11. M. Caillet, M. Clenet, A. Sharaiha, and Y.M.M. Antar, A broadband folded printed quadrifilar helical antenna employing a novel compact planar feeding circuit, IEEE Trans Antennas Propag 58 (2010), 2203–2209.
12. O.P. Falade, M.U. Rehman, G. Yue, C. Xiaodong, and C.G. Parini, Single feed stacked patch circular polarized antenna for triple band GPS receivers, IEEE Trans Antennas Propag 60 (2012), 4479–4484.
13. D.M. Elsheakh and A.M.E. Safwat, Meander line-loaded planar monopole antennas, Microwave Opt Technol Lett 54 (2012), 1851–1854.

15% BANDWIDTH 7 GHz GaN-MMIC DOHERTY AMPLIFIER WITH ENHANCED AUXILIARY CHAIN

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ABSTRACT: *This contribution presents the development and characterization of a GaN Doherty power amplifier for backhaul microwave links in the 6.35–7.35 GHz frequency range. To minimize the AM/AM distortion, a driver stage is integrated in the auxiliary branch. Such feature also allows to obtain a higher overall gain than the standard approach. Moreover, to enlarge the bandwidth a coupled lines directional coupler is adopted at the input to split the power to the two branches. Experimental characterization showed 10.5 dB Gain, 38.1 dBm saturated output power, 42% efficiency at 7 dB output back-off, and 15% bandwidth at 1 dB gain ripple.* © 2014 Wiley Periodicals, Inc. Microwave Opt Technol Lett 56:502–504, 2014; View this article online at wileyonlinelibrary.com. DOI 10.1002/mop.28108

Key words: *Doherty power amplifier; GaN-MMIC; high power amplifiers*

1. INTRODUCTION

The constant growth of services in mobile communications, such as web browsing, fast exchange of files, and streaming video, is asking for an extremely high data transfer within each node of the global network. As a section within this global network, backhaul links have to take part to this evolution to avoid bottleneck. Even if fiber optic backhaul links are the preferable solution in terms of data transfer capability, microwave backhaul links still maintain their attractiveness for sites where the fiber optic link cannot be exploited or efficiently implemented [1].

High data transfer on microwave physical layer can be achieved by using advanced signal-processing techniques that maximize the useful channel bandwidth, such as LTE and Worldwide Interoperability for Microwave Access [1]. As a consequence, microwave power amplifiers in backhaul transmitters have to operate with signals having high peak to average power ratio (PAPR) and large bandwidth.

The huge number of successful designs from S-band up to V-band applications have demonstrated that the Doherty Power Amplifier (DPA) is one of the best candidate to implement efficient transmitters when high PAPR signals are involved [2], also when implemented in Monolithic Microwave Integrated Circuit (MMIC) technology [3–5]. In fact, due to the frequency range in which microwave backhaul links operate, from 6 to 86 GHz, the MMIC approach is usually preferred. In this context, gallium nitride (GaN) technology provides an interesting chance to improve the output power/chip size ratio.

In the following, the development of a GaN-MMIC DPA oriented to the microwave backhaul links in the 7 GHz frequency range is presented. The breakthrough of this contribution is the adoption of an integrated driver stage in the auxiliary branch to increase the gain of the module, maintaining, at the same time, high levels of amplitude modulation (AM/AM) linearity. Methods to increase the gain in DPAs [6] and examples of DPA implementing driver stages are available in literature [7–9]. However, most of them [7,8] focus their investigation only on linearity improvements, whereas Ghim et al. [9] does not propose a real integration of the driver stage in the DPA architecture.

TABLE 1 Requirements for the Design

Requirement	Value	Note
Max output power (P_{out})	>37 dBm	At 1 dB of compression
Output back-off (OBO)	7 dB	From max output power
AM/AM distortion	<1 dB	In the whole dynamic
Power gain	>10 dB	At small signal level
Frequency range	6.35–7.35 GHz	
Drain bias voltage (V_{DD})	28 V	
Input/output termination	50 Ω	

2. DESIGN DESCRIPTION

The project was funded by Ericsson-AB. They selected, according to the microwave backhaul applications, the technology (0.25 μm GaN-3MI process provided by Triquint) and the requirements for the design, summarized in Table 1.

After a first investigation of the technological process, the average values of the knee (V_k = 5 V), pinch-off ($V_p = -4$ V), and built-in (V_{bi} = 1 V) voltages have been extracted. Moreover, to account for the losses in passive structures, $P_{out} = 37.5$ dBm has been selected as a target to dimension the DPA architecture in terms of active periphery. By applying the design approach in Ref. [10], the collected data are used to infer the values of the characteristic impedance of the output quarter-wave transmission line ($Z_0 = 105$ Ω) and of the optimum output resistance ($R_L = 47$ Ω). Also the maximum current required to the main device is estimated to be about $I_{Max,M} = 425$ mA. The value of $I_{Max,M}$ has been used to select the active periphery of the main device (6 × 100 μm).

