terms**—Doherty, gallium nitride, microwave monolithic integrated circuit (MMIC).

## I. INTRODUCTION

INCREASING the power amplifier (PA) efficiency is crucial in high-capacity microwave radios, where the thermal issues are critical due to the compact radio module configuration. The adoption of high peak-to-average power ratio (PAPR) modulated signals forces the PA to operate at large output backoff (OBO) to maintain an acceptable linearity, limiting the efficiency of the PAs commonly adopted for microwave radios well below 10% and 20% for GaAs and GaN-based examples, respectively. This letter presents the first example of design, for the 15-GHz point-to-point radio band, of a microwave monolithic integrated circuit (MMIC) Doherty PA (DPA) [5] based on 0.25- $\mu\text{m}$  GaN HEMTs. This technology has already been exploited for the state-of-the-art DPAs up to the C-band, while has never been tested at 15 GHz for the design of an advanced PA. Table I compares the proposed MMIC with similar DPAs in terms of frequency band, maximum output power, and drain efficiency at saturation and 6-dB OBO. The DPA of [2], thanks also to the use of a more advanced technology (0.15- $\mu\text{m}$  GaN) and of distributed networks and a large area, shows similar performance at higher frequency. On the other hand, it can be observed that the proposed

Manuscript received December 20, 2016; accepted January 6, 2017. Date of publication March 22, 2017; date of current version April 6, 2017. This work was supported by the EU Horizon 2020 research and innovation Marie Skłodowska Curie programme under Grant 654987.

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Digital Object Identifier 10.1109/LMWC.2017.2678440

TABLE I  
COMPARISON WITH SIMILAR MMIC DPAs

Ref.	Tech.	Freq. (GHz)	$P_{\text{OUT}}$ (W)	Gain (dB)	$\eta_{\text{SAT}}$ (%)	$\eta_{\text{OBO}}$ (%)	Area ( $\text{mm}^2$ )
[1]	GaAs	17	0.3	8	44	30	n.a.
[2]	GaN	21-24	4	17	43	26	6.8
[3]	GaAs	23-25	1.2	12.5	38	20	4.29
[4]	GaN	10	4	9.2	57	48	8.74
This	GaN	14.6	4	7	40	28	4.96

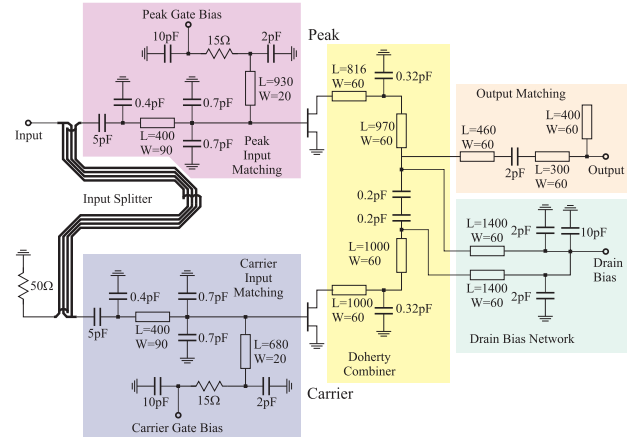


Fig. 1. Schematic of the integrated 15-GHz DPA. Lengths and widths in  $\mu\text{m}$ .

DPA compares well with the reported examples, despite the use of a technology at the limit of its capabilities.

## II. DESIGN

The designed DPA is based on the united monolithic semiconductor (UMS) 0.25- $\mu\text{m}$  GaN HEMT process (SiC substrate and two metal layers), characterized by a power density of 4 W/mm at the foundry suggested drain bias voltage of 25 V. Given the target output power of 4 W, and considering reasonable margins, the selected total periphery is of 1.2 mm. An even DPA configuration has been adopted, with the same device for carrier and peak stages. According to the foundry recommendations on maximum gate width and number of fingers, the  $8 \times 75 \mu\text{m}$  device has been chosen. At 15 GHz, the power gain on the optimum power load is around 11 dB, meaning an ideal DPA gain of around 8 dB. Accounting for the additional losses, it is clear that the design constraints are rather close to the limits of this technology. Fig. 1 shows the circuit schematic of the MMIC. Given the small area



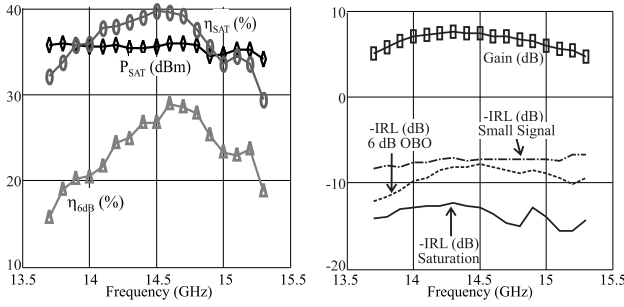


Fig. 7. CW measured results versus frequency.