Once stabilized, the simulations based on the nonlinear model provided by the foundry have shown a power gain of about 11 dB for the main amplifier. As a consequence, by combining two of these amplifiers with a 3-dB even input splitter to implement an even DPA, the resulting overall gain is about 8 dB, due to the Class C bias condition of the auxiliary amplifier [4]. Moreover, this solution does not allow to maintain the AM/AM distortion within the 1 dB range [3]. To fulfill an extremely flat AM/AM behavior, the uneven-DPA approach has to be adopted [11]. However, this solution brings to a further decrease of the gain (about 4–5 dB). As this inconvenience is mainly due to the low gain of the auxiliary amplifier and to the uneven input splitting factor, a driver stage is placed upstream of it. Consequently, accounting for the increased gain of the auxiliary chain due to the inserted driver, the input power splitter (IPS) can be drastically unbalanced in favor of the main amplifier. Thus, the gain of the whole DPA practically coincides with that of the main amplifier.

To properly select the size and bias point of auxiliary and driver devices, the following approach was used. The gate bias

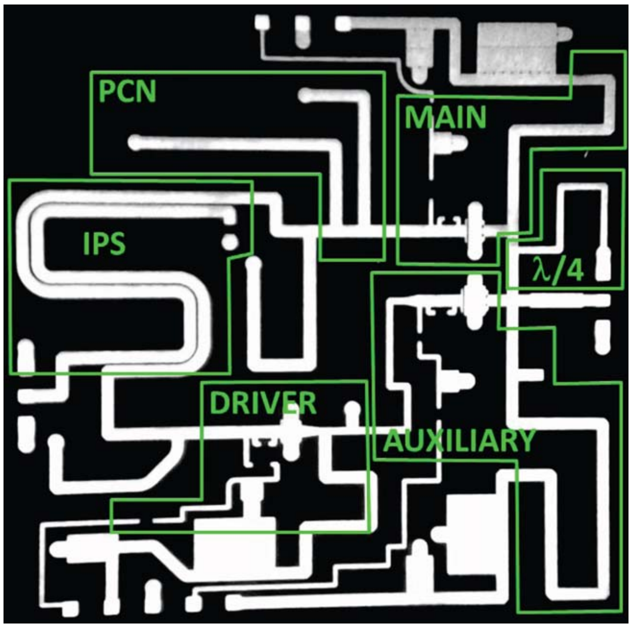

Figure 1 Photo of a chip sample. Overall dimensions are 5×5 mm^2. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com]

voltage of the auxiliary device is assumed to be slightly lower than the pinch-off voltage, resulting in a soft Class C, almost Class B, bias condition. As a consequence, the condition $I_{\mathrm{Max,A}} \approx 2I_{1,\mathrm{A}}$ can be considered, where $I_{1,\mathrm{A}}$ is the amplitude of the fundamental current component delivered by the auxiliary device. In Ref. [10] it has been demonstrated that $I_{1,\mathrm{A}}$ has to be $1.24I_{1,\mathrm{M}}$ to fulfill 7 dB of output back-off (OBO), where $I_{1,\mathrm{M}}$ is the amplitude of the fundamental current component delivered by the main device. As an almost Class B is adopted for the main device as well, $I_{\mathrm{Max,A}} \approx 540$ mA can be derived, resulting in a 6×160 μm device. For the driver amplifier, a 6×100 μm device has been selected, as for the main amplifier, to obtain a symmetrical load configuration at the input of the two DPA's branches and, thus, simplifying the design of the input splitter. The gate bias voltage of the driver device is optimized both to avoid DC current absorption when only the main amplifier is delivering power and to maximize the flatness of the AM/AM behavior.

Figure 1 reports a picture of the realized MMIC. To reduce the chip size, a combined lumped-distributed design approach is adopted. In particular, the output quarter-wave transmission line (λ/4 in Fig. 1) and the phase compensation network (PCN in Fig. 1) are implemented by using the equivalent T-network C-L-C and Π-network L-C-L, respectively [11]. In both of them, the inductive elements are realized with short circuited stubs. A further stub is added at the drain of each active device to bring the V_{DD} bias voltage and to compensate the parasitic drain-source capacitance.

The required input splitting factor is highly unbalanced in favor of the main branch (roughly 10 dB). Thus, a coupled lines directional coupler was preferred for the implementation of the IPS (IPS in Fig. 1). Through and coupled ports are connected to the inputs of the main and auxiliary branches, respectively. The isolated port is terminated on an integrated 50 Ω resistance. The adopted IPS implies a further advantage with respect to other power splitters (i.e., Wilkinsons or Branch-line), as it assures a wider bandwidth.

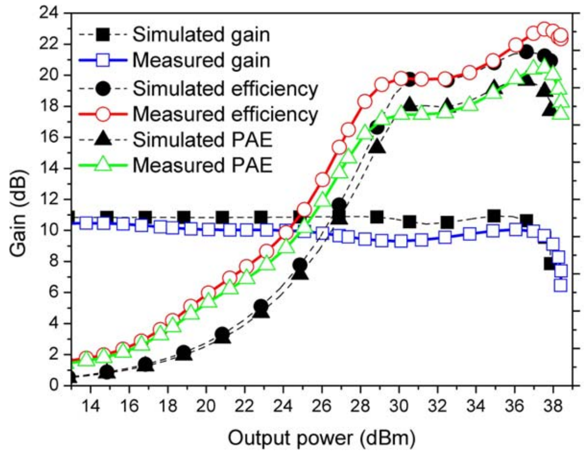

Figure 2 Simulated and measured large signal performance at 7 GHz for the nominal bias point. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com]

3. EXPERIMENTAL RESULTS

The amplifier has been characterized under large signal continuous wave operating conditions. Figure 2 compares measured and simulated large signal performance at 7 GHz for the nominal bias point: $V_{\mathrm{DD}} = 28$ V, $V_{\mathrm{GG,M}} = -3.6$ V, $V_{\mathrm{GG,A}} = -4.15$ V, $V_{\mathrm{GG,D}} = -4.65$ V. The measured saturated output power is greater than 38 dBm, whereas an output power level of 37.7 dBm has been registered at 1 dB of gain compression. The small signal gain is about 10.5 dB. The measured drain efficiency (PAE) is higher than 42% (36%) in the 7 dB of OBO with a peak of 47% (42%). Figure 3 reports the frequency behavior of the measured output power and efficiency at 1 dB gain compression ($P_{\mathrm{in}} = 29$ dBm) and at 7 dB of OBO ($P_{\mathrm{in}} = 21$ dBm), respectively. The results demonstrate an extremely flat behavior in 15% of bandwidth (6.35–7.35 GHz). In the entire bandwidth, a drain efficiency (PAE) higher than 40% (34%) at 7 dB of OBO has been registered.

4. CONCLUSION

In this article, the development of a GaN-MMIC DPA for backhaul microwave links has been described. An innovative solution to increase the gain and to reduce the AM/AM distortion of

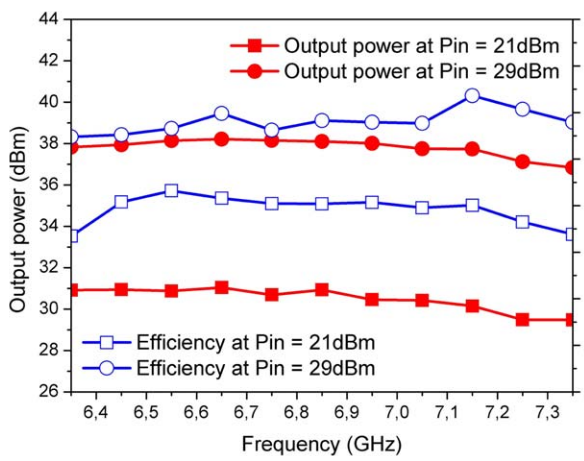

Figure 3 Measured large signal performance at 21 and 29 dBm of input power for the nominal bias point. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com]

the module by integrating a driver stage in the auxiliary chain has been proposed.

The adoption of a 10 dB coupled lines directional coupler as IPS has allowed the fulfillment of 15% of bandwidth without considerable gain and/or efficiency detriment.

The experimental results validated the design approach, showing a saturated output power greater than 38 dBm at 7 GHz with a drain efficiency (PAE) in between 42% (36%) and 47% (42%) in 7 dB of OBO.