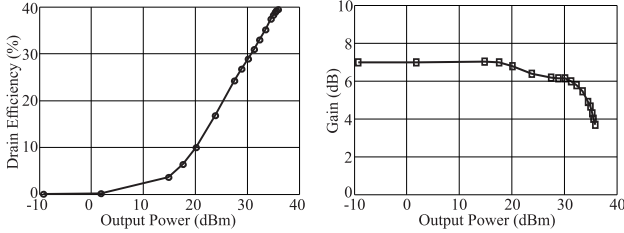


Fig. 8. CW characterization. Drain efficiency (left) and gain (right) versus output power at 14.6 GHz.

out, and the results on  $S_{21}$  are reported in Fig. 6. The  $S_{21}$  shift must be partly ascribed to process deviations on passive structures, and partly to active device deviations and EM simulation inaccuracies. Single tone CW measurements have been carried out on the 13.7–15.3 GHz band, i.e., where the PA shows a gain higher than 5 dB. Fig. 7 shows the CW measured results versus frequency. An output power of  $36 \pm 0.5$  dBm at 3-dB gain compression is achieved on the full bandwidth, with a corresponding drain efficiency higher than 29%. The 6-dB output back-off efficiency is higher than 16% on the full bandwidth, with the best result at 14.6 GHz, where it stands above 28%. With respect to the simulated results shown in Fig. 4, a lower drain efficiency is generally achieved. This deviation is partly due to the foundry device model that, to the best of our knowledge, has not been completely tested in class C at this frequency. In fact, to obtain a satisfactory flat gain versus drive response, the peak bias point has been properly retuned, thus reducing efficiency and maximum output power. Regarding the IRL, as expected from the previously drawn considerations on the input matching network design, it improves for increasing power drive. Fig. 8 reports the CW power sweep at 14.6 GHz, showing the gain and drain efficiency trends versus output power. A reasonably flat gain versus drive behavior can be observed.

To test the linearizability of the DPA, system level characterization has been performed [3]. Adopting a microwave arbitrary waveform generator (ESG4433B of Keysight), a typical point-to-point 256-quadrature amplitude modulated signal, with 28-MHz channel bandwidth and PAPR of 7.4 dB is applied to the DPA. The DPA output signal is collected with a vector signal analyzer (MXA9020A of Keysight), and elaborated to evaluate the spectrum and to extract the

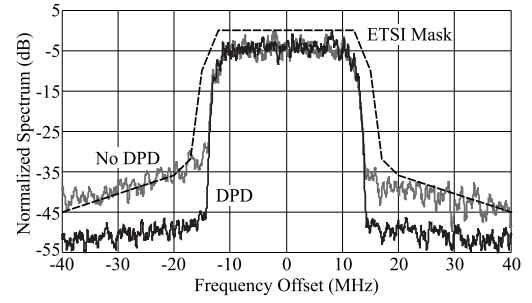


Fig. 9. Measured spectrum versus frequency with modulated signal (256-QAM, 28-MHz channel) at average power of 29 dBm. Gray trace: without DPD. Black trace: with DPD. Dashed line: ETSI mask.

predistortion model. The predistorted signal is then fed into the generator, and the output collected to verify the compliance with the system linearity specifications. Fig. 9 compares the PA output spectra with and without predistortion, for center frequency of 14.6 GHz and average output power of 29 dBm. Applying a simple memory polynomial predistortion of the sixth odd order with two memory taps [6], the adjacent channel power can be reduced, and the mask compliance (reference mask for a 6LA system [7]) achieved with an average drain efficiency of 28%. This suggests that the adoption of 0.25- $\mu$ m GaN technology is compatible with advanced PA design in the Ku-band, and that the proposed MMIC design could be applied to product development.

#### IV. CONCLUSION

Design and characterization of a Ku-band MMIC DPA have been presented, showing an output power of around 4 W and 6-dB back-off efficiency of 28%. Modulated signal measurements show that the device is compatible with linearity requirements after applying a simple predistortion.

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