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REFERENCES

1. J. Hansryd and J. Edstam, Microwave capacity evolution, Ericsson Rev J 1 (2011).
2. R. Giofré, L. Piazzon, P. Colantonio, and F. Giannini, Being seventy-five still young: The Doherty power amplifier, Microwave J 55 (2012), 72–88.
3. V. Camarchia, J. Fang, J. Moreno Rubio, M. Pirola, and R. Quaglia, 7 GHz MMIC GaN Doherty power amplifier with 47% efficiency at 7 dB output back-off, Microwave Wireless Comput Lett 23 (2013), 34–36.
4. J.-H. Tsai and T.-W. Huang, A 38–46 GHz MMIC Doherty power amplifier using post-distortion linearization, Microwave Wireless Comput Lett 17 (2007), 388–390.
5. J. Nam, J. Shin, and B. Kim, Load modulation power amplifier with lumped-element combiner for IEEE 802.11b/g WLAN applications, Electron Lett 42 (2006), 24–25.
6. P. Colantonio, F. Giannini, R. Giofré, and L. Piazzon, A design approach to increase gain feature of a Doherty power amplifier, In: Proceedings of European Microwave Integrated Circuits, 2009, pp. 25–28.
7. H.T. Jeong, I.S. Chang, and C.D. Kim, Compensation method for a nonlinear amplifier using the gain expansion phenomenon in a Doherty amplifier, Trans Microwave Theory Tech 54 (2006), 1425–1430.
8. Y.-S. Lee, M.-W. Lee, S.-H. Kam, and Y.-H. Jeong, A highly linear an efficient three-way Doherty amplifier using two-stage GaN hemt cells for repeater systems, Microwave Wireless Comput Lett 51 (2009), 2895–2898.
9. J.-G. Ghim, K.-J. Cho, J.-H. Kim, and S.P. Stapleton, A high gain Doherty amplifier using embedded drivers, In: Microwave Symp Digest, San Francisco, CA, 2006, pp. 1838–1841.
10. P. Colantonio, F. Giannini, R. Giofré, and L. Piazzon, Increasing Doherty amplifier average efficiency exploiting device knee voltage behavior, Trans Microwave Theory Tech 59 (2011), 2295–2305.
11. P. Vizimuller, RF design guide systems, circuits, and equations, Artech House, Norwood, MA, 1995.

SIMPLE, CONVENIENT, AND NONDESTRUCTIVE ELECTROMAGNETIC CHARACTERIZATION TECHNIQUE FOR COMPOSITE AND MULTISCALE HYBRID SAMPLES AT MICROWAVE FREQUENCIES

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ABSTRACT: *A new method is presented to characterize absorbing materials, based on a classical Line-Line method but more nondestructive and more convenient. This modified Line-Line technique is used to characterize polymer/carbon nanotubes composite foams. The advantages and limitations of this technique are highlighted and compared to those of the standard method. An advantageous use of the modified Line-Line method in the particular case of multiscale hybrid materials is also presented and discussed. Finally, some conclusions are drawn.* © 2014 Wiley Periodicals, Inc. Microwave Opt Technol Lett 56:504–509, 2014; View this article online at wileyonlinelibrary.com. DOI 10.1002/mop.28107

Key words: *electrical characterization; nanocomposite materials; line-line; waveguide; microwave*

1. INTRODUCTION

Nanocomposite materials composed of foamed polymers with embedded carbon nanotubes (CNTs) can be specifically designed to combine a low dielectric constant, because of their significant porosity and a rather high electrical conductivity due to the presence of conductive nanoparticles. The resulting very good shielding effectiveness and low reflectivity of these composites make them especially attractive as microwave absorbers for electromagnetic interferences shielding applications [1–4].

Nanocomposite foams are usually characterized using free space or guided wave techniques [5]. A very clean and efficient guided wave technique used for the characterization of foamed composites is the Line-Line method, which has been proposed in [6] for various types of materials such as microwave substrates, sandy soils, and liquids, using various transmission line topologies: microstrips, slotlines, and metallic rectangular waveguides. In the present article, only the waveguide topology is considered. The material-under-test (MUT) is successively placed inside two rectangular waveguides of different lengths (the inner volume of the waveguide completely filled by the MUT) and its effective permittivity, from which the dielectric constant and electrical conductivity can be retrieved, is extracted from the S-parameters measurements of the two filled waveguides. The Line-Line method has been shown to be quite equivalent to standard transmission-reflection and resonant cavity techniques [7]. Many characterization methods are based on the measurement of only one length of waveguide but require the numerical resolution of the inverse problem to extract permittivity values, [8,9].

However, the main disadvantage of the Line-Line technique is that the samples have to be cut to fit the waveguides and this process has to be repeated for each frequency band considered. First, it is a destructive process. Second, a clean and precise machining of the sample is not always possible, for example, when samples are hard or brittle. This is especially true at higher frequencies because the dimensions of the waveguide cross section become very small.

To characterize samples composed of nanocomposite foam embedded in a metallic honeycomb, as described in [10], a new